Impact of Airport Rubber Removal Techniques on Runways

DETAILS

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SYNTHESIS 11

AIRPORT
COOPERATIVE
RESEARCH
PROGRAM

Impact of Airport Rubber Removal Techniques on Runways

Sponsored by
the Federal
Aviation Administration

A Synthesis of Airport Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

AIRPORT COOPERATIVE RESEARCH PROGRAM

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SUBJECT AREAS
Aviation

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principle means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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Cover Figure: Vehicular-mounted shotblaster
Courtesy: Jenman (2006).

FOREWORD

Airport operators, service providers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to the airport industry. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire airport community, the Airport Cooperative Research Program authorized the Transportation Research Board to undertake a continuing project. This project, ACRP Project 11-03, "Synthesis of Information Related to Airport Practices," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an ACRP report series, *Synthesis of Airport Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Gail Staba
Senior Program Officer
Transportation Research Board

This synthesis study is intended to inform airport operators about the impacts of four common rubber removal methods on runways.

Runway rubber removal is an essential function to maintain safe landing areas for the nation's aviation industry. The FAA requires that strict standards for runway skid resistance be attained and maintained at all airports. One technique that has been used successfully throughout the world to enhance runway skid resistance is the cutting of grooves in the surface of those areas of the runway where touchdown and braking are critical. The use of grooved runways provides an increased level of safety by furnishing enhanced drainage through increased pavement macrotexture, which reduces the potential for hydroplaning when runways are wet. Buildup of rubber fills the micro- and macrotexture of the pavement, causing a serious loss of skid resistance when the runway is wet, and as a result must be periodically removed.

There are four methods to remove runway rubber: waterblasting, chemical removal, shotblasting, and mechanical means (including sand blasting, scraping, brooming, milling, and grinding). The use of these methods varies across the country based on a number of reasons, ranging from environmental restrictions to the availability of competent rubber removal contractors. The research on these methods has not been comprehensive. Additionally, field experience has shown that if these methods are not properly applied they can cause damage to the runways and especially to the grooves. Much of the equipment that is in use is also proprietary, making it difficult for airport operators to develop standards and specifications that can be used to confidently achieve the desired end result. Thus, this report synthesizes the state of the practice in runway rubber removal.

The information for the synthesis was gathered through a search of existing literature, survey results from questionnaires sent to airport operators and airlines, and through interviews conducted with airport operators.

Douglas D. Gransberg, University of Oklahoma, Norman, Oklahoma, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

IMPACT OF AIRPORT RUBBER REMOVAL TECHNIQUES ON RUNWAYS

SUMMARY

Runway rubber removal is an essential function to maintain safe landing areas for the nation's aviation industry. The FAA requires that strict standards for runway skid resistance be attained and maintained at all airports. One technique that has been used successfully throughout the world to enhance runway skid resistance is the cutting of grooves in the surface of those areas of the runway where touchdown and braking are critical. The use of grooved runways provides an increased level of safety by furnishing enhanced drainage through increased pavement macrotexture, which reduces the potential for hydroplaning when runways are wet. Increased macrotexture leads to increased pavement surface friction, which in turn leads to increased amounts of rubber deposits. An average landing leaves as much as 1.4 lb (700 g) of rubber in a thin layer on the runway. To make matters worse, the heat generated during the interaction causes a chemical reaction called polymerization that changes the rubber deposits into a hard, smooth material. This buildup of rubber fills the micro-and macrotexture of the pavement, causing a serious loss of skid resistance when the runway is wet; as a result, the rubber deposits must be periodically removed.

There are four methods to remove runway rubber: waterblasting, chemical removal, shotblasting, and mechanical means (including sandblasting, scraping, brooming, milling, and grinding). The use of these methods varies across the country based on a number of reasons ranging from environmental restrictions to the availability of competent rubber removal contractors. The research on these methods has not been comprehensive and consists of individual evaluations of at most two methods. In addition, field experience has shown that if these methods are not properly applied, they can cause damage to the runways and especially to the grooves. Much of the equipment that is in use is also proprietary, making it difficult for airport operators to develop standards and specifications that can be used to confidently achieve the desired end result. Thus, given these above circumstances, this report synthesizes the state of the practice in runway rubber removal.

The objective of this report is to synthesize the current information available in runway rubber removal, including the effects each removal method has on runway grooving, pavement surface, and to appurtenances normally found on an airport runway. Some regard this field as more of an art than a science. Thus, this report seeks to find those factors that can be controlled by the engineer when developing a runway rubber removal program. The synthesis identifies different approaches, models, and commonly used practices, recognizing the differences in each of the different rubber removal methods.

In addition to a rigorous literature review, the synthesis is based on new data from two sets of surveys with a response rate of 33%, six case studies, and the formal content analysis of current rubber removal specifications in use around the country. The survey on rubber removal was sent both to airports and members of the rubber removal industry. It resulted in 41 complete and 8 partial responses. The survey respondents were from 33 airports in 21 states, plus the District of Columbia, 2 Canadian provinces, and 1 New Zealand province. Industry responses came from 12 companies, of which 4 were international. The domestic industry responses covered a total of 11 states and 1 Canadian Province, as well as Australia, Canada, Germany, and New Zealand; 2 respondents indicated that they

worked in Europe and Asia, which total a North American geographic coverage of 24 U.S. states, plus the District of Columbia and 2 Canadian provinces. Six case study interviews were conducted with 5 U.S. airports and 1 in New Zealand and included all four rubber removal methods. A content analysis of 23 rubber removal specifications covering all four removal methods from 15 different sources in 8 states plus 3 U.S. military departments, NASA, and Transport Canada was done.

The intersection of information from the four different research instruments was used to derive 8 conclusions and 10 commonly used practices. The conclusions are summarized here, and the commonly used practices can be found at the end of each rubber removal method chapter.

1. Some case study airports have changed their approach from the prescriptive "remove rubber" logic to the performance-based "restore friction" logic. Three major airports in the nation have made this change and are reporting success. Doing so fundamentally supports the underlying reason for removing rubber in the first place: to improve runway skid resistance. These airport operators use a "toolbox" approach to restoring pavement skid resistance rather than merely selecting a single method to remove rubber. Changing the rubber removal paradigm creates a situation in which rubber removal methods become "tools" in the runway surface friction maintenance "toolbox." Airport pavement managers can then use one or more as conditions dictate to achieve required friction values.

2. Although most of the reported damage to runway grooves, pavement surface, and appurtenances appears to be associated with waterblasting, the case study interviews and survey responses found that this damage was usually the result of operator error or inexperience, and that when waterblasting is done correctly, runway groove and surface damage is not likely.

3. The previous conclusion leads to the inference that airport operators not depend solely on technology for satisfactory rubber removal. Two major U.S. airports explicitly cited the need for experienced rubber removal equipment operators to achieve the required results in their rubber removal contracts. Some airport operators either require or may consider prequalification of rubber removal contracts, as was found in several instances in the specification content analysis.

4. The major reason the airports use the chemical rubber removal method is the ability to conduct rubber removal operations using in-house maintenance equipment and personnel. One airport survey respondent stated that it used chemical removal because "we control the scheduling, treatment area, and the process itself." Thus, it is concluded that convenience combined with good performance experience are the major motivators for airports that use chemical rubber removal.

5. No single runway rubber removal method is superior to all others. The results of the case studies effectively belie that assertion. All four methods have proven themselves to be successful as well as economical in at least one of the six case studies. Therefore, this reinforces the idea that these methods are "tools" in the runway rubber removal "toolbox," and airport operators evaluate their specific requirements, climate, traffic, and local laws and regulations, while selecting the tool or combination of tools that best fits their specific runway rubber removal conditions.

6. No single runway rubber removal method is superior for a given pavement type. The study found that all methods had been successfully used on both asphalt and concrete pavements.

7. Size/traffic levels do not affect the decision on what type of rubber removal method to use. Again, all methods were successfully used on both large and small airports.

8. Geographic location also does not have any effect on the selection of runway rubber removal methods. All methods were in use successfully at both northern and southern airports.

CHAPTER ONE

INTRODUCTION

The FAA furnishes strict guidance for airports regarding their requirement to maintain a runway surface in a condition that furnishes sufficient skid resistance to permit the safe take-off and landings for all types of aircraft. Cutting or forming grooves in existing or new pavement is proven to be an effective technique for the prevention of hydroplaning during wet weather (National Aeronautics and Space Administration 1993; Speidel 2002). The grooving acts as an exaggerated pavement macrotexture and thereby increases the skid resistance. Runway pavement surfaces lose their texture over time because of a number of reasons. "Runways, like highways, deteriorate from weather and use. Left unchecked, such deterioration can eventually pose safety risks to planes that are taking off or landing" (U.S. General Accounting Office 2000). The airport operator responsible for its maintenance must continually monitor its condition and rectify those conditions that may lead to a loss of skid resistance.

One author posits that the factors that cause loss of skid resistance can be grouped into two categories:

- Mechanical wear and polishing action [from] rolling or braking on the runway;
- Accumulation of contaminants (Neubert 2006).

These two categories directly relate to the two physical properties of runway pavements that create the friction that produces a pavement's skid resistance. The first is called "microtexture," and it consists of the natural surface roughness of the aggregate, as shown in Figure 1. Microtexture is lost because of mechanical wear of the aggregates surface as it is polished by repetitive contact with aircraft tires and gets smoother. Soft aggregates, such as limestone, will lose their microtexture faster than hard aggregates, such as granite, and this factor must be accounted for when selecting rubber removal methods whose technologies have an impact on microtexture. The second category is "macrotexture" and relates to the resistant force provided by the roughness of the pavement's surface. Macrotexture is reduced as the voids between the aggregate and either the cement or binder in the pavement's surface are filled with contaminants. This can be a transient condition, such as icing, or a persistent condition, such as the accumulation of rubber deposits.

As can be seen from the title of this report, the primary focus of this study is to concentrate on processes and methods to remove one specific contaminant: rubber deposits. The removal of these deposits essentially restores the macrotexture of the runway. However, as will be seen later in the report, the research uncovered methods that, in the process of removing rubber, also have a positive effect on pavement microtexture. Thus, the report takes the approach that the overarching purpose of runway pavement maintenance activity is to restore skid resistance, not just remove rubber deposits. This fits well with the philosophy of the Foundation for Pavement Preservation, which advocates that public transportation agencies, including airport authorities, should "place the right treatment, on the right road [in this case runway], at the right time" (Galehouse et al. 2003).

Thus, this report synthesizes existing research and airport practices into a "toolbox" approach to runway rubber removal that would alter the definition of success from one that is process-oriented, *the removal of rubber*, to one that is performance-oriented, *the restoration of skid resistance*. Although this is a subtle shift in runway pavement maintenance philosophy, the implication for airport safety is huge. An airport can and, as will be seen in this report's case studies, often does remove all the contaminants from a given runway to the specified standards and is still not able to achieve acceptable friction values. To implement this philosophy, the airport operator may consider various methods that are discussed in this report merely as "tools" in the runway skid resistance maintenance "toolbox" rather than focus on a single method as the only solution for the airport's rubber removal requirements. With this attitude, the airport pavement manager can then evaluate the given problem and select the correct tool or set of tools that allows the skid resistance to be restored to the runway. Thus, this shifts the approach to the performance realm and makes the end result fit the real

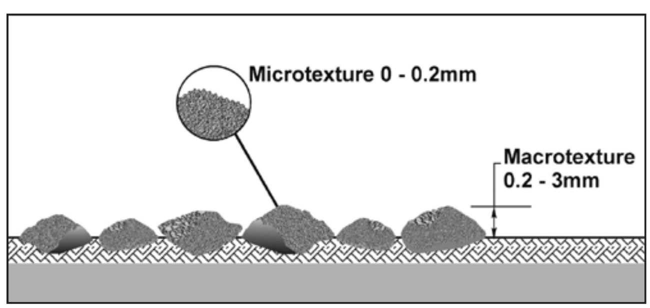

FIGURE 1 Runway pavement surface microtexture and macrotexture.

reason for performing these activities: the maintenance of a safe surface upon which aircraft can land.

A report by TRB Committee A2B07: Surface Properties–Vehicle Interaction appears to support this notion when it lists the following as important initiatives for the new millennium:

- Joint international programs to harmonize both texture and skid-resistance measurements;
- Development of improved friction surface treatments such as shot-peening [referred to as *shotblasting* in this report]; and
- Preparation of new standards … related to friction, texture, and roughness measurements (Yager 2000).

All three of these initiatives speak to the idea that managing surface texture is important for airport safety. The same report goes on to say that "new technology, such as lasers and computer processing and analysis software, have made pavement texture measurements much more accurate and less time consuming to obtain." Thus, it appears that technical tools are available for those airport pavement managers who are ready and willing to use them.

RUNWAY RUBBER REMOVAL BACKGROUND

FAA AC 150-5320-12C provides airport operators with guidance on how to construct, maintain, and measure skid-resistant airport pavement surfaces. The circular describes common rubber removal techniques and furnishes some guidance on their implementation. Every aircraft landing creates rubber deposits that accumulate primarily in the touchdown and braking areas of a runway (Apeagyei et al. 2007). These deposits build up over time and ultimately reduce surface friction. One author describes the issue in these terms:

> As rubber accumulates on a pavement surface, both the microtexture and the macrotexture are progressively reduced. This is not a problem during dry weather operations since the adhesional component is markedly increased [due to the rubber on rubber interface]. … However, during wet runway operations, the net frictional level is drastically reduced (McKeen et al. 1984).

Maintaining runway skid resistance is imperative to aircraft safety. The use of grooved runways provides an increased level of safety by furnishing enhanced drainage through increased pavement macrotexture, which reduces the potential for hydroplaning when runways are wet. To maintain this characteristic, the grooves must remain open. Groove deterioration over time not only reduces skid resistance but also decreases the grooves' desired drainage capability. A study of runway groove deterioration found that "the most serious distresses associated with groove deterioration were wear, groove closure, and rubber deposits," and "grooves in touchdown and braking areas are the most seriously damaged" (Apeagyei et al. 2007). Thus, periodic removal of rubber deposits is required to maintain a safe landing and braking surface. A narrative summary of significant rubber removal research is contained in Appendix D.

Rubber Removal as an Art Versus a Science

This synthesis study was initiated because a number of airports have concerns that rubber removal operations were damaging runway pavements. Therefore, the runway skid resistance problem becomes one of removing contaminants that are deleterious to friction without further damaging the surface structure that provides the physical properties that enhance surface friction. There are a number of generally accepted rubber removal methods, and each produces somewhat different results. Furthermore, the actual end-product quality of each rubber removal method can vary from operator to operator. Highly experienced operators who are familiar with their equipment are able to remove the required amount of rubber without causing unintended damage to the surface. On the other hand, a less experienced or less diligent operator using the same equipment can inflict a great deal of damage to the surface, grooves, joint sealant materials, and ancillary items such as striping and runway lighting merely by lingering too long in one area or failing to maintain a proper forward speed. Figure 2 is an example of what can happen to runway grooves if high-pressure waterblasting is not conducted by an experienced contractor whose equipment operators are well trained.

A number of the methods rely on proprietary equipment and processes that make it difficult to standardize specifications for effective rubber removal. This has led to the attitude that runway rubber removal is an art that cannot be easily defined by a set of rigorous, repeatable engineering specifications. It also leads to the idea that there is only one way to conduct these operations, and that is the way that has been successfully used in the past. This is not to dismiss the importance of empirical experience in the design and execution of rubber removal operations, but rather to highlight the idea that if an airport operator believes that there is only one way to successfully remove rubber at its airport, then it may be missing the opportunity to accrue the potential benefits of methods it has never used. In addition, if the success of a given method is highly dependent on equipment operator competence, the loss of a single equipment operator or contractor could conceivably change the outcome of the chosen rubber removal method.

It is the engineer's responsibility to document the physical properties of a given technology that promote the required performance characteristics. This theoretically creates a situation in which the technical process can be successfully replicated without regard to who or what is used to achieve the desired end state. This documentation can be articulated

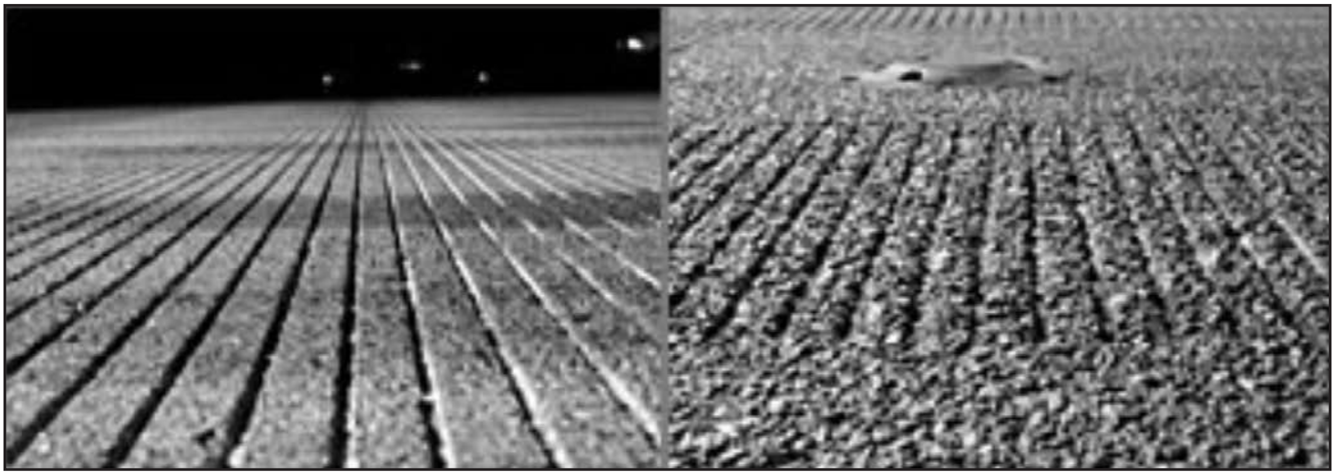

FIGURE 2 Runway grooves, before and after improperly conducted waterblasting.

in either prescriptive or performance terms. Prescriptive specifications are in essence recipes for performing a given task. If the operator diligently follows the recipe, the outcome will achieve the required level of quality. Performance specifications describe the required end state and allow the contractor to achieve it in any manner that furnishes the requirement within any technical constraints that have been established. Thus, rubber removal can be defined in either prescriptive terms or performance terms. A prescriptive rubber removal specification would normally contain the following specifics:

- One or more acceptable rubber removal methods;
- Constraints regarding production rates, closure times, etc.;
- A measure of desired rubber removal, such as 85% by number of rubber grains per measured square.

A performance specification would normally concentrate on furnishing a performance measure, such as a final required friction value, and allow the rubber removal contractor to select the means and methods it will use to achieve the performance criteria. In both cases, the success of the operation is measured by a rational metric and can be reliably replicated. Therefore, the issue becomes one of being able to document and articulate the required end state in objective, measurable terms as well as the technical, operational, administrative, and environmental constraints that must be met to successfully conduct rubber removal operations at a given airport.

KEY DEFINITIONS

In reading this synthesis, it is important that the vocabulary associated with rubber removal and the assurance of quality is clearly understood. Following the References, there is a section that contains a glossary of the technical terms used in the report as well as definitions for acronyms contained in the text. Thus, this section focuses on discussing the key terms that are particularly critical to understanding the work reported here. As such, these key terms are separated into two categories:

- Terms dealing with the rubber removal methods, and
- Terms dealing with runway surface friction.

Rubber Removal Method Terms

The synthesis essentially evaluates four methods of removing runway rubber deposits. Definitions for each along with other commonly used terms that were found in the literature are as follows:

- Waterblasting: This is a process that removes rubber by using water pumped through a rotary device at some specified pressure. The unit moves slowly along the surface to be cleaned. Specifications differentiate between "high pressure" (2,000 psi to 15,000 psi) and "ultra-high pressure" (pressures >15,000 psi up to 40,000 psi). This type of process is also termed "high-pressure water-jet" and "ultra-high-pressure watercutting" in the literature.
- Chemical removal: This is a process that depends on the use of some form of chemical-based compound to soften the rubber deposits and put them in a form that can be separated from the pavement using brushes, brooms, scrapers, or some other tool. The resultant debris and residue are then flushed from the runway using pressurized water. Depending on the environmental regulations in a given area, this process may also include vacuuming the residue for disposal off site in accordance with local regulations. This process is also referred to as a "detergent" or a "foam-based" removal method.
- Shotblasting: This is a process that relies on a machine that propels some form of abrasive particle onto the runway surface and blasts away the contaminants.

There are a number of different proprietary machines that range in pattern width from roughly 6 in. (15.2 cm) to 6 ft (1.8 m). The process involves a system that vacuums the debris, separates the abrasive particles for recycling, and stores the resultant debris for disposal. This process is also referred to as "high-velocity impact removal" and "shot-peening."
- Mechanical removal: This process is defined as any mechanical form of rubber removal that is not covered in the previous three methods. It includes grinding, milling, wire-bristle brushing, scraping with blades, and other mechanical means to remove rubber. "Sandblasting" is also included in this category to differentiate it from shotblasting.

These rubber removal methods are commonly used in the specifications that airport operators write to contract for rubber removal, and it is also important to understand the difference between two types of specifications that are discussed in this report. *Transportation Research Circular E-C037: Glossary of Highway Quality Assurance Terms* (Leahy et al. 2006) furnishes these definitions:

- Prescriptive specifications: "Specifications that direct the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material. Each step is directed by a representative of the highway agency [in this report's context, airport operator]. Experience has shown this tends to obligate the agency to accept the completed work regardless of quality."
- Performance specifications: "Specifications that describe how the finished product should perform over time … [and] specifications that describe the desired levels of fundamental engineering properties that are predictors of performance and appear in primary prediction relationships."

Gibson (1982) states that "performance specifications are also known as 'end result' specifications, while prescriptive specifications are known as 'recipe' specifications." He goes on to contrast the two by saying that a prescriptive specification "describes means as opposed to ends, and [is] concerned with type and quality of materials, method of construction, workmanship, etc." Gibson further states that a performance specification "is concerned with what a … product is required to do, and not with prescribing how it is to be constructed." These definitions are important for the rubber removal process in that airport operators were found to have used both types of specifications in their rubber removal operations.

Runway Surface Friction Terms

As mentioned in the introduction to this chapter, runway pavement microtexture and macrotexture are important to this study. The next definitions deal with the measurement of surface friction on runway pavements. The U.S. Air Force (USAF) *Engineering Technical Letter 04-10: Determining the Need for Runway Rubber Removal* (2004) contains of a table that lists eight different pavement friction testing devices. The use of a "mu value" as the standard surface friction measurement appears to be ubiquitous based on the literature and the survey responses. A device called the "mu meter" that measures the mu value is common enough to have an ASTM test method in practice. In addition, the use of the surface friction tester (commonly called the Saab friction tester or Saab friction test vehicle) is also very common. This is a different test method than the mu meter, and the reader must be careful to differentiate between the two when interpreting runway surface friction measurements. In addition to these, there are a number of other commonly used devices for measuring friction. Table 1 contains a list of different friction measurement devices and the corresponding trigger levels where rubber should be removed.

SYNTHESIS METHODOLOGY

This report is the result of an intersection between a comprehensive literature review, a national survey of both public and private organizations with runway rubber removal experience, information gained from a set of case studies, interviews with both airport authorities and rubber removal contractors, and a content analysis of a sample of runway rubber removal specifications that are currently in use across the nation. This methodology allowed not only for the collection of information on runway rubber removal

TABLE 1
FRICTION-LEVEL CLASSIFICATIONS FOR RUNWAY PAVEMENT SURFACES USING CONTINUOUS FRICTION MEASURING EQUIPMENT WITH SELF-WETTING SYSTEMS (USAF 2004)

Test Device	65 km/h (40 mph)		95 km/h (60 mph)	
	Action Level	Planning Level	Action Level	Planning Level
Airport surface friction tester	0.50	0.60	0.34	0.47
BV-11 skiddometer	0.50	0.60	0.34	0.47
Grip tester friction tester	0.43	0.53	0.24	0.36
Mu meter	0.42	0.52	0.26	0.38
RUNAR (operated at fixed 16% slip)	0.45	0.52	0.32	0.42
Runway friction tester (M 6800)	0.50	0.60	0.41	0.54
Safegate friction tester	0.50	0.60	0.34	0.47
Tatra friction tester	0.48	0.57	0.42	0.52

policies and procedures across the nation by means of the standard survey but for a confirmation of those findings through a rigorous analysis of runway rubber removal specifications and the information provided by the case study airports and contractors. The literature allows the findings from the other research instruments to be put in a global context to identify trends and similarities and capture the state of the art in the more general topic of managing runway skid resistance maintenance. The triangulation of these methods allows identification of emerging commonly used practices in this area.

Before describing the details of the research methodology, the relative importance of the various research instruments should be understood. As runway rubber removal is used throughout the North American airport industry, the general survey responses are probably the most important and would be expected in a typical TRB synthesis report. In addition to the airport operators, this study surveyed runway rubber removal contractors, which furnishes a back-check on the reported efficacy of each method from the perspective of the people who are actually doing the work. However, as both sets of survey responses can best be characterized as anecdotal, the study went beyond the typical synthesis literature review and survey to conduct two additional analyses: the case study interviews and the content analysis of runway rubber removal specifications. These helped develop lines of converging information with the literature review and the survey responses by furnishing a quantitative analysis of how airport authorities are actually applying the various methods to the runway rubber removal process. These furnished valuable insight into the perceived impact of each rubber removal method on grooved as well as other types of runway pavements. Thus, the study gives the greatest weight to the output from the survey responses and specification content analysis as they intersect with the literature review and uses the case study and interview output to validate conclusions drawn by those intersections.

Research Instruments

As stated above, the synthesis used a variety of research instruments. In addition, it surveyed both airport operators and members of the rubber removal industry. These members consisted primarily of contractors but also included material suppliers, equipment manufacturers, and a rubber removal consultant. It was recognized that the responses from the industry members would no doubt include a proprietary bias; however, the juxtaposition of airport operators' opinions versus those of their contractors furnishes an interesting and valuable contrast and, as is seen later, substantiates some of the more important conclusions of this study.

Airport Operator and Rubber Removal Industry Surveys

Surveys were issued to airport operators and members of the rubber removal industry; an overall response rate of 33% was achieved (see Appendix A for details of both surveys). A total of 41 complete and 8 partial responses were received. The survey respondents were from 33 airports in 21 states, plus the District of Columbia, 2 Canadian provinces, and 1 New Zealand province. Industry responses came from 12 companies, of which 4 were international. The domestic industry responses covered a total of 11 states and 1 Canadian province, as well as Australia, Canada, Germany, and New Zealand; 2 respondents indicated that they worked in Europe and Asia, which totals North American geographic coverage of 24 U.S. states, plus the District of Columbia and 2 Canadian provinces. Figure 3 illustrates the geographic coverage of the responses, and one can see that the ultimate population provides a reasonable representation of the national experience with runway rubber removal. It should be noted that there were overlapping responses from airports and contractors in 8 states. Thus, the specific survey responses can be analyzed from two perspectives in those areas. Finally, there were 5 responses that indicated that they could not complete the survey for a variety of reasons.

Using 100,000 arrivals as the standard to differentiate between large and small airports, the survey response had 24 large airports and 9 small airports. Also, arbitrarily using a line that extends from the southern borders of Virginia, Kentucky, Kansas, and Utah that then extends through Nevada and California as the demarcation between "northern and southern" climates; it also had 24 northern airports and 9 southern airports. These give the results a good cross section of both size and climate zones. One can also see a similar distribution to the contractor responses in Figure 3.

The majority of the survey respondents had more than 5 years of rubber removal experience, making their responses authoritative; 88% rated themselves as either "familiar" or "very familiar" with runway rubber removal. Survey respondents reported using all four runway rubber removal methods of interest in this study, with the majority having experience with either waterblasting or chemical removal. Figure 4 shows the geographic distribution of airport respondent rubber removal experience. It shows their current method(s) and methods they have used in the past and for which they furnished data. In some cases, airports are currently using more than one method in their routine rubber removal program. Finally, the airports that responded had experience with in-house rubber removal, contract rubber removal, and in some cases a combination of both.

Case Studies and Interviews

The surveys contained a question asking respondents to furnish case studies based on their experiences with more than

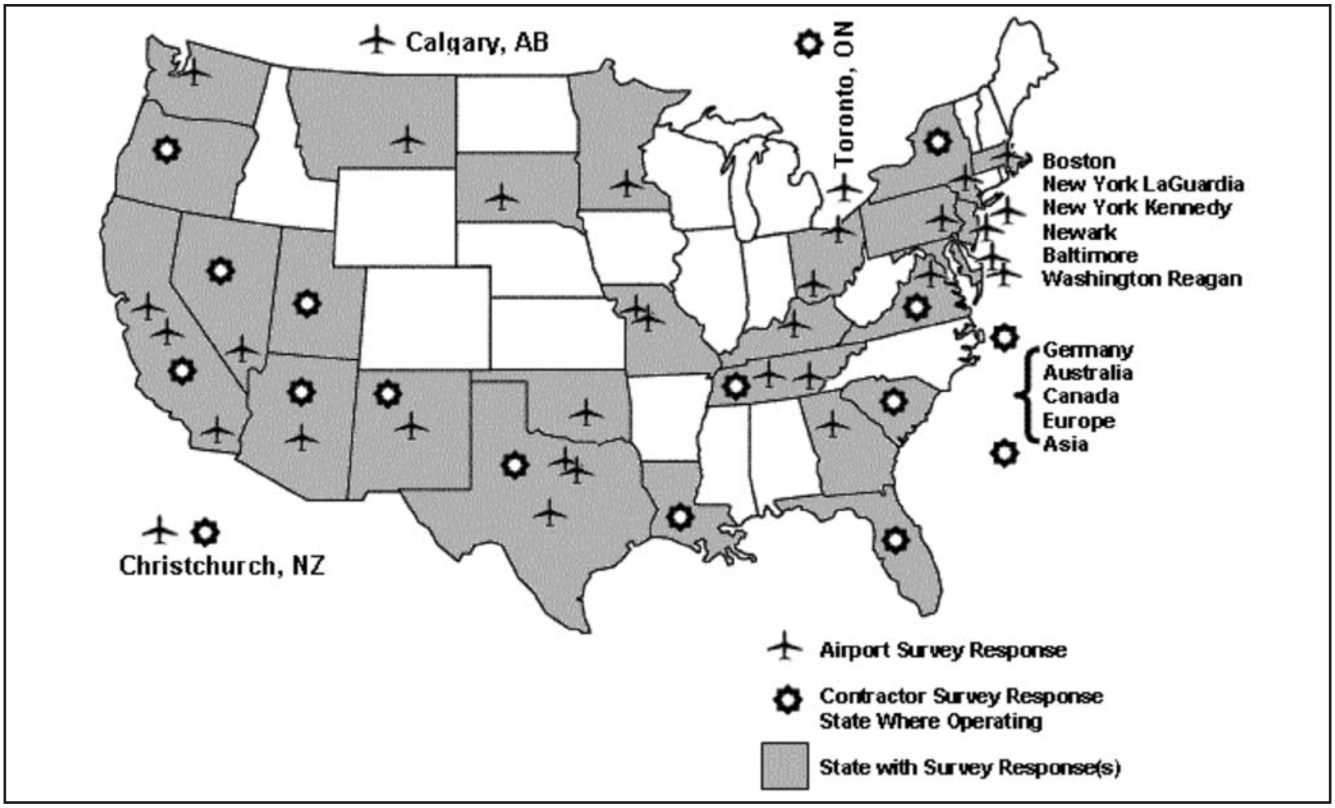

FIGURE 3 Geographic distribution of survey responses from airport operators and contractors.

one rubber removal method. Six airports agreed to an interview. They ranged from a small airport in Billings, Montana, to the Dallas–Fort Worth International Airport in Texas. In addition, case studies for each of the rubber removal methods covered in this study were obtained, including two types of waterblasting, two types of shotblasting, and an airport that uses its snow and ice removal equipment to mechanically remove rubber as part of its routine snow and ice removal program. Case studies were developed from both northern and southern airports as well as airports on both coasts and

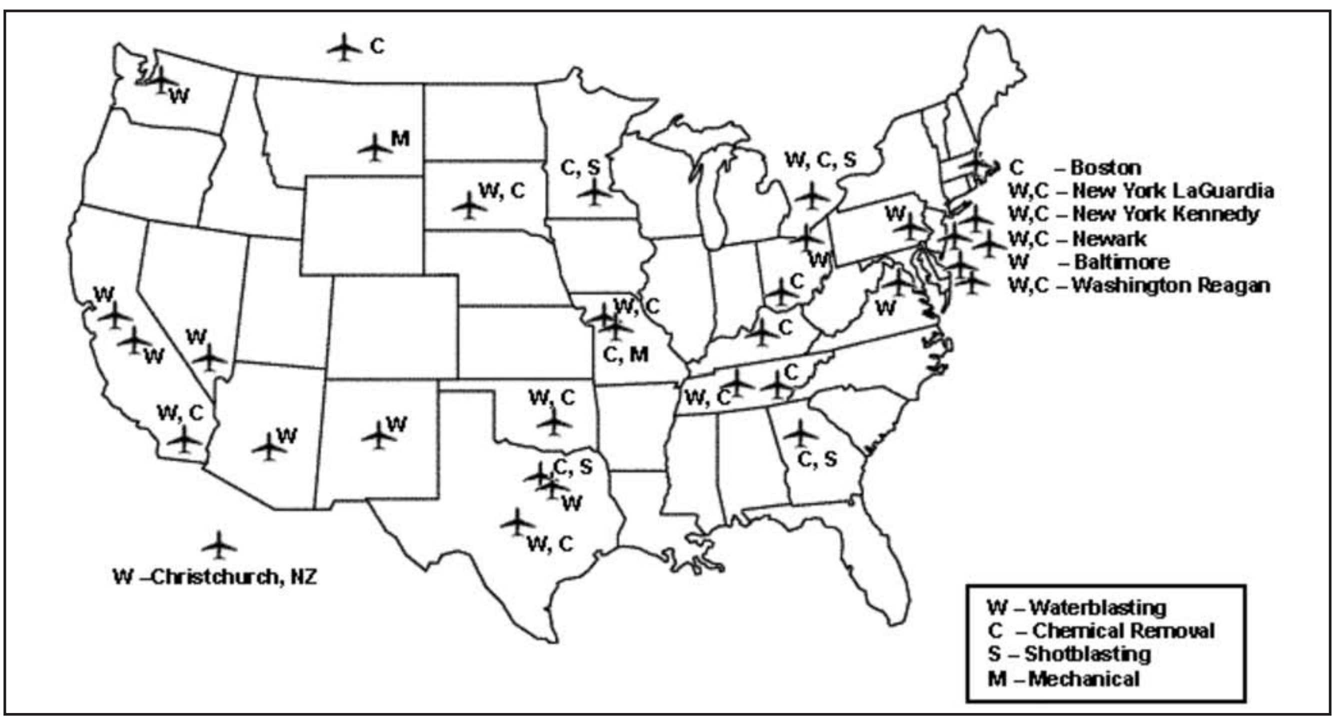

FIGURE 4 Geographic distribution of rubber removal method experience from airport respondents.

an airport in New Zealand, providing a climatic diversity within the case study population as well. In addition to the airport case study interviews, five rubber removal contractors, representing all the rubber removal methods except mechanical, were also interviewed.

The case studies were collected using a rigorous methodology developed by Yin (2004) based on the following three principles of case study research data collection:

1. Use of multiple sources,
2. Creation of a database, and
3. Maintaining a chain of evidence.

During the effort, it was acknowledged that single sources provide limited data and can create difficulty when drawing results, in addition to a lack of "trustworthiness and accuracy" (Yin 2004). Multiple sources help alleviate lack of trust, increase viability, and frequently provide supplementary realms of thought and research that strengthen the results. Therefore, the information gleaned from the case studies is coupled with information collected in the survey and the literature review to validate any conclusions drawn from the case study interviews. Note that the case study information was gathered by both face-to-face and telephone interviews. Both airport officials and rubber removal contractors were interviewed. A visit was paid to a manufacturing facility of a shotblasting equipment manufacturer and a detailed view of that particular process and the equipment used to conduct it was acquired. Not all the interviews resulted in the formal case studies that are contained in chapter six. Nevertheless, the data gathered from all the interviews were used to validate trends discovered by the other research instruments.

Rubber Removal Specification Content Analysis

One of the research instruments used in this synthesis consisted of a content analysis of 23 runway rubber removal specifications from 15 different sources in 8 states plus 3 U.S. military departments, NASA, and Transport Canada. In addition, these included specifications provided by 8 airports and 4 rubber removal contractors. This content analysis consisted of gathering and reviewing specifications for rubber removal from both airport operators and members of the rubber removal industry. Formal content analysis furnishes quantitative measurements of rubber removal requirements for both performance and prescriptive specification elements. They are found by counting the number of times that key rubber removal terms are either cited or expressed in each specification. This type of analysis can be used to develop "valid inferences from a message, written or visual, using a set of procedures" (Neuendorf 2002). The primary approach is to develop a set of standard categories into which words that appear in the text of a written document, in this case a rubber removal specification, can be placed, and then the method uses the frequency of their appearance as a means to infer the content of the document (Weber 1985). Thus, in this study, the content analysis consisted of two stages. First, all instances of the key words were found in each document and the context was recorded. Second, that context was used to determine, if possible, to which party in the contract the responsibility for the specified quality of the term in a given context was assigned. This allowed an inference to be made regarding the given owner's approach to rubber removal quality management for a particular method. When the results are accumulated for the entire population, trends can be identified and reported.

The use of this instrument in conjunction with the comprehensive review of the literature and the survey output allowed for the maintenance not only of a high level of technical rigor in the research but also followed Yin's (2004) previously described three principles in the process of research data collection. Again, intersecting the content analysis with the literature, case study, and survey output avoids the problems associated with single sources that lead to a lack of "trustworthiness and accuracy" (Yin 2004).

Commonly Used Practices

Although developing commonly used practices was not the primary purpose of this synthesis, a number have been identified and are organized in logical groups. The definition of a commonly used practice for this synthesis is a method or procedure that was found in the literature and confirmed as applicable through survey responses. The rubber removal specifications whose content was analyzed and the case study interviews are considered as proof of application for purposes of identifying commonly used practices.

Developing Conclusions

The development of the conclusions in chapter seven was done in a systematic manner using the triangulation of different information sources described in the previous section on research instruments. The first step was to relate the conclusions expressed by the authors of the reviewed literature to the output from the surveys, case studies, and specification content analysis, which represent the industry's acceptance of a given application. When a given conclusion from the literature was corroborated by a trend found in the instruments, it was included as a conclusion of this study. Second, trends were looked for from this synthesis study's output that were clear but not necessarily articulated in the literature. Again, if there was more than one source that displayed the given trend, it was included as a conclusion of this study. Finally, the output of the entire study was reviewed to identify gaps in the body of knowledge that should be filled by future research, and these are included as areas identified for future research.

CHAPTER TWO

WATERBLASTING RUBBER REMOVAL TECHNIQUES

INTRODUCTION

Horne and Griswold (1975) reported that waterblasting to remove runway rubber deposits on U.S. airports began in 1973. The motivation at that time appears to be a desire to find an environmentally benign method to replace chemical removal, which was considered "ecologically harmful … to water sheds surrounding airports." Because this method uses water as the agent that removes the rubber, it was seen to be environmentally benign, and in most cases, it does not require environmental permitting in today's regulatory climate. One word of caution regarding the need for permits should be noted, however. One of the case study airports, Dallas–Fort Worth, indicated that, although it used a chemical removal method whose prime agent was completely biodegradable, testing of residue indicated that it needed to be vacuumed and disposed of off site because of the heavy metal content of the rubber deposits themselves, which contain a high level of zinc, among other heavy metals. It would follow that a similar issue might be raised with the residue of waterblasting. In the airport survey, 8 of the 22 airports that used waterblasting cited "no environmental permit required," and the same 8 also checked "probability of pollution minimized" as two of their reasons for selecting waterblasting to remove rubber. Two of those airports cited this as their major reason for using the technology.

WATERBLASTING ADVANTAGES

The literature contains ample information regarding the advantages of waterblasting rubber removal. However, one has to be careful to look for intersections of the same information in two or more sources because much of the published information on rubber removal methods is commercial. Given that caution, the following are the major advantages found in the literature for using waterblasting to remove rubber deposits from runway pavements:

- Process speed: range 900 to 1,950 yd^2/h (743 to 1,641 m^2/h; Horne and Griswold 1975; USAF 1997; Speidel 2002; Pade 2007).
- Reasonable cost (McKeen and Lenke 1984; NASA 1993; Cenek et al. 1998; Speidel 2002; Waters 2005).
- Environmental compatibility (Horne and Griswold 1975; McKeen and Lenke 1984; Fwa et al. 1997; NLB 2007; Pade 2007).
- Ease of getting rubber removal equipment off the runway in the event of an emergency (Speidel 2002; Waters 2005; Cotter et al. 2006; Pade 2007).
- Improved pavement friction owing to improved microtexture (Toan 2005; Waters 2005; Pade 2007).

Figure 5 confirms the first advantage found in the literature. One can see that after "satisfaction with final product," "speed of operation" is the reason cited most frequently by the airports with waterblasting experience. Cost was also cited as a reason to choose waterblasting, which confirms the second advantage. Environmental compatibility is also confirmed by the survey. The previously mentioned issue of residue disposal may account for why the number is lower than would be expected based on the literature. "Minimizes impact on operations" correlates with the third advantage and was confirmed in the survey. Finally, three airports indicated that the method's ability to retexture in addition to cleaning the rubber confirms the last advantage.

In addition to the advantages cited in the literature, the survey showed that availability of competent waterblasting contractors was the third most important reason to airport operator officials. One airport uses in-house personnel and low-pressure waterblasting equipment. Finally, one airport used both in-house and contract resources. Roughly one-third of the airports indicated that they use waterblasting because of a "low probability of pavement damage."

Looking at the rubber removal contractor survey responses, roughly half cited "low probability of pavement damage" as the major reason an airport operator should select waterblasting. One indicated "minimizes impact on operations," and stated that it could clear the runway of its waterblasting equipment within 3 min of an order by the tower to do so. Another contractor cited "cost" as the major reason. In the remarks block that went with the question, one respondent indicated that environmental compatibility might be another reason after reduced pavement damage potential. Therefore, it can be seen that both the airport operator and contractor respondents agree with the advantages cited in the literature.

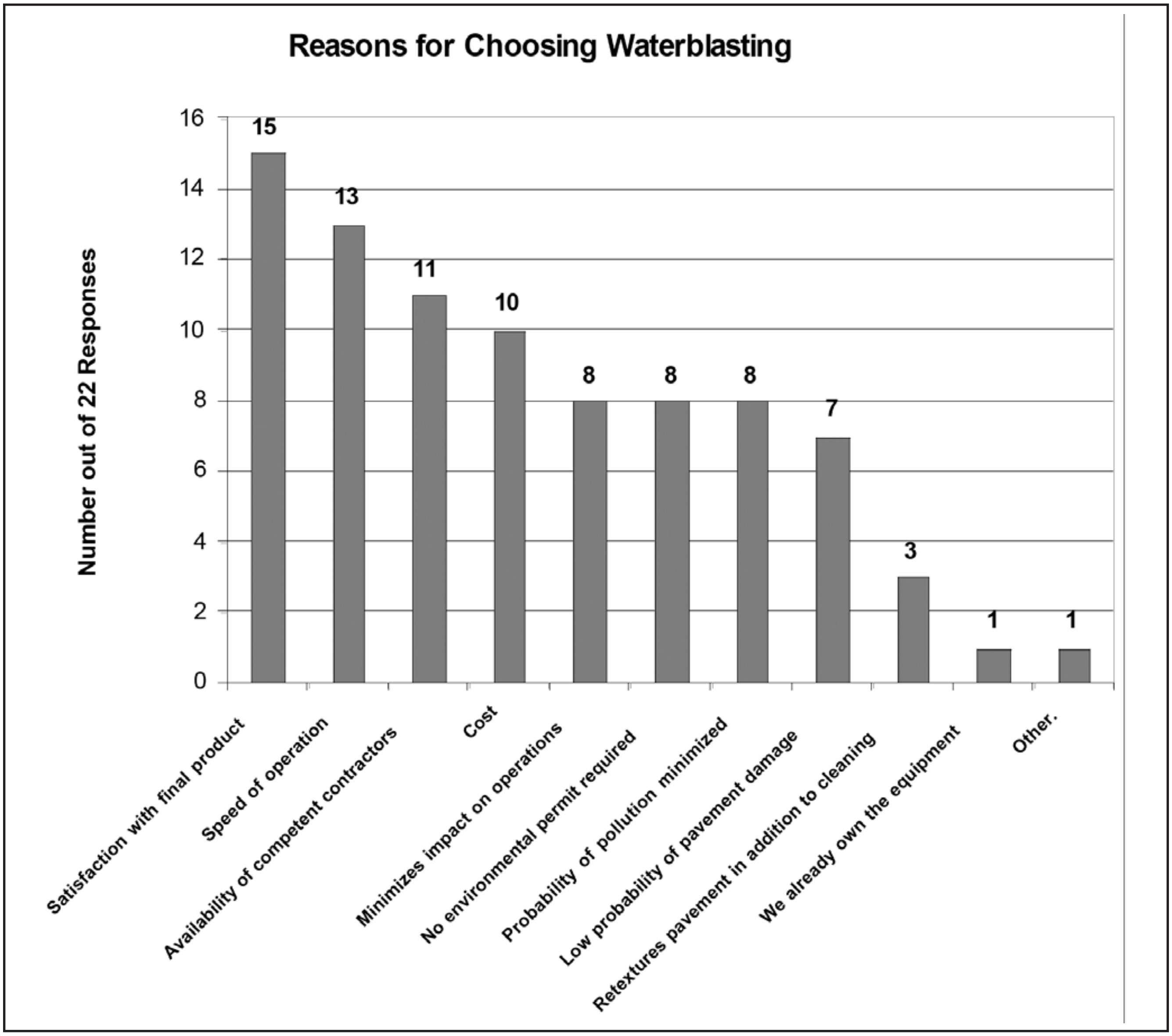

FIGURE 5 Airport operator survey responses for reasons for choosing waterblasting (Note: airports were allowed to check more than one reason).

Waterblasting Porous Friction Courses

Before getting into the disadvantages of waterblasting, an additional advantage of waterblasting that was supported by only a single citation in the literature needs to be discussed. Some airports in the United States and overseas use a surface layer of open graded asphalt as a friction course instead of grooved pavement. At one time, this was favored over grooving because it reduced the amount of tire damage that was incurred in landings (Bailey 2000). This application is commonly called a "porous friction course" (PFC). A recent research report on PFC stated that, "If sufficient rubber exists on a PFC surface, water may pool on the rubber leading to an increased potential of hydroplaning" (Cooley et al. 2007). However, the PFC's open graded matrix made rubber removal "barely feasible from this type of surface" (Bailey 2000) because most methods destroyed the drainage characteristics that were inherent to the PFC. An FAA research report on the subject of removing rubber from PFCs found that "the only method known to satisfactorily remove rubber deposits from PFCs is the high pressure water method" (McKeen and Lenke 1984). This report cites a maximum allowable water pressure of 8,000 psi (55 MPa). It also states that the PFC must be "properly constructed in accordance with current specifications" and "not damaged prior to rubber removal." The report also mentions that rubber may have been successfully removed from a PFC by mechanical means using steel-tipped brushes but states that the "details are sketchy."

WATERBLASTING DISADVANTAGES

The literature is remarkably sparse on the disadvantages of waterblasting. Nevertheless, there appear to be four disadvantages that have been mentioned by more than one author. They are as follows:

- Possible pavement damage owing to "polishing" effect on microtexture (Hiering and Grisel 1975a,b; Simpson 1989; Cenek et al. 1998; Speidel 2002; Cotter et al. 2006),
- Damage to grooves in runway pavements (Simpson 1989; Cotter et al. 2006),
- Environmental issue with appropriate disposal of residue (Waters 2005; Pade 2007), and
- Ambient air temperature limitations (Transport Canada 2003c; Cotter et al. 2006).

Impact on Microtexture

The first disadvantage contradicts one of the advantages reported in the previous section. None of the authors cited laboratory evidence to support their statement that "polishing" occurred in conjunction with waterblasting. Thus, as is seen in the section on waterblasting technologies in Appendix C, this assertion of fact was proven to be untrue by rigorous laboratory testing by Waters (2005). Hiering and Grisel (1975a,b) specifically looked for polishing after waterblasting based on an unnamed Canadian report, but found none in their trials in South Carolina and Texas. Only one of the airport survey waterblasting respondents indicated that it had experienced polishing, but it qualified the statement by indicating that polishing was observed in pavements that were greater than 6 years old. This leads one to the question of whether the reported polishing is directly related to the waterblasting or merely the normal polishing as a result of traffic that is found in all pavements as they age. In another vein, the cited work by Waters (2005) was on aggregates found in New Zealand; therefore, the polishing reported at one U.S. airport may be a function of the type of aggregate used in its runway pavements. Thus, it is conceivable that waterblasting could have a deleterious effect on some types of pavements while having a beneficial effect on others. This is intuitive in that it is known that soft aggregates lose their microtexture faster than hard aggregates.

Runway Pavement Damage

The next disadvantage, groove damage, is the prime focus of this synthesis. The surveys contained questions that specifically asked for the incidence of groove damage observed in conjunction with waterblasting. The survey also asked airports to report any other damage to the pavement and the runway appurtenances that may have been observed in their experience. Figure 6 shows that roughly one-third of the respondents reported runway groove damage after waterblasting. Of those, five of six airports experienced groove damage on asphalt pavements. Oklahoma City, one of the case study airports, experienced groove damage on a concrete pavement. It had been successfully using waterblasting on its concrete runways without problem prior to rehabilitating its main runway. The damage it experienced was on the newly repaved concrete runway, which the interviewee described as "green." The damage (surface spalling) was so severe that it discontinued waterblasting and now uses chemical removal (see chapter six for details). Thus, this incidence of groove damage should be taken as an anomaly.

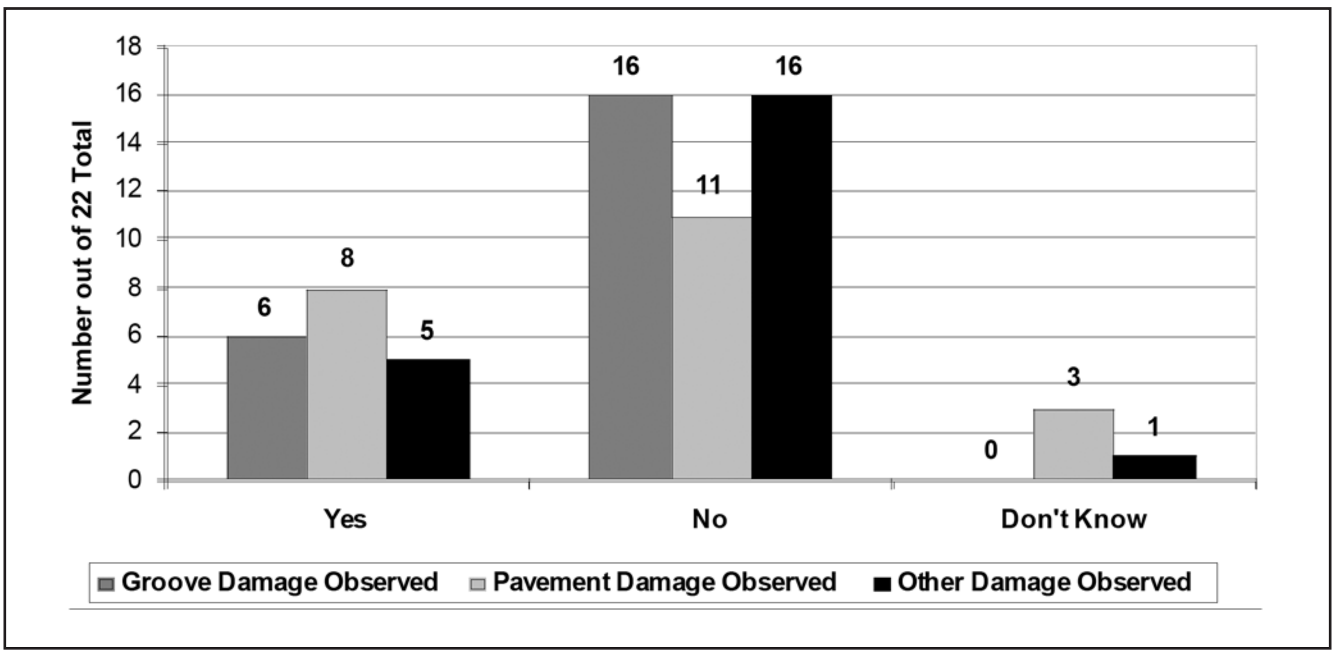

FIGURE 6 Airport operator survey responses for runway damages owing to waterblasting.

Another case study airport, San Francisco, ascribed the groove damages observed during waterblasting as "some groove edge deterioration" and stated that it "cannot be accurately correlated with high-pressure waterblasting." Another airport response indicated that groove damage occurred only if the water pressure exceeded the specified limit, and Christchurch, New Zealand, indicated its groove damage was "minor" and less damage was observed on "older mixes." Thus, five of six respondents with groove damage had some logical explanation for the damage. This, and because two-thirds of the population reported no groove damage leads to the conclusion that when waterblasting is done correctly, groove damage is not likely. This conclusion is supported by the rubber removal contractors' responses. Three of six reported having caused groove damage, but all three indicated that the damage was minor.

The survey also asked the respondents to report types of pavement damage observed other than groove damage. Figure 6 shows that eight airports indicated that waterblasting caused other pavement damage. One stated that pavement damage resulting from waterblasting occurred "only on asphalt surfaces that were old or had faulty areas." Two airports reported surface damage or minor loss of aggregate, and another two experienced damage to expansion joints and sealed cracks. One of the airports attributed the pavement damage to operator error or inexperience. Finally, the survey asked for damage to ancillary runway items. Damage to and dimming of runway lighting as well as runway markings was reported. Three of the five respondents cited loss of fines in this category. The contractor responses were mixed, and those that did admit to causing damage indicated that it was minor. Table 2 is a summary of the types of damage that either were reported in the survey or were cited in the literature.

TABLE 2
POTENTIAL DAMAGE FROM WATERBLASTING

Possible Damage	Survey Airports Reported (*n*)	Literature Citations Reported
Groove damage	6	Simpson 1989; Cotter et al. 2006
Microtexture degradation (polishing of aggregates)	1	Hiering and Grisel 1975; Simpson 1989; Cenek et al. 1998; Speidel 2002; Cotter et al. 2006
Spalling of concrete	1	NA
Damage to expansion joints and crack seal	2	NA
Damage to patches	1	NA
Damage to runway lighting	2	NA
Loss of aggregate/ fines	5	NA
Damage to paint/ markings	1	NA

NA = not available.

Residue Disposal

As previously discussed in the introduction, one of the case study airports found that the residue from rubber removal operations can be a hazardous material even if the agent used to remove the rubber is environmentally benign, owing to the heavy metal content of the rubber deposits themselves, which contain a high level of zinc, among other heavy metals. Thus, this would appear to confirm the disadvantage cited in the literature regarding environmental issues. Some airports listed "no environmental permit required" and "low probability of pollution" as reasons why they use waterblasting. One of the contractors cited "no environmental impact" as a reason an airport should use waterblasting. Thus, the survey appears to contradict the literature, and no conclusion can be reached on this issue.

Ultra-High-Pressure Waterblasting Variations

There appear to be two variations within the ultra-high-pressure (UHP) waterblasting category. The difference is the effect the process has on restoring surface microtexture. The first is generally called UHP waterblasting and has no reported ability to restore pavement microtexture. The literature contains several references to the belief that this technology may reduce microtexture (Spiedel 2002). For example, one report states, "It is known that the use of the ultra high pressure water method causes polishing of the aggregate…" (Cotter et al. 2006). The second is a New Zealand technology that is called UHP watercutting. When this was developed, the inventors chose to call it waterCUTTING to differentiate it from waterblasting as it uses a pressurization and distribution technology patterned after UHP water steel-cutting technology. This technology operates in the 36,000 psi (248.2 MPa) range at ultrasonic velocity (Mach 1.5) on the paved surface, and research has shown that it not only restores macrotexture by removing the contaminants from the surface voids, but it also improves microtexture on aggregates that are common in New Zealand (Waters 2005). This finding came as a surprise to the researchers in the cited report who were relying on a previous study that found that "UHP waterblasting removes the road film which clogs microtexture, but probably does not counter stone polishing" (Cenek et al. 1998). Waters (2005) conducted laboratory experiments to test the UHP *watercutter* to see if it would be different from the UHP *waterblaster* cited by Cenek et al. (1998). He found that "laboratory experiments using the Polished Stone Value test polishing apparatus, British Pendulum portable skid tester, and the ultra high-pressure watercutter confirmed that the UHP Watercutter could restore the microtexture of laboratory polished aggregate specimens to a state similar to

TABLE 3
RESULTS OF ULTRA-HIGH-PRESSURE WATERCUTTING (UHPWC) ON AGGREGATE MICROTEXTURE AS MEASURED BY POLISH STONE VALUE (PSV)

Type of Stone [and Source]	Skid Resistance Prior to Accelerated Polishing (Lab PSV Units)	PSV (After Accelerated Polishing as per BS812)	Skid Resistance After UHPWC (Lab PSV Units)
Control	61	52	66
Greywacke (Uriti)	Not tested	55	85
Blue rock (hard rock) [Plimmerton]	Not tested	55	67
Brown rock (overburden) [Plimmerton]	Not tested	64	81
Greywacke (pound rd)	72	57	70
20% rounded faces	72	58	71
Control	62	53	68

Source: Waters (2005).

the unpolished specimens." His findings are shown in Table 3. However, as New Zealand aggregates are generally of the hard igneous variety, it may be that this process will not have a similar effect on other types of aggregates found elsewhere in the world. As of this writing, this technology is only in use in Australia and New Zealand.

Survey Results on Waterblasting Operating Pressures

The survey showed that there was no low-pressure waterblasting in use given the earlier definition. Three airports reported using "low pressure" but were using either 3,000 psi (20.68 MPa) or 5,000 psi (34.47 MPa) systems, which fall into the high-pressure category based on Speidel's (2002) definition. The pressures reported ranged from a low of 3,000 psi (20.68 MPa) to a high of 40,000 psi (275.79 MPa). Table 4 shows the range and average for the two types of waterblasting for the 19 airports that reported waterblasting operating pressures.

Intuitively, one would expect to see lower operating pressures on the asphalt pavements based on references in the literature regarding waterblasting issues during periods with high temperatures (Transport Canada 2004). However, the survey did not bear this idea out. There was no trend discernable in the selection of high-pressure versus ultra-high-pressure waterblasting based on pavement type by the 19 airports that reported their operating pressures. In addition, there was no discernable trend in the use of various operating pressures by large versus small airports, nor was there a difference between airports located in northern climates versus southern climates.

WATERBLASTING SURVEY RESULTS

The survey of airport operators and rubber removal contractors generated good information on the state of the practice in this area. The questionnaires used can be seen

TABLE 4
WATERBLASTING PRESSURES USED BY AIRPORTS IN THE SURVEY

Population: 19 Airports					
High-Pressure Waterblasting (psi)			Ultra-High-Pressure Waterblasting (psi)		
Low	Average	High	Low	Average	High
3,000	7,250	15,000	20,000	31,778	40,000
Concrete Pavement					
High-Pressure Waterblasting 5 Airports (psi)			Ultra-High-Pressure Waterblasting 6 Airports (psi)		
Low	Average	High	Low	Average	High
3,000	6,714	10,000	20,000	30,833	40,000
Asphalt Pavement					
High-Pressure Waterblasting 8 Airports (psi)			Ultra-High-Pressure Waterblasting 6 Airports (psi)		
Low	Average	High	Low	Average	High
3,000	7,357	15,000	20,000	32,200	36,000

Note: 1.0 psi = 0.0069 MPa.

TABLE 5
AIRPORTS THAT REPORTED WATERBLASTING EXPERIENCE

ABQ	CHC	DCA	JFK	MKC	PHX	SFO	YYZ
BWI	CLE	EWR	LAS	OKC	RAP	SJC	
CHA	DAL	IAD	LGA	PHL	SAN	SEA	

in detail in Appendix A of this report. In addition, the consolidated data on waterblasting can be found as a part of Appendix B. There were 22 airports that reported to have either used or are currently using waterblasting to remove rubber from their runways. Table 5 contains a list of those airports. In addition to the information previously reported in this chapter, the survey furnished results in the following categories:

- Seasonality of waterblasting operations;
- Costs;
- Waterblasting operations specifications and performance criteria; and
- Crews and equipment, production rates, and runway closure requirements (see Appendix C for details).

Seasonality

Figure 7 shows the responses from airport operators regarding the months in which they conduct rubber removal by waterblasting. One can see that there are two fairly distinct periods: spring–summer (April through September) and fall–winter (October through March). When the 19 airports that used waterblasting and provided seasonal information were separated and compared by the large airport versus small airport category, the data in Figure 8 are achieved. The Christchurch airport reported doing rubber removal throughout the entire year. However, it is an anomaly in that its traffic is so low that it is able to remove rubber without shutting down its runways by scheduling the waterblaster to work between operations. Because of this, it was removed from the small airport sample in this analysis.

One can see in Figure 8 that the large airports on a percentage basis do more rubber removal in the spring–summer period and that they also continue to remove rubber throughout the calendar year, whereas small airports do most of their rubber removal in April, May, and September. In addition, both large and small airports have the greatest amount of rubber removal activity in the spring months and at the end of the summer. One can postulate that the first period is to get ready for the summer's heavier traffic and higher temperatures and that the second period is to remove the summer's accumulation of rubber deposits before the rain and snow season of the fall and winter. In addition, this confirms the information regarding seasonality found in the literature (Simpson 1989).

When the survey responses are split according to geographic region, one can understand the impact that routine removal of ice and snow has on those airports in the northern parts of North America, compared with those airports in the southern half that do snow and ice removal only irregularly. A trend is very clear in Figure 9. As

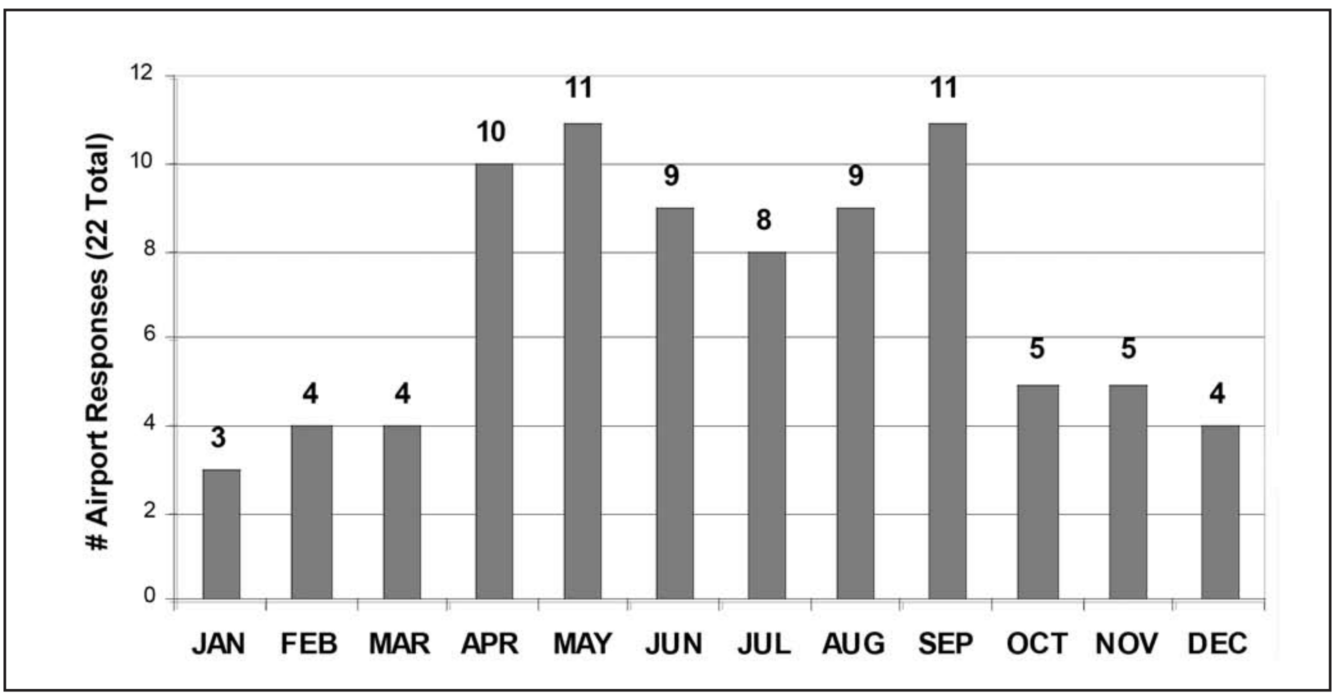

FIGURE 7 Waterblasting seasonality from airport operator survey responses.

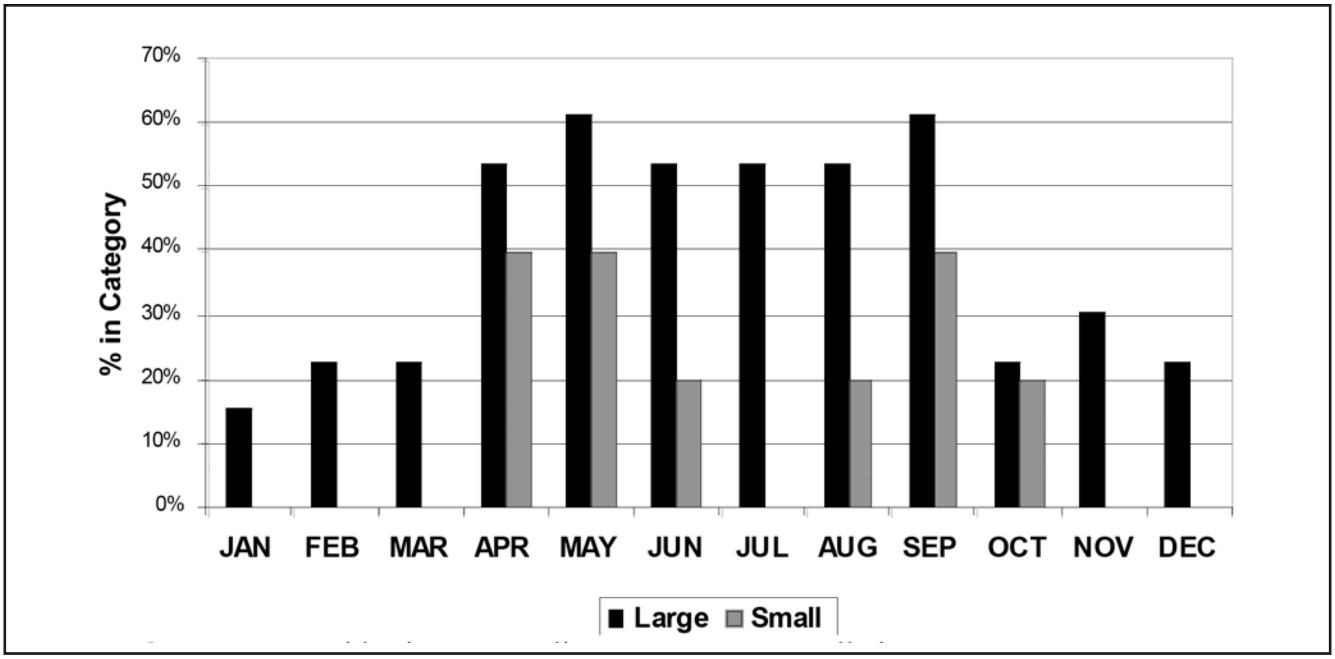

FIGURE 8 Waterblasting seasonality: Large versus small airports.

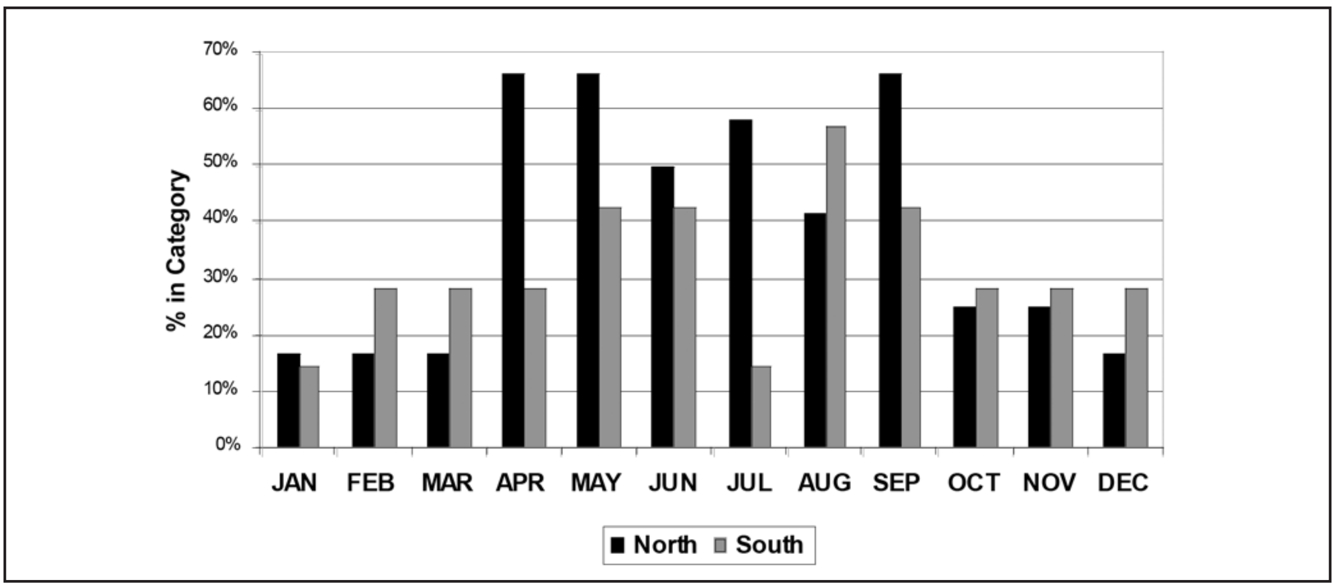

FIGURE 9 Waterblasting seasonality: Northern versus southern airports.

would be expected, the northern airports do more rubber removal during the spring–summer period than do southern airports, and the southern airports are able to spread out their rubber removal more evenly throughout the year. This is interesting in that one of the case study airports (Billings), which is a small, northern airport, found that it was able to dispense with rubber removal entirely by altering the way it conducted its routine snow and ice removal operations during the winter (see chapter six for details). There were three small northern airports in the waterblasting sample. One indicated that it did waterblasting during April and May only, and another reported that it did its rubber removal once a year in September. One of these was geographically close to Billings, and it is interesting to note that it did not need to remove rubber until the end of the summer. Although there are no data to support it, this leads one to speculate whether this airport also benefits from its winter snow and ice removal operations because it does not remove rubber in the spring, as do most of the other airports in the population.

TABLE 6
WATERBLASTING UNIT COSTS (2007 US$)

Airport Reported Unit Costs ($/yd^2) (*M*)			Contractor Reported Unit Costs ($/yd^2) (*M*)		
North America	International	Total Population	North American	International	Total Population
0.71	2.44	0.84	0.60	2.50	1.55
Airport Total Population Unit Costs ($/yd^2)			**Contractor Total Population Unit Costs ($/yd^2)**		
Low	Median	High	Low	Median	High
0.23	0.40	2.44	0.45	0.90	3.05

Waterblasting Unit Costs

Table 6 summarizes the unit cost data collected from both the airport and contractor surveys. The data have been sorted into three different groups. The first is the information from U.S and Canadian sources called North American. Next is the information from international sources, and finally the entire population is grouped as a single data set. One can see that the mean international costs are significantly higher than those from North America. The international responses also indicated lower production rates on the order of about one-third of those cited in North American responses. This may account for the cost being roughly three times higher. No other explanation for the disparity could be found in either the survey data or the literature. Next, Table 6 shows the range of the total population for each group and the median unit cost cited within that range. One can see that the contractor's cited costs are marginally higher than those cited by the airport respondents. When comparing the two groups, one must remember that the contractor population is small, with only 7 data points, whereas the airport population is twice as large, with 13 data points. Therefore, both populations are small, and no statistical inferences can be made, and the statistics shown in Table 6 should be regarded as descriptive, not conclusive.

WATERBLASTING SPECIFICATIONS

Of the 22 airport respondents that used waterblasting, only 1 exclusively conducted waterblasting rubber removal with in-house maintenance forces. Two others indicated that they used both contractors and in-house personnel. Thus, with this high level of contracting, the issue of specification writing is particularly critical for airports that use this form of runway rubber removal.

Survey Data on Waterblasting Specifications

As discussed in chapter one, this field uses both prescriptive and performance specifications. Prescriptive waterblasting specifications will typically contain limitations on operating pressure, a quantified amount of rubber to be removed, and some verbiage regarding pavement surface damage. They can also contain production-related restrictions, such as a minimum required production rate in area per unit time or a maximum time limit for runway closure. Performance specifications will typically speak to some qualitative or quantitative performance measure, such as friction mu value, that must be achieved after rubber removal. Twenty airports responded to the questions regarding their specifications. Figure 10 shows the responses to the question regarding the type(s) of specification currently in use. Of that group, two exclusively used prescriptive specifications and specified settings and equipment. Another six used performance specifications of one form or another, and nine used a combination of the two. Thus, three-quarters of the sample used some form of performance specification.

Within the group that used performance specifications, eight used a friction value measurement (quantitative performance requirement), and three used visual inspection criteria (qualitative performance requirement). Three had a specified removal rate, and one used a macrotexture measurement. The prescriptive specifications contained a percentage of rubber to be removed that ranged from 85% to 95%. One respondent indicated that they specified operating pressures but found it "very difficult to accurately determine" whether the head was actually operating at the specified pressure.

The seven contractor responses were split between three (all international respondents) that indicated performance criteria use only and four (all North American respondents) that stated that airports use both performance criteria and

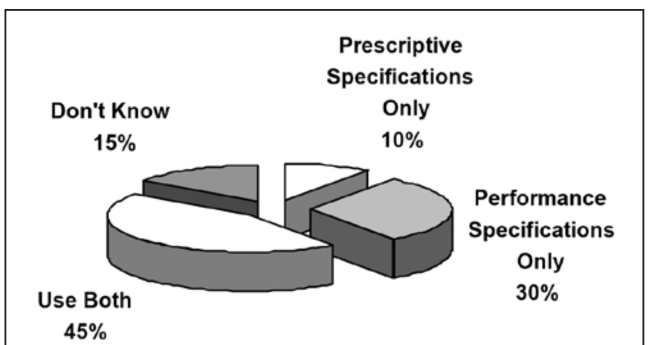

FIGURE 10 Waterblasting specification usages by airports.

prescriptive specifications in their rubber removal contracts. Of the three performance criteria responses, two cited visual criteria (qualitative) and one cited a friction value measurement (quantitative). The contractors also cited runway closure criteria as common in their contracts of the same 6- to 8-h magnitude as the airports.

Looking at the combination of performance specification use and contractor unit cost data, one can see that the North American contractor's unit costs are in line with those reported by the airports; therefore, it appears that using performance specifications in conjunction with certain prescriptive specifications does not have a negative impact on the cost of contracted rubber removal.

Waterblasting Specification Content Analysis

A formal content analysis was also conducted and is described in the first chapter on 12 sets of waterblasting specifications from five airports, three rubber removal contractors, four U.S. government agencies, and one Canadian government agency. It should be noted at this point that not all of the specifications included all of the items in the content analysis. Some were more comprehensive than others. The content analysis for this rubber removal method was divided into three categories:

1. General and equipment specifications,
2. System and environmental constraints, and
3. Specification type.

Table 7 shows the results of the first category's content analysis. A number of interesting aspects are revealed in the table. First, in most cases the specification writers do not differentiate between concrete and asphalt pavements. Transport Canada (2003a) does specify different pressures for high-pressure waterblasting on concrete versus asphalt pavements. All the specifications that listed the contract payment mechanism were unit price contracts that paid by the area cleaned. In this form, there is an inherent incentive to remove as much rubber as possible because the contractor gets paid by the area. All but one specification contained technical requirements for the waterblasting machine itself, which essentially described the allowable technology. This effectively restricts the use of an untried technology without the owner's permission. Finally, roughly half of the specifications required a minimum emergency evacuation time. This correlates with the advantages cited for waterblasting in the literature. It is also interesting to note that two airports also specified a set of minimum contractor qualifications. One was a case study airport, San Francisco, which indicated in the interview that damage problems at the airport were related to operator error.

The next category involved specifications related to the waterblasting system and the environment in which waterblasting was permitted to take place. Table 8 shows the outcome from this analysis. One can see that most of the specifications required the contractor to conduct some sort of trial or test strip before allowing full-scale rubber removal to begin. Most of these required the test to be conducted in daylight. This allows both the contractor and the owner to observe the results of calibrating the waterblasting and furnishes an extra measure of quality control for when the same operations must be conducted after dark. Half of the sample specified weather constraints of some sort. In a nutshell, they required the rubber to be removed in generally "dry" conditions when air and surface temperatures were above freezing and there was no danger that the water used in the process

TABLE 7
RESULTS OF WATERBLASTING SPECIFICATION CONTENT ANALYSIS: GENERAL AND EQUIPMENT SPECIFICATIONS

Specification Item	Specifications in Which Found (*n*)	Remark
Type of pavement specified	8	7 of 8 applied to both asphalt and concrete
Type of contract	8	All were unit price
Contractor qualifications	2	BWI & SFO required minimum of 3 years' waterblasting experience
Hours of operation	5	All required rubber removal at night
Allowable runway closure period	3	Typically 6 to 8 h
Allowable water pressures	6	3—high-pressure waterblasting 2—ultra-high-pressure waterblasting
High pressures	4	<6,000 psi (41.4 MPa) NASA <7,000 psi (48.3MPa) SFO <8,000 psi (55.2 MPa) U.S. Navy <6,961 psi (48 MPa) Canada—concrete <5,076 psi (35 MPa) Canada—asphalt
Ultra-high pressures	2	30,000–40,000 psi (207–276 MPa) BWI 10,000–30,000 psi (69–207 MPa) MIA
Equipment specifications	11	Most describe requirements for waterblaster
Emergency evacuation requirements	5	Typically 3 min from notification

Note: There were 12 specifications analyzed.

TABLE 8

RESULTS OF WATERBLASTING SPECIFICATION CONTENT ANALYSIS: SYSTEM AND ENVIRONMENTAL CONSTRAINTS

Specification Item	Specifications in Which Found (*n*)	Remark
Pretest/trial required	10	Describe test strips to optimize rubber removal waterblasting settings and demonstrate effectiveness
Weather general	5	Required to be done in "dry" weather
Air temperatures	6	5 required > 40˚F (4˚C); 1 Canada > 50˚F (10˚C)
Surface temperatures	4	3 required > 35˚F (2˚C); 1 required > 40˚F (4˚C)
Wind constraints	1	9 mph (15 kmph)
Minimum production rate	10	Average = 1,290 yd^2/h (1,079 m^2/h)
Debris removal required	9	5 required vacuuming and disposal of wastewater
Use of chemicals, abrasives forbidden	4	Cite environmental issues

Note: There were 12 specifications analyzed.

would freeze before it was removed from the site. The Canadian specification also required that wind conditions be low. Most of the specifications required a minimum production rate to ensure that a full runway touchdown zone could be completed in a single closure period, and they also required that the debris be removed and disposed of off site. Five also required that a vacuum truck be provided to capture wastewater. Finally, four specifications disallowed the use of chemicals or abrasives in conjunction with the waterblasting, citing environmental restrictions.

TABLE 9

RESULTS OF WATERBLASTING SPECIFICATION CONTENT ANALYSIS: SPECIFICATION TYPE

Specification Item	Specifications in Which Found (*n*)	Remark
Prescriptive specification	6	Remove 85% to 95% of rubber
Performance specifications	4	
Quantitative criterion	4	mu value
Qualitative criterion	3	Visual inspection
Used both types	2	
Other specifications included	8	Generally, means/ methods related

Note: There were 12 specifications analyzed.

The final category dealt with the type of specifications used and the criteria promulgated in those documents (see Table 9). Of the 12 specifications in the sample, 6 were purely prescriptive, 4 were purely performance, and the last 2 used both types. This literally splits the sample in half regarding the use of performance specifications. Of the 4 performance specifications, all used a quantitative performance criterion related to a measured friction value, and most also required a qualitative criterion based on visual inspection. As would be expected, there were also other specifications included in this sample. Most regarded constraints on means and methods, with the requirement to shut off the waterblaster when it was required to stop forward movement to avoid unintentional damage being the most common.

The content analysis confirmed much that was found in the other three research instruments and furnished validation for the identification of commonly used practices discussed in the next section. This analysis must be seen as very authoritative in that the use of a given specification in a rubber removal contract confirms without doubt the use of a given rubber removal practice in this field.

COMMONLY USED PRACTICES

There are four commonly used practices with regard to waterblasting that can be identified on the basis of the criteria established in chapter one. They are summarized as follows:

- Use friction value measurements in performance specifications:

  Thirty percent of the airport survey respondents solely used performance specifications for their waterblasting operations. When this total is combined with the 45% of respondents that use them in conjunction with prescriptive specifications, three-quarters of the airports that use waterblasting also use performance specifications to control those operations. This is confirmed by the content analysis in which half the specifications analyzed used performance criteria. In addition, 95% of waterblasting is done by contractors. Therefore, to ensure that runway friction values are being restored by this method, the majority of airports are promulgating friction value-related performance criteria.

- Use pre-rubber removal test strips or trials to calibrate the waterblaster:

  The survey responses, literature (Berman 1972; Horne and Griswold 1975; Lenke and Graul 1986), and specification content analysis (Table 7; 83% of sample) all contained information that supported the use of a daytime test strip to calibrate a waterblaster for a given pavement. In addition, some airports also use this test strip to create the baseline measurements that will be used in their performance criteria [Transport Canada 2004; U.S. Army Corps of Engineers (USACE) 2006].

- Require minimum production rates:

  Again, this practice derives from the intersection of information obtained from the survey responses, literature (Berman 1972; Horne and Griswold 1975; Cotter et al. 2006), and specification content analysis (Table 7; 83% of sample). Required minimum production rates ensure that the contractor furnishes enough personnel and equipment to be able to complete the necessary rubber removal in the allowable closure period. Analysis of survey responses confirmed that airports customized specifications based upon operational requirements. Thus, a small airport with less rubber to remove does not need the same level of resources that a large airport with a great deal more rubber to remove.

- Develop and use temperature specifications in waterblasting contracts:

  This practice is confirmed by the literature (USAF 1997; Transport Canada 2004; USACE 2006) and the content analysis (Table 7; 50% of sample). In addition, it is reinforced by the findings on seasonality that come from the survey. It is important that the rubber removal technique improve rather that deteriorate the surface condition of the runway. Allowing waterblasting to occur in temperatures when the water may freeze could ostensibly result in a runway closure owing to ice if the waterblaster breaks down during rubber removal. If this happens when the temperatures are not conducive to freezing, then the runway is merely wet and can be used.

In addition, there are two practices that, although they are not confirmed as commonly used, are provided for consideration by airports that use waterblasting to remove rubber from runways. They are as follows:

- At two airports where local procurement regulations permit, these two major airports require waterblasting contractors to meet some set of qualifications. The issue of groove and other runway damage has been linked through the case studies and the literature to operator error or inexperience rather than inherent technological deficiencies. Therefore, it appears logical that the airport would protect itself by ensuring that only experienced rubber removal contractors with well-trained and experienced crews are allowed to bid on their waterblasting contracts.
- The Transport Canada (2003a) specifications differentiate between concrete and asphalt runway pavements in the allowable pressures cited for high-pressure waterblasting. At this writing, there was no U.S. research found to support this, and only the Canadian specifications created a difference. However, it makes sense that as asphalt pavement is inherently softer than concrete, there may be a difference and it would be useful to use lower water pressures on asphalt.

CHAPTER THREE

CHEMICAL REMOVAL TECHNIQUES

INTRODUCTION

Chemical removal of runway rubber deposits was the standard until the environmental awakening of the 1960s and 1970s gave way to a concern about the impact of the chemicals on the watersheds into which they were introduced (Horne and Griswold 1975). This led many airports to try other rubber removal methods that did not have active chemicals as their primary rubber removal agent. Since that time, the manufacturers of rubber removal chemicals have developed chemical agents that are both "environmentally safe and effective in cleaning rubber deposits from contaminated surfaces" (Speidel 2002).

CHEMICAL REMOVAL ADVANTAGES

The literature contains a significant amount of information regarding the advantages of chemical rubber removal. The same caution regarding the need for multiple sources as in waterblasting applies because much of the published information on chemical rubber removal methods is commercial. Given that caution, the following are the major advantages found in the literature for using chemical methods to remove rubber deposits from runway pavements:

- Minimal potential for pavement damage because rubber is softened before it is removed (Horne and Griswold 1975; Speidel 2002; Cotter et al. 2006; *Responsible Runway Rubber Removal* 2006; Pade 2007).
- Ability to use existing in-house maintenance equipment and personnel (Speidel 2002; Transport Canada 2004; Cotter et al. 2006; Pade 2007).
- Process speed: range from 900 to 1,950 yd^2/h (743 to 1,641 m^2/h; USAF 1997; Speidel 2002; Cotter et al. 2006; Pade 2007).
- Biodegradable and environmentally benign chemicals (McKeen and Lenke 1984; Thames Water Environment and Quality 2001; Cotter et al. 2006; Monkeman 2006; USACE 2006).

Figure 11 confirms the first advantage found in the literature, with many airports selecting the previously cited advantages as reasons why they chose to use chemical removal. In addition to the advantages cited in the literature, the survey showed that "satisfaction with final product" was cited by one-half the airports. Only two airports cited the availability of competent contractors as a reason for their choice. This is interesting in that roughly half the airports indicated that they use contractors or used both in-house resources and contractors to conduct chemical rubber removal. Stated another way, two-thirds of the airports use internal resources to accomplish at least part of this work, which better lines up with the responses indicating that their reason for using the method is that they already own the equipment. Thus, this appears to confirm the validity of the reason cited by Transport Canada (2004) that conducting chemical rubber removal operations with internal assets is "mainly based on convenience, not cost, since the rubber can be removed periodically, one section at a time, during off-peak hours." This conclusion is reinforced in the response rate to the subsequent question that asked airports to cite the single most important reason of the ones shown in Figure 11. "Low probability of pavement damage" was the most popular response, and was closely followed by two convenience-related responses: "We already own the equipment" and "minimizes impact on operations." Thus, convenience coupled with confidence in the final result appears to be the major motivators for airports that use chemical rubber removal.

There were only two rubber removal contractor survey responses that indicated experience with this method, and only one responded regarding the reasons why an airport should use chemical rubber removal from the contractor's perspective: cost. The literature indicates that chemical removal is considered more expensive than waterblasting; however, the cost of materials is often offset by the ability of the airport to use its personnel and equipment (Speidel 2002).

CHEMICAL REMOVAL DISADVANTAGES

The literature appears to concentrate more on the disadvantages of chemical rubber removal than on its advantages, and that may be because this process is the benchmark against which other rubber removal methods are compared. In addition, it must also overcome the notion that chemicals are inherently bad for the environment. There appear to be six disadvantages that have been mentioned by more than one author. They are as follows:

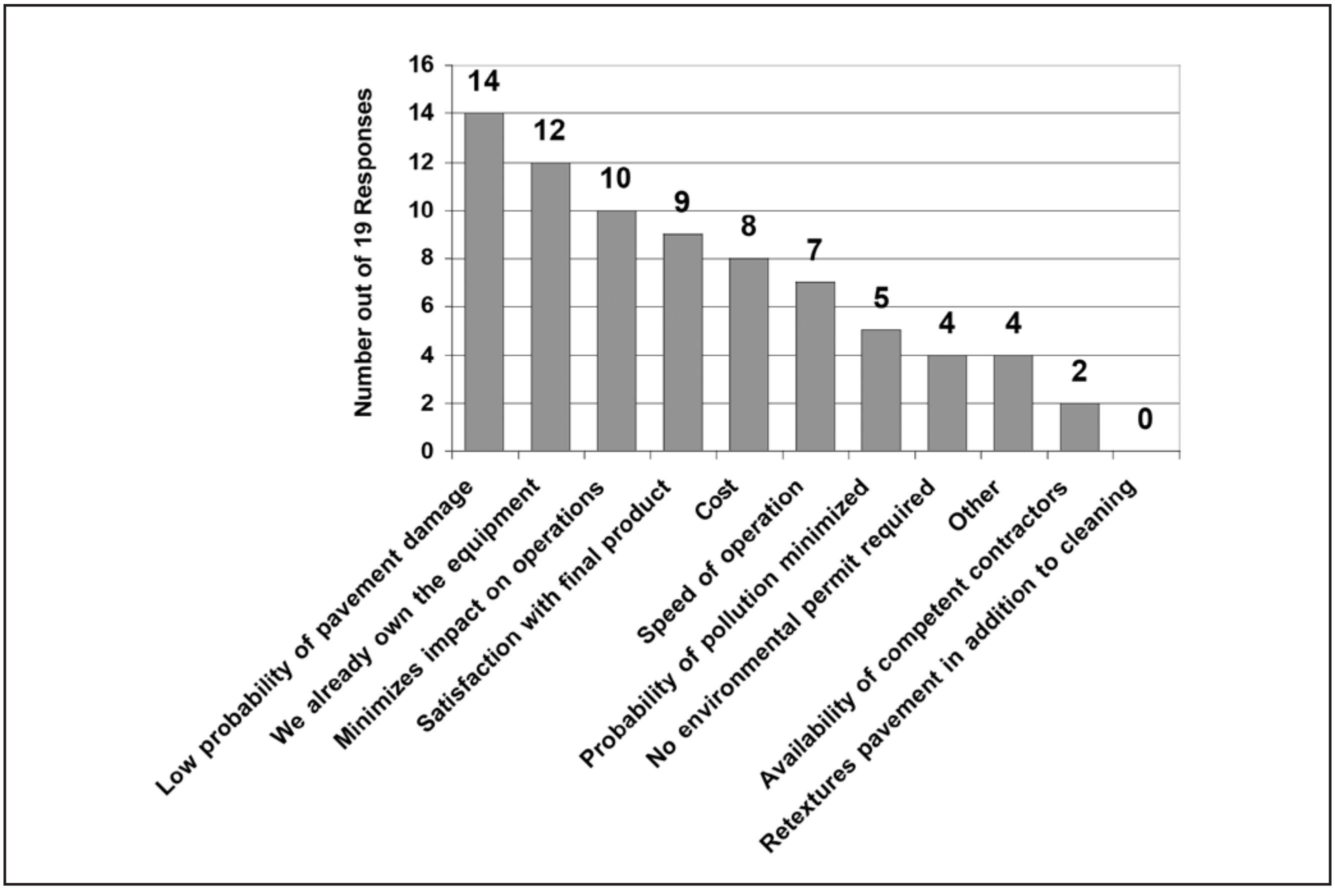

FIGURE 11 Airport operator survey responses for reasons for choosing chemical rubber removal.

- Environmental issue with appropriate disposal of residue (Horne and Griswold 1975; Toan 2005; Pade 2007; *Water Jet Solutions* . . . 2007).
- Possible pavement damage to asphalt pavements (McKeen and Lenke 1984; Cotter et al. 2006).
- Rubber not fully cleaned from grooves (Horne and Griswold 1975; *Water Jet Solutions* . . . 2007).
- Damage to in-house maintenance equipment hoses, etc., from the chemicals (Pade 2007; *Water Jet Solutions* . . . 2007).
- Inability to quickly reopen runway under rubber removal in an emergency (Cotter et al. 2006; Pade 2007).
- Cost (Speidel 2002; Pade 2007).

Environmental Issues

The first disadvantage contradicts one of the advantages reported in the previous section. There is no rational way to reconcile the differences. There are a number of chemicals that have been developed for runway rubber removal. The airport survey showed that roughly half the sample used either Avion 50 or Hurrisafe and the other half used a variety of other products. The commercial literature on the products advertises them as biodegradable and environmentally benign. A report from a public environmental agency in the United Kingdom was discovered that reported its tests on two chemicals that were proposed to remove rubber on the runway at Gatwick Airport in England, which stated:

> The two detergents in the formulation are widely used in a range of applications and the information available indicates no adverse effects have been observed or are expected. The surfactants are expected to be adequately biodegradable and there are no current adverse environmental implications associated with their use. (Thames Water Environment and Quality 2001)

However, there was also the information gained in the Dallas–Forth Worth case study where the airport found that, although the chemical used to remove the rubber was benign, the residue it produced was not and required disposal as a hazardous material in accordance with local regulations. Thus, this leads to the possible inference that perhaps the testing of the chemical agents themselves may be not sufficient to warrant the process as environmentally compatible.

Runway Pavement Damage and Groove Cleaning Efficiency

The next disadvantage, pavement damage, is of primary interest to this synthesis. The review of the literature was specifically focused on this issue, and the surveys contained questions that specifically asked for information regarding

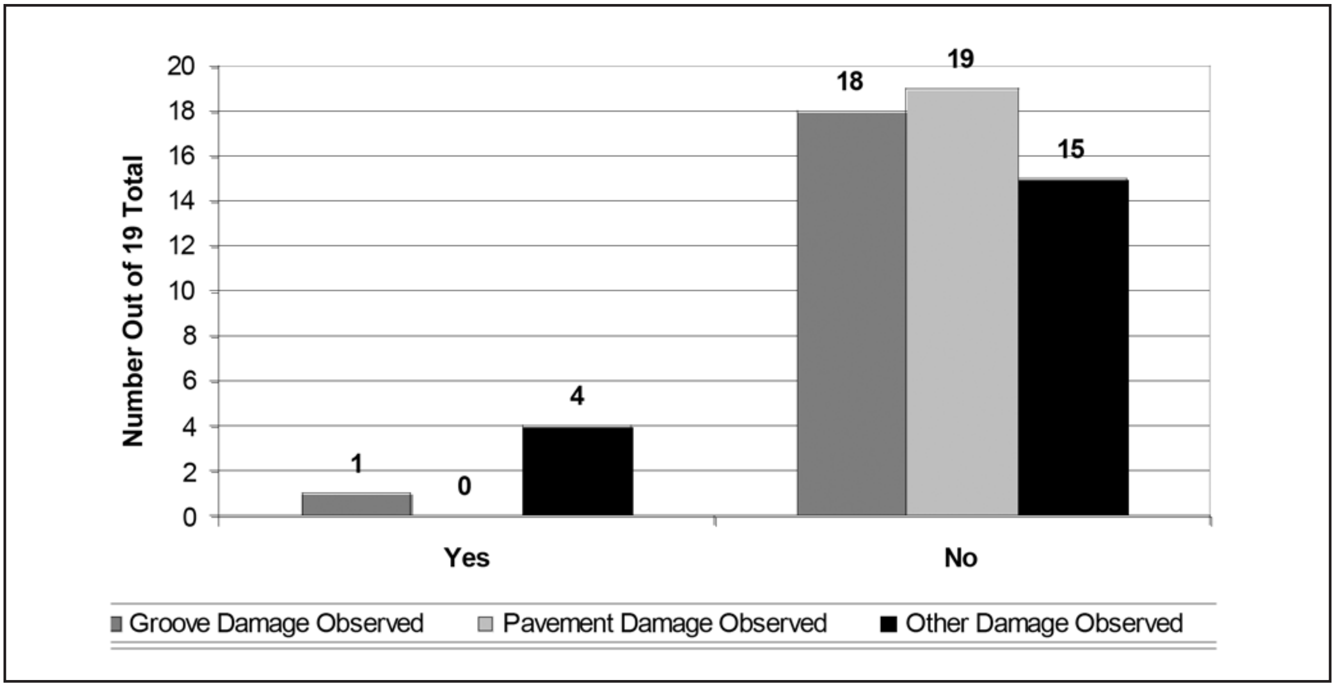

FIGURE 12 Airport operator survey responses for runway damages owing to chemical removal.

both groove damage and other pavement damage observed in conjunction with chemical rubber removal. The survey also asked airports to report any other damage to the pavement and the runway appurtenances that may have been observed in their experience. Figure 12 shows the results of those responses. One respondent reported runway groove damage after chemical removal. The airport observed "microtexture degradation" on pavement that was more than 6 years old. It has both concrete and asphalt runways and did not differentiate in its response. No airports reported observing general pavement damage. The literature contains a laboratory research report from the United Kingdom in which a specific rubber removal chemical was tested to determine whether it degraded the asphalt by measuring the indirect tensile stiffness modulus of samples that had been repeatedly exposed to the chemical. The results found no significant difference between the test samples and the control sample for the given chemical (Thames Water Environment and Quality 2001). However, this is merely one option, and similar testing would be needed on the suite of options before this finding could be generalized.

The survey did not specifically regard the ability of chemical rubber removal methods to efficiently clean the grooves in grooved runways. Nevertheless, one of the airports indicated that "chemical does not clean grooves very well." This confirms the disadvantage found in the literature, although it should be noted that only one airport mentioned this issue. Therefore, no conclusion can be drawn regarding this disadvantage.

Damage to Maintenance Equipment

Four airports indicated that they observed other damage. Two stated that the damage was to their maintenance equipment. One reported, "[It] eats the rubber hoses and paint off our equipment." The other stated that use of the chemical in airport maintenance equipment increased mechanical breakdowns, resulting in additional vehicle maintenance costs. The other two had problems with paint loss, one of which also reported runway light damage. That two-thirds of the airports cited the ability to use internal equipment as

TABLE 10
POTENTIAL DAMAGE FROM CHEMICAL REMOVAL

Possible Damage	Survey Airports Reported (*n*)	Literature Citations Reported
Microtexture degradation (polishing of aggregates)	1	NA
Damage to asphalt pavements due to chemical degradation of binder	NA	McKeen and Lenke 1984; Cotter et al. 2006
Damage to equipment from caustic chemicals	2	NLB 2007; Pade 2007
Damage to paint/markings	2	NA
Damage to runway lighting	1	NA

Note: Some airports reported more than one type of damage.
NA = not available.

a reason for selecting chemical removal indicates that this issue must not be an overriding problem and that airport maintenance personnel must be able to effectively manage it. One case study airport stated that it had worked with its chemical supplier to custom design a chemical formula that worked well for its equipment, runways, and environment. Potential damages from chemical removal are summarized in Table 10.

Runway Clearance Times

The only information gleaned on runway clearance times was from the literature and the case study interviews. Cotter et al. (2006) compared chemical removal to waterblasting, indicating that chemical removal was the preferred method, but stated as a caveat:

> However, it should be noted that the pressurized water method offers greater flexibility with regard to runway closure times and allows the runway to rapidly return to full service in the event of an emergency in the middle of the rubber removal operation.

Three of the case study airports used chemical removal, and each indicated that there was a need to enforce strict production rates on the chemical removal contractors and in-house rubber removal crews so as not interfere with airport operations. Another case study airport that used waterblasting mentioned that waterblasting allowed quick runway clearance in the event of an emergency, whereas chemical removal did not allow for that possibility. Thus, this disadvantage is confirmed by both literature and case study output.

Cost of Chemical Removal

The literature indicates that "the cost of chemical rubber removal is approximately double that of high pressure or ultra high pressure waterblasting, due to the cost of the chemicals themselves, whereas water is usually readily available at no cost to the contractor" (Speidel 2002). However, the survey data contradict this assertion, which found that the average waterblasting cost was $0.40 per square yard and the average chemical removal cost was $0.39 per square yard. The waterblasting costs were largely contract unit costs. As previously stated, the opposite is true regarding chemical costs because 13 of 19 airports use in-house forces. Perhaps the discrepancy between the survey and the literature is a failure to account for the cost of using airport personnel and equipment. The same author indicated that the use of internal personnel offsets the higher cost of materials. It is therefore impossible to draw an authoritative conclusion regarding the cost of chemical removal.

TABLE 11
AIRPORTS THAT REPORTED CHEMICAL RUBBER REMOVAL EXPERIENCE

ATL	BOS	DFW	JFK	MKC	RAP	YYC
AUS	CVG	EWR	LGA	MSP	SAN	YYZ
BNA	DCA	IAD	MCI	OKC	SFD	

CHEMICAL REMOVAL SURVEY RESULTS

The survey of airport operators and rubber removal contractors generated good information on the state of the practice in this area. The questionnaires used can be seen in Appendix A of this report. In addition, the consolidated data on chemical rubber removal can be found as part of Appendix B. There were 19 airports that reported to either have used or are currently using chemical methods to remove rubber from their runways (see Table 11). In addition to the information previously reported in this chapter, the survey furnished results in the following categories:

- Rubber removal chemicals;
- Seasonality of chemical rubber removal operations;
- Costs;
- Chemical rubber removal operations specifications and performance criteria; and
- Crews and equipment, production rates, and runway closure requirements (see Appendix E for details).

Runway Rubber Removal Chemicals

The literature contains a large quantity of commercial information on runway rubber removal chemicals. In addition, a number of research reports (Thames Water Environment and Quality 2001; Zoorob 2001; Cotter et al. 2006) are excellent supplements to the technical information provided by the manufacturers and suppliers of rubber removal chemicals and equipment. The intent of this study was not to develop an exhaustive list of all available chemical rubber removal products; nevertheless, the survey did ask airports and contractors to identify the products they use. Therefore, the information in the next section must be understood to be merely an accounting of survey responses and not in anyway judgmental as to the effectiveness of one product over another.

The airport survey results are shown in Table 12. Avion 50, Hurrisafe, and AVI-88 are the most often cited chemicals. There appears to be no trend regarding which chemicals are used by airport size or geographic location, except for Hurrisafe, which is used by large northern airports only. In addition, there is no trend when looking at what chemicals are used on the two different runway pavement types. Each of the chemicals with multiple responses is used on both concrete and asphalt pavements. In addition, two of the three chemicals were used by respondents with both types

TABLE 12
RUBBER REMOVAL CHEMICALS USED BY AIRPORTS IN THE SURVEY

Chemical Name	Responses (*n*)	Airports That Use or Have Used	Large/Small (*n*)	North/South (*n*)	Runway Type Concrete/Asphalt/Both
Avion 50	8	ATL, AUS, BNA, MCI, MKC, MSP, OKC, YYC	5/3	4/4	2/0/6
Hurrisafe	4	EWR, JFK, LGA, YYC	4/0	4/0	0/0/4
AVI-88	2	MSP, DFW	2/0	1/1	1/0/1
BioSol	1	YYC	1/0	1/0	0/0/1
Chemstation 6390	1	OKC	0/1	0/1	0/0/1
DC 101	1	SAN	1/0	0/1	1/0/0
Everything Clean	1	YYZ	1/0	1/0	0/1/0
Rubberaser*	1	Gatwick, RAF Leeming	1/1	NA	0/1/1
Alkaline liquid –sodium hydroxide (no brand name)	1	BOS	1/0	1/0	0/1/0

*This response is from a contractor survey.

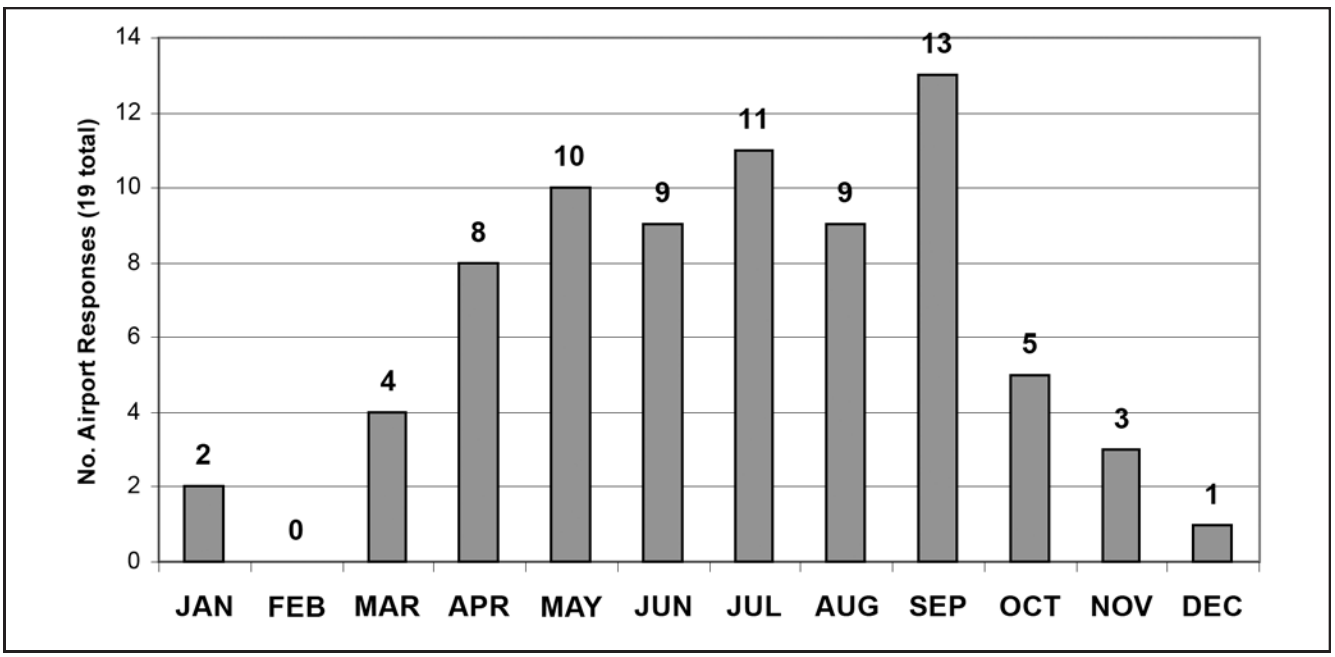

FIGURE 13 Chemical rubber removal seasonality from airport operator survey responses.

of runway surfaces at their airports. Thus, no conclusions can be drawn from this portion of the analysis of survey responses.

Seasonality

Figure 13 shows the responses from airport operators regarding the months in which they conduct chemical rubber removal. The same distinct periods as seen for water-blasting (see Figure 7) are used for chemical removal: spring–summer (April through September) and fall–winter (October through March). The majority of the chemical rubber removal occurs during the warmer seasons of the year. This makes sense because chemical methods use large amounts of water. Guide specifications quote minimum temperatures of 40ºF to 50ºF (5ºC to 10ºC; USACE 2006; Transport Canada 2003b).

Figure 14 shows the use of chemical rubber removal methods by airport size. Once again, large airports on a percentage basis do more chemical rubber removal in the spring–summer period, and they also continue to remove rubber throughout the calendar year. Small airports do most of their chemical rubber removal in the peak periods of

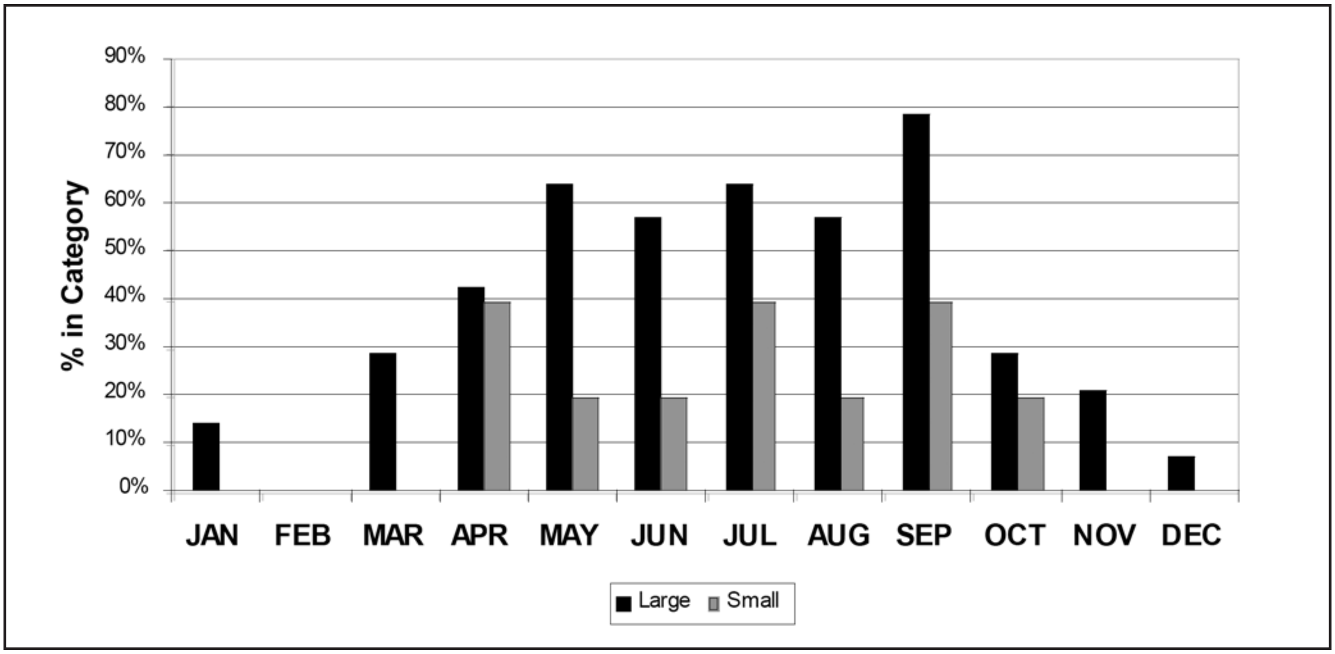

FIGURE 14 Chemical rubber removal seasonality: Large versus small airports.

April, July, and September, with additional removal occurring in the months between those peak months. In addition, both large and small airports have the greatest amount of rubber removal activity in the months in the spring and at the end of the summer. Again, it appears that, as with waterblasting, chemical rubber removal is driven by operational requirements to get ready for the summer's heavier traffic and higher temperatures and to remove the summer's accumulation of rubber deposits before low temperatures in the fall and winter make it impossible to conduct this type of pavement maintenance.

Sorting the survey responses by geographic region, one can test the notion regarding temperature-driven rubber removal operations. The trend is very clear in Figure 15. As would be expected, northern airports do more rubber removal during the spring–summer period than the southern airports, which are able to spread their rubber removal more

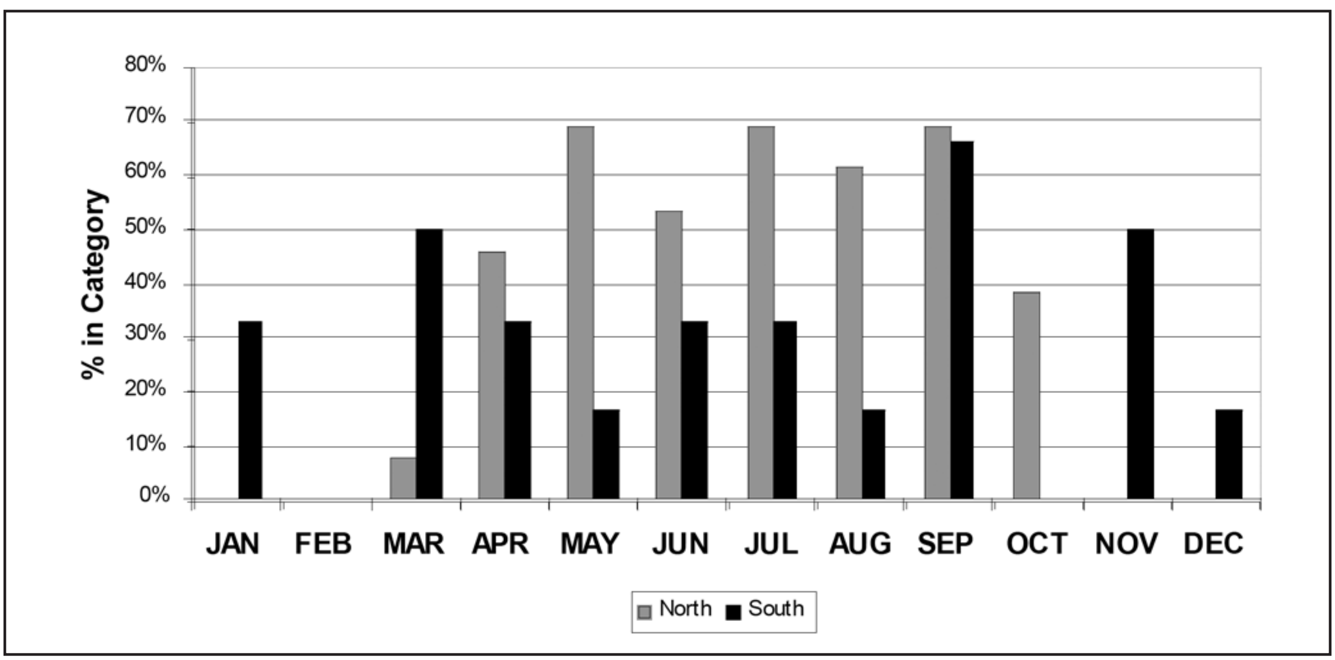

FIGURE 15 Chemical rubber removal seasonality: Northern versus southern airports.

evenly throughout the year. The highest level of activity for both groups occurred in September, confirming the hypothesis that airports seek to get the majority of the rubber off their runways before the weather changes to colder average temperatures. One can see that northern airports record no activity during the coldest months of the year, whereas southern airports are able to work during those months. It is also interesting that southern airports' level of activity during the hot summer months is lower than in some of the winter months. This may because there is a correlation with runway surface temperatures and the ability of the chemicals to act in an optimal manner.

Chemical Removal Unit Costs

Table 13 summarizes the unit cost data collected from the airport surveys. Again, the contractor surveys did not report this information. In addition, the two Canadian airports did not report these data. Thus, the table shows the information from 11 U.S. airports only. Four are southern airports, 7 are northern airports; 1 of the 11 is a small airport. The highest cost was reported by Dallas–Fort Worth, the case study airport that discovered it needed to dispose of the residue from its chemical rubber removal operations because of its high level of heavy metals; this disposal may have accounted for the high cost. A California airport had the second highest unit cost, at $0.77 per square yard, and also reported that it must dispose of the residue using an "environmental contractor per DEQ [Department of Environmental Quality] regulations." The survey specifically asked about residue disposal constraints. Five respondents cited a requirement to vacuum the residue and dispose of it off site, and 13 indicated that they allow it to be flushed off the runway into the surrounding soil. The 19th airport in the sample was the California airport that disposed of the residue, as previously mentioned.

CHEMICAL REMOVAL SPECIFICATIONS

Of the airport respondents that use chemical rubber removal, most conduct chemical rubber removal solely with in-house maintenance forces. Three others indicated that they use both contractors and in-house personnel. Six use contractors to do the rubber removal. Thus, the level of contracting is much less than with waterblasting, making the issue of specification writing less critical for these respondents. However, environmental concerns create a need for those airports that do contract for chemical rubber removal to shift the risk of a potential pollution incident to the rubber removal contractor, which must necessarily be done through the specifications that are part of the chemical rubber removal contract.

TABLE 13
CHEMICAL RUBBER REMOVAL UNIT COSTS (2007 US$)

Airport Reported Unit Costs ($/yd^2)		
Low	Mean	High
0.12	0.39	1.08

Survey Data on Chemical Removal Specifications

As discussed in chapter one, both prescriptive and performance specifications are used in chemical rubber removal contracts. Prescriptive chemical rubber removal specifications typically contain an approved list of chemicals, a quantified amount of rubber to be removed, and some verbiage regarding pavement surface damage. As with waterblasting, these specifications also articulate production-related constraints such as a minimum required production rate in area per unit time or a maximum time limit for runway closure. On the other hand, performance specifications inventory acceptable means and methods and usually cite either qualitative or quantitative performance measures, such as friction mu value, that must be achieved after rubber removal. The survey asked about the type of specifications used for chemical rubber removal. A total of 19 airports responded with the required information (Figure 16). Two-thirds of the sample used some form of performance specification, and the same thing can be said for prescriptive specifications in chemical rubber removal. That this method appears to evoke concerns about environmental compatibility may account for the greater percentage of prescriptive specifications than the other three methods.

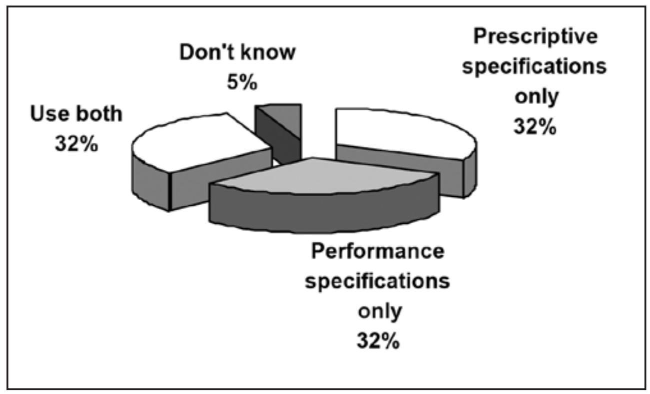

FIGURE 16 Chemical rubber removal specification usages by airports.

Most airports used a quantitative friction value measurement in their performance specifications. One respondent indicated that the "finished product must meet previously measured friction values for that runway." Several used removal rate criteria as a performance measure. The prescriptive specifications also contained a provision that 85% of the rubber be removed. The single contractor response indicated that airports where it worked used both performance and prescriptive specifications.

Chemical Removal Specification Content Analysis

The formal content analysis for chemical rubber removal methods used six sets of chemical rubber removal specifications from three airports and three governmental organizations. The content analysis for this rubber removal method was also broken into three categories:

1. General and equipment specifications,
2. System and environmental constraints, and
3. Specification type.

Table 14 shows the results of the first category's content analysis. First, because the survey showed that chemical rubber removal was generally done using in-house crews, one would not expect to see much more than material specifications. This was the case with all three airports. The governmental specifications were guide specifications published for use by aviation agencies in the United States and Canada. Therefore, the low numbers shown in the following series of tables are the result of this. All six specifications contained restrictions on the types of chemicals that were allowable. USACE did not name allowable chemicals but rather indicated that it "leave[s] only non-toxic biodegradable residue." Equipment specifications for brooms and chemical distributors were contained in four specifications. Beyond that, the governmental guide specifications were the only ones that discussed other restrictions.

TABLE 14
RESULTS OF CHEMICAL REMOVAL SPECIFICATION CONTENT ANALYSIS: GENERAL AND EQUIPMENT SPECIFICATIONS

Specification Item	Specifications in Which Found (*n*)	Remark
Type of pavement specified	3	Applied to both asphalt and concrete
Type of contract	3	All were unit price
Contractor qualifications	0	
In-house requirements	2	Canada and MSP
Hours of operation	2	All required rubber removal at night
Allowable runway closure period	2	Typically 6 to 8 h
Allowable chemicals	6	Avion 50, AVI-88 and Quatrex D4059; USACE only requires biodegradable chemical products
Equipment specifications	4	Most describe requirement for brooms and chemical application equipment

NOTE: There were 6 specifications analyzed.

TABLE 15
RESULTS OF CHEMICAL REMOVAL SPECIFICATION CONTENT ANALYSIS: SYSTEM AND ENVIRONMENTAL CONSTRAINTS

Specification Item	Specifications in Which Found (*n*)	Remark
Pretest/trial required	2	Demonstrate effectiveness
Weather general	3	Required to be done in "dry" weather
Air temperatures	2	>50°F (10°C)
Surface temperatures	1	>40°F (4°C)
Wind constraints	2	9 mph (15 kmph)
Minimum production rate	2	Average = 2,000 yd^2/h (1,675 m^2/h)
Debris removal required	4	1 also required removal of chemical drums
Environmental compatibility required	3	

Note: There were 6 specifications analyzed.

TABLE 16
RESULTS OF CHEMICAL REMOVAL SPECIFICATION CONTENT ANALYSIS: SPECIFICATION TYPE

Specification Item	Specifications in Which Found (*n*)	Remark
Prescriptive specification	2	Remove 85% of rubber
Performance specifications	4	
Quantitative criterion	0	
Qualitative criterion	4	Visual inspection
Used both types	0	
Other specifications included	5	Generally, means/methods related, reaction and agitating times, etc.

Note: There were 6 specifications analyzed.

The next category involved specifications related to the chemical rubber removal system and the environment in which chemical removal was permitted to take place. Table 15 shows the outcome from this analysis. Only two specifications required the preparation of a pre-removal test to demonstrate the effectiveness of the chemical and to test the concentrations proposed by the manufacturers. Again, half of the sample specified weather constraints of some sort. To summarize, they required the rubber to be removed in generally "dry" conditions when air and surface temperatures were above freezing and there was no danger that the water used in the process would freeze before it was removed from the site. The Canadian specification also required that wind conditions be low. A minimum production rate was included in the governmental guide specifications only. Four specifications required that the residue be removed and disposed of off site. Once again, the governmental guide specifications require environmental compatibility or testing to demonstrate compliance with local regulations. Presumably the airports, by specifying the approved chemicals, have already ensured environmental compliance.

The final category is the type of specifications used and the criteria used (Table 16). Of the specifications in the sample, two were purely prescriptive and four were purely performance. Of the performance specifications, all used a qualitative performance criterion based on visual inspection. The prescriptive specifications detailed a requirement to remove 85% of the rubber. As would be expected, there were also other specifications included in this sample. Most regarded constraints on means and methods, with the requirement regarding the time required for the chemical reaction to begin and the amounts of time for agitation and scrubbing with the brooms.

The content analysis confirmed much of what was found in the other three research instruments and furnished validation for identification of commonly used practices.

COMMONLY USED PRACTICES

As chemical rubber removal is overwhelmingly conducted by in-house pavement maintenance forces, there is little intersection among the various research instruments from which to draw commonly used practices. This process has been around a long time, and most airports that use it have found the materials, means, and methods that work for them. However, there are three practices for which the survey responses and the literature coincide.

- Use chemical removal in those situations where the airport needs flexibility in the timing of rubber removal operations:

  This is one of the reasons to use chemical rubber removal over other methods. Transport Canada's (2004) runway rubber removal policy articulated the idea that chemical rubber removal gave an airport the ability to not only use in-house personnel and equipment but also a great deal of flexibility with regard to the timing of these operations (Speidel 2002; Pade 2007). Public procurement regulations often create requirements that reduce the flexibility of the airport owing to contract provisions.

- Select chemical removal when the airport already owns the equipment, can use in-house personnel, and needs to ensure that the possibility of pavement damage is minimized:

  The airport respondents indicated that they were satisfied with the results and believed that there was a low probability that chemical removal would damage the runway pavement.

- Use rubber removal chemicals to pretreat or soften the rubber deposits before waterblasting:

  Three of the airports in the survey were found to do this as a means to enhance the effects of their waterblasting operations. In addition, two of the commercial waterblasting processes (one in the United States and one in Europe) include a combination of chemical pretreatment and high-pressure water to effect a more complete removal of the runway rubber.

CHAPTER FOUR

SHOTBLASTING RUBBER REMOVAL TECHNIQUES

INTRODUCTION

High-velocity impact removal, also called "shot-peening" (hereafter referred to as *shotblasting*), "directs high velocity–small diameter steel shot at the pavement surface which tends to pulverize and loosen the rubber or paint coating the runway surface into small particles" (Horne and Griswold 1975). Sandblasting is another form of high-velocity impact removal; however, but for purposes of this synthesis, it is covered in the next chapter on mechanical rubber removal to differentiate it from shotblasting and because it is not a very commonly used rubber removal method. Shotblasting technology also incorporates a vacuum/magnetic process to pick up the steel shot and resultant debris. This process internally separates the shot for reuse and deposits the debris in a container for disposal. It also removes foreign object debris (FOD), which appears to be a worry for some who are considering using shotblasting (Pade 2007). What is clear from the literature is that most airports select shotblasting when they need to retexture the runway's surface and removing rubber deposits is incidental to the retexturing process (Speidel 2002; Pade 2007; Transport Canada 2003c).

SHOTBLASTING ADVANTAGES

The literature contains an ample amount of information regarding the advantages of shotblasting for use in highway and bridge applications (*Surface Preparation for Epoxy Chip Seal* 2001; Anderson et al. 2007) but, unfortunately, is quite limited regarding shotblasting to remove runway rubber accumulations. As a result, the ability to cite multiple sources to ensure the appropriate level of research rigor is also limited. Therefore, the reader is cautioned that some of the items listed in this and the disadvantages section were developed using a single source as the criterion for making the list. Nevertheless, the major advantages found in the literature for using shotblasting to remove rubber deposits from runway pavements follow.

- Retextures the pavement in addition to removing rubber (Horne and Griswold 1975; Yager 2000; Speidel 2002; Jenman 2006; Pade 2007).
- Process speed: range from 1,111 to 3,588 yd^2/h (929 to 2,700 m^2/h; Speidel 2002; Transport Canada 2003c; Jenman 2006; Pade 2007).
- Ease of getting rubber removal equipment off the runway in the event of an emergency (Speidel 2002; Jenman 2006; Pade 2007).
- Environmental compatibility (Jenman 2006; Pade 2007).

There were only five airports respondents that had experience with shotblasting. Of that group, Boston responded that it uses shotblasting for pavement retexturing only, not rubber removal, and did not submit any shotblasting rubber removal survey data. San Francisco experimented with shotblasting, but believed that it might be too slow to be done without negatively affecting airport operations; thus, it did not submit any shotblasting data on its survey response. Therefore, the sample size is small, with only three respondents. Figure 17 confirms the first and second advantages found in the literature. One airport indicated that it used shotblasting to "increase [both] micro- and macrotexture." Environmental compatibility was not confirmed by the survey as no airports indicated either "probability of pollution minimized" or "no environmental permit required" as reasons for their choice of shotblasting. The information gleaned on runway clearance times comes only from literature. One author stated that the "equipment is truck-mounted and can easily be removed from the runway … in case of an emergency landing" (Pade 2007).

There were also three rubber removal contractor survey responses that indicated experience with shotblasting, and two of the three responded that the major reason an airport should use shotblasting is to retexture the pavement. One also indicated that, from the contractor's perspective, removing rubber was an insufficient reason in and of itself. That contractor believed that the airport should seek to increase friction values as the primary reason and that removing rubber was incidental to retexturing. This correlates with the response from Boston.

SHOTBLASTING DISADVANTAGES

The literature appears to concentrate more on the disadvantages of shotblasting rubber removal than on its advantages. This is probably because it is not seen as primarily a rubber removal method but rather a method to retexture that incidentally removes the rubber deposits as it changes the micro-

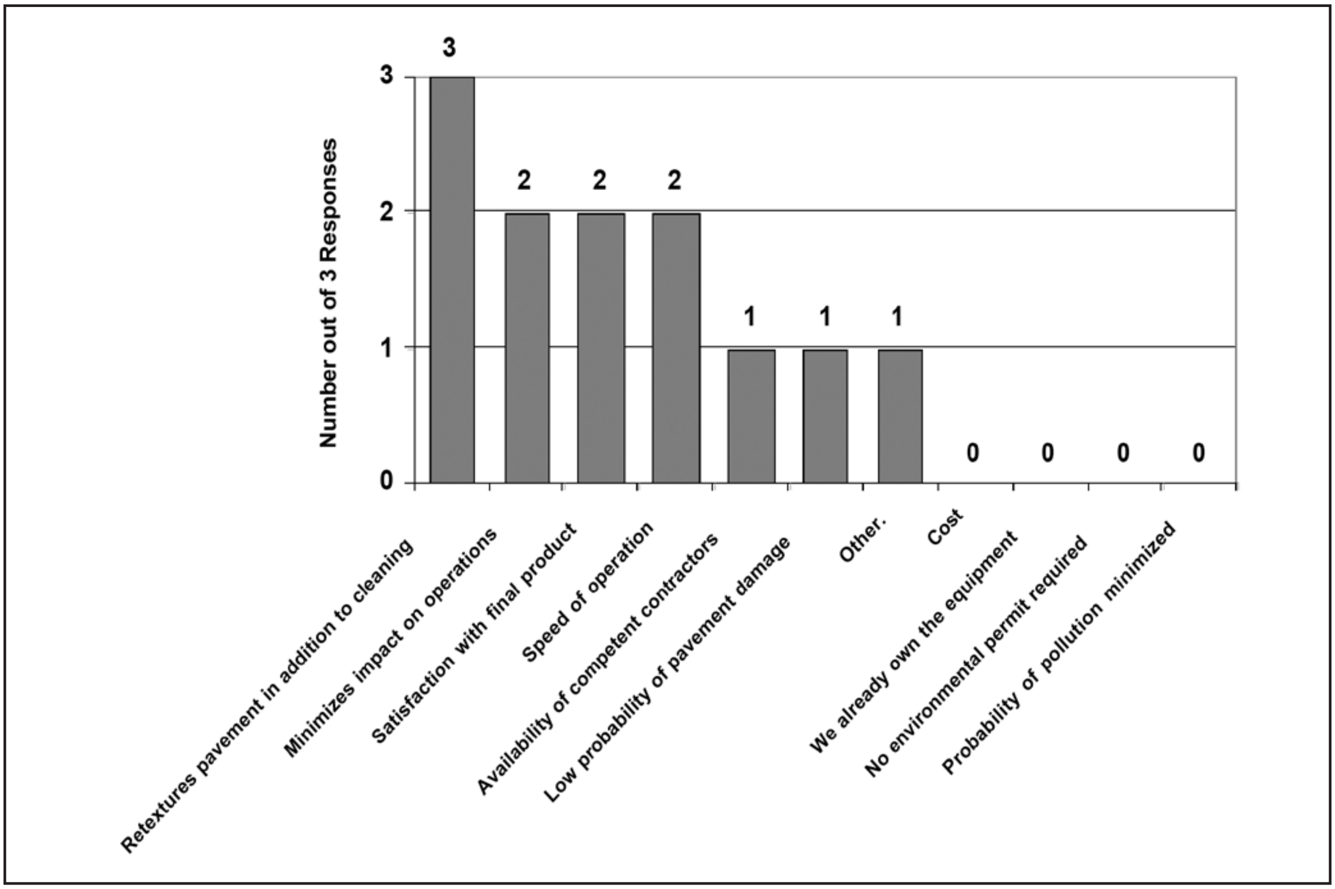

FIGURE 17 Airport operator survey responses for reasons for choosing shotblasting for rubber removal.

and macrotexture of the runway. In addition, shotblasting must also overcome the notion that it will produce FOD as an inherent byproduct. There appear to be five disadvantages, of which only three are mentioned by more than one author. They are as follows:

- Environmental issue with appropriate disposal of residue (*Water Jet Solutions for Airport Applications* 2007; Skidabrader 2007).
- Possible pavement damage to asphalt pavements (*Water Jet Solutions for Airport Applications* 2007).
- Process cannot be used in wet conditions (Horne and Griswold 1975; Transport Canada 2004; USACE 2006).
- FOD hazard owing to embedded shot (Pade 2007).
- Cost (Speidel 2002; Pade 2007).

Environmental Issues

Once again, the literature is divided regarding the environmental compatibility of this rubber removal method; however, in this case there is a rational way to reconcile the differences. The two references in the literature come from competing technologies. However, the information gained in the Dallas–Fort Worth case study is helpful in addressing this issue. Even though the chemical used to remove the rubber was benign, Dallas–Fort Worth found that the residue it produced was not. Thus, because the residue associated with shotblasting comes from the same airport, it would follow that it would also require disposal as a hazardous material in accordance with local regulations. In addition, a careful reading of the Jenman (2006) report shows that the advantage cited is that the process adds no new pollutants to the environment and that its residue and dust recovery process efficiently captures the runway contaminants in a manner that allows them to be safely disposed as required by regulations. Therefore, the issue of environmental compatibility becomes a function of the nature of the contaminants that are removed. Again referring to the Dallas–Fort Worth case study, one would expect that shotblasting residue contains an unsafe level of heavy metals, because the rubber deposits contain an unsafe level of heavy metals. Therefore, determining whether shotblasting is an environmentally compatible rubber removal process is dependent on the specific situation at each airport, including the local standards that must be met.

Runway Pavement Damage

Pavement damage as a disadvantage is the reason this synthesis is being prepared. As previously stated, not only was the literature review specifically focused on this issue, but the surveys also contained pavement and groove damage questions. The survey also asked airports to report any col-

TABLE 17
POTENTIAL DAMAGE FROM SHOTBLASTING

Possible Damage	Survey Airports Reported (n)	Literature Citations Reported
Groove damage	2	NLB 2007
Asphalt pavement damage	0	NLB 2007
Damage to paint/ markings	2	NA
Damage to runway lighting	1	NA

Note: Some airports reported more than one type of damage.
NA = not available.

lateral damage to runway appurtenances. With the small sample size, graphics such as those in the previous two chapters would be inappropriate. Two of the three airports indicated that they suffered groove deterioration as a result of shotblasting. The same two indicated that paint loss was also common, with one of those also reporting minor dimming of runway light lenses. Table 17 consolidates the information gained from the literature and the surveys with regard to runway pavement damage.

Weather Limitations on Shotblasting

There was no indication from any of the survey respondents regarding the inability to use shotblasting on wet runways. However, both U.S. and Canadian guide specifications require that the process be completed when "the pavement is dry or slightly damp, no rain is forecast" (Transport Canada 2004) and the "operation shall cease during rainfall" (USACE 2004). Finally, a guide specification developed by a shotblasting contractor confirms this: "This process is a dry process and is moisture sensitive and must be performed on dry pavement" (Skidabrader 2007).

Potential Foreign Object Debris Problem

This study found only one reference to FOD in relation to shotblasting. Specifically, Pade (2007) wrote that a disadvantage of shotblasting was "FOD hazard on airfields where steel shot becomes semi-embedded into the surface and then dislodged later in time." There is possibly a second more indirect reference found in a USAF Engineering Technical Letter which states,

> The use of … high velocity impact removal [shotblasting] shall be considered on a case-by-case basis. Use of … impact abrasive in the removal process must be approved in advance by the CO [contracting officer]. The Government specifically reserves the right to reject the use of any rubber removal process which the CO determines may pose unnecessary risks to aircraft due to foreign object damage (FOD) potential. … (USAF 1997)

During the case study interview at Oklahoma City, one of the interviewees indicated that they had not tried shotblasting because of a fear of potential FOD. This information appears to be belied by the issue that three large international airports are successfully using shotblasting and did not indicate in their survey responses any FOD issues.

Cost of Shotblasting

The literature indicates that "it [shotblasting] is very expensive to mobilize and operate" (Speidel 2002). "Overall cost is expensive" was also found in the literature (Pade 2007). A recent Washington State Department of Transportation (DOT) research report (Anderson et al. 2007) cited the unit cost to retexture 76,000 yd^2 of concrete pavement with a shotblaster at $1.25 per square yard. However, the airport survey data appear to contradict this assertion. Table 18 shows the unit costs reported in the survey. Thus, remembering that the sample size for shotblasting includes two U.S. airports and one Canadian airport, it appears that this disadvantage is not borne out by the survey data.

TABLE 18
SHOTBLASTING UNIT COSTS (2007 US$)

Airport Reported Unit Costs ($/yd²)		
Low	Mean	High
0.45	0.79	1.35

SHOTBLASTING SURVEY RESULTS

The survey of airport operators and rubber removal contractors generated good information on the state of the practice in this area. The questionnaires can be seen in detail in Appendix A of this report. In addition, the consolidated data on shotblasting can be found as a part of Appendix B. The following five airports reported either having used or currently using shotblasting to remove rubber from their runways.

- Atlanta, Georgia;
- Boston, Massachusetts;
- Dallas–Fort Worth, Texas;
- San Francisco, California; and
- Toronto, Ontario, Canada.

Boston and San Francisco reported experimenting with shotblasting but do not use it as a component of their runway rubber removal program. In addition to the information previously reported in this chapter, the survey furnished results in the following categories:

- Seasonality of waterblasting operations;
- Shotblasting operations specifications and performance criteria;

- Crews and equipment, production rates, and runway closure requirements (see Appendix E for details).

Seasonality

That shotblasting must be conducted on dry pavements without rain would appear to affect the seasonality of this rubber removal method. However, the three shotblasting respondents indicated the following months in which they conduct shotblasting: April, May, August, October, November, and December. This is interesting in that the only northern airport in the sample reported shotblasting in late fall. One southern airport uses shotblasting on a regular sequence to maintain friction values. The other southern airport does its shotblasting once a year in the spring, and the northern airport probably also does an annual retexturing in late fall. There is no discernable trend because the three data points are anecdotal.

SHOTBLASTING SPECIFICATIONS

Of the three airport respondents that used shotblasting, all used contractors, which makes the issue of specification writing important for this rubber removal method. One shotblasting contractor furnished the researcher with a copy of specifications that it recommends airports use (Skidabrader 2007). Comparing this with owner-generated shotblasting specifications provided an interesting insight into the two perspectives. The contractor's specification of roughly 2,800 yd^2/h (2,341 m^2/h) actually required more than double the rate cited in the USAF specification (USAF 1997) of 1,100 yd^2/h (929 m^2/h) and about 85% of the rate required by Transport Canada (2003c) 3,600 yd^2/h (3,000 m^2/h). The contractor's guide specification is also a performance specification based on a macrotexture measurement taken from the ASTM E-2380-05 outflow meter.

Survey Data on Shotblasting Specifications

As mentioned in the preceding chapters, airports use both prescriptive and performance specifications. Prescriptive shotblasting rubber removal specifications are the same as for the other methods, generally citing a quantified amount of rubber to be removed and some verbiage regarding pavement surface damage. These specifications also use production-related constraints such as a minimum required production rate in area per unit time or a maximum time limit for runway closure. Performance specifications cite quantitative performance measures, such as friction mu value, that must be achieved after rubber removal. Of the three airports in the sample, one used a prescriptive specification of 100% rubber removal, another used a performance criterion for a friction value, and the third used both. The two contractor responses to the question indicated that airports where it worked used both performance and prescriptive specifications.

Shotblasting Specification Content Analysis

The formal shotblasting content analysis was conducted on three sets of shotblasting specifications from two governmental agencies and one contractor using the same three categories as the previous two analyses. No airport specifications were found for this analysis. Thus, these three are all guide specifications. Very little can be written to expand on the information shown in Table 19, which is self-explanatory.

TABLE 19
RESULTS OF SHOTBLASTING SPECIFICATION CONTENT ANALYSIS: GENERAL AND EQUIPMENT SPECIFICATIONS

Specification Item	Specifications in Which Found (*n*)	Remark
Type of pavement specified	2	Applied to both asphalt and concrete
Type of contract	3	All were unit price
Contractor qualifications	0	
Hours of operation	1	Required rubber removal at night
Allowable runway closure period	1	8 h
Equipment specifications	3	Most describe requirement for shotblasting and vacuum equipment
Emergency evacuation requirements	1	Typically 3 min. from notification

Note: There were 6 specifications analyzed.

The next category regards the constraints on the shotblasting system and environmental constraints (see Table 20). Both governmental guide specifications required a test section be established to calibrate the settings for the equipment on the given pavement type. These were also used to establish baselines for friction value performance measures and to demonstrate that the shotblaster could effectively remove the required amount of rubber without damage to the pavement and its grooves. All three required that shotblasting be conducted in dry weather, which confirms the information found in the literature regarding this system's aversion to moisture (Speidel 2002). However, there was only one instance where the specification went on to be more specific regarding the climatic conditions in which shotblasting could take place.

Table 21 shows the results of the specification type analysis: All the shotblasting specifications were performance-based. Two used a qualitative visual criterion, and the other used a quantitative measurement of friction. This specification also cited two ASTM texture measurement methods to verify that surface texture had also been improved. The other specifications dealt with the collection and disposal of the debris, as well as measures to ensure that no steel abrasive particles would remain to create an FOD hazard.

TABLE 20
RESULTS OF SHOTBLASTING SPECIFICATION CONTENT ANALYSIS: SYSTEM AND ENVIRONMENTAL CONSTRAINTS

Specification Item	Specifications in Which Found (*n*)	Remark
Pretest/trial required	2	Calibrate shotblaster, establish friction performance standard and demonstrate effectiveness
Weather general	3	Required to be done in "dry" weather
Air temperatures	1	> 50˚F (10˚C)
Surface temperatures	1	> 40˚F (4˚C)
Wind constraints	1	9 mph (15 kmph)
Minimum production rate	2	Average = 3,200 yd^2/h (2,675 m^2/h)
Debris removal required	2	1 requires disposal in compliance with environmental regulations

Note: There were 6 specifications analyzed.

The content analysis confirmed much that was found in the other three research instruments and furnished validation for the identification of commonly used practices that are discussed in the next section.

COMMONLY USED PRACTICES

The use of shotblasting is very limited when compared with waterblasting and chemical removal. Therefore, only one commonly used practice has been identified in the research.

TABLE 21
RESULTS OF SHOTBLASTING SPECIFICATION CONTENT ANALYSIS: SPECIFICATION TYPE

Specification Item	Specifications in Which Found (*n*)	Remark
Prescriptive specification	0	
Performance specifications	3	
Quantitative criterion	1	Friction mu value
Qualitative criterion	2	Visual inspection
Used both types	0	
Other specifications included	3	Generally, means/ methods related

Note: There were 6 specifications analyzed.

- Use shotblasting to restore surface micro- and macrotexture in conjunction with other rubber removal methods on those areas of the runway that do not achieve satisfactory friction values after rubber is removed.

This practice is supported by the literature (Horne and Griswold 1975; Yager 2000;Speidel 2002; Jenman 2006; Pade 2007), the survey (100% of respondents select it to retexture), the case study airports (Dallas–Fort Worth and Boston use shotblasting in this manner), and the content analysis in which texture tests are included in one of the specifications. Thus, to restate the practice, shotblasting is used for retexturing and not be selected for rubber removal alone. The rubber removal is an incidental result of the use of shotblasting to retexture runway pavements that have lost their skid resistance for reasons other than rubber accumulations.

CHAPTER FIVE

MECHANICAL REMOVAL TECHNIQUES

INTRODUCTION

Mechanical removal of runway rubber deposits has probably been around as long as airports have recognized the need to remove rubber to recover runway friction values. For purposes of this synthesis report, this category includes all methods that are not included in the previous three rubber removal methods. Thus, this category can run the gamut from the simple use of stiff bristle rotary brooms through sandblasting to sophisticated milling machines. Sand blasting was used in early runway friction research by NASA to remove contaminants from test runways and provide a "surface texture somewhat more representative of … runways in use today" (Horne et al. 1965). "Sand blasting and mechanical grinding of paint and rubber-coated pavements have proven to be effective, but contaminant removal rates tend to be low requiring long runway closure times" (Horne and Griswold 1975). This impact on airport operations leads most airports to use other rubber removal methods that have a more satisfactory production rate. In addition, as most mechanical methods literally remove a thin (1/8 to 3/16 in.; 3 to 5 mm) layer of pavement surface along with the rubber, they are probably the least friendly toward grooved runway pavements, and the grooves often have to be redone to return to their "design depths of 1/4 in. (6 mm) to effectively drain water from the surface" (Speidel 2002).

MECHANICAL REMOVAL ADVANTAGES AND DISADVANTAGES

The literature is extremely sparse regarding mechanical runway rubber removal. As a result, the multiple sources were at times actually one author referring to the work of a previous author. This resulted in the advantages listed in this section and the disadvantages in the next section being developed using a single source as the criterion for making the list. Given that caution, the following are the advantages found in the literature for using mechanical methods to remove rubber deposits from runway pavements:

- Improves surface friction characteristics by removing existing polished surface as well as contaminants (Horne et al. 1965; Speidel 2002; Pade 2007).
- Removes high areas that cause bumps, "profiling" (Speidel 2002; Pade 2007).
- Can use existing equipment to remove rubber; that is, runway sweepers with steel-tipped brushes (Carpenter 1983).

There appear to be four disadvantages that have been mentioned in the literature. They are as follows:

- Environmental issue with appropriate disposal of residue (Horne and Griswold 1975; Toan 2005; *Water Jet Solutions for Airport Applications* 2007; Pade 2007).
- Possible groove damage (Speidel 2002; Pade 2007).
- Slow production (Horne and Griswold 1975).
- Microcracking of structure leading to accelerated aging of surface (Pade 2007).

As with shotblasting, the population of airport responses for mechanical removal is small: two survey responses. Neither used any of the technologies mentioned in the literature. Thus, the surveys cannot be used to differentiate between the advantages and disadvantages of mechanical rubber removal. Neither can they be used to draw conclusions, as was done in the previous chapters. The paucity of both literature information and reported usage in the field indicates that mechanical methods are used primarily for other purposes, and rubber removal is merely an incidental occurrence that is inherent to the technology. One author supports this opinion when he states, "Like shot blasting, the primary reason for the [grinding/milling] machine is not the removal

TABLE 22

POTENTIAL DAMAGE FROM MECHANICAL RUBBER REMOVAL

Possible Damage	Survey Airports Reported (n)	Literature Citations Reported
Groove damage	0	Speidel 2002; Pade 2007
Asphalt pavement damage	0	Pade 2007
Damage to expansion joints and crack seal	0	NA
Damage to patches	0	NA
Damage to paint/markings	0	NA
Damage to runway lighting	0	NA

of rubber from [the] pavement surface" (Pade 2007). Table 22 synopsizes the potential damages that might be incurred with mechanical rubber removal and is primarily based on the concept that these processes inherently remove a thin layer from the runway's surface and everything that is contained in that layer.

MECHANICAL REMOVAL SURVEY RESULTS

There were only two airport responses. Neither of them used the methods discussed in the literature. Both returned incomplete questionnaires because the questions asked did not directly apply to the methods in use. One of the respondents—Billings, Montana—was the subject of a case study interview whose details can be found in chapter six.

Airport Survey Responses

Of the two airport responses, one was a small northern airport, Billings, Montana, which furnished the case study for this method. It found that its routine snow and ice removal operations removed sufficient rubber during the winter to retain safe levels of runway friction. It attributed this success to the use of a carbide steel blade on its snow plows during ice events, which is different from the blade used for snow. It also believed that the deicing fluid (FAA-approved Cryotech E-36) softened the rubber deposits and, combined with the grit from the sand, further facilitated the removal of rubber accumulations along with the ice and snow. Billings has a PFC asphalt runway and is concerned that using other rubber removal methods might damage the pavement. In its survey response, it did not indicate any other reasons for choosing mechanical methods, and as it does no formal runway rubber removal, did not respond to the other questions as well.

The other airport that reported mechanical removal was a large northern airport. It used "jet brooms with wire rotating brushes" in conjunction with chemical removal operated by in-house maintenance personnel. This airport uses the wire brushes on both concrete and asphalt runways and conducts rubber removal operations in July and August. It stated that it "already own[ing] the equipment" and "minimiz[ing] impact on airport operations" as its reasons for choosing mechanical removal. It also indicated that the major reason for using this method was that it enhanced the results of the chemical rubber removal. It also returned an incomplete questionnaire in that its costs, production rates, etc., were reported as part of the chemical rubber removal operations.

Rubber Removal Contractor Response

There was one response to the contractor survey that indicated mechanical rubber removal experience. This contractor uses diamond grinding on both concrete and asphalt runways. It stated that it conducted these operations throughout the entire year. Thus, there is no specific season for using grinders to remove rubber. The response stated that the major reason an airport should select grinding is that it retextures the pavement in addition to removing the rubber. This appears to support the earlier assertion that mechanical methods are used primarily for purposes other than the removal of runway rubber. This response cited a production rate of 1,200 yd^2/h (1,003 m^2/h) and that the typical runway closure was 10 h. The respondent reported that airports that employ this method typically use unit price contracts with visual (i.e., qualitative) performance criteria, and that no damage was observed in conjunction with grinding operations. The unit cost for grinding averages \$3.00 per square yard. This can be compared with a 2000 Wisconsin DOT bid tabulation for 3,200 yd^2 (2,676 m^2) of runway sandblasting, where the bids ranged from \$0.46 to \$1.10 per square yard.

MECHANICAL REMOVAL SPECIFICATIONS

That runway rubber removal by mechanical means appears to be a secondary effect that occurs when a runway's surface is being altered for some other reason made obtaining rubber removal specification information on this topic difficult, and the result was sparse, as can by seen in the following sections.

Survey Data on Mechanical Removal Specifications

As previously stated, the two airport responses in this category used in-house personnel and conducted mechanical removal as a part of both routine snow and ice removal or chemical removal. Therefore, there were no airport survey data regarding specifications to report. The one contractor response indicated that diamond grinding was conducted using a qualitative performance specification based on the visual verification that the rubber had been removed rather than a friction measurement.

Mechanical Removal Specification Content Analysis

The formal content analysis described in the first chapter was done on two sets of mechanical rubber removal specifications from one government agency and one contractor. The government specification restricted itself to sandblasting, and the contractor specification was applicable to sandblasting, milling, and grinding. Both must be considered guide specifications. Table 23 shows the output for the first analysis category and is self-explanatory.

The second category of analysis is shown in Table 24. Both specifications required a test strip be established. However, the reason for this was to prove that rubber could be adequately removed from the runways without damaging the pavement. This makes sense in that, with

TABLE 23

RESULTS OF MECHANICAL REMOVAL SPECIFICATION CONTENT ANALYSIS: GENERAL AND EQUIPMENT SPECIFICATIONS

Specification Item	Specifications in Which Found (*n*)	Remark
Type of pavement specified	2	Applied to both asphalt and concrete
Type of contract	2	All were unit price
Contractor qualifications	0	
Hours of operation	0	
Allowable runway closure period	0	
Equipment specifications	2	Most describe requirement for shotblasting and vacuum equipment
Emergency evacuation requirements	0	

Note: There were 6 specifications analyzed.

TABLE 24

RESULTS OF MECHANICAL REMOVAL SPECIFICATION CONTENT ANALYSIS: SYSTEM AND ENVIRONMENTAL CONSTRAINTS

Specification Item	Specifications in Which Found (*n*)	Remark
Pretest/trial required	2	Prove that removal can be done without damage
Weather general	1	Required to be done in "dry" weather
Air temperatures	0	
Surface temperatures	1	> 40°F (4°C)
Wind constraints	0	
Minimum production rate	0	
Debris removal required	1	Requires disposal in compliance with environmental regulations

Note: There were 6 specifications analyzed.

the exception of sandblasting, the mechanical methods remove a thin layer of pavement surface. Therefore, airports use mechanical removal carefully and ensure that excessive damage is not incurred. The rest of the table is self-explanatory.

The final category's analysis results are shown in Table 25. This table is also self-explanatory.

TABLE 25

RESULTS OF MECHANICAL REMOVAL SPECIFICATION CONTENT ANALYSIS: SPECIFICATION TYPE

Specification Item	No. of specifications in which found	Remark
Prescriptive specification	1	Remove 85% of rubber
Performance specifications	1	
Quantitative criterion	0	Friction mu value
Qualitative criterion	1	Visual inspection
Used both types	0	
Other specifications included	2	Generally, means/methods related

Note: There were 6 specifications analyzed.

COMMONLY USED PRACTICES

Owing to the paucity of information, there are no commonly used practices that can be developed from this study.

CHAPTER SIX

RUBBER REMOVAL CASE STUDIES

INTRODUCTION

This chapter reviews findings as they relate to the case studies obtained during the course of the study. Relevant case studies for each type of removal technique are developed. A rigorous structured interview protocol was used to ensure uniformity in the information developed and to create a "chain of evidence" (Yin 2004). The major categories of information collected for each case study are as follows:

- Airport identification and location data,
- Pavement type data,
- Rubber removal method data,
- Damage data,
- Rational for selecting given rubber removal methods,
- Relative success and failures of each method in use, and
- Other relevant information.

Several interviews were conducted in person, which allowed for inspection of the equipment in use, the results of any damage, and other items. The remaining interviews were conducted by telephone. The major thrust of the interview was to document successes or failures with various rubber removal methods. Table 26 is a summary of the airport case studies. It can be seen that all four rubber removal methods are covered, with two of the airports having either tried and rejected or changed methods. In addition, half of the airports are in the large category and half are in the small. There are two southern airports and four northern airports. Thus, the case studies adequately cover the survey research.

In addition to the airport case study interviews, the researcher also interviewed five rubber removal contractors. These interviews were not conducive to refining to specific case studies. However, they did provide valuable background information and led to specific questions in the airport case studies that helped sharpen the focus of the structured interviews themselves. Three of the contractors worked internationally, which provided an excellent contrast between North American and international practices and allowed for specific detailed questions of the interviewees that helped in comparing and contrasting the commonly used practices in North American with those in use in the rest of the world. The following rubber removal contractors were interviewed. (Contact information for the members of the rubber removal industry who contributed to this study is contained in Appendix D.)

- Blastrac, Inc., Edmond, Oklahoma: shotblasting—self-contained rubber removal process machine.
- Skidabrader, Ruston, Louisiana: shotblasting—self-contained rubber removal process machine.
- Vindotco, Ltd., Brigg, United Kingdom: chemical (Rubberaser) with high-pressure waterblasting—self-contained rubber removal process machine.
- Trackjet, Melrichtstadt, Germany: ultra-high-pressure waterblasting—series of machines to complete rubber removal.
- Fulton Hogan Ltd., Christchurch, New Zealand: ultra-high-pressure watercutting—self-contained rubber removal process machine.

The remainder of this chapter is devoted to presenting the six airport case studies. They have been reduced to the same format in accordance with the case study rules proposed by Yin (2004). This allows both the reader and the researcher to directly compare and contrast each case with all others. It also supports developing conclusions by making the information gleaned from the data highly visible and makes the recognition of Yin's "multiple sources" rule much easier.

As mentioned earlier, there were six case studies at the airports as shown in Figure 18. The distribution of these covers both coasts as well as the northern and southern borders of the United States, plus one international airport in New Zealand. One airport, Dallas–Fort Worth, has experience with three of the methods: waterblasting, chemical rubber removal, and shotblasting. Its case study is detailed in the shotblasting section and perhaps contains the most authoritative information regarding the subject at a global perspective.

AIRPORT CASE STUDIES

There were four case study airports that had experience with waterblasting. San Francisco is currently using the method. Christchurch is currently using UHP watercut-

TABLE 26
AIRPORT CASE STUDY SUMMARY INFORMATION

	BIL	DFW	BOS	OKC	SFO	CHC
Pavement type	Asphalt PFC	Concrete grooved	Asphalt grooved	Concrete grooved	Asphalt grooved	Asphalt grooved
Method	Mechanical using snow/ice removal equipment	Chemical/ shotblasting	Chemical/ shotblasting	Chemical/ waterblasting	Waterblasting	Waterblasting
Contract or in-house	M: In-house	C: Contract S: Contract	C: In-house S: Contract	C: In-house W: Contract	W: Contract	W: Contract
Frequency	M: 2–4 times per winter	4–5 per year	As required by friction values	2 time per year	5 times per year	As required by friction values
Months in rubber is removed	M: Oct.–April	C: Jan., Apr., Aug., Nov. S: May	C: May–Oct. S: NA	C: June, Oct. W: N/A	W: Jan.–Dec., as required	W: Jan.–Dec., as required
Production rate (yd²/h)	N/A	C: 1,890 S: 4,500	1,600/3,300	C: 1,100 W: 1,100	W: 1,350	W: 360
Runway closure time (h)	N/A	C: 8 S: 8	C: 5 S: 8	C: 8 W: 8	W: 6–7	W: None
Performance criteria	Friction mu value	Friction mu value	Friction mu value	85% removal	Friction mu value	Friction mu value + texture depth
Unit cost ($/yd²)	None	C: 0.99–1.08 S: 0.56	C: 0.11 S: 0.72–1.35	C: 0.36 W: 0.70	W: 0.36–0.54	W: 2.49
Damage	None	C: None S: Groove wearing and lighting lens dimming	C: None S: N/A	C: None W: Spalling to new grooved concrete runways	W: Groove wearing	W: Minor removal of fines and binder from surface and some stones from the cut edge
Remarks	Able to maintain satisfactory friction values by using its standard snow and ice removal chemicals and equipment	Shotblasting for retexturing on pavement that does not meet friction value after rubber removal by chemical	Shotblasting for retexturing on pavement that does not meet friction value after rubber removal by chemical	Residue allowed to drain into surrounding soil. No cost for disposal and no permit required	Residue is collected and disposed off site at a cost of $70/yd3 (not included in above unit cost)	Residue is collected and disposed off-site. Able to conduct removal without runway closure

Note: C = Chemical; M = Mechanical; S = Shotblasting; W = Waterblasting; N/A = not available.

ting. Oklahoma City discontinued the use of the method after suffering damage to fairly new (less than 2 year old) concrete runways, and Dallas–Fort Worth has switched to other methods. Therefore, these case studies represent a nice range of both technology as well as good and bad experiences. As Oklahoma City is currently using chemical rubber removal methods, the details of this case are located in the next section. In addition, it should be noted that San Francisco experimented with shotblasting and decided not to adopt that method based on the results of the test. Finally, Dallas–Fort Worth decided to stop using waterblasting because of an unacceptable level of joint sealant damage that they blamed on operator incompetence. Dallas–Fort Worth now uses chemical removal and shotblasting, and the details of this case study are contained in the shotblasting section of this chapter.

San Francisco, California

ACRP Case Study: San Francisco International Airport (SFO), San Francisco, California

Pavement type (concrete or asphalt): Asphalt

Frequency of airport rubber removal on grooved runways: Five times per year

Time of year rubber removal is usually accomplished: Throughout year as required

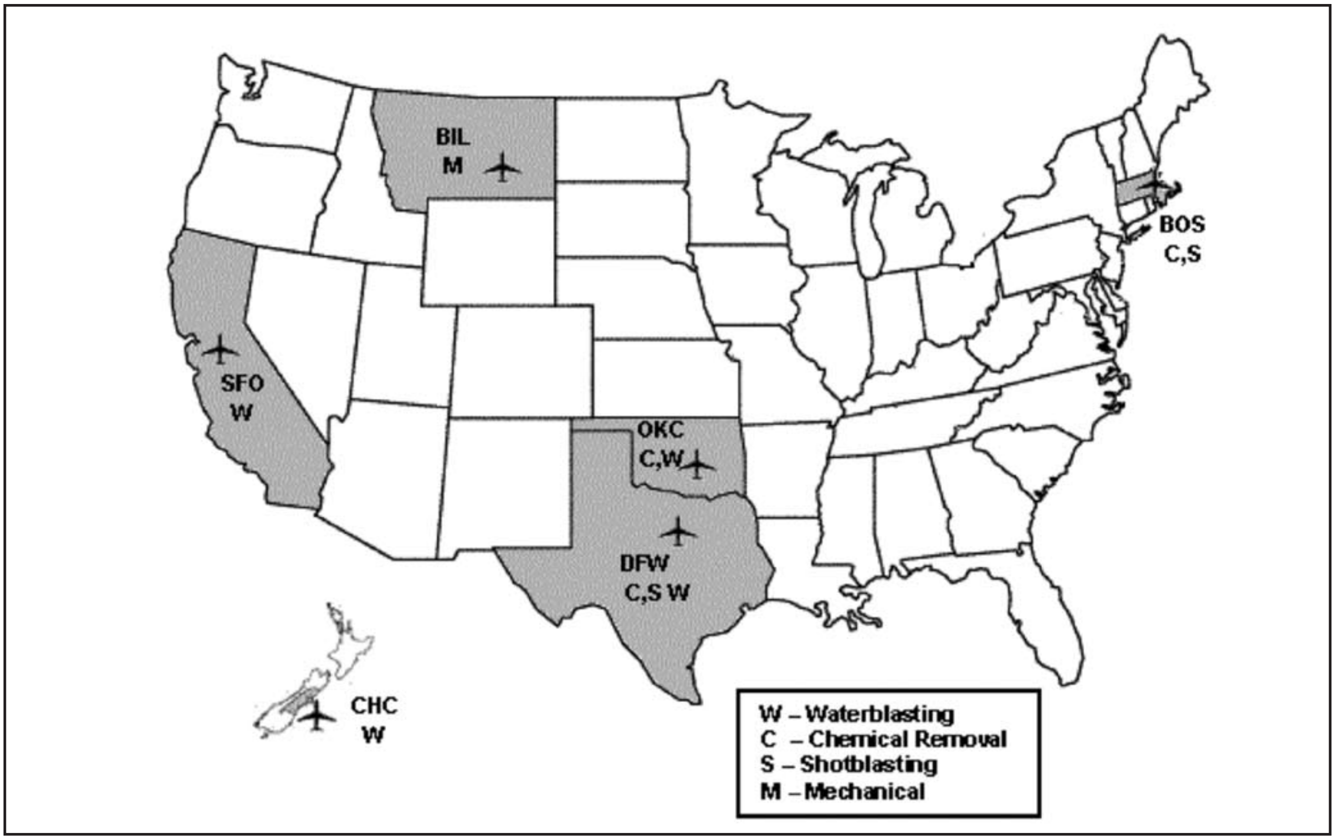

FIGURE 18 Geographic distribution of case study airports

Rubber removal methods employed: SFO currently uses high-pressure waterblasting.

Reasons for choosing method: SFO has been using waterblasting since 1992 and is satisfied with the results when the operation is performed by an experienced operator. Its primary reason for using this process is that it complies with very strict environmental restrictions in place in San Francisco and waterblasting minimizes the probability of pollution. The residue is collected through a vacuum recovery system and is disposed of off site in a regulated disposal facility. Waterblasting does not require a permit. SFO believes the process is fast enough to minimize impact on airport operations. In addition, the pool of competent contractors is adequate to support both competition and satisfactory performance. The airport has found that an experienced operator can remove the necessary rubber deposits without serious damage to the runway. Although some groove edge deterioration after waterblasting was observed, it was not substantial and SFO is not positive that it was a direct result of the waterblasting. However, in those cases where operator skill or experience was not adequate, damage to runway lighting, pavement markings, and crack sealant was experienced.

SFO tried shotblasting on a test strip as a potential alternative to its current technique, but believed the results were unacceptable. It appeared to be too slow to accomplish without negative impact on airport operations.

Types and number of equipment used and crew size: The waterblasting rubber removal process uses a water pressure head truck with recovery. A broom sweeper is used if the residue recovery system fails to completely recover the residue. The broom sweeps the unrecovered residue for collection and disposal. The contractor furnishes a crew of at least three workers; two airport staff members are required for oversight.

Surface area of rubber removal and duration of runway closure: The waterblasting process has a production rate of 1,350 yd^2/h (1,087 m^2/h), which supports a 6- to 7-h runway closure period.

Contracting method employed or in-house: Waterblasting is done by contract.

Value of contract unit price: The waterblasting costs \$0.36 to \$0.54 per square yard. The cost of off-site residue disposal is roughly \$70.00 per cubic yard.

Performance criteria specified to contractor or rubber removal team: The finished product must meet measured friction values for the specific runway based on the friction mu value.

Any damage reports to grooved runways that could be attributed to rubber removal operations and techniques:

Damage to runway lighting, pavement markings, and crack sealant was observed with waterblasting when the operator was not experienced. There was groove edge deterioration after waterblasting, but it was not believed to be substantial enough to preclude the use of the process. In addition, waterblasting has been determined to cause unacceptable damage on pavements that are oxidized. At SFO, these pavements are generally older than 6 years. The process strips the brittle binder from the aggregate. As a result, SFO schedules runway resurfacing on a 6-year rotation.

Other potential impacts on airport operations and airport maintenance functions: SFO may consider using chemical removal if it finds that waterblasting operator competency drops to an unacceptable level. Inexperienced operators cause the airport to assign more inspections and finds that technical issues such as correctly setting up and executing overlaps between passes are often done improperly.

Christchurch, New Zealand

ACRP Case Study: Christchurch International Airport (CHC), Christchurch, New Zealand

Pavement type (concrete or asphalt): Asphalt grooved

Frequency of airport rubber removal on grooved runways: As required by friction testing

Time of year rubber removal is usually accomplished: Year round as required

Rubber removal methods employed: Waterblasting using an ultra-high-pressure watercutter (UHPWC)

Reasons for choosing method: The primary reason is that the equipment is mobile enough to permit the crew to work between flights, with no need for runway closures. In addition, it requires no environmental permits as the residue is vacuumed and disposed of off site in the same manner as used for demolished pavements.

Types and number of equipment used and crew size: The contractor uses six UHPWC rigs and each has a crew of two.

Surface area of rubber removal and duration of runway closure: The process furnishes a production rate of roughly 360 yd^2/h (300 m^2/h). As traffic is light at this airport, the crew is allowed to work between operations, and no formal runway closure is scheduled.

Contracting method employed or in-house: Watercutting is done by contract.

Value of contract unit price: $2.49 per square yard, including the cost of disposal

Performance criteria specified to contractor or rubber removal team: Minimum texture depth after rubber removal is measured using the New Zealand sand circle test. In addition, visual inspection of the area is made to verify complete rubber removal. Finally, skid tests are administered to verify that friction values conform to minimums.

Any damage reports to grooved runways that could be attributed to rubber removal operations and techniques: CHC has observed minor removal of fines and binder from surface and some stones from the cut edge.

Other potential impacts on airport operations and airport maintenance functions: Not applicable.

Chemical Removal Case Studies

There were three case study airports that used chemical rubber removal methods. Of those, Boston is also experimenting with shotblasting as a means to restore friction values. Dallas–Fort Worth routinely uses both methods. Its contract requires the rubber removal contractor to subcontract for shotblasting if chemical removal fails to restore acceptable friction values. As a result of their experience, the details of the Dallas–Fort Worth case study are in the shotblasting section.

Boston, Massachusetts

ACRP Case Study: Boston Logan International Airport (BOS), Boston, Massachusetts

Pavement type (concrete or asphalt): Asphalt

Frequency of airport rubber removal on grooved runways: As required by friction values

Time of year rubber removal is usually accomplished: May through October

Rubber removal methods employed: BOS currently uses a chemical removal method that has proved satisfactory for removing rubber, but the airport has found that rubber removal alone is not sufficient to restore runway friction values to required levels on older pavements where the aggregate has become polished. Therefore, it decided to experiment with shotblasting. After a satisfactory test strip, it used shotblasting for retexturing the pavement with satisfactory results on three occasions.

Reasons for choosing method: The airport has used chemical removal because of its cost, the speed of the operation, and that it can use in-house maintenance forces and already owns the equipment. When the removal of rubber proved to be insufficient for restoring friction values, the airport tried shotblasting. The operator was pleased with the enhanced pavement friction values that shotblasting provided through retexturing the pavement. Its major reason was to retexture the pavement and restore both macro- and microtexture.

Types and number of equipment used and crew size: The chemical removal process uses two chemical spray trucks and two mechanical brooms. The shotblasting requires the shotblasting machine.

Surface area of rubber removal and duration of runway closure: The chemical removal process has a production rate of 1,600 yd^2/h (1,338 m^2/h), which supports a 5-h runway closure period for rubber removal on one typical runway end. The shotblasting when used for retexturing has a production rate of 3,300 yd^2/h (2,759 m^2/h).

Contracting method employed or in-house: Current chemical removal is done using in-house forces, and shotblasting is done by contract.

Value of contract and unit price: Chemical removal costs approximately $0.105 per square yard, not including the cost of in-house labor. Shotblasting costs approximately $0.72 to $1.35 per square yard, depending on the area that requires retexturing after chemical removal is complete.

Performance criteria specified to contractor or rubber removal team: The finished product must meet FAA required friction mu values, as measured by the airport's Saab. For shotblasting, macrotexture was measured using the ASTM sand patch test both before and after to verify that macrotexture had indeed been improved. The test results showed macrotexture had been improved from 30% to 50%.

Any damage reports to grooved runways that could be attributed to rubber removal and retexturing operations and techniques: No damage has been observed in chemical removal rubber removal. The first two shotblasting retexturing operations removed considerable fines from around the aggregate, effectively shortening the service life of the pavement. A different shotblasting machine was used the third time, which did much less damage to the pavement surface. The airport uses shotblasting as a last resort to restore friction on its asphalt pavements because of the loss of fines associated with the process.

Other potential impacts on airport operations and airport maintenance functions: No foreign object or debris issues were observed with the shotblasting technique.

Oklahoma City, Oklahoma

ACRP Case Study: Will Rodgers International Airport (OKC), Oklahoma City, Oklahoma

Pavement type (concrete or asphalt): Concrete

Frequency of airport rubber removal on grooved runways: Twice per year in late spring and early fall

Time of year rubber removal is usually accomplished: Summer (June and September)

Rubber removal methods employed: OKC currently uses chemical removal methods after experiencing pavement damage with waterblasting techniques.

Reasons for choosing method: OKC had used waterblasting successfully for a number of years on its grooved concrete runways. It rehabilitated one of its main runways and attempted to use the same method on the new concrete after 2 years. The waterblasting pressure was less than 40,000 psi (275.79 MPa), the specification for previous rubber removal operations. OKC found that waterblasting on new concrete caused spalling and damaged joint seal material. It believes that the age of the concrete was the main factor for the damage caused by the waterblasting. In addition, the waterblasting method required the contractor to vacuum the residue and obtain a disposal permit to dispose it off site.

OKC then switched to chemical removal techniques that use a process that has been tested by the state Department of Environmental Quality and requires no environmental permit and no need to vacuum the residue. The major chemical agent is biodegradable, noncorrosive, and requires no special safety equipment for airport personnel who use it. In addition, the chemical method costs about 50% less than the waterblasting technique and allows the airport to do the work with in-house personnel and existing equipment. Airport rubber removal crews believe the chemical removal method is faster, and it causes no damage to the deicing truck's hoses, tips, etc., that are used to apply the chemical. Finally, the chemical's manufacturer has worked with the airport and modified the compound to make it more effective for specific conditions.

To summarize, OKC believes that the change of rubber removal methods allowed it to increase the effectiveness of their rubber removal program by allowing it to do the work with in-house maintenance personnel, at lower costs, with no risk of pavement damage, and no need to procure special permits.

Types and number of equipment used and crew size: OKC uses a standard deicing truck to apply the chemical. It then follows with a stiff wire-core polyethylene rotary brush that is compatible with the brooming machine. Two brooms are used: one with heavy bristles, followed by another with standard bristles. The brooms move at 3 mph, with a 45 psi (0.31 MPa) down pressure. The crew consists of five personnel plus a supervisor. The process involves spraying water on the surface, followed by the chemical, which is followed by approximately 3 h of brooming and adding more water during brooming to keep the surface wet. The residue is allowed to drain into the surrounding soil.

Surface area of rubber removal and duration of runway closure: The team breaks the process down to areas that can be covered by 500 gal (1,893 L) of chemical at the design rate. The runway is closed for a total of 8 h.

Contracting method employed or in-house: Chemical removal is done by in-house snow and ice removal crews; waterblasting was done by contract.

Value of contract unit price: Chemical removal costs approximately $0.36 per square yard. The waterblasting that was used previously cost $0.72 per square yard.

Performance criteria specified to contractor or rubber removal team: 85% removal by number of rubber grains per measured square

Any damage reports to grooved runways that could be attributed to rubber removal operations and techniques: No damage has been observed in chemical removal. Concrete pavement spalling and joint material damage had been observed with waterblasting.

Other potential impacts on airport operations and airport maintenance functions: OKC has found that chemical removal works best in cooler months when there is no danger of freezing temperatures.

Shotblasting Case Studies

As previously stated, there were three case study airports that had shotblasting experience. San Francisco experimented with it and rejected it. Boston experimented with it and decided to implement it in addition to its routine chemical rubber removal program. Dallas–Fort Worth has been using shotblasting to augment its chemical rubber removal program for some time. SFO and BOS have been detailed previously. Therefore, only Dallas–Fort Worth is described in this section.

Dallas–Fort Worth, Texas

ACRP Case Study: Dallas Fort Worth International Airport (DFW), Dallas, Texas

Pavement type (concrete or asphalt): Concrete

Frequency of airport rubber removal on grooved runways: Four to five times per year

Time of year rubber removal is usually accomplished: Throughout year as required: scheduled on a quarterly basis

Rubber removal methods employed: DFW currently uses a combination of chemical removal methods combined with shotblasting to produce a comprehensive runway friction performance maintenance contract. It uses a performance requirement that is based on friction values, and requires that the chemical rubber removal contractor furnish a shotblasting subcontractor to retexture those runway areas that fail to achieve required friction values after chemical removal is complete. This is important in that runways can lose skid resistance resulting from the polishing of the aggregate. Thus, removing rubber deposits may not be sufficient to restore runway surface microtexture and macrotexture. Thus, the DFW approach is to focus the contract on restoration of surface friction rather than merely rubber deposit removal.

Reasons for choosing method: DFW had previously used waterblasting to remove rubber deposits but changed to the above method after suffering an unacceptable level of joint sealant material damage from waterblasting. It ascribes the damage to operator ability rather than a technical issue with the waterblasting technology. Inexperienced operators failed to move at a forward speed that precluded damage to joint material. As DFW contracts for these services, it believed that it could not guarantee that it would get an experienced operator that would not damage the joint material because of constraints of the procurement process. The residue was required to be vacuumed and disposed of off site because of the heavy metal content of the rubber deposits, which contain a high level of zinc, among other heavy metals.

DFW next tried shotblasting. However, it experienced undesired paint removal and had to repaint after using this process, which created both a cost and an operational issue. In addition, the shotblasting wore the grooves down and dimmed the light lens on the end of pavement lighting system. The operator was pleased with the enhanced pavement friction values that shotblasting provided through retexturing the pavement.

DFW then switched to chemical removal techniques using a process that does not induce any pavement or other collateral damage to runways. The process requires that the residue be vacuumed and removed for disposal off site because of the heavy metal content of the rubber residue and not the characteristics of the chemical itself. Early use of this method found that, even though the chemical process had satisfied the requirements for rubber removal, some runways still did not have acceptable friction values because of loss of micro- and macrotexture through polishing of the pavement aggregate. This led DFW to restructure the chemical rubber removal contract to include retexturing those areas that did not meet requirements after rubber removal through selective shotblasting.

To summarize, DFW has evolved the rubber removal contract into a performance contract to regain friction values rather than just remove rubber. This is an important distinction. A rubber removal contractor can flawlessly remove the rubber per its contract, but if the pavement condition is such that loss of both macro- and microtexture so that minimum friction values have not been restored, the runway may be unsafe even though longer rubber deposits no longer exist.

Types and number of equipment used and crew size: The chemical removal process uses a spray rig, two mechanical brooms, a vacuum truck, and a tanker truck with an average crew of four workers. The shotblasting requires the shotblasting machine.

Surface area of rubber removal and duration of runway closure: The chemical removal process has a production rate of 1,890 yd^2/h (1,580 m^2/h), which supports an 8-h runway closure period. Shotblasting when used for rubber removal has a production rate of 4,500 yd^2/h (3,763 m^2/h), which also supports an 8-h runway closure period.

Contracting method employed or in-house: Current chemical removal and shotblasting are done by contract; previous waterblasting was also done by contract.

Value of contract unit price: Chemical removal costs approximately $0.99 to $1.08 per square yard, including the cost of off-site residue disposal. Shotblasting costs approximately $0.72 to $1.35 per square yard depending on the area that requires retexturing after chemical removal is complete. Shotblasting for purely rubber removal (i.e., not a part of the chemical removal contract) costs $0.56 per square yard. The drop in price is the result of the increase in the number of units in the contract. The waterblasting that was used previously cost $0.32 per square yard.

Performance criteria specified to contractor or rubber removal team: The finished product must meet previously measured friction values for the specific runway based on the friction mu value. In addition, the required production rate of 1,890 yd^2/h (1,580 m^2/h) is specified. Retexturing using shotblasting is required for those areas that fail to meet friction values after chemical removal.

When shotblasting alone is used to remove rubber, the requirement is 100% removal of rubber deposits. In addition, the required production rate of 4,500 yd^2/h (3,763 m^2/h) is specified.

Contract performance for friction values is determined as follows:

- Five 500-foot long test strips are established in the center of the runway,
- The friction is measured on each strip and an average value of the set is calculated,
- Postremoval friction values must be within 5% of the average test strip value, and
- The test strips are remeasured if they are mechanically altered in any way.

Any damage reports to grooved runways that could be attributed to rubber removal operations and techniques: No damage has been observed in chemical removal. Joint material damage was observed with waterblasting. Groove wearing and runway light lens dimming were observed with shotblasting.

Other potential impacts on airport operations and airport maintenance functions: DFW typically removes rubber with the chemical method on a quarterly basis. Once a year, it uses shotblasting in lieu of chemicals to retexture in addition to removing rubber.

Mechanical Rubber Removal Case Study

There was only one airport, Billings, Montana, that used mechanical means to remove runway rubber deposits, and it did not use either of the classic mechanical methods: grinding or milling. It used its in-house snow removal equipment. By installing a different type of blade on the snow plows, it found that it could remove enough rubber in conjunction with its routine winter snow and ice removal operations that it did not need to undertake specific rubber removal operations.

Billings, Montana

ACRP Case Study: Billings–Logan International Airport (BIL), Billings, Montana

Pavement type (concrete or asphalt): Asphalt porous friction course

Frequency of airport rubber removal on grooved runways: Officially, none. Billings has found that its routine snow and ice removal operations are sufficient to remove enough rubber that its runways remain within friction value standards. Typically, it experiences two to four ice events each winter, and the operator attributes the effect to sand grit combined with the deicing chemicals and use of steel blades on its snow plows.

Time of year rubber removal is usually accomplished: Winter

Rubber removal methods employed: BIL uses standard deicing chemicals (FAA-approved Cryotech E-36) and FAA-approved sand in combination with a carbide steel snow plow blade, followed by stiff bristle snow brooms to remove ice from runways during ice events.

Reasons for choosing method: The surface of the primary 10,500-ft (3,048-m) runway is a PFC. The research on potential rubber removal techniques showed that there is no 100% guarantee that damage would not occur to the runway during the process. BIL has a relatively low number of landings with heavy aircraft; therefore, there is a small amount of rubber buildup. BIL has proven that it has the ability to keep this under control through routine snow and ice removal operations during the winter months.

Types and number of equipment used and crew size: The numerous passes over the rubber buildup with high-speed runway brooms, blowers, and snowplows keep this manageable through routine runway snow and ice removal operations. The airport uses carbide steel blades on its snowplows during ice events instead of the rubber blades that it uses during snow events. Routine friction measurements tests demonstrate no significant problem that needs to be remedied.

Surface area of rubber removal and duration of runway closure: Not applicable

Contracting method employed or in-house: In-house snow and ice removal crews

Value of contract unit price: Not applicable. Cost is borne by routine snow and ice removal operations.

Performance criteria specified to contractor or rubber removal team: Not applicable

Any damage reports to grooved runways that could be attributed to rubber removal operations and techniques: Not applicable

Other potential impacts on airport operations and airport maintenance functions: Not applicable

CONCLUSIONS

Several conclusions can be drawn from the analysis of the case study airports combined with the information gleaned from the contractor interviews. First, and foremost, is that some case study airports have changed their approach from the prescriptive "remove rubber" logic to the performance-based "restore friction" logic. Both DFW and BOS either have or are adopting this in their rubber removal programs. In addition, Toronto and Atlanta also apply this strategy to their programs. The DFW experience is an example of the quest for the "perfect solution." This airport has tried three of the four methods and finally settled on the toolbox approach of using chemical rubber removal as its primary method but supplements it with shotblasting to retexture runways whose friction values are below minimum after chemical rubber removal.

The next conclusion is that case study airport operators cannot depend solely on technology for satisfactory rubber removal. Both DFW and SFO explicitly cited the need for experienced rubber removal equipment operators to achieve the results sought in their rubber removal contracts. One survey respondent who had been successfully using waterblasting indicated that it would be changing to chemical removal "if operator competence keeps declining." The fear of collateral damage to not only pavement grooves but also of other components to the runway pavement and its appurtenances because of mishandling of rubber removal equipment affects the decisions being made by airports as to which method to use. This would argue for the switch to performance contracts cited as well as for prequalifying runway rubber removal contractors and their key employees as a part of the procurement process.

The final conclusion is that case study airports have used all four reviewed methods successfully, negating the idea that one rubber removal method might be inherently better than all others. All four methods have proven themselves to be successful as well as economical in at least one of the six case studies. Surveyed airport practice reinforces the idea that these methods are "tools" in the runway rubber removal "toolbox," and airport operators evaluate their specific requirements, climate, traffic, and local laws and regulations, selecting the tool or combination of tools that best fits their specific runway rubber removal problem.

CHAPTER SEVEN

CONCLUSIONS AND SUGGESTIONS

INTRODUCTION

The information included in this chapter is the result of the analysis information collected from survey responses from 33 airports in 21 states plus the District of Columbia, 2 Canadian provinces, and 1 New Zealand province, and from 12 members of the runway rubber removal industry. The survey information was intersected with literature information from 76 different sources as well as the formal content analysis of 23 runway rubber removal specifications from 15 different sources. Finally, information developed from six runway rubber removal case studies at 5 U.S. and 1 foreign airport was added to furnish validation for the conclusions expressed here.

ANALYSIS OF TOTAL POPULATION

Four chapters looked at one rubber removal method separately. Taking all airport survey responses as a single population and comparing it with contractor responses as a single population also furnishes some interesting information regarding runway rubber removal in general. First, it is worthy to look at the reasons for choosing a given rubber removal method as a whole to determine what the major underlying motivations are of airport pavement maintenance managers as a group. Figure 19 shows the number of responses in each category for all the methods taken as a single population. The major reason is satisfaction with process. In other words, the airport pavement maintenance managers are saying, "We use the methods we use because they work." Thus, empirical data are more important to the decision than technical potential. This allows one to infer that any given airport will probably have to have a negative experience with a given method before it is willing to change to a different one. This inference is borne out by the case study information where both Oklahoma City and Dallas–Fort Worth switched from waterblasting to chemical removal because the damage they suffered on their runways.

The second most frequent response supports this inference in that it dealt with the airport managers' feeling about whether or not a given method would cause damage to the

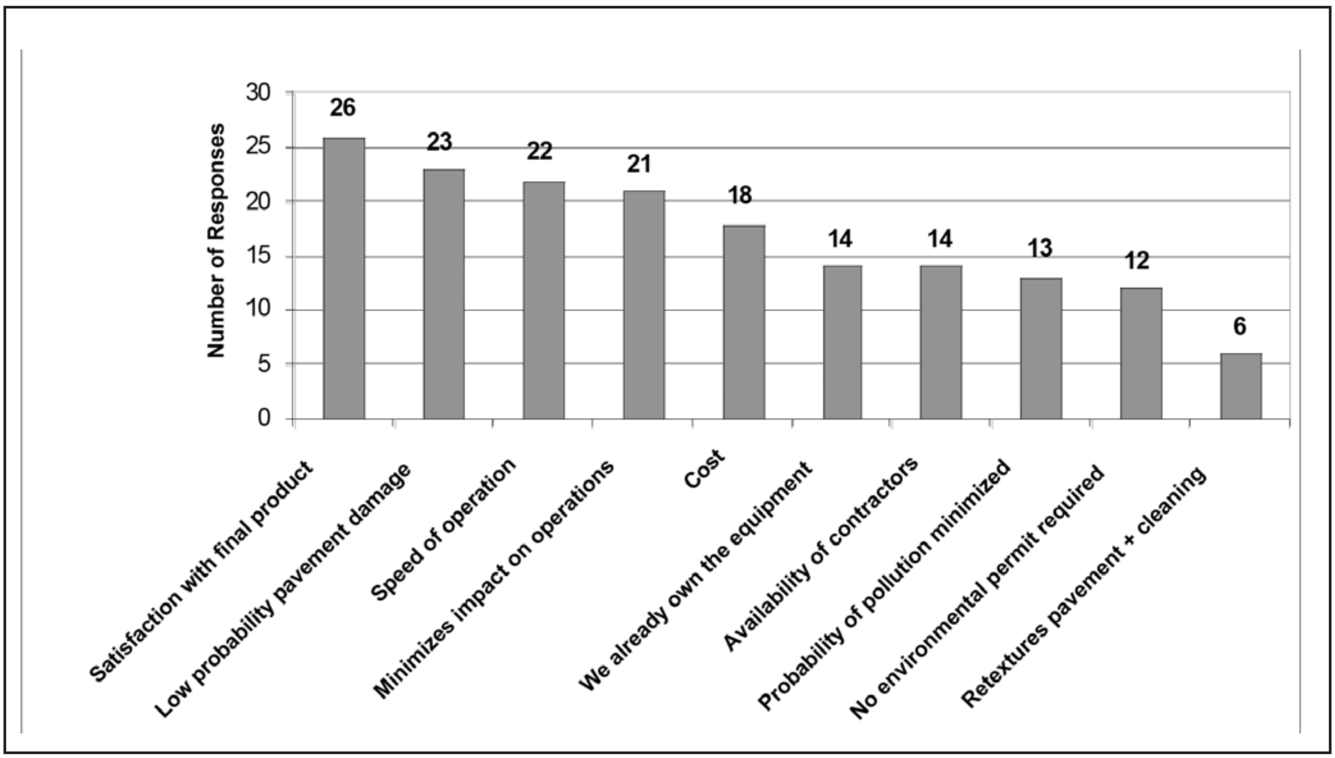

FIGURE 19 Reasons for selecting rubber removal method for all airport respondents.

pavements. Third and fourth places went to the categories that dealt with method productivity and its impact on airport operations. The three categories that relate to cost finished fifth, sixth, and seventh, and most interesting, the two environmental categories were among the last group of categories. The retexturing ability relates to ultra-high pressure (UHP) watercutting and shotblasting only and as a result should not be considered in this analysis. Therefore, it can be concluded that the major motivators for the selection of rubber removal methods would rank as follows:

1. Performance,
2. Production rate,
3. Cost, and then
4. Environment.

Next, a look at seasonality for the entire population gives the reader a feeling for the relative level of activity regardless of method type across the calendar year. Figure 20 shows that the highest levels of activity are seen after the winter months and at the end of the summer, which tracks with the conclusions drawn for the individual rubber removal methods discussed in the previous chapters.

Finally, it is interesting to look at the types of specifications used without respect to rubber removal method. This is shown in Figure 21. Although a large segment of the population uses both prescriptive and performance types of specifications, it can be seen that performance specifications are more common than prescriptive specifications. Combining performance with the "both" category shows that 78% of the respondents have experience using performance specifications in regard to their runway rubber removal programs. This shows that most airports are already experienced with performance specifications and, therefore, supports the notion mentioned in the first chapter that runway rubber removal would benefit from a shift from the prescriptive approach, which focuses on how much rubber is removed, to the performance approach, which focuses on restoring friction values.

Given the earlier discussion about runway rubber removal methods in general, one can now move to identifying the conclusions that have been reached in the synthesis analysis. The information for the overall population should assist the reader in establishing a global context against which to

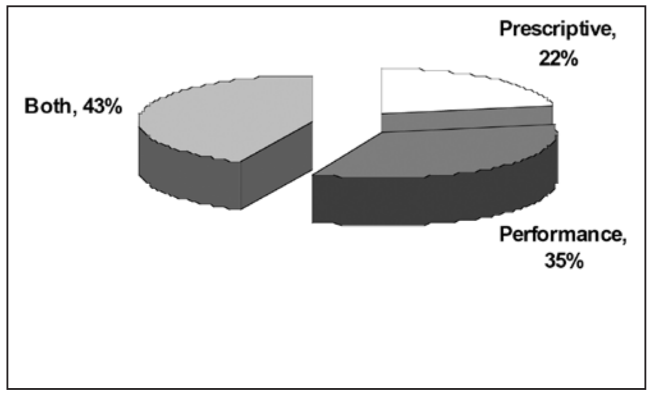

FIGURE 21 Runway rubber removal specification usage for entire airport population.

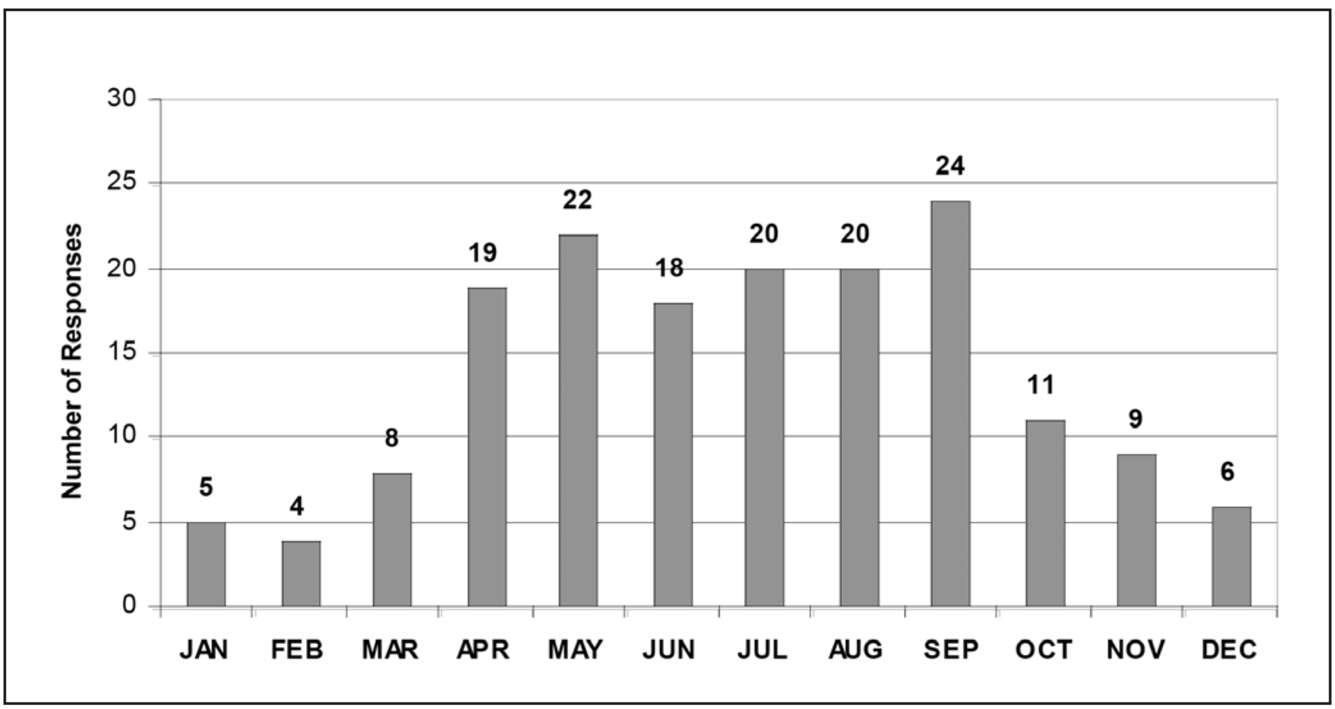

FIGURE 20 Rubber removal seasonality for entire airport population.

benchmark the conclusions and recommendations proposed for each specific method.

POTENTIAL RUNWAY DAMAGES OWING TO RUBBER REMOVAL

Table 27 is a consolidated listing of the types of runway groove, pavement, and appurtenance damage that were reported in this study. The reader is cautioned to not read this as an inherent "guarantee" of damage due to rubber removal method selection. As will be seen, all of the methods are being used successfully, and the issue of damage appears be more one of operator competency rather than inherent technology. Thus, the fact that runways can be damaged by all available methods if used improperly makes a strong argument for prequalification of runway rubber removal contractors and the need for training of in-house rubber removal crews.

STANDARD FOR RENDERING CONCLUSIONS

The standard used by the researcher to arrive at a conclusion was simple and straightforward. The conclusion had to spring from an intersection of information gathered in the literature and confirmed as fact by evidence that it was used in practice. That evidence came from the survey responses, case studies, and analysis of specifications. The commonly used practices for each rubber removal method are listed in their respective chapters and will not be repeated here. It suffices to say that six were identified and can be immediately implemented by airports where they would be applicable.

CONCLUSIONS

The conclusions cited in the following sections were developed as described previously and come from two separate sets of analyses. The first is the direct analysis of the research data after they were reduced and sorted per the methodology described in the first chapter. The second is the indirect analysis of what was missing in the reduced data. Although this is certainly more abstract and somewhat less authoritative, the inferences from which they are drawn are valid nevertheless. To differentiate these from the direct analysis conclusions, they will be termed "observations."

Conclusions from the Direct Analysis

The direct analysis of the research output yielded the following four conclusions:

1. Airport operators use a "toolbox" approach to restoring pavement skid resistance rather than merely selecting a single method to remove rubber.

2. Damage observed in runway grooving, pavement, and to appurtenances is largely the result of equipment operator error rather than the inherent qualities of a given technology.

3. Based on the above conclusion, some airport operators either require or may consider prequalification of rubber removal contractors or additional training for in-house rubber removal crews.

4. The primary reason airport operators select chemical rubber removal relates to their ability use in-house personnel and equipment.

TABLE 27
POSSIBLE DAMAGE FROM RUBBER REMOVAL METHODS

Possible Damage	Waterblasting	Chemical Removal	Shotblasting	Mechanical Removal
Groove damage	X		X	X
Spalling of concrete	X			
Damage to asphalt pavements	X	X	X	X
Microtexture degradation (polishing of aggregates)	X	X		
Loss of aggregate/fines	X		X	
Damage to expansion joints and crack seal	X		X	X
Damage to patches	X		X	X
Damage to equipment from caustic chemicals		X		
Damage to runway lighting	X	X	X	X
Damage to paint/markings	X	X	X	X

The first conclusion is that airports commonly use a "toolbox" approach to restoring skid resistance through runway rubber removal. This approach to runway surface friction encourages airport pavement managers to use two or more of the runway rubber removal methods as "tools" to maintain satisfactory surface friction values. Case study examples include the inclusion of routine snow and ice removal operations, such as those used in the Billings, Montana, case study, as a deliberate part of the runway surface friction maintenance strategy as well as enhancing chemical rubber removal with mechanical means as was reported by one airport in the survey. The Dallas–Fort Worth experience personifies the quest for the "perfect solution." This airport has tried three of the four methods and finally settled on the "toolbox" approach of using chemical rubber removal as its primary method but supplementing it with shotblasting to retexture runways whose friction values are below minimum values after chemical rubber removal. In addition, two other airports (one northern and the other southern) also apply this strategy to their programs. The upshot is to ensure that the means achieve the desired result. In a prescriptive approach, the mandated result is the removal of a prescribed amount of rubber. Whether done by in-house personnel or contractors, the removal of 100% of the rubber does not necessarily translate to the restoration of required surface friction values. Therefore, restoring skid resistance through runway rubber removal requirements rests in the performance realm and reflect the reason for performing the rubber removal in the first place, making "restore satisfactory friction values" the approach of choice by some airports using some measurable metric.

The next conclusion regards groove, pavement, and other types of damage to the runway and its ancillary fixtures as a result of rubber removal methods. Most of the reported damage occurred in conjunction with waterblasting, with six instances of reported groove damage. However, five of the respondents with groove damage had some logical explanation for the damage. This, along with the fact that two-thirds of the population reported no groove damage, leads to the conclusion that when waterblasting is done correctly, groove damage is not likely. This conclusion is supported by the rubber removal contractors' responses. Three of six reported having caused groove damage, but all three indicated that the damage was minor. Those airports that were concerned about groove or pavement damage appeared to have selected chemical removal methods. One airport switched from waterblasting to chemical removal after suffering damage to new concrete runways. Shotblasting and mechanical removal methods by the nature of their process inherently create some damage to grooves by removing a thin layer of pavement surface, which may necessitate recutting the grooves. Shotblasting was also reported to cause unwanted paint removal and dimming of runway light lens, which would appear to be expected given the nature of that process. All in all, the amount of damage reported across the population was minimal and apparently related to controllable operator error rather than uncontrollable features of the technology.

This leads to the next conclusion that airport operators do not depend solely on technology for satisfactory rubber removal. Both Dallas–Fort Worth and San Francisco explicitly cited the need for experienced rubber removal equipment operators to achieve the results sought in their rubber removal contracts. Another survey respondent that had been successfully using waterblasting indicated that it would be changing to chemical removal "if operator competence keeps declining." The fear of collateral damage to pavement grooves and other components and appurtenances to the runway affects the decisions being made by airports as to which method to use. This argues for the switch to performance contracts as well as for prequalifying runway rubber removal contractors and their key employees as a part of the procurement process.

The study also concludes that the major reason the airports use chemical rubber removal methods is the ability to conduct rubber removal operations using in-house maintenance personnel. The study found that two-thirds of the airports use internal resources to do chemical rubber removal, and 12 survey responses also indicated that one reason for using the method is that they already own the equipment. This intersects with the literature in which in 2004 Transport Canada stated that the major reason to conduct chemical rubber removal operations with internal assets is "mainly based on convenience, not cost, since the rubber can be removed periodically, one section at a time, during off-peak hours." Airports cited already owning the equipment as the single most important reason to use chemical removal methods. This was followed by "low probability of pavement damage" and "satisfaction with final product." Finally, one survey respondent stated that it used chemical removal because "we control the scheduling, treatment area and the process itself." Thus, it is concluded that convenience combined with good performance experience are the major motivators for airports that use chemical rubber removal.

Conclusions from the Indirect Analysis

The indirect analysis of the synthesis output allows one to discuss a set of observations that can be derived from looking at what was not found in the research. The following are conclusions derived from the indirect analysis of this study's output:

1. No single runway rubber removal method is superior to all others.

2. No single runway rubber removal method is superior for a given pavement type.

3. Size and traffic levels do not affect the decision on what type of rubber removal method to use.

4. Climatic conditions also do not have any effect on the selection of runway rubber removal methods.

The focus of this study was to relate runway rubber removal methods specifically to runway groove damage and secondarily to other forms of damage to the runway pavement and its appurtenances. Presumably, the data might show one method to be superior to all others. That was not the case. The results of the case studies effectively debunk that hypothesis. All four methods have proven themselves to be successful as well as economical in at least one of the six case studies. Therefore, this reinforces the idea that these methods are "tools" in the runway rubber removal "toolbox," and airport operators evaluate their specific requirements, climate, traffic, and local laws and regulations, selecting the tool or combination of tools that best fits their specific runway rubber removal problem.

The next observation tests the idea that certain runway rubber removal methods will be more appropriate on asphalt runways and others will be more appropriate for concrete runways. Perhaps surprisingly, the use of each method was split virtually down the middle for each method as follows:

- Waterblasting: 12 concrete, 13 asphalt;
- Chemical removal: 13 concrete, 16 asphalt;
- Shotblasting: 2 concrete, 1 asphalt; and
- Mechanical removal: 1 concrete, 2 asphalt.

Thus, the study finds that no single method is more appropriate than any other based on runway pavement type. This conclusion is reinforced by the fact that nowhere in the literature was there a mention to this effect. There were a number of assertions that waterblasting polishes the aggregate on pavement surfaces (Hiering and Grisel 1975a,b; Simpson 1989; Cenek et al. 1998; Speidel 2002; Cotter et al. 2006), which was disproved by Waters (2006), but the literature did not differentiate between asphalt and concrete pavement surfaces.

Next, as the analysis consisted of dividing the airports into large versus small based on amount of traffic, there was a hypothesis that one method might prove to be better for large airports with more traffic and hence, per the literature, more rubber to remove (Speidel 2002). There was no such trend. The use of the various methods was fairly uniform across the entire sample population. Therefore, it appears that size and traffic levels do not affect the decision about what type of rubber removal method to use. The analysis also divided the sample into northern versus southern airports. This was to test the idea that the climatic region might dictate the applicability of methods. Intuitively, one would expect that northern airports might avoid methods with large amounts of water to permit rubber removal to take place during colder temperatures. But this was not the case. Again, there was no trend indicating that climatic conditions had any effect on the selection of runway rubber removal methods.

Common Rubber Removal Practice

The major finding of this synthesis report results in a finding that airports approach rubber removal increasing from the prescriptive one of "remove rubber" to a performance-based approach of "restore friction." Two of the case study airports, Dallas–Fort Worth and Christchurch, have done this and report having good success. Another, Boston, has recently made the move to using shotblasting to restore friction after it has cleaned the rubber off its runways with chemicals. Because 78% of the airports and 100% of the contractors in the study indicated that they have experience with performance specifications in their rubber removal programs, the shift in rubber removal philosophy toward performance is ongoing. Finally, the TRB Committee on Surface Properties–Vehicle Inaction essentially calls for this when it stated that its vision for the 21st century included "programs to harmonize both texture and skid-resistance measurements" and "development of improved friction surface treatments such as shot-peening."

Figure 22 is a flow chart that illustrates a routine program of runway friction measurement that would discover when friction values have dropped below the values given in Table 1. The operator would then remove the accumulated rubber and take new friction measurements. If the friction values are still too low, this would indicate the need to retexture

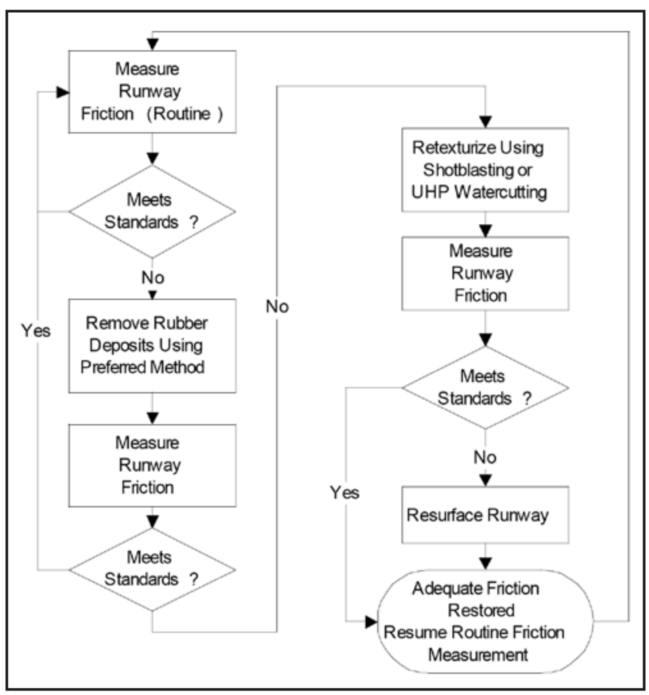

FIGURE 22 Runway friction maintenance decision flow chart.

the pavement using either shotblasting or UHP watercutting as permitted by the situation. On completion, the runway should be within standards. However, if it is not, that would indicate a need to replace the surface as there are no longer any viable tools in the friction maintenance toolbox.

Therefore, given the conclusions found in the synthesis, there must necessarily be follow-up on this research and fill the gaps found in the body of knowledge relating to runway rubber removal. That is the subject of the next section.

FURTHER RESEARCH

The preceding chapters have mentioned those areas where more information is required to expand the body of knowledge in runway rubber removal. Therefore, research could be conducted to fill those information gaps. This study found that more research is necessary in the following five areas:

- Harmonizing the suite of friction measurements and correlating them to pavement texture;
- Studying the relative effectiveness of each method in terms of runway age, types of aggregate used in the pavement, and the impact of rubber removal on pavement service life based on pavement properties;
- Developing definitive guidance for limiting water pressures used in high-pressure and UHP waterblasting for concrete versus asphalt pavements;
- Determining the effect of routine snow and ice removal chemicals on rubber removal so that airport pavement managers can include these in their runway friction maintenance planning; and
- Development of a comprehensive guide for a runway friction maintenance toolbox.

Friction and Texture Measurement Research

The major objective of runway rubber removal is to regain the skid resistance that was inherent in the pavement's surface before the rubber filled the micro- and macrotexture. Airport pavement managers need tools to assist them in measuring and assessing the conditions of their runway surfaces. *Engineering Technical Letter 04-10 (Change 1): Determining the Need for Runway Rubber Removal* lists eight different friction-testing devices whose output varies from device to device. In addition, although the connection between pavement texture and friction is understood, measuring both micro- and macrotexture is an inexact science at best. For instance, volumetric techniques have been found to have reproducibility of only around 40% (Patrick et al. 2000). Airports need a simple, reliable system to measure pavement textures that can be quickly done in the field. They also need to be able to relate the output from friction measurements to texture measurements to be able to plan runway friction maintenance activities.

Thus, the objective of the proposed research would be to synthesize the results of the various friction measurement technologies and harmonize that with both U.S. and international standards for runway skid resistance. It would also investigate the various technologies for micro- and macrotexture measurement, seeking a methodology that is both robust and accurate in the field. The method should not require an extensive or elaborate setup so that it can be easily used by maintenance personnel on runways without the need for long-term closures. A technology that measures macrotexture based on digital imagery under development in New Zealand (Pidwerbesky et al. 2006) might be promising for this type of application in that it requires only a digital camera mounted at a precise height above the pavement on a tripod and, thus, is able to collect pavement texture data very quickly. The research would result in a reliable set of friction and texture measurement tools that are directly related to both U.S. and international standards for runway skid resistance.

Relative Rubber Removal Method Effectiveness Research

It was hoped when this study was commissioned that quantitative data on the relative effectiveness of each rubber removal method would be found. That information was not forthcoming, which leads to the inference that this critical information is missing in the body of knowledge. Therefore, a study that focuses on the quantitative impact of each rubber removal method is in order. This study should seek to separate both friction improvement and pavement damage information by pavement type. It should also delve into the impact of each method on micro- and macrotexture for different pavement mix designs and specifically capture information by aggregate type. It should also use laboratory testing to quantify the effect of rubber removal chemicals on a range of common asphalt binders. The result of the study would be a comprehensive comparison of rubber removal method effectiveness by pavement type and other salient pavement characteristics. This would permit airport operators to develop a rubber removal program that has been optimized for each airport's environmental, climatic, and pavement characteristics. It would include information on trigger values for rubber removal and retexturizing and provide quantitative information of how each rubber removal method affects a given pavement's service life as well as other lifecycle cost considerations.

Waterblasting Pressure Research

Although both high- and UHP waterblasting were found be successfully applied to both asphalt and concrete surfaces, the ranges of pressures found in chapter two were really quite broad and indicate a need to develop more precise guidance based on rigorous field testing. In addition, as a number of the survey and case study respondents indicated that waterblasting's greatest danger was operator error or inexperience, it appears logical that airport engineers could use sound engineering information on the technical aspects of waterblasting to ensure that contractors and in-house personnel are relying on a rational approach developed from engineering experiments rather than just personal experience. This research would greatly enhance moving runway rubber removal from being considered an "art" with variable results to a "science" with predictable, reproducible results. Thus, the research should consist of determining the pressures at which groove and pavement surface damage occurs for various mix designs on both asphalt and concrete runways. This experiment could also be extended to include joint sealant and crack sealant. It would result in a matrix of safe operating pressures for waterblasting on a set of common runway pavements.

Rubber Removal from Snow and Ice Removal Chemical Research

This proposed research would result in a new tool for the airport runway friction management toolbox. The Billings case study proved that, given low levels of traffic, routine snow and ice removal operations can be used to control rubber deposits to a level that yields satisfactory friction values. Thus, as most airports conduct some level of snow and ice removal each winter, quantifying the impact of those operations on runway rubber allows airports to leverage their cost by including them in the runway friction management approach. To do so with confidence, several items need more information. First, the effect of common runway deicing chemicals on runway rubber accumulations needs to be researched. There was anecdotal information gained in this synthesis that indicates that these chemicals may indeed soften the rubber deposits, allowing snow plows and brooms to more easily remove the rubber as they remove the snow and ice. However, this needs to be proven. In addition, the use of steel-tipped brushes was found to remove runway rubber (Carpenter and Barenburg 1983), and one surveyed airport used steel brushes to enhance their chemical rubber removal approach. Thus, it would appear that research to discover whether alterations to snow and ice removal equipment, such as Billings adding carbide snow plow blades for ice events, could indeed be used to reduce the amount of runway rubber that would need to be removed during the post-winter months. It must be noted that the FAA specifically discourages the use of snow removal equipment to remove rubber because of the potential damage to joints and sealants (R. Joel, personal communication, 2007).

Runway Friction Toolbox Guide Research

This recommended research project could perhaps build on the first one of harmonizing friction measuring techniques. The objective of this project would be to take the theoretical and engineering research and turn it into a practical guide for both large and small airport pavement managers on how to manage runway friction using the "toolbox" approach suggested in the conclusions. This research should also include an investigation into the costs and benefits associated with various friction maintenance tools, and it should synthesize that information into a runway friction lifecycle cost model that could, in turn, be used to justify investments for capital equipment and contracts for the materials and services necessary to support an active runway friction management program. The idea for this research came during the case study interview with the maintenance manager in Billings, Montana. This individual stated that he had done research on how best to remove rubber from the porous friction course that is the current surface at the Billings airport and came to the conclusion that it was best to leave it alone. However, the runway is to be resurfaced with grooved asphalt pavement in the near future, and he needs information on how best to design his runway friction maintenance program for the new pavement. Thus, it appears that this research is both needed and timely.

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GLOSSARY AND ACRONYMS

GLOSSARY

Chemical removal: This is a process that depends on the use of some form of chemical-based compound to soften the rubber deposits and put them in a form where they can be separated from the pavement using brushes, brooms, scrapers, or some other tool. The resultant debris and residue are then flushed from the runway using pressurized water. Depending on the environmental regulations in a given area, this process may also include vacuuming the residue for disposal off site. This process is also referred to as a "detergent" or a "foam-based" removal method.

Friction value: This is a measure made by a specified piece of equipment in accordance with a prescribed test procedure that is used to relate a given surface condition to some aspect of the coefficient of friction for an airport runway.

Macrotexture: "Macrotexture refers to the larger irregularities in the road surface (coarse-scale texture) that affects hysteresis. These larger irregularities are associated with voids between stone particles. The magnitude of this component will depend on several factors. The initial macrotexture on a pavement surface will be determined by the size, shape, and gradation of coarse aggregates used in pavement construction, as well as the particular construction techniques used in the placement of the pavement surface layer. Macrotexture is also essential in providing escape channels to water in the tire-surface interaction, thus reducing hydroplaning." (Noyce et al. 2005).

Mechanical removal: This process is defined as any mechanical form of rubber removal that is not covered in waterblasting, chemical removal, and shotblasting. It includes grinding, milling, wire-bristle brushing, scraping with blades, as well as other mechanical means to remove rubber. "Sandblasting" is also included in this category to differentiate it from shotblasting.

Microtexture: "Microtexture refers to irregularities in the surfaces of the stone particles (fine-scale texture) that affect adhesion. These irregularities are what make the stone particles feel smooth or harsh to the touch. The magnitude of microtexture depends on initial roughness on the aggregate surface and the ability of the aggregate to retain this roughness against the polishing action of traffic" (Noyce et al. 2005).

Mu meter: A mu meter is a device for measuring side force friction of paved surfaces as prescribed by ASTM E670-94 (2000) test method: "This test method utilizes a measurement obtained by pulling the Mu-Meter, containing two freely rotating test wheels angled to the direction of motion, over a wetted pavement surface at a constant speed while the test wheels are under a constant static load. This method provides a continuous graphical record of the side force friction along the whole length of the test surface and enables averages to be obtained for any specified length. The values stated in inch-pound units are to be regarded as the standard."

Mu value: "Designates a friction value representing runway surface conditions. Values range from 1 to 100, 0 is the lowest and 100 is the maximum. With snow and ice on the runway, a mu value of 40 or less is the level at which aircraft braking performance starts to deteriorate and directional control begins to be less responsive. NOTAMs will be issued when the values are below 40" (Lankford 2000).

Performance specifications: "Specifications that describe how the finished product should perform over time … [and] specifications that describe the desired levels of fundamental engineering properties that are predictors of performance and appear in primary prediction relationships" (Leahy et al. 2006).

Prescriptive specifications: "Specifications that direct the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material. Each step is directed by a representative of the highway agency. Experience has shown this tends to obligate the agency to accept the completed work regardless of quality" (Leahy et al. 2006).

Retexturing: This refers to the restoration of microtexture, macrotexture, or both. Airport pavement managers may select certain rubber removal methods because of their ability to retexture as the rubber is removed, or they may choose to use these technologies to retexture surfaces that are no longer capable of generating required friction values because of polishing separately from routine rubber removal.

Shotblasting: This is a process that relies on a machine that propels some form of abrasive particle onto the runway surface and blasts away the contaminants. There are a number of different proprietary machines that range in pattern width from roughly 6 in. to 6 ft. The process involves a system that vacuums the debris, separates the abrasive particles for recycling, and stores the resultant debris for disposal. This process is also referred to as "high-velocity impact removal" and "shot-peening."

Shot-peening: Shot-peening is another name for shotblasting or high-velocity impact method for rubber removal

Skid resistance: This is a measure of the frictional characteristics of an airport runway surface with respect to aircraft tires.

Surface friction tester: "The Surface Friction Tester (SFT) serves as the benchmark friction measuring device for the purpose of measuring and defining standard runway coefficient of friction levels. The SFT has a fifth friction-measuring wheel which retracts up into the trunk compartment when not being used for testing. The test wheel is braked by a chain attached to the rear axle which gives the tire a slip in the order of 15%" (Transport Canada 2007).

Waterblasting: This is a process that removes rubber by using water pumped through a rotary device at some specified pressure. The unit moves slowly along the surface to be cleaned. Specifications differentiate between "high pressure" [2,000 psi (13.79 MPa) to 15,000 psi (103.42 MPa)] and "ultra-high pressure" [pressures > 15,000 psi (103.42 MPa) up to 40,000 psi (275.79 MPa)]. This type of process is also termed "high-pressure water-jet" and "ultra-high-pressure watercutting" in the literature.

ACRONYMS

FOD: Foreign object damage

GAO: Government Accounting Office

MPa: mega Pascal

NOTAM: Notice to Airmen

PSV: Polish stone value

PFC: porous friction course

SFT: Surface friction tester

UHP: ultra-high pressure

AIRPORT CODES

Airport	State	Code
Albuquerque	NM	ABQ
Atlanta	GA	ATL
Austin	TX	AUS
Baltimore	MD	BWI
Billings	MT	BIL
Boston	MA	BOS
Calgary	AB	YYC
Chattanooga	TN	CHA
Cleveland	OH	CLE
Christchurch	NZ	CHC
Cincinnati	OH	CVG
Dallas–Fort Worth	TX	DFW
Dallas Love	TX	DAL
Kansas City Int'l	MO	MCI
Kansas City Wheeler	MO	MKC
Las Vegas	NV	LAS
Louisville	KY	SFD

Airport	State	Code
Minneapolis–St. Paul	MN	MSP
Nashville	TN	BNA
Newark	NJ	EWR
New York LaGuardia	NY	LGA
New York JFK	NY	JFK
Oklahoma City	OK	OKC
Phoenix	AZ	PHX
Philadelphia	PA	PHL
Rapid City	SD	RAP
San Francisco	CA	SFO
Seattle	WA	SEA
San Diego	CA	SAN
San Jose	CA	SJC
Toronto	ON	YYZ
Washington Dulles	VA	IAD
Washington Reagan	DC	DCA

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APPENDIX A
QUESTIONNAIRES

Two surveys were issued in conjunction with this synthesis. The first was to airport operators, and the second was to members of the rubber removal industry. For purposes of the report, the first is referred to as the "operator survey" and the second is referred to as the "contractor survey." The blank surveys are shown below.

OPERATOR SURVEY

Survey for Airport Operators That Require Runway Rubber Removal (Airports and State/Regional Transportation Agencies)

The Transportation Research Board's Airport Cooperative Research Program has commissioned a study on rubber removal techniques for grooved runways. The goal of the research is to synthesize the salient information on each technique in a single document which can be used as a reference by airport operators. Another objective is to identify innovative methods or techniques which have been found to be particularly effective in achieving their objectives without damage to runway surfaces. As someone with experience in this area, we would like to have your input on this subject. If you are not the appropriate person at your airport to complete this survey, please forward it to the correct person.

Survey Results: The results of the survey will be collated and developed into a research report outlining response rates, performance levels, and highlighted examples of common practice airport runway rubber removal.

Access to Research Report: All of the survey respondents will receive a copy of the research report once the project is complete.

Confidentiality: All answers provided by survey respondents will be treated as confidential and aggregated with other responses in the reporting. The name of participating airports and specific respondents will not be disclosed in the research report.

NOTE: If you are responsible for rubber removal at more than one airport, please answer questions 1, 2 and 3 for each airport respectively.

Q1:

	Airport #1	Airport #2	Airport #3
Airport location			
Annual arrivals at your airport?			
Percentage of these arrivals that contribute to rubber deposits?			
Number of runways			

Q2: Please indicate the number of years of experience with runway rubber removal:

- ☐ Less than 2
- ☐ 2–5
- ☐ 6–10
- ☐ More than 10

Q3: Please indicate the current nature of your employment:

- ☐ Local Government
- ☐ State Government
- ☐ Federal Government
- ☐ Airport Commission/Authority
- ☐ Airport Management
- ☐ Consultant
- ☐ Other

Q4: If you answered "Other" to the above question, please specify.

____

Q5: How familiar are you with runway rubber removal?

- ☐ Not familiar
- ☐ Somewhat familiar
- ☐ Familiar
- ☐ Very familiar

Q6: What method(s) does your agency use for runway rubber removal? (Check all that apply)

- ☐ Waterblasting (low, medium, high, or ultra-high pressure)
- ☐ Chemical removal
- ☐ High-velocity impact removal (shotblasting)
- ☐ Mechanical removal
- ☐ Other:

Q7: If you answered "Other" to the above question, please specify.

____

Q8: How do you accomplish rubber removal?

- ☐ Use in-house maintenance forces
- ☐ Use contractors
- ☐ Use both

For each rubber removal method that you use, please complete the following information.

Waterblasting (If you do not use this technique, skip this section and go to the next section)

Q9: Have you used waterblasting to remove rubber? If you have never used this technique, skip this section and go to the next section.

- ☐ Yes
- ☐ No

Q10: Type of waterblasting

- ☐ Low pressure: Average pressure ____ psi
- ☐ Medium pressure: Average pressure ____ psi
- ☐ High pressure: Average pressure ____ psi
- ☐ Ultra-high pressure: Average pressure ____ psi
- ☐ Other

Q11: Pavement type

- ☐ Concrete
- Asphalt
- ☐ Other: Please specify______________________

Q12: Months of year waterblasting is usually completed

- ☐ January
- ☐ July
- ☐ February
- ☐ August
- ☐ March
- ☐ September
- ☐ April
- ☐ October
- ☐ May
- ☐ November
- ☐ June
- ☐ December

Q13: What are the reasons you use waterblasting? (Check all that apply)

- ☐ Cost
- ☐ We already own the equipment
- ☐ Availability of competent contractors
- ☐ Minimizes impact on operations
- ☐ Satisfaction with final product
- ☐ No environmental permit required
- ☐ Probability of pollution minimized
- ☐ Low probability of pavement damage
- ☐ Speed of operation
- ☐ Retextures pavement in addition to cleaning
- ☐ Other

Q14: If you answered "Other" to the above question, please specify in this box.

____

Q15: What is the SINGLE MOST IMPORTANT reason you choose to use waterblasting?

- ☐ Cost
- ☐ We already own the equipment
- ☐ Availability of competent contractors
- ☐ Minimizes impact on operations
- ☐ Satisfaction with final product
- ☐ No environmental permit required
- ☐ Probability of pollution minimized
- ☐ Low probability of pavement damage
- ☐ Speed of operation
- ☐ Retextures pavement in addition to cleaning
- ☐ Other

Q16: Please list the type and number of pieces of equipment used in your waterblasting operations (regardless if they are done in-house or contracted):

Equipment Type ______________________________

Number ______________________________

Average crew size ______________________________

Q17: Please indicate the following data for your waterblasting operation:

- ☐ Typical production rate for your waterblasting operations: ____ Square Yards per Hour
- ☐ Typical duration of runway closure during your waterblasting operations: ____ Hours
- ☐ Average unit cost for your waterblasting operations: ____ $/Square Yard

Q18: Do you specify the settings and equipment for your waterblasting operations or use performance criteria?

- ☐ We specify the settings and equipment
- ☐ We use performance criteria
- ☐ We use both
- ☐ Don't know

Q19: If you use specifications, what is specified to the contractor or rubber removal team?

- ☐ A friction mu as measured
- ☐ 85% removal by number of rubber grains per measured square
- ☐ Other

Q20: If you answered "Other" to the above question, please specify in this box.

____

Q21: If you use performance criteria, what is specified to the contractor or rubber removal team?

- ☐ Overnight ____ hours per night for ____ number of nights
- ☐ Close runway and divert arrivals to alternate runway; ____ total hours
- ☐ Other: Please specify below

Q22: If you answered "Other" to the above question, please specify in this box.

____

Q23: Have you experienced pavement groove damage as a result of your waterblasting operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q24: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q25: What is the approximate age of the pavement that experienced damage during waterblasting?

- ☐ 0 to 2 years
- ☐ 2 to 4 years
- ☐ 4 to 6 years
- ☐ Greater than 6 years
- ☐ Other: Please specify ______________________

Q26: Have you experienced other types of pavement damage as a result of your waterblasting operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q27: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q28: What is the approximate age of the pavement that experienced damage during waterblasting?

- ☐ 0 to 2 years
- ☐ 2 to 4 years
- ☐ 4 to 6 years
- ☐ Greater than 6 years
- ☐ Other: Please specify ______________

Q29: Have you experienced other types of damage as a result of waterblasting operations?

- ☐ Yes
- ☐ No

Q30: If the answer to the above question is "Yes," please detail the types of damage (i.e., paint loss, runway light breakage, etc.).

____

Q31: Do you have a standard specification that you use for your waterblasting operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

- ☐ Yes
- ☐ No
- ☐ Don't know

Chemical Removal (If you do not use this technique, skip this section and go to the next section)

Q32: Have you used chemical removal to remove rubber?

- ☐ Yes
- ☐ No

Additional comment, if any: ______________

Q33: Type of chemical removal:

Chemical/process name ______________

Q34: Pavement type (check all that apply)

- ☐ Concrete
- ☐ Asphalt
- ☐ Other: Please specify

Q35: Months of year chemical removal is usually completed

- ☐ January
- ☐ February
- ☐ March
- ☐ April
- ☐ May
- ☐ June
- ☐ July
- ☐ August
- ☐ September
- ☐ October
- ☐ November
- ☐ December

Q36: What are the reasons you use chemical removal? (Check all that apply)

- ☐ Cost
- ☐ We already own the equipment
- ☐ Availability of competent contractors
- ☐ Minimizes impact on operations
- ☐ Satisfaction with final product
- ☐ No environmental permit required
- ☐ Probability of pollution minimized
- ☐ Low probability of pavement damage
- ☐ Speed of operation
- ☐ Retextures pavement in addition to cleaning
- ☐ Other

Q37: If you answered "Other" to the above question, please specify.

____

Q38: What is the SINGLE MOST IMPORTANT reason you choose to use chemical removal?

- ☐ Cost
- ☐ We already own the equipment
- ☐ Availability of competent contractors
- ☐ Minimizes impact on operations
- ☐ Satisfaction with final product
- ☐ No environmental permit required
- ☐ Probability of pollution minimized
- ☐ Low probability of pavement damage
- ☐ Speed of operation
- ☐ Retextures pavement in addition to cleaning
- ☐ Other: Please specify ______________

Q39: *Please list the type and number of pieces of equipment used in your chemical removal operations (regardless if they are done in-house or contracted):*

Equipment Type ______________________________

Number ______________________________

Average crew size ______________________________

Q40: *Please indicate the following data for your chemical removal operation:*

☐ Typical production rate for your chemical removal operations:____ Square Yards per Hour

☐ Typical duration of runway closure during your chemical removal operations: ____ Hours

☐ Average unit cost for your chemical removal operations: ____ $/Square Yard

Q41: *Do you specify the settings and equipment for your chemical removal operations or use performance criteria?*

☐ We specify the settings and equipment

☐ We use performance criteria

☐ We use both

☐ Don't know

Q42: *If you use specifications, what is specified to the contractor or rubber removal team?*

☐ A friction mu as measured.

☐ 85% removal by number of rubber grains per measured square

☐ Other: Please specify below

Q43: *If you answered "Other" to the above question, please specify in this box.*

____

Q44: *If you use performance criteria, what is specified to the contractor or rubber removal team?*

☐ Overnight ____ hours per night for ____ number of nights

☐ Close runway and divert arrivals to alternate runway; ____ total hours

☐ Other: Please specify below

Q45: *If you answered "Other" to the above question, please specify in this box.*

____

Q46: *What do you require be done with the residue after removal?*

☐ Require residue to be removed from the airport.

☐ Allow it to be flushed into the surrounding soil

☐ Other: Please specify below

Q47: *If you answered "Other" to the above question, please specify in this box.*

____

Q48: *Have you experienced pavement groove damage as a result of your chemical removal operations?*

☐ Yes

☐ No

☐ Don't know

Q49: *If the answer to the above question is "Yes," what type of damage have you experienced?*

____

Q50: *What is the approximate age of the pavement that experienced damage during chemical removal?*

☐ 0 to 2 years

☐ 2 to 4 years

☐ 4 to 6 years

☐ Greater than 6 years

☐ Other: Please specify ______________

Q51: *Have you experienced other types of pavement damage as a result of your chemical removal operations?*

☐ Yes

☐ No

☐ Don't know

Q52: *If the answer to the above question is "Yes," what type of damage have you experienced?*

____

Q53: *What is the approximate age of the pavement that experienced damage during chemical removal?*

☐ 0 to 2 years

☐ 2 to 4 years

☐ 4 to 6 years

☐ Greater than 6 years

☐ Other: Please specify ______________

Q54: Have you experienced other types of damage as a result of your chemical removal operations?

☐ Yes

☐ No

☐ Don't know

Q55: If the answer to the above question is "Yes," please detail the types of damage (i.e., paint loss, runway light breakage, etc.).

____

Q56: Do you have a standard specification that you use for your chemical removal operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

☐ Yes

☐ No

☐ Don't know

Shotblasting (If you do not use this technique, skip this section and go to the next section)

Q57: Have you used shotblasting to remove rubber?

☐ Yes

☐ No

Additional comment: ________________________

Q58: Type of shotblasting

☐ Name of process: ________________________

Q59: Pavement type

☐ Concrete

☐ Asphalt

☐ Other: Please specify: ____________________

Q60: Months of year shotblasting is usually completed

☐ January	☐ July
☐ February	☐ August
☐ March	☐ September
☐ April	☐ October
☐ May	☐ November
☐ June	☐ December

Q61: What are the reasons you use shotblasting? (Check all that apply)

☐ Cost

☐ We already own the equipment

☐ Availability of competent contractors

☐ Minimizes impact on operations

☐ Satisfaction with final product

☐ No environmental permit required

☐ Probability of pollution minimized

☐ Low probability of pavement damage

☐ Speed of operation

☐ Retextures pavement in addition to cleaning

☐ Other: Please specify below

Q62: If you answered "Other" to the above question, please specify in this box.

____

Q63: What is the SINGLE MOST IMPORTANT reason you choose to use shotblasting?

☐ Cost

☐ We already own the equipment

☐ Availability of competent contractors

☐ Minimizes impact on operations

☐ Satisfaction with final product

☐ No environmental permit required

☐ Probability of pollution minimized

☐ Low probability of pavement damage

☐ Speed of operation

☐ Retextures pavement in addition to cleaning

☐ Other: Please specify ____________________

Q64: Please list the type and number of pieces of equipment used in your shotblasting operations (regardless if they are done in-house or contracted):

Equipment Type __________________________

Number __________________________

Average crew size ________________________

Q65: Please indicate the following for your shotblasting operations:

- ☐ Typical production rate for your shotblasting operations:____ Square Yards per Hour
- ☐ Typical duration of runway closure during your shotblasting operations:____ Hours
- ☐ Average unit cost for your shotblasting operations: ____ $/Square Yard

Q66: Do you specify the settings and equipment for your shotblasting operations or use performance criteria?

- ☐ We specify the settings and equipment
- ☐ We use performance criteria
- ☐ We use both
- ☐ Don't know

Q67: If you use specifications, what is specified to the contractor or rubber removal team?

- ☐ A friction mu as measured.
- ☐ 85% removal by number of rubber grains per measured square
- ☐ Other: Please specify below

Q68: If you answered "Other" to the above question, please specify in this box.

____

Q69: If you use performance criteria, what is specified to the contractor or rubber removal team?

- ☐ Overnight ____ hours per night for ____ number of nights
- ☐ Close runway and divert arrivals to alternate runway; ____ total hours
- ☐ Other: Please specify below

Q70: If you answered "Other" to the above question, please specify in this box.

____

Q71: Have you experienced pavement groove damage as a result of your shotblasting operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q72: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q73: What is the approximate age of the pavement that experienced damage during shotblasting?

- ☐ 0 to 2 years
- ☐ 2 to 4 years
- ☐ 4 to 6 years
- ☐ Greater than 6 years
- ☐ Other: Please specify ____________________

Q74: Have you experienced other types of pavement damage as a result of your shotblasting operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q75: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q76: What is the approximate age of the pavement that experienced damage during shotblasting?

- ☐ 0 to 2 years
- ☐ 2 to 4 years
- ☐ 4 to 6 years
- ☐ Greater than 6 years
- ☐ Other: Please specify ____________________

Q77: Have you experienced other types of damage as a result of your shotblasting operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q78: If the answer to the above question is "Yes," please detail the types of damage (i.e., paint loss, runway light breakage, etc.).

____

Q79: Do you have a standard specification that you use for your shotblasting operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

- ☐ Yes
- ☐ No
- ☐ Don't know

Mechanical Removal (If you do not use this technique, skip this section and go to the next section)

Q80: Have you used mechanical removal techniques to remove rubber?

- ☐ Yes
- ☐ No

Additional comment: ______________________

Q81: Type of mechanical removal

- ☐ Grinding
- ☐ Milling
- ☐ Other: Please specify below

Q82: If you answered "Other" to the above question, please specify in this box.

____

Q83: Pavement type

- ☐ Concrete
- ☐ Asphalt
- ☐ Other: Please specify ____________________

Q84: Months of year mechanical removal is usually completed

- ☐ January
- ☐ February
- ☐ March
- ☐ April
- ☐ May
- ☐ June
- ☐ July
- ☐ August
- ☐ September
- ☐ October
- ☐ November
- ☐ December

Q85: What are the reasons you use mechanical removal? (Check all that apply)

- ☐ Cost
- ☐ We already own the equipment
- ☐ Availability of competent contractors
- ☐ Minimizes impact on operations
- ☐ Satisfaction with final product
- ☐ No environmental permit required
- ☐ Probability of pollution minimized
- ☐ Low probability of pavement damage
- ☐ Speed of operation
- ☐ Retextures pavement in addition to cleaning
- ☐ Other: Please specify below

Q86: If you answered "Other" to the above question, please specify in this box.

____

Q87: What is the SINGLE MOST IMPORTANT reason you choose to use mechanical removal?

- ☐ Cost
- ☐ We already own the equipment
- ☐ Availability of competent contractors
- ☐ Minimizes impact on operations
- ☐ Satisfaction with final product
- ☐ No environmental permit required
- ☐ Probability of pollution minimized
- ☐ Low probability of pavement damage
- ☐ Speed of operation
- ☐ Retextures pavement in addition to cleaning
- ☐ Other: Please specify ____________________

Q88: Please list the type and number of pieces of equipment used in your mechanical removal operations (regardless if they are done in-house or contracted):

Equipment Type ____________________

Number ____________________

Average crew size ____________________

Q89: Please indicate the following data for your mechanical removal operation:

- ☐ Typical production rate for your mechanical removal operations? ____ Square Yards per Hour
- ☐ Typical duration of runway closure during your mechanical removal operations? ____ Hours
- ☐ Average unit cost for your mechanical removal operations? ____ $/Square Yard

Q90: Do you specify the settings and equipment for your mechanical removal operations or use performance criteria?

- ☐ We specify the settings and equipment
- ☐ We use performance criteria
- ☐ We use both
- ☐ Don't know

Q91: If you use specifications, what is specified to the contractor or rubber removal team?

- ☐ A friction mu as measured.
- ☐ 85% removal by number of rubber grains per measured square
- ☐ Other: Please specify below

Q92: If you answered "Other" to the above question, please specify in this box.

____

Q93: If you use performance criteria, what is specified to the contractor or rubber removal team?

- ☐ Overnight ____ hours per night for ____ number of nights
- ☐ Close runway and divert arrivals to alternate runway; ____ total hours
- ☐ Other: Please specify below

Q94: If you answered "Other" to the above question, please specify in this box.

____

Q95: Have you experienced pavement groove damage as a result of your mechanical removal operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q96: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q97: What is the approximate age of the pavement that experienced damage during mechanical removal?

- ☐ 0 to 2 years
- ☐ 2 to 4 years
- ☐ 4 to 6 years
- ☐ Greater than 6 years
- ☐ Other: Please specify ____________________

Q98: Have you experienced other types of pavement damage as a result of your mechanical removal operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q99: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q100: What is the approximate age of the pavement that experienced damage during mechanical removal?

- ☐ 0 to 2 years
- ☐ 2 to 4 years
- ☐ 4 to 6 years
- ☐ Greater than 6 years
- ☐ Other: Please specify ____________________

Q101: Have you experienced other types of damage as a result of your mechanical removal operations?

- ☐ Yes
- ☐ No

Q102: If the answer to the above question is "Yes," please detail the types of damage (i.e., paint loss, runway light breakage, etc.).

____

Q103: Do you have a standard specification that you use for your mechanical removal operations? If yes, would you please send a copy to the survey contact shown at the bottom of the survey?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q104: Do you have any other information that you would be willing to share that would be of value to this study? If so, please indicate in the comment box.

Q105: Please furnish us with information for a point of contact to whom any follow-up questions can be addressed if necessary. We will also send an electronic copy of the final research report to this individual:

Name: ______________________________

Telephone: ___________________________

E-mail: ______________________________

Q106: Do you have a runway rubber removal case study that demonstrates either success (i.e., no damage) or failure (damage observed) that you would be willing to contribute? If you answer yes, the consultant will contact you via e-mail and arrange for a telephonic interview regarding the case study. Prior to the interview, you will receive an outline of the types of information needed in the interview.

- ☐ Yes
- ☐ No

Additional comment: ____________________

Thank you for your assistance in completing this survey. Your responses will help provide insights into how to better remove rubber from airport runways. If you have any questions regarding the survey, please contact Doug Gransberg, dgransberg@ou.edu, 405-325-6092.

CONTRACTOR SURVEY

Survey for Airport Runway Rubber Removal Contractors and Suppliers

This survey was designed for rubber removal contractors. If you are not a contractor but have knowledge of these operations, please complete the survey to the best of your ability for the conditions that you know to be typical

Q1: What state is your business located?

Q2: Please indicate the number of years of experience with runway rubber removal:

☐ Less than 2 ☐ 2–5

☐ 6–10 ☐ More than 10

Q3: Please list the states in which your organization either conducts or supports runway rubber removal operations:

____

____

____

____

____

____

Q4: Please indicate the current nature of your employment:

☐ Rubber removal contractor

☐ Rubber removal equipment/material supplier

☐ Consultant

☐ Other

Q5: How familiar are you with runway rubber removal?

☐ Not familiar

☐ Somewhat familiar

☐ Familiar

☐ Very familiar

Q6: What method(s) does your organization use for runway rubber removal? (Check all that apply)

☐ Waterblasting (low, medium, high or ultra-high pressure)

☐ Chemical removal

☐ High-velocity impact removal (shotblasting)

☐ Mechanical removal

Other: Please specify ____________________

Q7: What types of rubber removal contracts do you normally bid on?

☐ Lump sum

☐ Unit price

☐ Cost reimbursable

☐ Other: Please specify ____________________

Q8: If you use more than one rubber removal method, does that change the way you complete the work?

☐ No

☐ Yes, we use a subcontractor for a portion of the work

☐ Other: Please specify below

Q9: If you answered "Other" to the above question, please specify.

____

For each rubber removal method that you use, please complete the following information.

Waterblasting (If you have never used this technique, skip this section and go to the next section)

Q10: Have you used waterblasting to remove rubber?

☐ Yes

☐ No

Additional comment, if any: ____________________

Q11: Type of waterblasting

☐ Low pressure: Average pressure _____ psi

☐ Medium pressure: Average pressure _____ psi

☐ High pressure: Average pressure _____ psi

☐ Ultra-high pressure: Average pressure _____ psi

Other: Please specify ____________________

Q12: Pavement type

☐ Concrete

☐ Asphalt

☐ Other: Please specify ____________________

Q13: Months of year waterblasting is usually completed

- ☐ January
- ☐ February
- ☐ March
- ☐ April
- ☐ May
- ☐ June
- ☐ July
- ☐ August
- ☐ September
- ☐ October
- ☐ November
- ☐ December

Q14: What is the one MAJOR reason you think that an airport should use waterblasting?

- ☐ Cost
- ☐ Minimizes impact on operations
- ☐ No environmental permit required
- ☐ Probability of pollution is minimized
- ☐ Low probability of pavement damage
- ☐ Speed of operation
- ☐ Retextures pavement in addition to cleaning
- ☐ Other: Please specify below

Q15: If you answered "Other" to the above question, please specify.

____

Q16: Please list the type and number of pieces of equipment used in your waterblasting operations (regardless if they are done in-house or contracted)

Equipment Type ______________________________

Number ______________________________

Average crew size ______________________________

Q17: Please indicate the following data for your waterblasting operation:

- ☐ Typical production rate for your waterblasting operations: _____ Square Yards per Hour
- ☐ Typical duration of runway closure during your waterblasting operations: _____ Hours
- ☐ Average unit cost for your waterblasting operations: _____ $/Square Yard

Q18: Does the airport specify the settings and equipment for your waterblasting operations or use performance criteria?

- ☐ They specify the settings and equipment
- ☐ They use performance criteria
- ☐ They use both
- ☐ Don't know

Q19: If they use specifications, what is specified to the contractor or rubber removal team?

- ☐ A friction mu as measured
- ☐ 85% removal by number of rubber grains per measured square
- ☐ Other

Q20: If you answered "Other" to the above question, please specify in this box.

____

Q21: If they use performance criteria, what is specified to the contractor or rubber removal team?

- ☐ Overnight _____ hours per night for _____ number of nights
- ☐ Close runway and divert arrivals to alternate runway; _____ total hours
- ☐ Other: Please specify below

Q22: If you answered "Other" to the above question, please specify in this box.

____

Q23: Have you experienced pavement groove damage as a result of your waterblasting operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q24: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q25: What is the approximate age of the pavement that experienced damage during waterblasting?

- ☐ 0 to 2 years
- ☐ 2 to 4 years
- ☐ 4 to 6 years
- ☐ Greater than 6 years
- ☐ Other: Please specify ____________________

Q26: Have you experienced other types of pavement damage as a result of your waterblasting operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q27: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q28: What is the approximate age of the pavement that experienced damage during waterblasting?

- ☐ 0 to 2 years
- ☐ 2 to 4 years
- ☐ 4 to 6 years
- ☐ Greater than 6 years
- ☐ Other: Please specify ____________________

Q29: Have you experienced other types of damage as a result of waterblasting operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q30: If the answer to the above question is "Yes," please detail the types of damage (i.e., paint loss, runway light breakage, etc.).

____

Q31: Do you have a standard specification that you use for your waterblasting operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

- ☐ Yes
- ☐ No
- ☐ Don't know

Chemical Removal (If you do not use this technique, skip this section and go to the next section)

Q32: Have you used chemical removal to remove rubber?

- ☐ Yes
- ☐ No

Additional comment, if any: ____________________

Q33: Type of chemical removal:

- ☐ Chemical/process name

Q34: Pavement type (check all that apply)

- ☐ Concrete
- ☐ Asphalt
- ☐ Other: Please specify

Q35: Months of year chemical removal is usually completed

☐ January	☐ July
☐ February	☐ August
☐ March	☐ September
☐ April	☐ October
☐ May	☐ November
☐ June	☐ December

Q36: What is the one MAJOR reason an airport should use chemical removal?

- ☐ Cost
- ☐ Minimizes impact on operations
- ☐ No environmental permit required
- ☐ Probability of pollution is minimized
- ☐ Low probability of pavement damage
- ☐ Speed of operation
- ☐ Retextures pavement in addition to cleaning
- ☐ Other: Please specify below

Q37: If you answered "Other" to the above question, please specify.

____

Q38: Please list the type and number of pieces of equipment used in your chemical removal operations (regardless if they are done in-house or contracted)

Equipment Type ______________________

Number ______________________

Average crew size ______________________

Q39: Please indicate the following data for your chemical removal operation:

☐ Typical production rate for your chemical removal operations: _____ Square Yards per Hour

☐ Typical duration of runway closure during your chemical removal operations: _____ Hours

☐ Average unit cost for your chemical removal operations: _____ $/Square Yard

Q40: Does the airport specify the settings and equipment for your chemical removal operations or use performance criteria?

☐ They specify the settings and equipment

☐ They use performance criteria

☐ They use both

☐ Don't know

Q41: If they use specifications, what is specified to the contractor or rubber removal team?

☐ A friction mu as measured.

☐ 85% removal by number of rubber grains per measured square

☐ Other: Please specify below

Q42: If you answered "Other" to the above question, please specify in this box.

____

Q43: If they use performance criteria, what is specified to the contractor or rubber removal team?

☐ Overnight _____ hours per night for _____ number of nights

☐ Close runway and divert arrivals to alternate runway; _____ total hours

☐ Other: Please specify below

Q44: If you answered "Other" to the above question, please specify in this box.

____

Q45: What do they require be done with the residue after removal?

☐ Require residue to be removed from the airport.

☐ Allow it to be flushed into the surrounding soil

☐ Other: Please specify below

Q46: If you answered "Other" to the above question, please specify in this box.

____

Q47: Have you experienced pavement groove damage as a result of your chemical removal operations?

☐ Yes

☐ No

☐ Don't know

Q48: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q49: What is the approximate age of the pavement that experienced damage during chemical removal?

☐ 0 to 2 years

☐ 2 to 4 years

☐ 4 to 6 years

☐ Greater than 6 years

☐ Other: Please specify

Q50: Have you experienced other types of pavement damage as a result of your chemical removal operations?

☐ Yes

☐ No

☐ Don't know

Q51: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q52: What is the approximate age of the pavement that experienced damage during chemical removal?

☐ 0 to 2 years

☐ 2 to 4 years

☐ 4 to 6 years

☐ Greater than 6 years

☐ Other: Please specify

Q53: Have you experienced other types of damage as a result of your chemical removal operations?

☐ Yes

☐ No

☐ Don't know

Q54: If the answer to the above question is "Yes," please detail the types of damage (i.e., paint loss, runway light breakage, etc.).

____

Q55: Do you have a standard specification that you use for your chemical removal operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

☐ Yes

☐ No

☐ Don't know

Shotblasting (If you do not use this technique, skip this section and go to the next section)

Q56: Have you used shotblasting to remove rubber?

☐ Yes

☐ No

Additional comment, if any: ____________________

Q57: Type of shotblasting

Name of process ______________________________

Q58: Pavement type

☐ Concrete

☐ Asphalt

☐ Other: Please specify

Q59: Months of year shotblasting is usually completed

☐ January	☐ July
☐ February	☐ August
☐ March	☐ September
☐ April	☐ October
☐ May	☐ November
☐ June	☐ December

Q60: What is the one MAJOR reason you think an airport should use shotblasting?

☐ Cost

☐ Minimizes impact on operations

☐ No environmental permit required

☐ Probability of pollution is minimized

☐ Low probability of pavement damage

☐ Speed of operation

☐ Retextures pavement in addition to cleaning

☐ Other: Please specify below

Q61: If you answered "Other" to the above question, please specify.

____

Q62: Please list the type and number of pieces of equipment used in your shotblasting operations (regardless if they are done in-house or contracted):

Equipment Type ________________________

Number _______________________________

Average crew size _______________________

Q63: Please indicate the following for your shotblasting operations:

☐ Typical production rate for your shotblasting operations: _____ Square Yards per Hour

☐ Typical duration of runway closure during your shotblasting operations: _____ Hours

☐ Average unit cost for your shotblasting operations: _____ $/Square Yard

Q64: Do airports specify the settings and equipment for your shotblasting operations or use performance criteria?

☐ They specify the settings and equipment

☐ They use performance criteria

☐ They use both

☐ Don't know

Q65: If they use specifications, what is specified to the contractor or rubber removal team?

☐ A friction mu as measured.

☐ 85% removal by number of rubber grains per measured square

☐ Other: Please specify below

Q66: If you answered "Other" to the above question, please specify in this box.

____

Q67: If you use performance criteria, what is specified to the contractor or rubber removal team?

☐ Overnight _____ hours per night for _____ number of nights

☐ Close runway and divert arrivals to alternate runway; _____ total hours

☐ Other: Please specify below

Q68: If you answered "Other" to the above question, please specify in this box.

____

Q69: Have you experienced pavement groove damage as a result of your shotblasting operations?

☐ Yes

☐ No

☐ Don't know

Q70: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q71: What is the approximate age of the pavement that experienced damage during shotblasting?

☐ 0 to 2 years

☐ 2 to 4 years

☐ 4 to 6 years

☐ Greater than 6 years

☐ Other: Please specify ________________

Q72: Have you experienced other types of pavement damage as a result of your shotblasting operations?

☐ Yes

☐ No

☐ Don't know

Q73: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q74: What is the approximate age of the pavement that experienced damage during shotblasting?

☐ 0 to 2 years

☐ 2 to 4 years

☐ 4 to 6 years

☐ Greater than 6 years

☐ Other: Please specify ________________

Q75: Have you experienced other types of damage as a result of your shotblasting operations?

☐ Yes

☐ No

Q76: If the answer to the above question is "Yes," please detail the types of damage (i.e., paint loss, runway light breakage, etc.).

____

Q77: Do you have a standard specification that you use for your shotblasting operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

☐ Yes

☐ No

☐ Don't know______________________________

Mechanical Removal (If you do not use this technique, skip this section and go to the next section)

Q78: Have you used mechanical removal techniques to remove rubber?

☐ Yes

☐ No

Additional comment, if any: ________________

Q79: Type of mechanical removal

☐ Grinding

☐ Milling

☐ Other: Please specify below________________

Q80: If you answered "Other" to the above question, please specify in this box.

____

Q81: Pavement type

- ☐ Concrete
- ☐ Asphalt
- ☐ Other: Please specify ____________________

Q82: Months of year mechanical removal is usually completed

- ☐ January
- ☐ February
- ☐ March
- ☐ April
- ☐ May
- ☐ June
- ☐ July
- ☐ August
- ☐ September
- ☐ October
- ☐ November
- ☐ December

Q83: What is the one MAJOR reason you think an airport should use mechanical removal?

- ☐ Cost
- ☐ Minimizes impact on operations
- ☐ No environmental permit required
- ☐ Probability of pollution is minimized
- ☐ Low probability of pavement damage
- ☐ Speed of operation
- ☐ Retextures pavement in addition to cleaning
- ☐ Other

Q84: If you answered "Other" to the above question, please specify.

____

Q85: Please list the type and number of pieces of equipment used in your mechanical removal operations (regardless if they are done in-house or contracted):

Equipment Type ____________________

Number ____________________

Average crew size ____________________

Q86: Please indicate the following data for your mechanical removal operation:

- ☐ Typical production rate for your mechanical removal operations: _____ Square Yards per Hour
- ☐ Typical duration of runway closure during your mechanical removal operations: _____ Hours
- ☐ Average unit cost for your mechanical removal operations: _____ $/Square Yard

Q87: Do airports specify the settings and equipment for your mechanical removal operations or use performance criteria?

- ☐ They specify the settings and equipment
- ☐ They use performance criteria
- ☐ They use both
- ☐ Don't know

Q88: If they use specifications, what is specified to the contractor or rubber removal team?

- ☐ A friction mu as measured.
- ☐ 85% removal by number of rubber grains per measured square
- ☐ Other: Please specify below

Q89: If you answered "Other" to the above question, please specify in this box.

____

Q90: If they use performance criteria, what is specified to the contractor or rubber removal team?

- ☐ Overnight _____ hours per night for _____ number of nights
- ☐ Close runway and divert arrivals to alternate runway; _____ total hours
- ☐ Other: Please specify below

Q91: If you answered "Other" to the above question, please specify in this box.

____

Q92: Have you experienced pavement groove damage as a result of your mechanical removal operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q93: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q94: What is the approximate age of the pavement that experienced damage during mechanical removal?

- ☐ 0 to 2 years
- ☐ 2 to 4 years
- ☐ 4 to 6 years
- ☐ Greater than 6 years
- ☐ Other: Please specify ____________________

Q95: Have you experienced other types of pavement damage as a result of your mechanical removal operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q96: If the answer to the above question is "Yes," what type of damage have you experienced?

____

Q97: What is the approximate age of the pavement that experienced damage during mechanical removal?

- ☐ 0 to 2 years
- ☐ 2 to 4 years
- ☐ 4 to 6 years
- ☐ Greater than 6 years
- ☐ Other: Please specify

Q98: Have you experienced other types of damage as a result of your mechanical removal operations?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q99: If the answer to the above question is "Yes," please detail the types of damage (i.e., paint loss, runway light breakage, etc.).

____

Q100: Do you have a standard specification that you use for your mechanical removal operations? If yes, would you please send a copy to the survey contact shown at the bottom of the survey?

- ☐ Yes
- ☐ No
- ☐ Don't know

Q101: Do you have any other information that you would be willing to share that would be of value to this study? If so, please indicate in the comment box.

____

Q102: Please furnish us with information for a point of contact to whom any follow-up questions can be addressed if necessary. We will also send an electronic copy of the final research report to this individual:

Name: __________________________________

Telephone: _______________________________

E-mail: __________________________________

Q103: Do you have a runway rubber removal case study that demonstrates either success (i.e., no damage) or failure (damage observed) that you would be willing to contribute? If you answer yes, the consultant will contact you via e-mail and arrange for a telephonic interview regarding the case study. Prior to the interview, you will receive an outline of the types of information needed in the interview.

- ☐ Yes
- ☐ No

Additional comment: ______________________

Thank you for your assistance in completing this survey. Your responses will help provide insights into how to better remove rubber from airport runways. If you have any questions regarding the survey, please contact Doug Gransberg, dgransberg@ou.edu, 405-325-6092.

APPENDIX B
CONSOLIDATED SURVEY RESPONSE DATA

SURVEY FOR AIRPORT OPERATORS

Note: Some questions' responses have been combined with others to make the results more comprehensive. Therefore, the question numbers are not totally sequential as those question numbers have been removed.

Q1 and Q6: List of all airport respondents

	Airport	State	Code	No. of Arrivals	Type of Rubber Removal	Size Category	Location Category
1	Albuquerque	NM	ABQ	90K	W	S	S
2	Atlanta	GA	ATL	490K	C, S	L	S
3	Austin	TX	AUS	100K	W,C	L	S
4	Baltimore	MD	BWI	190K	W	L	N
5	Billings	MT	BIL	150K	M	S	N
6	Boston	MA	BOS	410K	C	L	N
7	Calgary	AB	YYC	250K	C	L	N
8	Chattanooga	TN	CHA	77.5K	C	S	S
9	Cleveland	OH	CLE	130K	W	L	N
10	Christchurch	NZ	CHC	42K	W	S	N
11	Cincinnati	OH	CVG	NR	C	L	N
12	Dallas-Fort Worth	TX	DFW	350K	C,S	L	S
13	Dallas Love	TX	DAL	124K	W	L	S
14	Kansas City Int'l	MO	MCI	80K	C, M	S	N
15	Kansas City Wheeler	MO	MKC	60K	C, W	S	N
16	Las Vegas	NV	LAS	300K	W	L	S
17	Louisville	KY	SFD	90K	C	S	N
18	Minneapolis-St. Paul	MN	MSP	240K	C, S	L	N
19	Nashville	TN	BNA	240K	W, C	L	S
20	Newark	NJ	EWR	220K	W, C	L	N
21	New York LaGuardia	NY	LGA	200K	W, C	L	N
22	New York JFK	NY	JFK	200K	W, C	L	N
23	Oklahoma City	OK	OKC	60K	W,C	S	S
24	Phoenix	AZ	PHX	280K	W	L	S
25	Philadelphia	PA	PHL	257K	W	L	N
26	Rapid City	SD	RAP	25K	W, C	S	N
27	San Francisco	CA	SFO	180K	W	L	N
28	Seattle	WA	SEA	180K	W	L	N
29	San Diego	CA	SAN	121K	W, C	L	S
30	San Jose	CA	SJC	100K	W	L	N
31	Toronto	ON	YYZ	400K	W,C,S	L	N
32	Washington Dulles	VA	IAD	189K	W	L	N
33	Washington Reagan	DC	DCA	135K	W,C	L	N

Type: W = waterblasting; C = chemical; S = shotblasting; M = mechanical. Size: L = large; S = small. Location: N= northern; S = southern.

Q2: Please indicate the number of years of experience with runway rubber removal.

Less than 2	2–5	6–10	More than 10
3	2	9	19

Q3: Please indicate the current nature of your employment.

Local Government	State Government	Federal Government	Airport Commission/ Authority	Airport Management	Consultant
7	1	0	17	8	0

Q5: How familiar are you with runway rubber removal?

Not familiar	Somewhat familiar	Familiar	Very familiar
1	3	11	18

Q8: How do you accomplish rubber removal?

Use in-house maintenance forces	Use contractors	Use both
11	19	3

Waterblasting

The numbers reported below are for those airports that use this rubber removal method.

Q10: Type of waterblasting and pressures used

Airport	Low	Medium	High	Ultra-high
MKC	3,000	5,000	8,000	10,000
CLE			20,000	
OKC			40,000	
DCA			3,000	
SFO	7,500	15,000	25,000	35,000
ABQ			Use high pressure	
IAD			35,000	
CHA			6,000–7,000	
LAS		7000		
PHL		10,000–12,000		
SJC			Use high pressure	
YYZ			30,000	
DAL	Use low pressure			
PHX		7,000		
SAN	3,000			
JFK			20,000–35,000	
LGA,			20,000–35,000	
EWR			20,000–35,000	
RAP				Unknown

CHC				36,000

Q11: Pavement type

Concrete	Asphalt	Other
12	13	0

Q12: Months of year waterblasting is usually completed

January—3
February—4
March—4
April—10
May—11
June—9
July—8
August—9
September—11
October—5
November—5
December —4

Q13: What are the reasons you use waterblasting? (Check all that apply)

10—Cost
1—We already own the equipment
11—Availability of competent contractors
8—Minimizes impact on operations
15—Satisfaction with final product
8—No environmental permit required
8—Probability of pollution minimized
7—Low probability of pavement damage
13—Speed of operation
3—Retextures pavement in addition to cleaning
1—Other

Q15: What is the SINGLE MOST IMPORTANT reason you choose to use waterblasting?

2—Cost
0—We already own the equipment
2—Availability of competent contractors
0—Minimizes impact on operations
8—Satisfaction with final product
0—No environmental permit required
1—Probability of pollution minimized
2—Low probability of pavement damage
2—Speed of operation

1—Retextures pavement in addition to cleaning

1—Other: "Was included in AIP project"

Q16 and Q17: Please indicate the following data for your waterblasting operation.

Equipment/Number	Equipment/Number	Average Crew Size	Production Rate (yd²/h)	Closure (h)	Unit Cost ($/yd²)
Osprey rubber removal truck/machine		1	3,000	8	1.66
Water blast truck/1	Vacuum/1	3	1,111	8	0.39
Power Deck/2	Pumper truck/1	6	770	8	0.72
Hydroblast/1	Sweeper /1	2			
Water pressure power head truck with recovery/1	Sweeper—only used when recovery fails/1	5	1,350	7	
Water blaster/1	Sweeper/1	2	1,580	7	
Self-contained/2		3	1,600	7	0.40
Blast machine/1	Water truck/1	4	1,350	8	
Water blaster/1	Vacuum/1	4	2,000	6	0.54
Stripe hog 8000		2	1,450	6	2.61
18 Wheeler w/ water blasting device (3 in.-4 in.) path/1	Water resupply truck 1	4	1,900	6–8	
Trailer-mounted medium pressure cleaning and recycling		2	2,500	8	0.35
Hydroblast truck/1	Vacuum/1		1,350	6–8	
Hydroblast truck/1	Vacuum/1		1,350	6–8	
Hydroblast truck/1	Vacuum/1		1,350	6–8	0.58
Oshkosh/sweepster brooms	Water tank trucks			NA	0.23
UHPwatercutter/6		12	360	NA	

NA = not applicable

Q18: Do you specify the settings and equipment for your waterblasting operations or use performance criteria?

We specify the settings and equipment	We use performance criteria	We use both	Don't know
2	6	9	3

Q19: If you use specifications, what is specified to the contractor or rubber removal team?

A friction mu as measured	85% removal by number of rubber grains per measured square	Other
8	4	7

Other responses: Visual inspection; prescribed power head pressure but very difficult to enforce; 95% eradication; visual; changing from 85% to friction mu; removal rate; visual + measure texture depth by sand circle.

Q23: Have you experienced pavement groove damage as a result of your waterblasting operations?

Yes—6; No—16; Don't know—0

Q24: If the answer to the above question is "Yes," what type of damage have you experienced?

Spalling of surface; groove edge deterioration but is not substantial and cannot be accurately correlated with high-pressure waterblasting; groove deformation if water pressure exceeds limit; texture appeared somewhat rougher with open pores; minor damage to all surface, less on older mix.

Q25: What is the approximate age of the pavement that experienced damage during waterblasting?

0 to 2 years —3; 2 to 4 years —2; 4 to 6 years —0; Greater than 6 years—5

Q26: Have you experienced other types of pavement damage as a result of your waterblasting operations?

Yes—8; No—11; Don't know—3

Q27: If the answer to the above question is "Yes," what type of damage have you experienced?

Only on asphalt surfaces that are old or have faults; operator error results in runway lighting, pavement, and crack seal deterioration, though not substantial and inconsistent; expansion joint damage; occasional loss of chip at cut edge; damage to surface course asphalt; polishing

Q28: What is the approximate age of the pavement that experienced damage during waterblasting?

0 to 2 years —2; 2 to 4 years—1; 4 to 6 years—0; Greater than 6 years—3;

Other: Please specify: 1—varies from 4 to 40 years

Q29: Have you experienced other types of damage as a result of waterblasting operations?

Yes—5; No—16; Don't know—1

Q30: If the answer to the above question is "Yes," please detail the types of damage.

Occasional centerline light damage; loss of fines

Q31: Do you have a standard specification that you use for your waterblasting operations?

Yes—7; No—9; Don't know—2

Chemical Removal

Q33: Type of chemical removal:

Q34: Pavement type (check all that apply)

Rubber Removal Chemicals Used			Pavement Type	
Chemical #1	Chemical #2	Chemical #3	Asphalt	Concrete
Avion 50			X	X
Avon 50			X	X
AVI-88	Avion 50		X	X
Avion-50 (Chemtek)	SAI-21 (Sneed & Associates)		X	X
Avion 50	Chemstation 6390		X	X
Avion 50			X	X
Avion 50				X
Alkaline liquid cleaning compound, no brand name	Major ingredient is sodium hydroxide		X	
Hurrisafe	Avion 50	BioSol, Evergreen Solutions	X	X
AVI-88				X
Everything Clean/all-purpose cleaner			X	
Avion 50				X
Saric Solutions, DC 101				X
Hurrisafe			X	X
Hurrisafe			X	X
Hurrisafe			X	X
Avion 50				X

Q35: Months of year chemical removal is usually completed

2—January
0—February
4—March
8—April
10—May
9—June
11—July
9—August
13—September
5—October
3—November
1—December

Q36: What are the reasons you use chemical removal? (Check all that apply)

8—Cost
12—We already own the equipment
2—Availability of competent contractors
10—Minimizes impact on operations
9—Satisfaction with final product
4—No environmental permit required
5—Probability of pollution minimized
14—Low probability of pavement damage
7—Speed of operation
0—Retextures pavement in addition to cleaning
4—Other

Q37: If you answered "Other" to the above question, please specify.

We do not use chemical any more. It is too expensive and does a lot of damage to our equipment. It also takes several guys and several pieces of equipment; product contains lithium to mitigate accelerated ASR (alkali-silca reactivity). Strengthens concrete.

Q38: What is the SINGLE MOST IMPORTANT reason you choose to use chemical removal?

1—Cost

5—We already own the equipment

1—Availability of competent contractors

1—Minimizes impact on operations

4—Satisfaction with final product

0—No environmental permit required

1—Probability of pollution minimized

4—Low probability of pavement damage

1—Speed of operation

0—Retextures pavement in addition to cleaning

1—Other: Please specify: Respondent did not specify

Q39 and Q40: Please list the type and number of pieces of equipment used in your chemical removal operations (regardless if they are done in-house or contracted).

Equipment/Number	Equipment/Number	Average Crew Size	Production Rate (yd²/h)	Closure (h)	Unit Cost ($/yd²)
Batts chemical truck/2	Rotary front end broom	5			
Chemical spray truck	Jet broom towed via pick-up				
Chemical application truck–sprayer/1; flush truck—4,000-gal tanker/1	Rotary runway broom with metal tine brushes/2		1,111	7	0.31
Rotary broom/4	4,500-gal spray deicer/2	7	3,125	8	0.16
Pull broom/2; water truck/2; chemical trailer/1	1-ton truck/1; dupervisor truck/1	5	800	8	0.36
Rotary broom/2	Water truck 3	6		7	
Trailered tank with boom sprayer/1; 3,000-gal water truck/1	Semi-trailer with 2 water tanks and heated power washers; light all/1	3	500	5	0.12
Batts chemical truck/2	Sweepsters/2		1,600	5	0.105
Sprayer/1; vacuum truck/1	Sweeper/1–2	5	?	6	
Spray rig/1; vacuum truck/1	Mechanical brooms/2; tanker/1	4	1,890	8	1.08
Oshkosh sweeper/3	Oshkosh water truck/1	4	2,083	5.5	
4,500-gal liquid deicers/2; 8,500-gal tankers/2	Oshkosh snow brooms/3	7	2,500	6	0.63
Johnson broom			2,200	4.5	0.77
Distributor truck/1; rotary broom/1	Vacuum truck/1		1,350	7	0.25
Distributor truck/1; rotary broom/1	Vacuum truck/1		1,350	7	0.25
Distributor truck/1; rotary broom/1	Vacuum truck/1		1,350	7	0.25
Oshkosh Sweepster rotary brooms/2; water trucks/2	Water tanker truck with spray bar/1			5	

Q41: Do you specify the settings and equipment for your chemical removal operations or use performance criteria?

We specify the settings and equipment	We use performance criteria	We use both	Don't know
6	6	6	1

Q42: If you use specifications, what is specified to the contractor or rubber removal team?

A friction mu as measured	85% removal by number of rubber grains per measured square	Other
9	2	4

Q43: Other responses: The finished product must meet previously measured friction values for that runway; removal rate

Q46: What do you require be done with the residue after removal?

Require residue to be removed from the airport.	Allow it to be flushed into the surrounding soil	Other
5	13	1

Other responses: Residue disposed of by environmental contractor per DEQ regulations

Q48: Have you experienced pavement groove damage as a result of your chemical removal operations?

Yes	No	Don't know
1	18	0

If "Yes," what type of damage have you experienced? Microtexture degradation mitigated by surface texturing (scarification) on a tri-annual schedule; chemical does not clean grooves very well.

Q50: What is the approximate age of the pavement that experienced damage during chemical removal?

0 to 2 years—0; 2 to 4 years—0; 4 to 6 years—0; Greater than 6 years—1

Q51: Have you experienced other types of pavement damage as a result of your chemical removal operations?

Yes—0; No—19

Q54: Have you experienced other types of damage as a result of your chemical removal operations?

Yes —4; No—15

Q55: If the answer to the above question is "Yes," please detail the types of damage (i.e., paint loss, runway light breakage, etc.).

Eats all the rubber hoses and paint off our equipment. Mechanical breakdowns resulting in additional vehicle maintenance; paint removal and runway light damage; paint loss along TDZ centerline.

Q56: Do you have a standard specification that you use for your chemical removal operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

Yes—4; No—11; Don't know—2

Shotblasting

Q58 and Q59: Type of shotblasting

Shotblasting Method Used	Pavement Type	
	Asphalt	Concrete
Blastrac	X	
Skidabrader		X
High-velocity impact method	X	
Skidabrader		X

Q60: Months of year shotblasting is usually completed

0—January

0—February

0—March

1—April

1—May

0—June

0—July

1—August

0—September

1—October

1—November

1—December

Q61: What are the reasons you use shotblasting? (Check all that apply)

0—Cost

0—We already own the equipment

1—Availability of competent contractors

2—Minimizes impact on operations

2—Satisfaction with final product

0—No environmental permit required

0—Probability of pollution minimized

1—Low probability of pavement damage

2—Speed of operation

3—Retextures pavement in addition to cleaning

1—Other: Please specify below: YYZ: increase macro- and microtextures

Q63: What is the SINGLE MOST IMPORTANT reason you choose to use shotblasting?

0—Cost

0—We already own the equipment

0—Availability of competent contractors

0—Minimizes impact on operations

1—Satisfaction with final product

0—No environmental permit required

0—Probability of pollution minimized

1—Low probability of pavement damage

0—Speed of operation

1—Retextures pavement in addition to cleaning

Q64 and Q65: Please list the type and number of pieces of equipment used in your shotblasting operations (regardless if they are done in-house or contracted).

Equipment/Number	Equipment/Number	Average Crew Size	Production Rate (yd^2/h)	Closure (h)	Unit Cost (\$/yd^2)
Shotblasting machine/1		2	4,500	8	0.56
Skidabrader/1	Magnet/1	3	33,341,111	5–6	1.35
Skidabrader/2	Electromagnet truck/2	6	67,503,125	7	0.45

Q66: Do you specify the settings and equipment for your shotblasting operations or use performance criteria?

We specify the settings and equipment	We use performance criteria	We use both	Don't know
06	1	1	1

Q67: If you use specifications, what is specified to the contractor or rubber removal team?

A friction mu as measured	85% removal by number of rubber grains per measured square	Other
2	1	1

Other: 100% removal of rubber deposits

Q71: Have you experienced pavement groove damage as a result of your shotblasting operations?

Yes—2; No—1; Don't know—0

Q72: If the answer to the above question is "Yes," what type of damage have you experienced?

DFW: Excessive wear on the grooves. Rounding off of the edges of the grooves

ATL: Grooves deteriorating

Q73: What is the approximate age of the pavement that experienced damage during shotblasting?

Greater than 6 years—2

Q74: Have you experienced other types of pavement damage as a result of your shotblasting operations?

Yes—0; No—3; Don't know—0

Q77: Have you experienced other types of damage as a result of your shotblasting operations?

Yes—2; No—1

Q78: If the answer to the above question is "Yes," please detail the types of damage.

DFW: Removal of pavement markings that DFW has to repaint the next day. We get minor damage to the light lenses, which causes the in-pavement lights to be less bright.

ATL: Paint loss

Q79: Do you have a standard specification that you use for your shotblasting operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

Yes—1; No—2; Don't know—0

Mechanical Removal

Q81: Type of mechanical removal

Grinding—0; Milling—0; Other—2

Q82: If you answered "Other" to the above question, please specify.

Use jet broom with wire rotating brooms

Our primary 10,500-ft. runway is the only surface we have considered for rubber removal. This surface is Porous Friction Course (PFC) and from the research we gathered on all of the above techniques we were not 100% guaranteed that one of these would damage the runway during the process. We have a relatively low number of landings with heavy aircraft; therefore, a small amount of rubber buildup. We have proven that we have the ability to keep this under control since we perform snow removal operations during the winter months. The numerous passes over the rubber buildup with high-speed runway brooms, blowers and snowplows keeps this manageable. While conducting friction measurements tests we have not recorded a significant problem that needs to be remedied. In addition, we can keep this potential problem under control due to the fact that FAA normally pays to rehabilitate a runway surface every 10–15 years.

Q83: Pavement type

Concrete—1; Asphalt—2

Q84: Months of year mechanical removal is usually completed

0—January

0—February

0—March

0—April

0—May

0—June

1—July

1—August

0—September

0—October

0—November

0—December

Q85: What are the reasons you use mechanical removal? (Check all that apply)

0—Cost

1—We already own the equipment

0—Availability of competent contractors

1—Minimizes impact on operations

0—Satisfaction with final product

0—No environmental permit required

0—Probability of pollution minimized

0—Low probability of pavement damage

0—Speed of operation

0—Retextures pavement in addition to cleaning

1—Other: Please specify below: Used in conjunction with chemical removal process

Q87: What is the SINGLE MOST IMPORTANT reason you choose to use mechanical removal?

Other: Please specify: Used in conjunction with chemical removal process

Q88: Please list the type and number of pieces of equipment used in your mechanical removal operations (regardless if they are done in-house or contracted).

Equipment Type	Number
Jet broom	1
Average crew size	1

Q89–94: No responses received from the 2 airports.

Q95: Have you experienced pavement groove damage as a result of your mechanical removal operations?

Yes—0; No—1; Don't know—0

Q96–106: No responses received from the 2 airports.

Survey for Airport Runway Rubber Removal Contractors and Suppliers

Q1–Q6:

Location	Experience (years)	States Where You Work	Type of Company	Type of Rubber Removal
Virginia	> 10	Anywhere	Both rubber removal contractor and consultant	W
New Zealand and Australia	6–10	New Zealand and Australia	Rubber removal contractor	W
New Zealand	6–10	New Zealand and Australia	Rubber removal contractor	W
Germany Europe	> 10	Vietnam, Korea, Arabia, India, Europe, Russia,	Contractor and supplier	W
Florida and Tennessee	6–10	More than 10 states	Rubber removal contractor and equipment contractor	W
Arizona	> 10	Arizona, California, Oregon, Nevada, New Mexico, Texas, Utah	Both rubber removal contractor and manufacturer	W
Louisiana	> 10	All over U.S. and Canada	Runway texturing	S
International	> 10	Internationally	Association representative	S, M
Canada and U.S.	> 10	North America	Owner and consultant	W,C,S
New York	< 2	None at this time	Rubber removal equipment/ material supplier	C

Note: C = chemical; M = mechanical; S = shotblasting; W = waterblasting.

Q7: What types of rubber removal contracts do you normally bid on?

1—Lump sum; 9—Unit price; 0—Cost reimbursable

Q8: If you use more than one rubber removal method, does that change the way you complete the work?

8—No; 0—Yes, we use a subcontractor for a portion of the work

Waterblasting

Q11 and Q12: Type of waterblasting

Contractor	Low	Medium	High	Ultra-high	Concrete	Asphalt	Other
Virginia			8,000-10,000		X	X	
New Zealand and Australia			20,000	36,000		X	Chipseal, slurry, microsurfacing
New Zealand			40,000	36,000	X	X	Chipseal, slurry, microsurfacing
Germany			3,000	36,000	X	X	
Florida and Tennessee	7,500	15,000	25,000	25,000–30,000	X	X	
Arizona	5,000	7,500	10,000	40,000	X	X	
Canada and U.S.			20,000–40,000		X	X	

Q13: Months of year waterblasting is usually completed: 7 of 7 responses indicate all 12 months.

Q14: What is the one MAJOR reason you think that an airport should use waterblasting?

1—Cost

1—Minimizes impact on operations

0—No environmental permit required

0—Probability of pollution is minimized

2—Low probability of pavement damage

0—Speed of operation

0—Retextures pavement in addition to cleaning

3—Other: Please specify below

Q15: If you answered "Other" to the above question, please specify.

NZ: None stands out most of the above are reasons for using watercutting.

GER: our technology removes 100% rubber or paint with zero damage to the texture below, prolonging lifetime of the surface by 50 % i.e., cost, no environment impact, leave runway within 3 minutes after call from tower.

FL & TN: It restores friction values most effectively without mechanical impact to the surface.

Q16 and Q17: Please list the type and number of pieces of equipment used in your waterblasting operations (regardless if they are done in-house or contracted).

Contractor	Equipment/Number	Equipment/Number	Average Crew Size	Production Rate (yd²/h)	Closure (h)	Unit Cost **($/yd²)**
Virginia	High-pressure waterblaster/1; ultra-high-pressure waterblaster/1	Vacuum sweeper/2; Skidsteer broom/1	4	1,111	24	0.45
New Zealand and Australia	Ultra-high-pressure watercutter/5		2	360	0	3.05
New Zealand	Ultra-high-pressure watercutter/6		2	360	Work between flights	2.44
Germany	1 truck with trailer capable to work 5.5 h		1	960	2–6	2.00
Florida and Tennessee	We have 6 stripe hog units, 2 persons per truck		2	1,500	6	0.45
Arizona	Ultra-high pressure/2	High-pressure hot water/2	2	3,000	6	0.90

Q18: Does the airport specify the settings and equipment for your waterblasting operations or use performance criteria? [QUERY: do you want to set this up as a table as in previous section?]

0—They specify the settings and equipment; 3—They use performance criteria; 4—They use both

Q19: If they use specifications, what is specified to the contractor or rubber removal team?

3—A friction mu as measured; 2—85% removal by number of rubber grains; 3—Other

Q20: If you answered "Other" to the above question: Visual—requirement to remove rubber from surface; visual—finished area shall not have rubber deposit or be seriously damaged by removal; friction value above .7 and 98 % rubber removal; paint removal without any damage

Q23: Have you experienced pavement groove damage as a result of your waterblasting operations?

4—Yes; 3—No

Q24: If the answer to the above question is "Yes," what type of damage have you experienced?

Minor damage removed the odd stone from the cut edge of the groove; minor removal of fines and binder from surface and some stones from the cut edge; degradation of the edges of the grooves; spalling

Q25: What is the approximate age of the pavement that experienced damage during waterblasting?

1—0 to 2 years; 1—Greater than 6 years; 1—Other: Please specify: 15 years

Q26: Have you experienced other types of pavement damage as a result of your waterblasting operations?

2—Yes; 3—No; 2—Don't know

Q27: If the answer to the above question is "Yes," what type of damage have you experienced?

Minor removal of chip from poorly compacted chip seals

Q28: What is the approximate age of the pavement that experienced damage during waterblasting?

1—Greater than 6 years

Q29: Have you experienced other types of damage as a result of waterblasting operations?

0—Yes; 5—No

Q31: Do you have a standard specification that you use for your waterblasting operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

3—Yes; 3—No

Chemical Removal

Q33: Type of chemical removal: 2 contractor responses

Chemical/process name: Hurrisafe, Avion 50

Q34: Pavement type (Check all that apply)

1—Concrete; 1—Asphalt

Q35: Months of year chemical removal is usually completed

1—September

Q36: What is the one MAJOR reason an airport should use chemical removal?

No responses

Q37–39: No responses

Q40: Does the airport specify the settings and equipment for your chemical removal operations or use performance criteria?

1—They use both

Q41: If they use specifications, what is specified to the contractor or rubber removal team?

1—A friction mu as measured.

Q43 and Q44: No responses

Q45: What do they require be done with the residue after removal?

0—Require residue to be removed from the airport; 1—Allow it to be flushed into the surrounding soil

Q47: Have you experienced pavement groove damage as a result of your chemical removal operations?

1—Don't know

Q50: Have you experienced other types of pavement damage as a result of your chemical removal operations?

1—Don't know

Q53: Have you experienced other types of damage as a result of your chemical removal operations?

1—Don't know

Q55: Do you have a standard specification that you use for your chemical removal operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

1—Don't know

Shotblasting

Q56: Have you used shotblasting to remove rubber? 3 contractor responses

Q57: Type of shotblasting

Name of process: Skidabrader and Blastrac

Q58: Pavement type

1—Concrete; 1—Asphalt

Q59: Months of year shotblasting is usually completed

1—August

Q60: What is the one MAJOR reason you think an airport should use shotblasting?

1—Cost

Q61–Q63: No responses

Q64: Do airports specify the settings and equipment for your shotblasting operations or use performance criteria?

1—They use both

Q65: If they use specifications, what is specified to the contractor or rubber removal team?

1—A friction mu as measured.

Q69: Have you experienced pavement groove damage as a result of your shotblasting operations?

1—Yes; 0—No; 0—Don't know

Q70: If the answer to the above question is "Yes," what type of damage have you experienced?

Spalling

Q71: What is the approximate age of the pavement that experienced damage during shotblasting?

1—0 to 2 years

Q72: Have you experienced other types of pavement damage as a result of your shotblasting operations?

1—Don't know

Q75: Have you experienced other types of damage as a result of your shotblasting operations?

0—Yes; 1—No

Q77: Do you have a standard specification that you use for your shotblasting operations? If yes, please send a copy to the survey contact shown at the bottom of the survey.

0—Yes; 1—No; 0—Don't know

Mechanical Removal

Q78: Have you used mechanical removal techniques to remove rubber?

1—Contractor response

Q79: Type of mechanical removal

1—Grinding

Q81: Pavement type

1—Concrete; 1—Asphalt

Q82: Months of year mechanical removal is usually completed

Indicated all 12 months

Q83: What is the one MAJOR reason you think an airport should use mechanical removal?

1—Retextures pavement in addition to cleaning

Q85: Please list the type and number of pieces of equipment used in your mechanical removal operations (regardless if they are done in-house or contracted).

Equipment Type: Diamond Products PC 6000 diamond grinder

Q86: Please indicate the following data for your mechanical removal operation:

Typical production rate for your mechanical removal operations? 1,200 yd^2/h

Typical duration of runway closure during your mechanical removal operations? 10 h

Average unit cost for your mechanical removal operations? \$3.00/yd^2

Q87: Do airports specify the settings and equipment for your mechanical removal operations or use performance criteria?

1—They use performance criteria

Q88: If they use specifications, what is specified to the contractor or rubber removal team?

1—Other: Visual

Q90: If they use performance criteria, what is specified to the contractor or rubber removal team?

Overnight 10–12 h per night for 1,200 yd^2

Q92: Have you experienced pavement groove damage as a result of your mechanical removal operations?

0—Yes; 1—No

Q95: Have you experienced other types of pavement damage as a result of your mechanical removal operations?

0—Yes; 1—No

Q98: Have you experienced other types of damage as a result of your mechanical removal operations?

0—Yes; 1—No

Q100: Do you have a standard specification that you use for your mechanical removal operations?

0—Yes; 1—No

APPENDIX C
RUBBER REMOVAL TECHNIQUE TECHNICAL DATA

In the interest of highlighting the important information for airport operators in the body of the synthesis report, the technical descriptions of each runway rubber removal method has been assembled in this appendix. It contains the fundamental information necessary for the reader who may be unfamiliar with the technology to understand how it works. This appendix also contains the details gleaned from the survey for equipment and crews used by the various survey respondents.

WATERBLASTING TECHNOLOGIES

Waterblasting apparatus comes in a number of forms. Each version of waterblasting technology consists of a series of interrelated components that are discussed in the next section. There are two configurations for waterblasters. The first is vehicular-mounted and can be operated from the cab of the vehicle by the driver. Figure C1 is a picture of a typical waterblaster in use in North America, and Figure C2 is one that is manufactured in Europe and used internationally. The second configuration has a detachable spray bar apparatus and is controlled by an operator who walks behind the vehicle, which carries the remaining system components. Figure C3 shows this version as used in New Zealand.

Waterblasting Components

The waterblasting system essentially consists of the following components:

- Water tank,
- Pump,
- Pressurizing system,
- Spray bar apparatus to deliver the pressurized water to the surface (called "rotating spray bar," "blast head," or "cutter head"),
- Vacuum apparatus, and
- Residue storage tank.

FIGURE C1 North American vehicular-mounted and controlled waterblaster (NLB 2007).

FIGURE C3 New Zealand ground-mounted and controlled watercutter (Waters 2005).

FIGURE C2 European vehicular-mounted and controlled waterblaster (Pade 2007).

Figure C4 is a schematic that illustrates the pressurizing system for the ultra-high-pressure watercutter system used in New Zealand. It is typical of the pressurization systems used for waterblasting equipment in the United States. The spray bar apparatus comes in widths from 8 to 48 in. (23 to 122 cm) depending on the manufacturer.

Waterblaster Classifications

The literature is inconsistent with the definitions for the various types of waterblasting. That there is no industry standard was confirmed by the wide range in operating pressures for different classifications of waterblasting found in the survey responses. The questionnaire asked respondents to indicate operating pressures for "low-," "medium-," "high-," and "ultra-high-" pressure waterblasting. Only one respondent indicated that it used "medium," and the other responses showed no discernable trend as to what pressure range defined the other three classifications. Thus, for purposes of this report, the operating pressure categories used by Speidel (2002) and paralleled by a 2003 Transport Canada waterblasting specification were used to create a structure for the research. The report discusses three major types of waterblasting technologies, differentiated by the water pressures used in the process. The first type is low-pressure waterblasting, and any process that operates below 2,000 psi (13.8 MPa) is in this category. The next category, high-pressure waterblasting, is generally thought to operate in the range of 2,000 to 15,000 psi (13.8 to 103.4 MPa). This process uses about 30 gal (113.6 L) of water per minute (Speidel 2002). The Transport Canada specifications limit pressures on this type of waterblasting to 5,000 psi (35 MPa) on asphalt runways and 7,000 psi (48 MPa) on concrete surfaces (Transport Canada 2003c). The third category is called ultra-high-pressure (UHP) waterblasting and operates at pressures up to 40,000 psi (275.8 MPa) or 36,000 psi (250 MPa) in the Canadian specification (Transport 2003c). UHP waterblasting uses only around 8 gal (30.3 L) of water per minute (Speidel 2002).

Waterblasting Crews, Equipment, and Production

In the survey, 17 airports reported their waterblasting equipment and crew sizes. For the most part, the equipment consisted of the following pieces, with the number of responses indicated in parentheses:

- Waterblasting machine (17),
- Vacuum truck (5),
- Broom sweeper (3), and
- Water supply truck (4).

Three of the airports used more than one waterblasting system, presumably to meet production requirements within the runway closure window. It must also be noted that some waterblasting systems such as the UHP watercutter in use

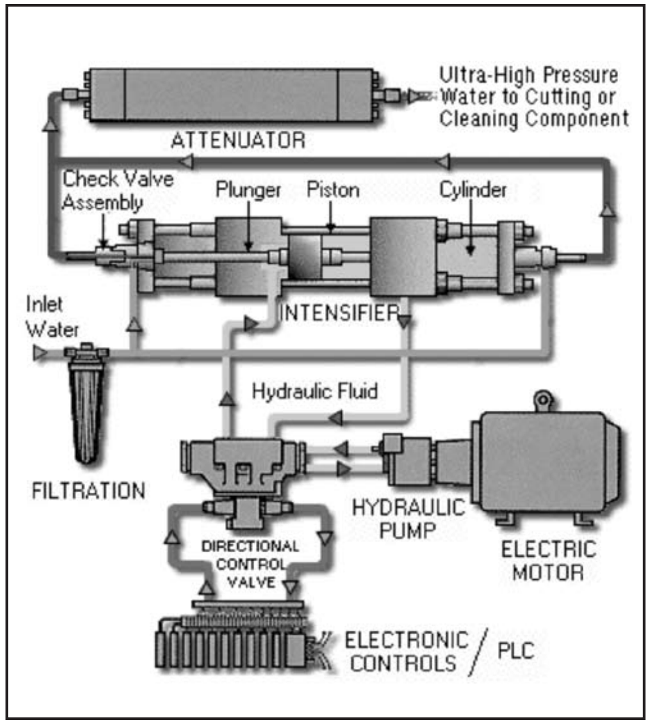

FIGURE C4 Pressurizing system for the ultra-high pressure watercutter (Waters 2005).

at Christchurch and the system used by San Francisco have vacuum recovery systems integral to the equipment; therefore, no inference can be made as to the necessity for airports to recover the waterblasting residue and dispose of it in some prescribed manner. The same comment is true for sweepers. The major purpose of the sweeper after waterblasting is to remove any foreign object debris (FOD) that might remain. However, San Francisco was one of the airports that reported using a sweeper, but qualified the statement by saying it is only used if the vacuum recovery system in the waterblaster malfunctions. The contractor responses confirmed the airport operator responses regarding types and numbers of equipment used.

The average crew size for a typical waterblasting operation was 4. Respondents ranged from a low of 1 person to a high of 12. Those responses that were on the high end also reported airport personnel that drove escort trucks and inspected the work. It is possible that the others only reported the number of personnel required to operate the waterblasting equipment spread and did not include supervisory or safety people from the airports' internal staff. This inference is strengthened by the fact that the contractor reported crew size ranged from 1 to 4 persons.

Production rate is an issue in all runway rubber removal operations. A number of the rubber removal specifications include minimum production rates (USAF 1997; Transport Canada 2003c) or maximum runway closure periods (San Francisco 2002; Transport Canada 2003; San Diego 2005). All airport respondents indicated that runway clo-

FIGURE C5 Vehicular-mounted and self-contained chemical distributor (Monkeman 2006; Saric 2006).

sures period range from 6 to 8 h, except Christchurch, where the rubber removal is done between operations. The airport respondents cited a range in production from a low of 360 yd^2/h (300 m^2/h) to a high of 3,000 yd^2/h (2,508 m^2/h), with an average product rate of 1,535 yd^2/h (1,284 m^2/h). Of the 15 airports that furnished these data on their waterblasting operations, 5 reported using UHP waterblasting. There was no appreciable difference in high-pressure and UHP waterblasting production rates in this sample. The contractor responses indicated average crew sizes of two persons. In addition, the production rates were considerably lower than those cited by the operators. Of the seven contractor waterblasting responses, three were from international firms, and the production rates ranged from 360 yd^2/h (300 m^2/h) to 3,000 yd^2/h (2,508 m^2/h), which exactly mirrored the airport operator range and confirms the validity of those data.

CHEMICAL REMOVAL TECHNOLOGIES

Chemical rubber removal equipment comes in a number of forms. Each version of chemical rubber removal technology consists of a set of equipment. The equipment can be either specially designed for chemical runway rubber removal or merely the standard runway maintenance equipment that is used for snow and ice removal as well as other routine tasks. There are two configurations for chemical rubber removal equipment. The first is a vehicle-mounted, self-contained unit that sprays the chemicals, brushes them, and vacuums the residue and can be operated from the cab of the vehicle by the driver. Figure C5 shows a picture of a typical chemical distributor and a self-contained chemical removal machine, and Figure C6 is the rear view of a European manufactured machine that is used internationally. In addition, the U.S. Air Force developed a "deployable" chemical rubber removal machine (Figure C7) that has a multipurpose function in that the apparatus is mounted on a single small vehicle that can perform the necessary functions one at a time. The second configuration consists of a number of pieces of single-purpose equipment that operate as a team. This configuration is normally formed out of the airport's runway maintenance equipment pool. This configuration has two different types. The first is self-propelled; the second type is skid-mounted, which is smaller and can be deployed in the back of a trailer or a light truck.

Chemical Removal System Components

The chemical rubber removal system consists of the following components:

- Chemical tank,
- Pump,

FIGURE C6 European vehicular-mounted chemical distributor (Zoorob 2001).

FIGURE C7 U.S. Air Force deployable chemical rubber removal machine (Cotter et al. 2006).

- Spray bar apparatus to deliver the chemical to the surface,
- Rotary brooms or other equipment to agitate the chemical and scrub the rubber off the surface,
- Water tank/truck to flush the surface after brooming,
- Vacuum apparatus (if required by local environmental requirements), and
- Residue storage tank (if required by local environmental requirements).

Figure C8 is a picture of a typical large-scale chemical rubber removal equipment spread. It shows the chemical distributor followed by rotary brooms.

Chemical Removal Crews, Equipment, and Production

In the survey, 17 airports reported their chemical rubber removal equipment and crew sizes. For the most part, the equipment consisted of the following pieces, with the number of responses indicated in parentheses:

- Chemical distributor truck (12);
- Trailer/skid-mounted chemical distributor (2);
- Vacuum truck (5);
- Broom sweeper, self-propelled or towed (15); and
- Water supply truck (6).

The average crew size for a typical chemical rubber removal operation was five. Respondents ranged from a low of three to a high of seven personnel. The responses on the high end indicated that they also used multiple pieces of equipment.

Production is an important factor in all runway rubber removal operations. A number of the rubber removal specifications include minimum production rates (USAF 1997; Transport Canada 2003a) or maximum runway closure

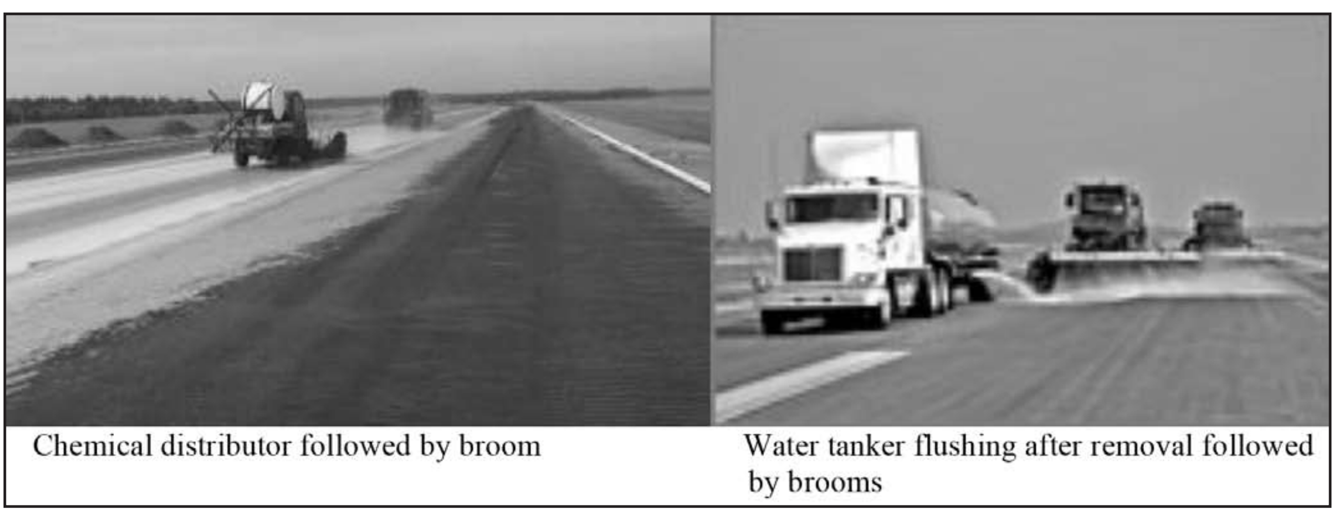

FIGURE C8 Typical chemical rubber removal equipment in action (Cotter et al.2006; Zoorob 2001).

periods (San Francisco 2002; Transport Canada 2003a; San Diego 2005). The airport respondents indicated that runway closures period range from 5 to 12 h. The airport respondents cited a range in production from a low of 500 yd^2/h (418 m^2/h) to a high of 3,125 yd^2/h (2,613 m^2/h), with an average product rate of 1,655 yd^2/h (1,384 m^2/h). Of the 13 airports that furnished these data on their chemical rubber removal operations, there was no appreciable difference in production rates for different chemicals in this sample. No contractor responses were received for chemical rubber removal product rates.

SHOTBLASTING TECHNOLOGIES

Shotblasting equipment generally comes in two types. The first is a vehicle-mounted, self-contained unit with the apparatus that propels the abrasive steel shot as well as the magnetic vacuum system that picks up the abrasive shot and residue, separates it, and captures the residue and dust in a container for disposal. This type can be operated from the cab of the vehicle by the operator. Figure C9 is a picture of the largest version of a vehicle-mounted shotblaster that has a cutting width of approximately 6 ft (1.8 m), and Figure C10 is a picture of a smaller version with a cutting width of approximately 4 ft (1.2 m). The second configuration is a smaller ground-mounted version (Figure C11) that is "capable of cutting 6–20 in. [15–51 cm] at a pass" (Speidel 2002).

Shotblasting System Components

The shotblasting system consists of the following components:

- Shot propelling apparatus,
- Vacuum system,
- Magnetic separator,
- Residue container, and
- Follow-on magnetic brush/broom to pick up any debris that might have been left by the shotblasting system

Figure C12 is a schematic diagram of a typical shotblasting equipment's process. It shows how the abrasive shot is propelled by the impellor and is then retrieved along with the debris, separated, and either returned to the shot hopper or fed into the residue/dust collection bin.t

Shotblasting Crews, Equipment, and Production

In the survey, the airports reported their shotblasting equipment and crew sizes. For the most part, the equipment consisted of the following pieces, with the number of responses indicated in parentheses:

- Shotblasting machine (3) and
- Follow-on magnet vehicle (2).

FIGURE C9 Large vehicular-mounted shotblaster (Wambold and Henry 2002).

FIGURE C10 Vehicular-mounted shotblaster (Jenman 2006).

FIGURE C11 Small walk-behind shotblaster (Jenman 2006).

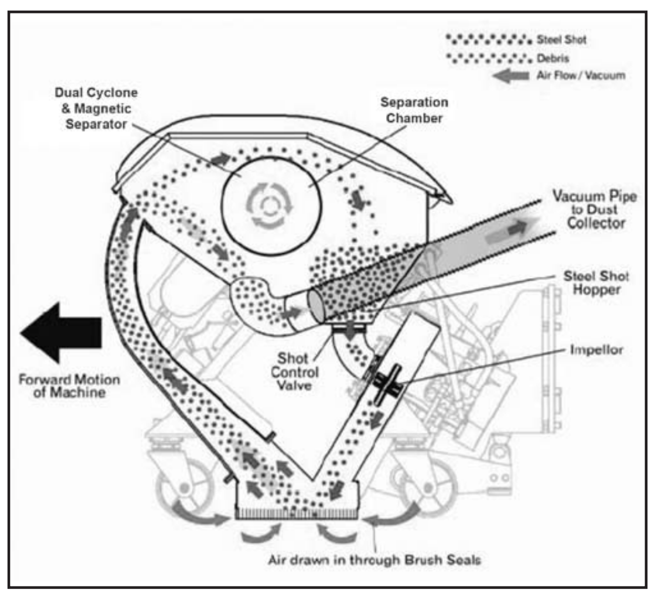

FIGURE C12 Typical shotblasting apparatus process (Jenman 2006).

The average crew size for a typical shotblasting operation was four. Respondents ranged from a low of two to a high of six personnel. Atlanta indicated that it also had two shotblasting machines and, hence, double the crew requirements.

As previously stated, one airport had tried shotblasting but believed it might be too slow, making production a critical factor for selecting this mode of rubber removal. A number of the rubber removal specifications include minimum production rates (USAF 1997; Transport Canada 2003d; Skidabrader 2007) or maximum runway closure periods (San Francisco 2002; Transport Canada 2003d; San Diego 2005). The airport respondents indicated that runway closures period range from 5 to 7 h. The airport respondents cited a range in production from a low of 3,334 yd^2/h (2,788 m^2/h) to a high of 6,750 yd^2/h using two machines (5,644 m^2/h), with an average product rate of 3,736 yd^2/h per machine (3,124 m²/h). The contractor responses for product rates averaged about 3,500 yd²/h (2,926 m²/h).

MECHANICAL REMOVAL TECHNOLOGIES

Mechanical rubber removal equipment comes in a number of forms. Those various technologies are as follows:

- Milling,
- Grinding,
- Sandblasting,
- Scraping (i.e., snow plows with blades),
- Brooming with stiff bristles, and
- Other potential applications of routine pavement maintenance equipment.

Figure C13 is an image of standard pavement milling machine in use in the highway industry and its milling head. This technology also comes in smaller forms, as shown in Figure C14. Generally, the large-size milling machine would not be used to remove rubber from runways because the quantity of milling would not justify the cost of mobilization. However, this method would remove surface rubber in addition to milling if the milling were being done in conjunction with resurfacing an entire runway. The smaller machine in the second figure would be more appropriate for removing runway rubber.

Figure C15 shows a typical pavement diamond-grinding machine in use prior to resurfacing an airport runway. Figure C16 shows an example of grinding to remove paint on an asphalt runway pavement. Again, the scale of the operation will determine whether it is economically feasible to use grinding for runway rubber removal.

Figure C17 shows both a typical sandblasting unit that was used to remove rubber from runways and the results of using that unit.

FIGURE C13 Milling machine and milling head (Washington 2002).

FIGURE C14 Small milling machine (DDC 2007).

FIGURE C15 Diamond grinder in operation on airport (McLake 1999).

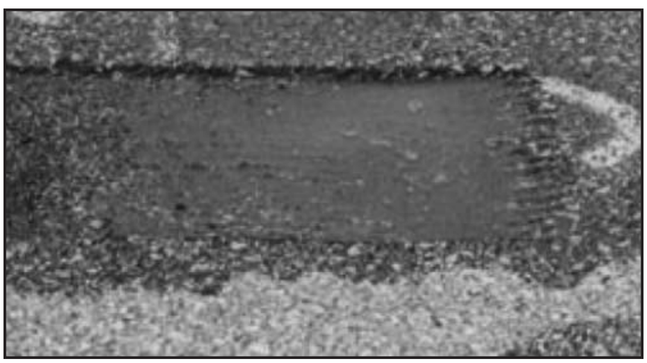

FIGURE C16 Example of grinding on asphalt surface (Skidabrader 2002).

FIGURE C17 Sand blasting unit and runway rubber removal results.

APPENDIX D

SUMMARY OF RUBBER REMOVAL RESEARCH

The survey of the literature shows that formal research into different methods of runway rubber removal began in the mid-1970s. It built on earlier seminal research in the area of runway surface friction measurement and the impact of runway contaminants such as ice, snow, and deicing chemicals on aircraft braking performance conducted by Yager and others at NASA's Langley Research Center (Leland et al. 1968; Yager et al. 1970). In 1975, NASA published a report regarding the use of a "high-pressure water blast with rotating spray" (hereafter referred to as waterblasting) to remove rubber and paint from runways (Horne and Griswold 1975). The motivation for the research appears to be related to the fear that chemical rubber removal methods that were employed at the time no longer complied with newly enacted environmental standards. The report states, "Chemical rubber and paint removal treatments are little used at the present time because of ecologically harmful side effects to water sheds surrounding airports." It also discussed the perceived efficacy and potential for pavement damage of other available removal methods. It discusses sandblasting, mechanical grinding, and "shot-peening" (hereafter referred to as shotblasting). The study furnishes a set of proposed waterblasting specifications with prescriptive means and methods based on the results of the study. The report concludes that despite some minor observed pavement damage that waterblasting represented the most promising technology for that period, especially in light of environmental restrictions.

EARLY RESEARCH BY FAA AND NASA

The FAA commissioned two studies of replacing chemical rubber removal with "high-pressure water-jet" (i.e., waterblasting) removal techniques. Research and testing was conducted at an air force base (AFB) in the Charleston, South Carolina (Hiering and Grisel 1975a), and at the Houston Intercontinental Airport in Texas (Hiering and Grisel 1975b). One of the major aspects of the research was to confirm or refute a report from the Canadian Department of Transport that waterblasting created an ancillary deleterious effect on the pavement by polishing the surface while removing rubber. Thus, the research not only measured waterblasting's effectiveness in removing rubber, it also measured the change in frictional characteristics of the runways before and after rubber removal. The studies were carried out on both portland cement concrete runways (hereafter referred to as *concrete* runways) and hot-mix asphaltic concrete runways (hereafter referred to as *asphalt* runways). The studies concluded that waterblasting was

- A quick and environmentally acceptable method of removing rubber from a runway,
- Capable of removing rubber deposits from a runway surface without damaging or changing the surface, and
- No runway polishing effects were discernable (Hiering and Grisel 1975b).

The next piece of significant research was published in 1980: *National Runway Friction Measurement Program* (MacLennan et al. 1980). This was a large-scale effort that conducted friction testing on 491 runways at 268 U.S. airports. The results were statistically analyzed to establish rational engineering relationships between measured runway friction values and pavement type, texture depth, grooving, and rubber accumulation. Thus, the research drew a direct connection for the first time between runway grooving and rubber accumulation with regard to surface friction. More important, it established a rational engineering standard based on a repeatable test procedure for determining both the need and the timing of runway rubber removal. Most important, it confirmed the beneficial effects of runway grooving in those areas where the potential for rubber accumulation was the highest. Unfortunately for this synthesis, it did not differentiate between rubber removal methods.

RUBBER REMOVAL SPECIFICATION RESEARCH

The previous research studies contained recommendations that their results be used to develop specifications for runway rubber removal. To facilitate and perhaps standardize this effort, FAA commissioned a study entitled "Runway Rubber Removal Specification Development" (Lenke and Graul 1984). A major component of this study was the creation of a field test procedure that was used to measure the effectiveness of the following five pavement texture measurement technologies in correlating with the "mu meter":

- ASTM (E 965) sand patch test,
- Silicone putty test,
- Penn State drag tester,

- Chalk wear tester, and
- Stereophotography.

The study found that predictive friction models using the above techniques were too variable and recommended that "mu meter" output be used alone for developing contract specifications for rubber removal. It was also designed to furnish a means to quantify rubber accumulation and contains a very valuable analysis of the above texture measuring test methods for those airport authorities that may become interested in including pavement texture analysis in their runway pavement management system.

Research for a master's thesis on this subject was published by Simpson in 1989. It contained an excellent analysis and discussion of the state of the art at that time. It included a survey of airport maintenance managers, operations managers, and interestingly, pilots. The survey captured qualitative experiential data regarding rubber removal programmatic practices as well as the perceptions of these three groups as to efficacy of those operations. One of its findings was a difference in opinion as to seasonal variations in rubber accumulations. The majority of maintenance managers believed that there were more rubber accumulations in the summer, attributing higher pavement temperatures and increased traffic as the cause. Operations mangers were split between whether or not there was a seasonal variation at all, and the majority of the pilots did not perceive any seasonal variation. This outcome is very interesting because it delved into the perceived impact of rubber accumulation on the full realm of airport pavement management. One might think that the pilots' perception would be a function of their experience making landings on rubber-covered runways. On the other hand, one would expect the maintenance managers to be more focused on observing rubber buildup because it is their job to remove it when it reaches some level determined either by visual inspection or some engineering measurement. The next interesting finding dealt with the perceived amount of time after rubber removal for rubber deposits to begin building back up. The outcome was that 83% of maintenance managers and 93% of operations managers believed that the accumulations had returned within 3 months of removing them. This is important in that it helps pin down the required maintenance cycle for rubber removal and, coupled with the seasonal perception by maintenance managers, leads to a possible rubber removal cycle of at least twice per year: once in the spring and again in the fall. This information can be validated by the results of this ACRP synthesis survey because it asked for the seasonal timing from each airport respondent. The final important finding in this thesis was, once again, the coupling of runway pavement friction and runway pavement texture. Simpson confirmed the better performance of grooved pavements in maintaining friction values in areas that accumulated rubber deposits and expressed the same need as Lenke and Graul (1984) for better pavement texture testing methods and a way to correlate them with friction values. Simpson concludes that this is necessary to be able to develop meaningful rubber removal specifications when he states:

> A simple reliable inexpensive surface texture measurement method should be developed. … If such a method were developed and its readings correlated with the friction measuring devices, rubber removal specifications could be written to require a minimum increase in tire-pavement friction from removal operations.

Thus, this thesis also confirms the notion that runway rubber removal should be procured using a performance-based specification rather than a method-based prescriptive specification.

Transport Canada appears to embrace a performance-based approach to runway rubber removal. Its 2004 policy document on the subject states that the "objective of the rubber removal program is to clean the pavement surface and restore and/or maintain the runway surface friction characteristics to a minimum of 90% of the coefficient of friction measured on non-contaminated surfaces of the same or similar pavements." It actually maintains a set of specifications for the following four methods of runway rubber removal (Transport Canada 2004):

- Chemicals and water—contractor performed,
- Chemicals and water—in-house performed,
- Ultra-high-pressure waterblasting, and
- Shotblasting.

The difference between the first two methods is obviously in who does the work. It states that the use of in-house personnel is contemplated for purpose of "convenience not cost since the rubber can be removed periodically, one section at a time, during off-peak hours." It is interesting to note that its specification for shotblasting is titled *Runway Rubber Removal and Retexturing by Shotblasting.* Although it is not explicitly stated in the document, this leads one to believe that this agency sees the use of shotblasting for more than just rubber removal and is promulgating a specification that leads to improved pavement texture in addition to the removal of accumulated rubber deposits. Although this specification does not articulate a required change in friction value as might be expected, it does contain a performance requirement for the finished product as follows:

> Determine in trial sections the proper combination of operating speed and abrasive power settings to give a lightly textured surface visually free of rubber contamination, with the colour of the natural surface clearly visible. Use minimum power setting necessary for the removal of rubber. (Transport Canada 2003d)

All the Canadian specifications contain performance criteria for production rates (chemical and waterblasting—1,350 m^2/h [1,650 yd^2/h]; and shotblasting—3,000 m^2/h [3,588 yd^2/h]) and maximum shift lengths (chemicals—6 h; waterblasting and shotblasting—8 h) to not pose a conflict with airport operational requirements.

APPENDIX E

RUBBER REMOVAL CONTRACTOR CONTACT INFORMATION

The following is a list of the contact information for runway rubber removal contractors that furnished input to this study:

- Blastrac, Inc., Edmond, Oklahoma. Shotblasting equipment manufacturer—self-contained rubber removal process machine

  Greg Bowers, 770.533.1888, greg.bowers@blastrac.com, 13201 Santa Fe Ave., Oklahoma City, OK 73114

- Chemtek, Inc., Durham, North Carolina. Runway rubber removal chemical supplier

  David Rigsbee, 888.229.0931, david@chemtekinc.com, 100 Meredith, Suite 275, Durham, NC 27713

- Fort Brand Services, Inc., Plainview, New York.

  Fred DiBenedetto, 516.576.3200x218, fdibenedetto@fortbrand.com, 50 Fairchild Ct., Plainview, NY 11803

- Fulton Hogan Ltd., Christchurch, New Zealand. Ultra-high-pressure watercutting—self-contained rubber removal process machine

  Jeff Waters, ++ 64.3.357.3684, jeff.waters@fh.co.nz

- Hi-Lite Markings, Inc. Adams Center, New York. Waterblasting contractor

  Brian Becker, 315.583.6111, Brian@hi-lite.com, 18249 Hi-Lite Dr. Adams Center, NY 13606

- Skidabrader, Ruston, Louisiana. Shotblasting—self-contained rubber removal process machine

  Gary Billiard, 318.251.1935, noskidn@earthlink.net, Humble Equipment Co., 1720 Industrial Dr., Ruston, LA 71270

- Vindotco, Ltd., Brigg, United Kingdom. Chemical (Rubberaser) with high-pressure waterblasting—self-contained rubber removal process machine

  Malcolm Donald, +44.1652.652444, VINDOTCO@aol.com, Elwes Street, Brigg, North Lincs England DN20 8LB

- Trackjet, Melrichtstadt, Germany. Ultra-high-pressure waterblasting—series of machines to complete rubber removal

  Dieter Pade, +49.174.9000.1952, d.pade@gmx.de

  Al Swainston, 423-991-0022, bigvan@bellsouth.net

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation