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IDEA

Innovations Deserving Exploratory Analysis Programs

Highway IDEA Program

Cleaning Device to Remove Debris and Chemicals for Crack/Joint Sealing

Final Report for NCHRP-IDEA Project 148

Prepared by:
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August 2011

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

This NCHRP-IDEA investigation was completed as part of the National Cooperative Highway Research Program (NCHRP). The NCHRP-IDEA program is one of the four IDEA programs managed by the Transportation Research Board (TRB) to foster innovations in highway and intermodal surface transportation systems. The other three IDEA program areas are Transit-IDEA, which focuses on products and results for transit practice, in support of the Transit Cooperative Research Program (TCRP), Safety-IDEA, which focuses on motor carrier safety practice, in support of the Federal Motor Carrier Safety Administration and Federal Railroad Administration, and High Speed Rail-IDEA (HSR), which focuses on products and results for high speed rail practice, in support of the Federal Railroad Administration. The four IDEA program areas are integrated to promote the development and testing of nontraditional and innovative concepts, methods, and technologies for surface transportation systems.

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Cleaning Device to Remove Debris and Chemicals for Crack/Joint Sealing

NCHRP IDEA Project Final Report

Project NCHRP-148

Prepared for the IDEA Program

Transportation Research Board

The National Academies

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August, 2011

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EXECUTIVE SUMMARY

The need for the new device was initiated based on the practical request of the Nebraska Department of Roads (NDOR) for a tool to be developed that efficiently prepares pavement cracks and joints for sealing. NDOR was particularly interested in the tool's ability to remove de-icing chemical buildup that forms on the crack and prevents sealant adhesion.

Flexible and rigid pavement joints and cracks are sealed or filled to mitigate further damage caused by the infiltration of water and the buildup of foreign debris. "Materials and procedures for sealing and filling cracks in asphalt surfaced pavement" (FHWA-RD-99-147) recommends crack sealing for 5 to 19 mm (*1*). However, the traditional procedures for preparing roadway joints and cracks for sealing/filling— which include air blasting, sanding, routing, and hot air blasting—are largely ineffective, labor intensive, or dangerous.

The most viable solution found was a combination of preparation methods that included air blasting and abrasive wire brushing. The simple and innovative design of this tool is an air powered rotary wire brushing system with onboard air nozzles that blow out the pavement crack behind the wire brush. The device is illustrated in Figure 1. Incorporating a pneumatically powered rotary motor allows for a seamless connection between existing maintenance vehicles' air compressor systems, which reduces the need for further retrofit costs and eliminates the need to haul flammable liquids.

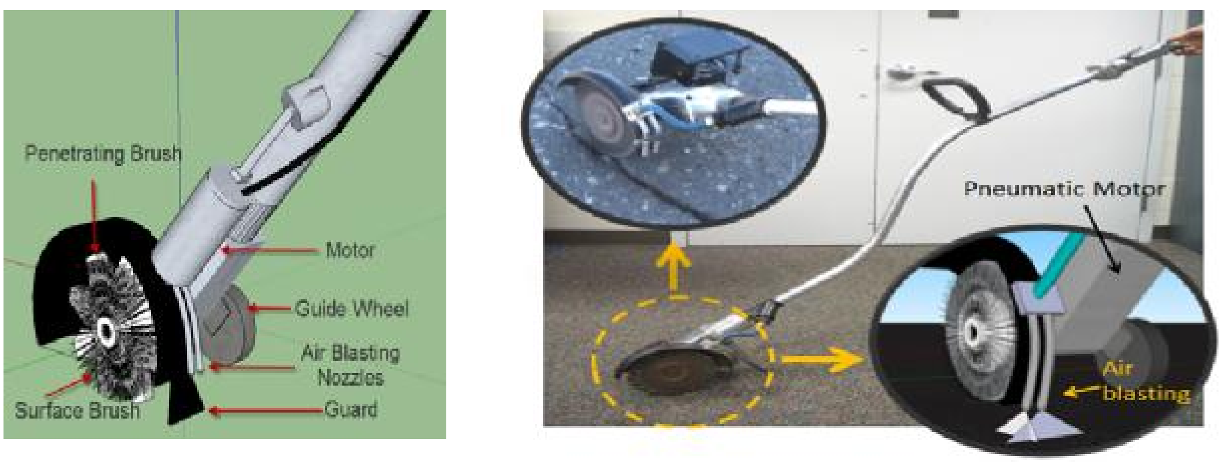


FIGURE 1: Crack Cleaning Device Concept and Product.

Throughout development a number of hypotheses were tested and there were several issues to overcome. The first of which was discovering the most effective rotary brush type to be used for crack preparation. After testing a number of brush types and thicknesses it was found that a ¼" twisted wire brush performs best. An adequate guide wheel assembly was also machined for the device in two different forms which included a height-adjustable mechanism and a free moving spring system that enables the operator to plunge into cracks when desired. Additionally, issues regarding the shape and size of the device's shaft had to be overcome. Originally, it was thought that a straight shaft design would allow for more freedom of motion, giving the user the ability to stand erect while using the device. It was discovered that most operators wished to stand over the device and use leverage to work the device into the pavement cracks. For that reason, an ergonomically curved shaft or wand was machined and fitted to the device.

In addition to a number of innovative design concepts, a number of field and laboratory tests have been conducted. While the entire device is a product based on the feedback of actual pavement maintenance crews, many of the details were processed in the manufacturing lab. The first concept to be tested in the lab was the device's ability to generate heat by the frictional force of the wire rotary wheel, which would warm the pavement crack to an acceptable level to receive sealant on cold days. The test results showed that generating heat is not a time-efficient process since it requires multiple passes to generate desirable levels of heat. In addition, the effectiveness of the onboard air blasting nozzles was investigated. The device was fitted with two nozzles, one that shot directly into the cleaned crack, and one that fanned on the surface of the crack to disperse debris away from the pavement crack. Perhaps the most important laboratory test was identifying the device's efficiency in removing de-icing chemical residue from pavement cracks. The residue was simulated using aerosol paint and visually inspected and rated on a percent cleaned basis. The device preformed this task efficiently.

The crack cleaning device has been tested a number of times by actual industry roads maintenance personnel at NDOR and the City of Omaha in Nebraska. From such testing, its high potential for significantly improving the current crack/joint sealing practices was recognized (Figure 2). A continuous improvement process according to industry feedback, including the nation's largest roadway maintenance equipment/material supplier CRAFCO Inc., proved to be an invaluable method of creating such a practical device. It was the group of operators who tested the device and motivated improvements like a guide wheel assembly, nozzle design, and shaft design. Overall, the operators were very receptive to the concept and impressed with the performance of the crack cleaning device.

FIGURE 2: Test by a local roads maintenance crew.

Business development is currently ongoing. The roads maintenance group in the City of Omaha has recently requested their own adoption of the device and is currently testing the device at with crack and pothole cleaning and repair projects. As of today, the ruggedness of the device is proved by the City of Omaha's daily use of device for a total of about 30 hours. Since a wire brush can be simply replaced with a router bit or a rotary masonry cutting blade, the device can rout cracks and cut a pothole area in conjunction with a jackhammer before placing a new patch. Through the long term field use by the City of Omaha, the practicality and versatility will be further proven.

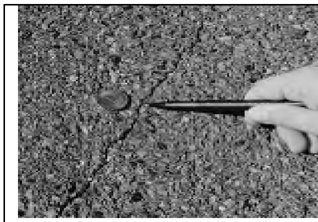
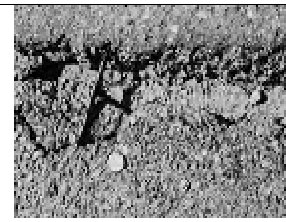
NUtech Ventures, a nonprofit corporation dedicated to linking companies, entrepreneurs and investors with the University of Nebraska-Lincoln researchers who are driven to develop commercial products or services based on their pioneering research, is currently working with the research team in order to solidify a viable course of action for commercialization. This plan includes either (1) establishing a start-up company at the Scott Technology Center, a small business incubator that partners directly with the University of Nebraska; or (2) licensing the technology to a road maintenance company such as CRAFCO Inc., Lab Manufacturing, Asphalt Sealcoating Direct or others.

Utilizing the developed device for crack and joint preparation will undoubtedly lead to an increase in overall quality of pavement maintenance. This improved quality will promote an increase of the useful life of pavements, and postpone the allocation of valuable tax revenue towards the rehabilitation or new construction of existing roadways.

1 IDEA PRODUCT

Flexible and rigid pavement joints and cracks are sealed or filled to mitigate further damage caused by the infiltration of water and the buildup of foreign debris. "Materials and procedures for sealing and filling cracks in asphalt surfaced pavement" (FHWA-RD-99-147) recommends crack sealing for 5 to 19 mm (*1*). Also, Unified Facilities Criteria (UFC) provides guidelines for crack preparation based on crack size as shown in Table 1.

TABLE 1: Crack Preparation Methods Based on Crack Size (*2*)

			
Pass: Less than ¼" (6mm)	Routing: ¼ to ¾" (6-19 mm)	Air blaster, wire brush, sand blaster: ¾ to 2" (19 to 50 mm)	Cut: greater than 2" (50 mm)

The traditional procedures for preparing roadway joints and cracks for sealing/filling are largely ineffective, labor intensive and/or dangerous. Although routing is the best approach among the methods listed in Table 1 for cleaning cracks, it is not a solution for complete preparation for crack sealing. Routing only excavates narrow cracks and still leaves de-icing chemicals on both sides of the crack surface. The surface preparation is very important for better bonding between surface and sealing material (Figure 1). Also, routing which generally uses a 3/8" carbide-tipped rotary impact bit is not effective for cleaning de-icing chemicals in wider cracks unless multiple routing paths are used. Furthermore, several districts in the state of Nebraska hesitate to rout cracks because routing equipment is very heavy and makes it difficult to follow cracks unless they are straight. In fact, it often results in the creation of another crack while routing random cracks. Pulling such heavy equipment downhill or on a windy day often puts the operator in dangerous situations as well.

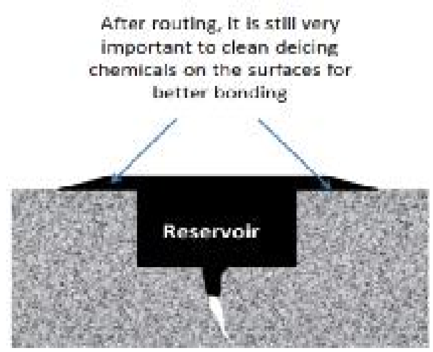


FIGURE 1: Elevation view of routed crack after sealing.

The explanation of the typical current practices used for crack/joint cleaning clearly highlights the remaining problems of each process. It is the team's intention to continue the development of a new crack cleaning method that introduces a combination of the above procedures into one customizable versatile device.

Considering the wants and needs of the Nebraska Department of Roads (NDOR) and local contractors, the main objective of the research is to develop a low-cost effective mechanical tool to prepare pavement cracks and joints for sealing or filling. The cleaning mechanism incorporates two of the already accepted pavement preparation methods into one tool. The device utilizes a pneumatically powered rotary wire brush to clean stubborn vegetation and accumulated de-icing materials from pavement cracks of mid- to large size. Directly behind the rotary brush, a set of air blasting nozzles is used to further expel fine grained particles. The device yields a low cost purchase price for the tool itself, while effectively and efficiently preparing pavement cracks and joints for sealer or filler, which will further reduce long-term pavement maintenance cost.

Traditionally the two incorporated preparation methods had to be completed by at least two different crew members. Based on the current design, crew size can be decreased by one member. There is no need for a second individual to follow behind the wire brusher to finish cleaning out the fine particulates the brush missed. Labor costs are often a primary constraint when it comes to construction and road maintenance. The cost savings of one less crew member has the potential to yield large dividends.

The safety benefits of this device cannot be overlooked. It is expected that a number of the environmental and safety concerns associated with cleaning a pavement crack has been eliminated with the device. The concept of using pneumatic power also eliminates the need to haul flammable liquids to power the rotary brushes. The only other effective method of preparing pavement cracks abrasively to remove de-icing chemicals is sand blasting. Unfortunately, in addition to the additional crew member needed to sweep up and blow out left behind sand particulate, sand blasting causes outdoor air quality issues and breathing problems for the operator and surrounding crew.

There is a clear benefit in regard to the mechanical efficiency of the device being powered pneumatically only. This allows for a decrease in maintenance cost due to the simplistic air powered motor, rather than the traditional small engine used to power the rotary brushes. It has been clearly proven through a number of field tests conducted by industry personnel that the crack cleaning device is easily attached to the most current air blasting devices and maintenance trucks equipped with air compressors. This leads to further cost reduction through the elimination of equipment retrofits.

After taking into consideration the direct benefits of the device, it is important to quickly investigate the secondary benefits of owning such a tool. First, by more efficiently and effectively cleaning joints and cracks, this treatment will be used on a higher percentage of cracks, thus yielding an increase in preventative maintenance and a decrease in new construction costs. According to the Montana DOT, for every one dollar spent on preventative roadway maintenance, four to ten dollars are saved in rehabilitation costs. Michigan found that for their state, rehabilitation and reconstruction costs fourteen times more per mile of roadway than preventative care. These cost savings translate into tangible budget factors that could funnel state allocated money into other needed projects (*3*). Utilizing two effective means of crack and joint preparation will undoubtedly lead to an increase in overall quality. This upgrade in quality will promote an increase in the useful life of pavements, and postpone the allocation of valuable tax revenue towards the rehabilitation or new construction of existing roadways.

2 CONCEPT AND INNOVATION

The basic concept of the innovation incorporates two traditional crack cleaning methods in one device: (1) wire brushing and (2) air blasting. The device uses a pneumatically driven rotary wire brush to clean cracks of mid- to large size debris and vegetation. Directly behind the rotary brush, variable direction air blasting nozzles on the device (Figure 2) are used to further expel fine grained particulate like concrete dust, fine sand, and most importantly, winter de-icing chemicals from the walls and surfaces of the pavement cracks. The device was constructed with a high torque pneumatic motor, machined aluminum pipes and associated fittings, and a varied selection of industrial wire brush wheels.

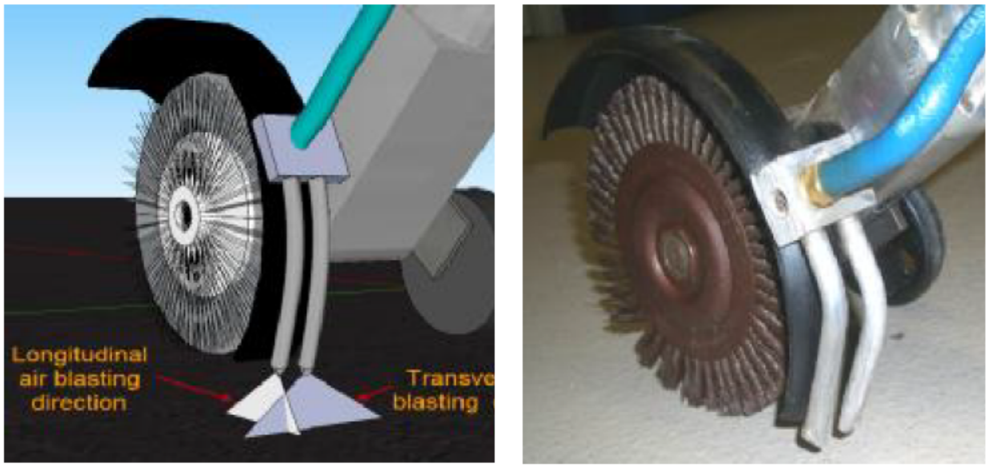


FIGURE 2: Air nozzle design in 3D (left) and actual model (right).

The device is also equipped with a guide wheel, plunging springs, ergonomically designed shaft, and a convenient trigger mechanism (Figure 3a). Furthermore, the device can rout cracks and cut a pothole area in conjunction with a jackhammer before placing a new patch by simply replacing a wire brush with a router bit (Figure 3b) or a rotary masonry cutting blade. The device yields a low cost alternative to simply and effectively prepare pavement cracks and joints for sealing or filling.

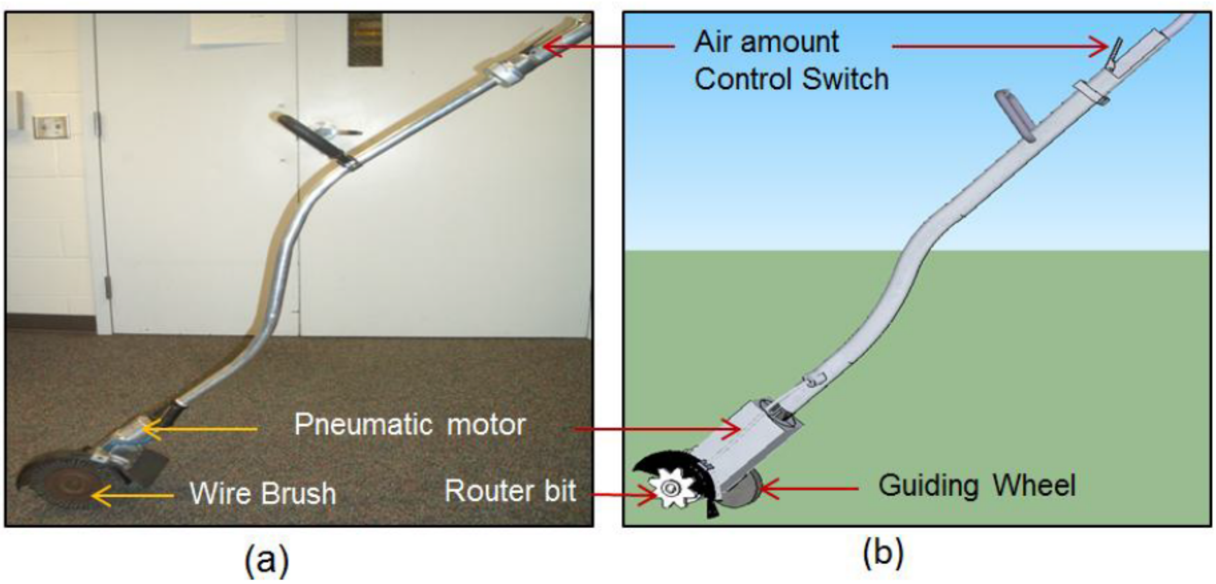


FIGURE 3: Innovative design concept of the crack/joint cleaning device.

3 INVESTIGATION

In this report, a chronological approach has been adopted to illustrate the progression of the device's development through all stages of prototyping and testing. At the conclusion of the field test section of this report, individual design outcomes will be highlighted. For organizational purposes, all site visits will be listed at the beginning of this chapter, with individualized design improvements being explained later.

3.1 INDUSTRY FEEDBACK AND FIELD TESTS

Visits were made to the Nebraska Department of Roads (NDOR) local maintenance yard in Omaha, Nebraska to meet with James Laughlin, highway maintenance superintendent of state personnel in charge of crack sealing, and observe the equipment they currently use. These visits served as a means of providing a baseline of design requirements for a working prototype. The baseline characteristics that the prototype included were air hose sizes, connection types, air pressures, and likely brush widths. In addition to insights into what is required of the device, Mr. Laughlin also outlined how the state's crack sealing process is conducted in his maintenance district including information relative to typical crew size, activities, and other additional perspectives that can only be provided by industry personnel.

At the beginning of the project, a regional panel of experts was selected at NDOR's recommendation. These experts were instrumental in providing the research team with practical industry knowledge of the crack sealing process. The members selected for the expert panel are as follows:

- Ray Branstiter (Maintenance Superintendent District 3): ray.branstiter@nebraska.gov
- Rodney Weber (Maintenance Superintendent District 3): rodney.weber@nebraska.gov
- Dick Soden (Maintenance Superintendent District 3): dick.soden@nebraska.gov

The panel members were selected only from District 3 for easier meeting schedule and location setup. In addition to these three people, two more NDOR experts have helped aid in developing and testing the prototype using their nearby facilities and equipment:

- James Laughlin (Maintenance Superintendent District 2): james.laughlin@nebraska.gov
- Don Haydon (Asphalt/Preventive Maintenance Specialist): donald hayden@nebraska.gov

3.1.1 First Local Field Test with NDOR (Night Operation)

On June 8, 2010, the first field test was conducted at an actual crack sealing site with the NDOR highway maintenance crews in District 2. There were two primary objectives of this initial field test: (1) to observe industry personnel performing conventional crack cleaning and sealing, and (2) to allow the same personnel to use the developed crack cleaning device (Figure 4). Overall, comments on the device were positive:

- The device is easy to learn how to use.
- The device is powerful enough to clean typical cracks.
- The device is easily maneuvered with the aid of wheel.
- The device would not slow down the crack cleaning process if incorporated into state procedures.

FIGURE 4: NDOR crews using a conventional hot air blaster (left) and the new device (right).

On the other hand, the crew did provide very useful critiques that will be considered while improving the device for the market. These comments included:

- Adding a heat lance to the device may benefit the District 2 group to reduce additional tasks.
- A second handle should be added to the device for the hand not pulling the trigger.
- The shield needs to be improved to reduce flying debris.

3.1.2 Regional Panel Visits

On July 28, 2010 the research team traveled to Norfolk, Nebraska to meet with the NDOR Regional Panel that was selected to assist in supporting the development of the crack cleaner. Figure 5 shows a crack cleaning trial by the NDOR crews.

The overall reception of the crack cleaner's first fully functional demonstration was very positive. The regional panel was excited about the device's light weight and nimble design. It was indicated that the device would significantly reduce physical strain on the current crack cleaning crew. The panel was pleased with the effectiveness of the device at cleaning and preparing cracks for sealant. The panel agreed that wire brushing the inside and outside of the cracks would clean the remaining de-icing chemicals from the previous season. In addition, the panel agreed that the device can efficiently clean/prepare previously sealed damaged joints, which will be further discussed later.

However, the panel did provide the research team with a number of suggestions and comments for the improvement of the crack cleaner. These suggestions included:

- Replacing with a smaller diameter shaft
- Adding a height-adjustable wheel
- Adding a handle

FIGURE 5: First regional panel field test and demonstration.

This testing was followed by an additional demonstration of the most recent prototype in the fall of the same year. The new prototype incorporated the expert panel's previous suggestions regarding shaft size, wheel assembly and trigger mechanism. An important note is the users' comfort with the ergonomic design. Prior testing of the device's effectiveness were positive, however operators felt the tool could lead to operator fatigue and general discomfort. In its current form, the expert panel felt many of these concerns were solved and indicated their comfort in adding such a tool to their maintenance arsenal (Figure 6).

In addition to a demonstration of the cleaner as a rotary wire brushing tool, the panel also tested the device with a rotary router bit. Routing pavement cracks is generally done to expand the width of a pavement crack to a level in which enough sealant can be placed for a proper bond to take place. The crack cleaner preformed marginally well with the router bit although several design modifications were still needed. The regional expert panel, as well as the research team sees the future development of this option as a viable method of increasing the device's versatility.

FIGURE 6: Second regional panel field test.

3.1.3 City of Omaha Urban Maintenance Crew Field Test

Due to the difficulty of arranging a demonstration schedule with other State DOTs or contractors, the final field test was conducted on March 4, 2011 with the City of Omaha roads maintenance group. In contrast to state maintenance crews, the Omaha crew could speak extensively to the crack preparation and sealing process in an urban environment. Because the city crews are often rushed to make pavement repairs and open lanes without further impeding traffic flow, routing or time consuming preparation methods are not feasible options. For the City of Omaha crews, air blasting is the only viable preparation method for crack preparation.

After testing the device at their own maintenance yard, a number of constructive comments were provided. The first comment was attuned to the device's flexibility. Since there are considerably more maintenance projects in an urban environment, crew members were suggesting multiple alternative uses for the tool. One such application was the device's ability to cut control joints at a consistent depth without using a bulky concrete saw, or preventing the operator from hunching over a skill saw. The Omaha crew also recognized the issue of deicing chemicals inhibiting sealant adhesion to pavement cracks, and found the device to be rather effective at preparing pavement cracks. Another suggested application was cutting an area of pothole by replacing a rotary wire brush with a masonry cutting blade. This will make a pothole preparation job much easier for a jackhammer before placing a new hot mix asphalt patch.

FIGURE 7: City of Omaha Field Test.

From this visit, two suggested improvements were made which are important to the device's use in an urban environment:

- An increased debris guard
- An angle-adjustable air nozzle

The increased debris guard was suggested not only for the safety and protection of the operator, but also for passing vehicles and pedestrians. The adjustable nozzle trajectory using a funnel was suggested to blow out debris away from the crack to the side of the roadway no matter what the direction the device is moving.

As a testament to the device's acceptance by industry maintenance crews, the City of Omaha has requested to rent the device to use in this year's sealing season. The opportunity to fully deploy the crack cleaning device for an entire sealing season is one that the research team is seriously considering. As per their request, the device has been rented to the City of Omaha during this spring and summer for street maintenance. However, due to the flood problems this summer, the device was only used for crack cleaning rather than pothole repairs. The device has been continuously used for about 30 hours in actual crack sealing projects without any mechanical problems, which proves the device's ruggedness. As a minor comment, it was suggested by the crew that a lube port that does not let the oil escape through the rear air nozzles is needed to keep motor lubed since the current design lets the oil come out through the two rear air nozzles.

The feedback generated from such an extensive beta testing will provide us a solid base of future improvement as a step towards industry acceptance.

3.1.4 Annual Transportation Research Board Meeting

In January of 2011, the project's findings and a short synopsis of the crack cleaner's development were presented at the Annual Transportation Research Board Meeting in Washington D.C. The reception of the device was met well by members of both academia and industry. In addition, a railroad professional suggested the crack cleaners cross application as a rail cleaning device. A contact was made with CRAFCO Inc., the nation's largest pavement maintenance equipment company. After further communication about the device, CRAFCO Inc. has shown an interest in the tool and agreed to act in an oversight capacity for further development. Topics the company wishes to investigate are the unit's productivity level and the addition of air quality control options.

3.2 FIELD TESTING DESIGN ISSUES

A great deal of design considerations and device improvements were realized as a result of conducting field tests. A number of the substantial topics are discussed in the following sections.

3.2.1 Air Compressor Compatibility

Initially, there were several questions throughout the first prototyping phase about the availability of a compatible power source for the device. Such inquiries could only be answered through field testing. Three issues in particular were resolved in regards to this area: the availability of an appropriately sized air supply, the coupling of the device to the air supply, and the dirt/moisture filters on the air supply. Fortunately, the air compressor used by NDOR and the City of Omaha for crack cleaning provide enough air volume and pressure (110 to 170 PSI) with a ¾" diameter hose for the device to operate properly (Figure 8).

FIGURE 8: NDOR road maintenance air compressor

3.2.2 Coupling of the Power Supply

Several connection pieces to the power supply have been considered to allow enough air volume to enter the device. It was identified that a 1" Chicago fitting was a common connection type used in the local industry, including NDOR and the City of Omaha (Figure 9). Thus, the working prototype has been permanently furnished with a Chicago fitting at the power supply connection.

FIGURE 9: Chicago coupling used in this project.

3.2.3 Dirt/Moisture Filter on the Power Supply

It was previously assumed that any pneumatic power supply large enough to be used by state maintenance crews would be fitted with dirt and moisture filters. Although it was unusual, the pneumatic power supply at the first test site with the NDOR group did not have a functioning moisture filter. Figure 10 shows a crack after it has been cleaned using the new device. Note the darker shaded pavement in and around the crack illustrating moisture on the pavement. This is troublesome for two reasons. First, when the moisture is introduced to the pavement surface the air blaster's effectiveness at blowing fine particulate out of the crack/crack surface is reduced. Second, the crack/crack surface must be completely dry for the sealing agent applied over the crack to adhere properly. Had a heat lance not been following the device, crack sealant would not have been able to be installed. Fortunately, the air compressors used by the other NDOR districts and the City of Omaha for crack cleaning were equipped with functioning moisture filters and did not introduce any moisture on the pavement surface during crack cleaning device testing.

FIGURE 10: Moisture introduced to the pavement from the air compressor.

3.2.4 Brush Selection

It is crucial that the brush selected for sealant preparation be versatile enough to accommodate varied crack widths and sizes, and durable enough to withstand the abuse that accompanies the cleaning process. Several different brushes that were tested as part of this study are shown in Figure 11.

FIGURE 11: Tested rotary wire brushes.

Three wire brushes, all with a 7” diameter, were tested with the first prototypes. The first brush was 7/8” thick and made of crimped carbon steel. The thickness of the brush face, coupled with the rigid bristles of the brush did not allow the device to penetrate a test crack to the desired level. It was originally thought that the thicker brush face would be flexible enough to both penetrate the crack and clean the immediately surrounding pavement. Unfortunately, this was not the case. Another problem with individually stranded wire brushes is their low maximum rpm capacity. The high speeds of rotation produced by a pneumatic motor would easily damage individually stranded wire brushes. The next brush to be tested was again made from carbon steel with a thick brush face. Twisted or braded wire was selected to promote the brush’s durability and improve rpm ratings. Unfortunately, results of this brush were similar. The brush face was too wide, and bristles were too rigid to penetrate the pavement crack. Lastly, a narrow brush face of ¼” twisted wire (Figure 12) was selected as the most promising brush type. This brush preformed significantly better at cleaning pavement cracks, while maintaining a high level of durability.

FIGURE 12: Twisted wire narrow faced brush test.

As noted earlier, the twisted wire brush was adopted in favor of crimped or straight wire brushes for a number of reasons. During the initial field test, it was apparent that the correct decision had been made. The brush was well sized for most cracks. There were, however, several smaller cracks on the roadway being sealed. By interviewing maintenance crews, it was found that these smaller cracks are typically sealed with little preparation other than air blasting. If the device is still passed over these smaller cracks, even if the brush does not penetrate the surface, the two on-board air nozzles should be enough for preparing the cracks for sealant.

As a future design of a brush, a combination of wire brushes would successfully prepare all components of an existing pavement crack (Figure 13). By extending the arbor length of the device, two wide face crimped wire brushes of a smaller diameter can be installed adjacent to the brush being used for crack cleaning. The wide faced brushes are used for cleaning the pavement surface directly adjacent to the pavement crack allowing for improved sealant adhesion at the surface of the crack. As continued development takes place, efforts will be made to investigate the viability of manufacturing a combined wire brush as one piece in various sizes.

FIGURE 13: Combination brush design.

3.2.5 Air Blasting

Air blasting is effective at expelling dust and relatively loose small contaminants. However, for cracks which have any level of vegetation or wedged material, air blasting alone is less effective. Additionally, air blast is not an effective method for removing the thin layer of de-icing chemicals that coat most crack walls and surface in cold weather regions. For these reasons, the crack cleaning device was designed to utilize both air blasting and wire brushing.

The first air blasting attachment fitted to the device was a simple nozzle that tapped into the air line for the motor. The single nozzle approach coupled with the rotating wire brush cleaned most debris from the crack; however, it did not clean debris from the surface of the crack. For that reason, two nozzles were added to the device: one crimped vertically to ensure a crack void of fine particulate, and one crimped horizontally aimed at the surface of the crack to ultimately ensure a good bond between the crack sealant and surface pavement (Figure 2).

During the first field test, simple impromptu tests were conducted that pitted the new device against the current NDOR District 2's accepted process: hot air blasting. When a hot air blaster is used, extreme caution must be taken to ensure the pavement is not overheated, which would result in the asphalt binder becoming brittle and leading to premature failure. Care should also be taken to never allow for direct flame methods to be used as the charring effect will lead to a soot residue and cause poor initial bonding. However, it was not difficult to find such a direct flame problem in the current practices as shown in Figure 14. Visual results of these tests were promising. Figure 15 shows a crack prepared by the prototype vs. a crack prepared by the air blaster used by NDOR. The device appeared to clean out more debris from the crack than air blasting/heat lancing. Additionally, the surface of the pavement was cleaned better with the prototype than the traditional method, likely giving the crack sealant a stronger bond to the pavement. From Figure 15 (right), it is apparent that a darker crack is visible. This illustrates that additional dirt has been removed by the prototype device after the NDOR air blaster/heat lance had passed over the crack.

FIGURE 14: Current hot air blasting process.

FIGURE 15: A crack after air blasting/heat lance (left) and the same crack after being cleaned by the prototype device (right).

3.2.6 Ergonomic Shaft and Handle Assembly

The repetitive motion of the crack cleaning/sealing process requires that the operator be comfortable while using the cleaning device during his or her daily shift. During the initial research phase, it was found that De Quervain's disease, trigger finger, tenosynovitis, and Raynaud's syndrome would all be potential outcomes of poor design for a device of this type (*4*)(*5*).

After the first field test, the maintenance crews suggested that: the handle be placed in the middle of the shaft or wand, and the shaft diameter be reduced from 1" to ¾" because holding tightly to a 1" shaft for an extended period of time generated much more fatigue in the hands of the operator than did a smaller diameter shaft. These changes are shown in Figure 16. The shaft size was reduced to allow users to more easily grasp the shaft if needed.

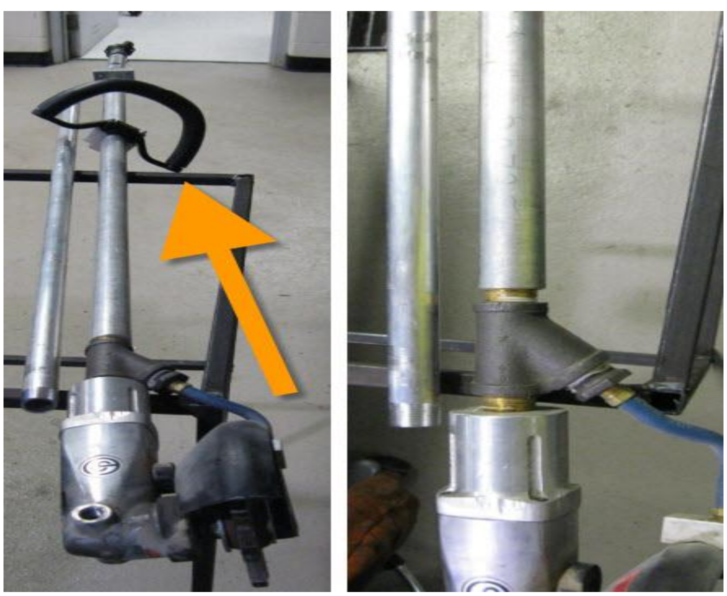


FIGURE 16: Added handle and smaller pipe diameter ready to be installed.

After the improvements were made, many users of the device still found the cleaner to be uncomfortable to use due to shaft design. In the past, the research team felt it best to utilize a long straight shaft for the device to allow the operator to stand either hunched over with the shaft to the side of their body, or upright grasping the shaft in front of their body as previously shown in Figure 5. After tests with several subjects, however, the s-shaped shaft was noted to be more comfortable to use for a prolonged period of time compared to the straight one (Figure 17). It is because the s-shape of the shaft allows the operator to stand more erect while pushing down on the device with less pressure.

FIGURE 17: Finalized shaft design.

3.2.7 Guide Wheel Assembly

During the research team's field visit with the NDOR District 2 maintenance group, a small fixed wheel was used to support the crack cleaner for the operator's benefit. From the field test, the crew recommended a swiveling caster wheel might be more applicable to chase variable cracks. Received as sound advice, the research team added a swiveling wheel to the device. Unfortunately, when taken to NDOR District 3, the swiveling caster proved to be too difficult to maneuver. When chasing even a straight crack, the wheel flips around causing the operator to veer off track from the crack. Thus, it was decided to revert back to a fixed wheel system.

The District 3 and District 2 crews did suggest a mechanism that would allow them to plunge deeper into a crack if necessary. In order to accomplish this, a simple spring assembly was manufactured and fixed to the stationary caster as shown in Figure 18 (left). Putting the spring around vertical shoulder bolts allows the operator to apply a little more downward force to plunge the wire brush deeper into the crack. The research team has also manufactured an optional adjustable locking mechanism to the wheel assembly to give the operator a choice in the setting the minimum crack depth he or she would be cleaning as show in Figure 18 (right).

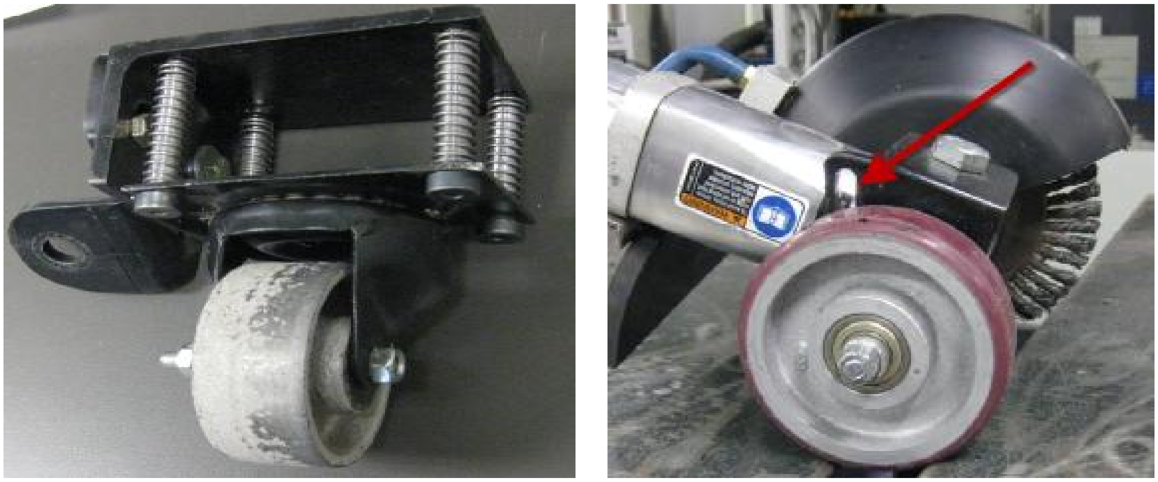


FIGURE 18: Spring mechanism with a stationary caster (left) and height adjustable assembly (right).

3.3 INTERNAL LABORATORY TEST

A number of laboratory tests were conducted as part of this project in an attempt to finalize the prototyped crack cleaner's design. Final tests included: brush size and stiffness effectiveness, heat generation, shaft ergonomics, and chemical residue removal effectiveness.

Further brush size and stiffness tests were conducted in an effort to more clearly define preferred brushes for the current prototype. Heat generation tests were conducted to investigate how much heat would be generated by the friction that a wire brush creates against the pavement. Shaft ergonomics tests were conducted at the request of the past operators of the device, as fatigue and possible safety issues were identified as possible hazards due to prolonged usage. The crack cleaner's ability to remove roadway chemicals was tested at the request of roadway personnel who work in cold weather climates and have difficulty in removing the de-icing chemicals that inhibit crack sealant from adhering to the sidewalls of the pavement cracks.

A test bed was created to be as mobile as possible, capable of being used inside or outside a temperature controlled environment. The test bed was constructed with various crack sizes of ¼", 3/8", ½", and ¾" with the simulated cracks being both straight, curved and at depths of ½" and ¾" (Figure 19).

FIGURE 19: As modeled(left) and as tested standardized crack test bed(right).

To replicate the same CFM and PSI capable of most commercial crack cleaning/sealing operations, a 185 CFM air compressor was used for each lab test. Ensuring the setup of the device was similar to that of field use enabled the research team to more confidently interpret test results.

3.3.1 Chemical Residue Removal Effectiveness

It is a very challenging task to remove de-icing chemicals and grime that stick to the crack walls and surface after the winter season regardless of what kind of air nozzle, heat lance, or router is used.

To test the effectiveness of the device for removing this winter buildup, the aforementioned test bed was utilized. The bed allowed for a varied number of crack widths to be tested with the device's recommended brush. Because the test was conducted in a warm season, an orange construction aerosol spray paint was used to simulate de-icing chemicals and grime buildup on the walls and surface. Aerosol paint was used to evenly spray small particles which simulated how the dissolved chemicals would settle evenly on the pavement, whereas brushed-on paint would not have evenly coated the crack area.

The test was conducted visually with an assessment of the painted cracks before and after the cleaning device was used. Figure 20 shows the test bed prior to any testing, and Figure 21 shows the test bed after testing. The test was completed in a very similar fashion to the thermography test above, with visual inspections being made after a specific number of passes or time spent cleaning the crack.

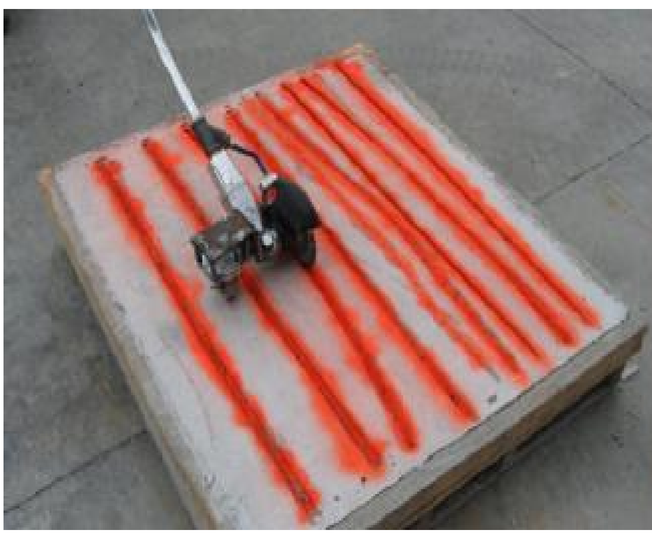


FIGURE 20: Test bed prior to testing.

FIGURE 21: Test bed after testing.

Testing results were very promising. Figure 22 shows the inside of a 1/2" crack after one pass by a 3/8" brush along the left sidewall. The right side of the crack wall (a) shows how the crack was coated and the left side of the crack (b) shows the left side of the crack wall after a single pass. Visual inspection proves the crack cleaner's effectiveness at removing grime and de-icing chemicals that are not simply blown out during air blasting.

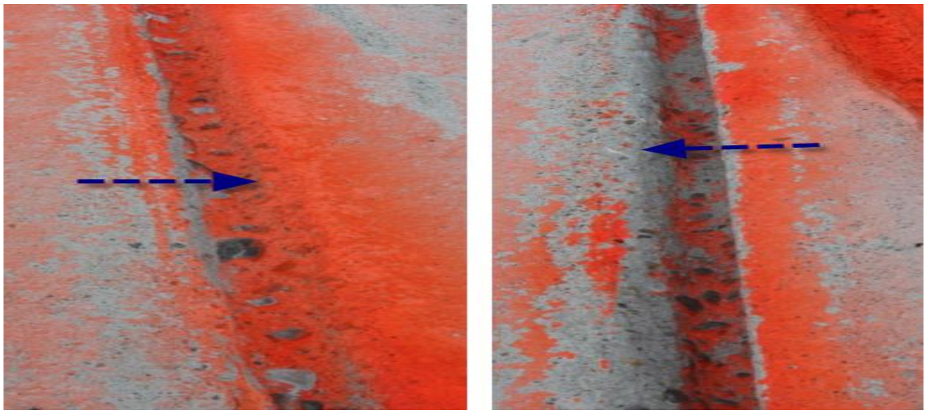


FIGURE 22: Crack wall prior to testing (left) and crack wall after testing (right).

3.3.2 Heat Generation

Warming cleaned pavement cracks is an essential step in the pavement sealing operation in cold weather climates. This is not done with the traditional method of air blasting. To warm the cracks in cold weather climates, a hot air lance is incorporated within the process. Commercial grade sealants require the material be at least 40°F for a proper bond (*6*). If the sealant is placed on too cold of a surface, the sealant will set up before it bonds to the pavement, and will likely deteriorate or simply fall out of the crack prematurely (*3*). For many of the same reasons, in both hot and cold climates the crack being sealed is cleaned with both an air shaft and heat lance, which not only warms the crack but also removes any remaining moisture.

In an effort to further improve the crack cleaning/sealing process, it was tested whether the friction created by metal wire strands of a rotating brush against pavement cracks would generate an adequate amount of heat to warm the crack to an acceptable level for receiving sealant directly. The test was conducted by measuring the temperature of the test bed before the crack cleaner was used on the crack being tested, and again after the crack cleaner was used for a specific number of passes. Each pass was completed at a constant rate of speed of 0.5 m/s for 3'-4" in length. Figure 23 shows the test bed before, during and after one pass. As can be seen from the infrared thermal images, there is a very minimal change in the temperature of the crack after one pass.

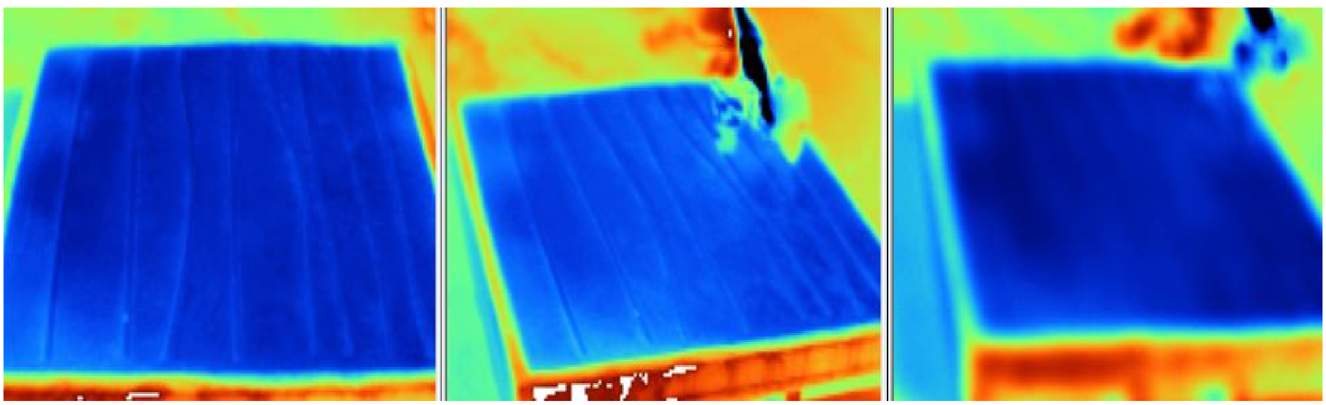


FIGURE 23: Thermal images of test bed before, during, and after one pass.

After four passes with the crack cleaner, the temperature of the test crack increased 2.1°F. This is illustrated in Figure 24. The wire brush itself has heated to nearly 100 °F after nearly four minutes. This is only slightly above the required degrees that pavement must be at before sealant can be applied. After forty seconds cleaning one crack, the temperature differential increased to 4.4°F (Figure 25). Although the device is capable of generating the adequate amount of heat through multiple passes, the test results proved that the use of wire brushing for the purpose of warming cracks is not a time-efficient process. This is because the cleaning speed is critical to the overall productivity of crack sealing process. These outcomes need to be further highlighted during cold weather periods early or late in the paving season when temperatures can be much lower.

Taking the results of this test into consideration along with the presence of pneumatic pressure, the research team considers the addition of a hot air lance as a simple retrofit to the cleaning device. This retrofit is currently outside of the project scope, but could be investigated during continued development stages.

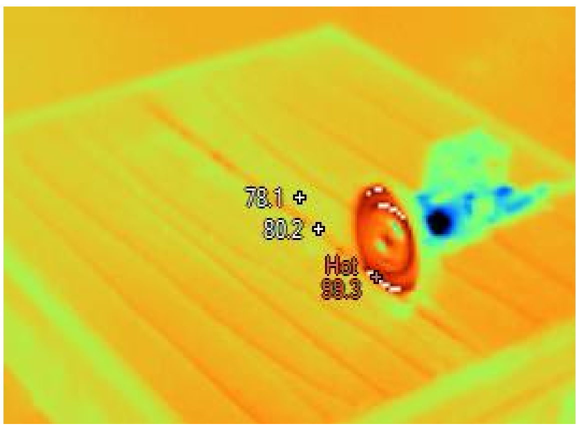


FIGURE 24: Thermography image after four passes.

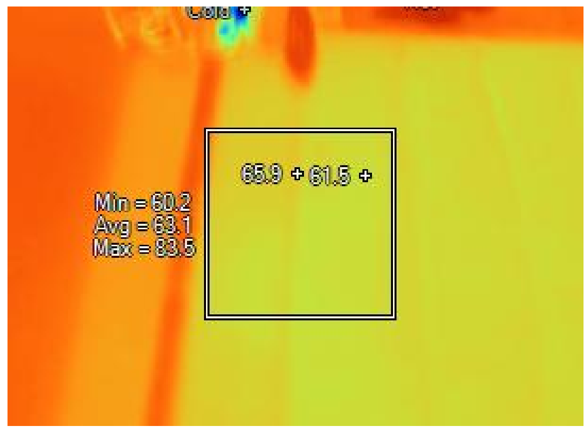


FIGURE 25: Thermography image after 40 seconds.

3.3.3 Cleaning Previously Sealed Cracks

Previously sealed cracks are often problematic for maintenance crews because they often require resealing in some places where the tar has either lost adhesion or cohesion. However, it is difficult to blow out the moisture and debris because the tar still covers the crack. Figure 26 shows the device's effectiveness in solving this problem. Although it was not significant, the device showed some of its faults in the process. While cleaning previously sealed cracks with the wire brush under a hot weather condition, the tacky sealant became lodged on the inside of the device's safety shield and on the individual wire strands of the brush. After trying several methods, a lubricant and cleaner such as "WD-40" was found to efficiently solve this problem when it was sprayed on the brush and inside of the shield before and after using the device.

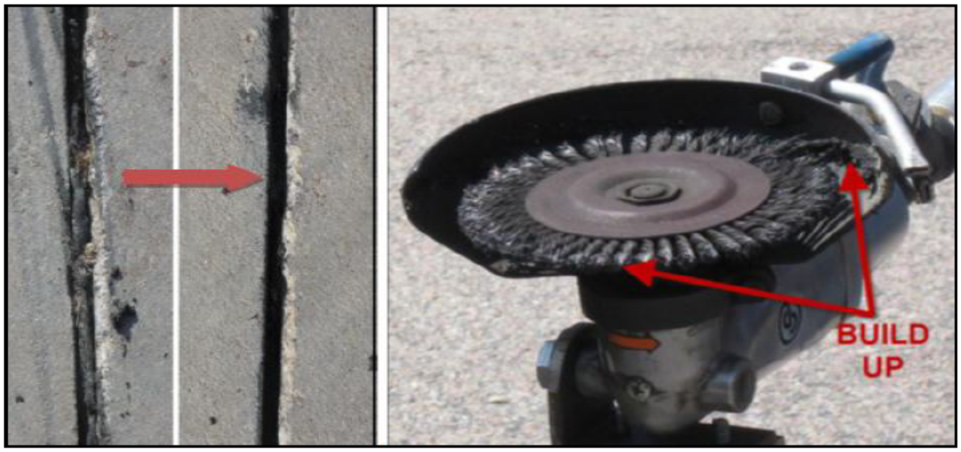


FIGURE 26: Effective preparation of previously sealed crack, with sealant reside buildup being shown on the device.

3.4 ECONOMIC ANALYSIS

The effectiveness of the device has been proven from a laboratory standpoint by testing for individual variables and through a number of industry field tests. The economic viability of the device is an essential component in regards to industry acceptance. In this study, the operating cost of the traditional crack cleaning method is directly compared with the proposed method as part of the crack cleaning device. The estimated results are similar in both the methods because the crack cleaner incorporates an additional level of abrasive cleaning in the same device beyond the traditional method of air blasting. This means that the same number of crew members is taking part in the pavement cleaning process and hence the labor costs are the same (Table 2).

On the other hand, if the crack cleaning device is compared to other abrasive crack cleaning methods like individual wire brushing and sand blasting, at least one less operator is needed to be part of the maintenance crew. Because production efficiency was not studied, hourly labor costs and equipment costs alone were compared. An abridged listing of maintenance crew labor costs is provided in Table 2.

TABLE 2: Labor Costs and Crew Makeup

Labor Costs for Crack Cleaning and Preparation	$/Hr *(7)*	Typical Crew#	Typical Abrasive Crew#	Proposed Crew#
Highway Crew Supervisor	21.48	1	1	1
Common Highway Laborer	10.30	1	2-3	1
Miscellaneous Highway Laborer (Opers. Compressor, Heat Lance, etc.)	13.28	1	2	1
Truck Driver (2 axle)	14.44	1	1	1

The cost of employing an additional crew member to perform traditional wire brushing is estimated as an extra $82.40/day, whereas an additional $188.64/day can be expected if two additional crew members are needed for sandblasting. With an expected price point as less than $1,000 for the crack cleaning device, the cost of the device will be paid off within a few days when compared against typical abrasive crack preparation methods. The financial impact is further highlighted in Table 3 which shows the first cost of typical crack cleaning equipment compared to the crack cleaning device.

TABLE 3: Crack Preparation Equipment Costs

Equipment Costs	
CRAFCO Crack Vac with Compressor	$60,000
CRAFCO Model 200 Router	$9,920
Heat Lance W/ 60’ Hose	$3,045
Wire Brusher 4HP (Billy Goat)	$875.00
Roughly estimated **Crack Cleaning Device** (wire brush/routing + air blast)	Under $1,000

4 PLANS FOR IMPLEMENTATION

The University of Nebraska is uniquely suited to guide this prototype through the various phases of research and towards industry acceptance. The investigators have been working with NDOR in both rigid and flexible pavement applications for several years. Our established partnership with NDOR, the City of Omaha, and local contractors will be invaluable in a number of ways. First of all, the projects partners’ input throughout the period of development ensured the outcome of this project is one of practicality. Secondly, the research team can further utilize a large assortment of test beds to analyze the effectiveness of each prototype. Thirdly, by directly partnering with NDOR, unquestionably the largest user of these types of products within the project’s target customer base, it is expected that the eventual statewide acceptance of product would be granted for use on highway applications. After the device is approved for state projects, it is anticipated that local contractors will also recognize the usefulness of owning this new cost effective piece of equipment as well as the indirect benefits it yields.

The roads maintenance group in the City of Omaha has shown their interest in adopting the device for crack and pothole cleaning and repair. Since a wire brush can be simply replaced with a router bit or a rotary masonry cutting blade, the device can rout cracks and cut a pothole area in conjunction with a jackhammer before placing a new patch. As previously described in Section 3.1.3, only crack cleaning was tested by the City of Omaha crews this spring and summer due to flooding problems in the area. The pothole repair tests will be conducted later this year to further prove the practicality and versatility of the device.

NUtech Ventures, a nonprofit corporation dedicated to linking companies, entrepreneurs and investors with the University of Nebraska-Lincoln researchers (who are driven to develop commercial products or services based on their pioneering research), is currently working with the research team in order to solidify a viable course of action for commercialization, which includes (1) establishing a start-up company at the Scott Technology Center, a small business incubator that partners directly with the University of Nebraska (Figure 27); or (2) licensing the technology to a road maintenance company such as CRAFCO Inc., Lab Manufacturing, Asphalt Sealcoating Direct, or others. CRAFCO has taken an interest in the device and agreed to act in an oversight capacity for further development.

Furthermore, the university's research facilities are fortunate enough to be located adjacent to the Scott Technology Center, a small business incubator that partners directly with the University of Nebraska. The Scott Technology Center seeks to aid in the development of innovative, technology based products or ideas hatched in academia by providing the infrastructure crucial in taking concepts to market. Benefits of the incubator include subsidized space, technology infrastructure, business development aids, and administrative support (8).

FIGURE 27: Scott small business incubator.

5 CONCLUSIONS

At the close of this research, the team involved has learned a number of lessons from the work conducted as a part of this project. Some of the major findings include:

- *Onboard pneumatic systems that typical pavement crews transport are viable power sources for operating a rotary wire brush/air blasting crack cleaning device.* Utilizing pneumatic power eliminates the need for expensive combustion engine tools and limits the amount of hazardous fuel that must be transported with the crew.
- *Field tests conducted by actual industry personnel provided a high level of practical insight and knowledge simply not considered in the laboratory.* On each site visit, the industry crews were very open and willing to test the device and provide their honest opinions of the device and how it could be improved. In addition, it is important to note the differences between maintenance crews and their location. Even in the same state, a wide range of different operating methods were observed and noted. Visiting a number of crews allowed for a complete perspective of how the device can be effectively tailored to reach its maximum potential in industry.
- *An ergonomic shaft design is very important to an operator.* After conducting a number of interviews and laboratory tests, a curved shaft or wand was ultimately selected for the device. This ergonomically curved shaft provides better control of the device in and out of cracks and less fatigue to the operator compared to a straight shaft.
- *Rotary powered wire brushing is an effective method at removing de-icing chemicals.* After several laboratory tests, it was determined that the crack cleaning device was very effective at removing debris stuck to the sides of pavement walls. Two passes, one forward and one backwards proved to be effective enough to remove 80% of simulated dried on chemicals according to a visual inspection.

- *Narrow faced twisted wire brushes were found to be most effective at crack preparation.* Throughout the device's development, a number of different types of brushes varying in size, material, bristle type and costs were tested. Ultimately, a ¼" twisted wire stainless rotary brush was found to be very economical and perform the best overall.
- *Pneumatically driven rotary wire brushing is effective at cleaning previously sealed pavement cracks.* Maintenance crews are often found crack sealing on roadways that have been sealed in the past. Often times, it is important to reseal a pavement crack. In order to ensure adequate bonding the old sealant must be removed if it shows weak bonding or is damaged. Based on the limited field tests on both the asphalt and concrete pavements, the crack cleaning device was found to easily remove previous sealant from cracks exhibiting premature failure. Further tests may be needed in the future with different types of sealant under different ambient temperatures to verify its effectiveness in general.
- *Creating adequate amount of frictional heat through a number of passes with the device is not a time-efficient process.* It is identified that the device is not time efficient to generate frictional heat to warm cracks because the cleaning speed is very critical to the overall productivity of crack sealing process. An addition of a hot air lance as a simple retrofit to the current cleaning device would be a more effective solution.

In summary, Figure 28 shows the versatility of functions provided by the developed device which can be readily applied to several pavement maintenance tasks. Utilizing the developed device for crack and joint preparation will undoubtedly lead to an increase in overall quality of pavement maintenance, thus increasing the useful life of pavements and reducing overall roads maintenance cost.

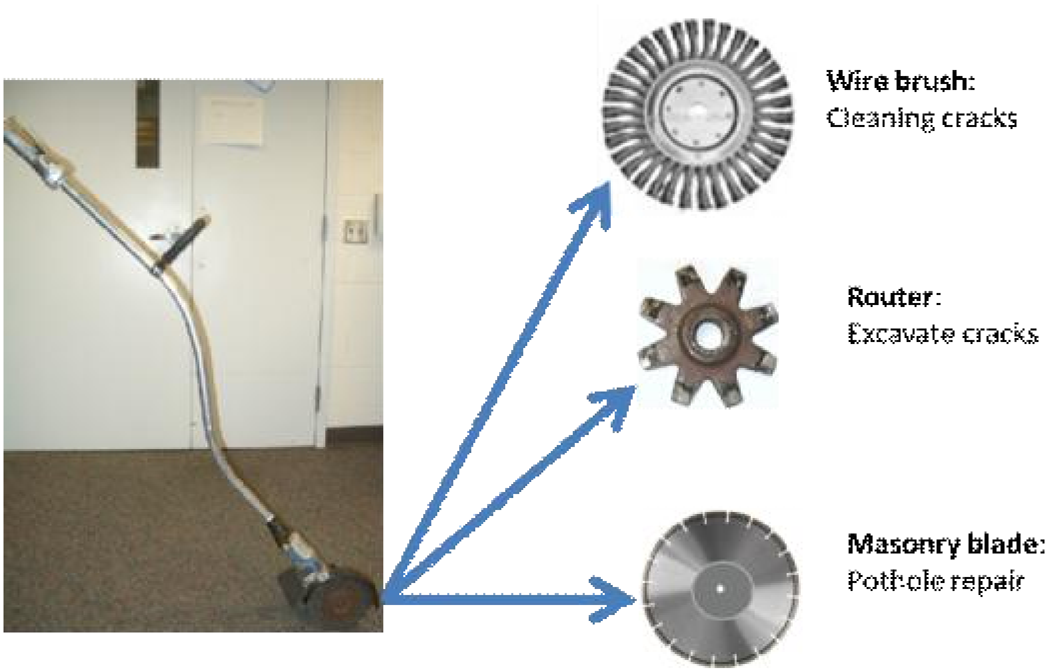


FIGURE 28: Versatile functions provided by a single pneumatic powered device developed in this project.

6 INVESTIGATOR PROFILE

The principal investigators are well-suited to successfully complete this project. Dr. Yong Cho's research is in the area of advanced technologies in automated construction and maintenance. His most recent research includes infrared camera-driven highway road construction quality control, an effectiveness study of non-nuclear gauges for hot mix asphalt pavement and soil, as well as research related to the topics of a tele-operated inspection system for hazardous environments, 3D laser-based rapid 3D workspace modeling for construction equipment, Building Information Modeling (BIM), and sustainability in construction. While pursuing his doctoral degree at the University of Texas at Austin, Dr. Cho worked on an Automated Road Maintenance Machine (ARMM) project funded by FHWA, Texas DOT, and CRAFCO Inc. for automated crack sealing. His major projects related to construction and maintenance are as follows:

Status	Funding Agency	Period	Title
Past	FHWA & Texas DOT	1998-1999	Automated Road Maintenance Machine (ARMM) For Crack Sealing
Past	Nebraska Department of Road (NDOR)	07/1/07-06/31/09	Infrared Thermography-driven Flaw Detection And Evaluation of Hot Mix Asphalt (HMA) Pavements
Current	NDOR	07/1/09-6/30/11	Non-nuclear Methods for Hot Mix Asphalt (HMA) And Soil Quality Assurance And Control
Current	NDOR	07/1/09-6/30/11	Effectiveness Study For Temporary Pavement Marking Removal
Current	NCHRP-IDEA	1/1/10-3/31/11	Cleaning mechanism To Remove Debris And Chemicals For Crack/joint Sealing (Type I)
Awarded	NSF	07/1/11-6/30/16	Rapid 3D Workspace Modeling For Automated Construction Equipment Operation

As Co-PI, Mr. John Bonsell is the director of the rapid manufacturing lab and a machine shop at the Peter Kiewit Institute (PKI). Mr. Bonsell is a certified manufacturing engineer. He is in charge of the facilities used for this research housed in the 192,000 sq. ft. PKI building on the Omaha campus of the University of Nebraska-Lincoln. Laboratory space and equipment for this project include a full range of modern machine tools including CNC mills and lathes, Coordinate Measuring Machines, Abrasive Water Jet Cutting, and Wire EDM. Secondary processes for fabrication are state-of-the-art welding machines and sheet metal equipment. Using 3D-CAD stations to perform the design, prototypes have been produced on one of two prototyping machines. An in-house heavy duty industrial vacuum system installed at PKI has been used for laboratory testing. An available infrared camera was used to measure the temperature of frictional heat generated by the device. A Selective Laser Sintering Machine (SLS 2000) or a color Z-Corp 450 produced models and even parts for the model. The facilities at PKI are well equipped to do what is required to produce a viable product ready for production if the market warrants it.

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