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Rapid Airfield Damage Recovery: Deployable Saw Technology Evaluation

Haley P. Bell and Jay Rowland

December 2017

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Abstract

This report presents a technical evaluation of selected saw technologies, tools, and methodologies for improving the efficiency of sawing around damaged pavement associated with crater repair. Previous evaluations of saw technologies identified the Caterpillar SW345B and SW360B wheel saw attachments as the best tools for cutting portland cement concrete for Rapid Airfield Damage Recovery (RADR). However, the next generation of RADR is focusing on lighter and leaner efforts, particularly in regards to equipment size. Selected saw technologies slightly larger and heavier were included in the evaluation in hopes that the saw-cutting rates increased significantly from those of the Caterpillar SW345B and SW360B wheel saw attachments. The evaluation results of all selected saw technologies were compared to the performance of the Caterpillar SW345B and SW360B wheel saws. Results indicate the wheel saw attachments tested are not lighter, leaner, or faster than the SW345B and SW360B wheel saw attachments. The results also showed that a diamond-blade saw attachment, when compared to a walk-behind diamond-blade saw currently utilized for ADR, is more ideal for concrete crater repairs.

Contents

Abstract ii

Figures and Tables iv

Preface vi

Unit Conversion Factors vii

1 Introduction 1

1.1 Background 1
1.2 Market research 3
1.3 Objective and scope 4

2 Test Section Description and Characterization 5

2.1 Test site preparation 5
2.2 Material characterization 6
2.3 PCC construction 9

3 Evaluated Technologies 14

3.1 Equipment 14
3.1.1 Caterpillar 279C XPS, 299D XHP, and 299D XPS compact track loaders 14
3.1.2 Caterpillar SW45, SW360B, and SW460B wheel saw attachments 16
3.1.3 Cuts, Inc. SS3600, SS3600HF, and SS4800HF diamond blade saw attachments ... 18
3.2 Cutting tools 19
3.2.1 Caterpillar prototype cutting tools (75148-1) 20
3.2.2 Kennametal cutting tools (RP15) 20
3.2.3 Diamond saw blades 21

4 Field Evaluation and Results 23

4.1 Field evaluation 23
4.2 Wheel saw evaluation results 24
4.2.1 Saw-cutting rates 24
4.2.2 Cutting teeth wear 27
4.3 Diamond-tipped saw blade evaluation results 30
4.3.1 Evaluation #1 30
4.3.2 Evaluation #2 35
4.4 Saw evaluation summary 37

5 Conclusions and Recommendations 40

5.1 Conclusions 40
5.2 Recommendations 41

References 42

Appendix A: PCC Mix Design 44

Report Documentation Page

Figures and Tables

Figures

Figure 1. Plan and profile views of test section. 5
Figure 2. Compacting crushed limestone base material. 6
Figure 3. DCP testing. 7
Figure 4. Measuring the density and moisture of the base layer using the nuclear density gauge. 7
Figure 5. Representative DCP result of base and subgrade materials. 9
Figure 6. Placing PCC in Lane 3. 11
Figure 7. Using a vibratory truss screed and placing PCC in Lane 3. 11
Figure 8. Finishing Lane 3 and placing and screeding PCC in Lane 1. 12
Figure 9. Applying curing compound to the PCC surface of Lane 3. 12
Figure 10. Placing and screeding PCC in Lane 2 using a pump truck. 13
Figure 11. Caterpillar 299D XHP CTL. 15
Figure 12. Caterpillar SW460B wheel saw attachment. 16
Figure 13. Caterpillar 279C CTL with SW45 wheel saw attachment. 17
Figure 14. Cuts, Inc. SS3600 diamond blade saw attachment. 18
Figure 15. Cuts, Inc. SS4800HF diamond blade saw attachment without the blade. 19
Figure 16. Prototype wheel saw tooth, Caterpillar 75148-1. 20
Figure 17. Wheel saw tooth, Kennametal RP15. 21
Figure 18. Diamond-tipped saw blade. 22
Figure 19. Caterpillar 299D XHP with SW460B wheel saw attachment. 25
Figure 20. One plunge cut with the Caterpillar wheel saw attachment. 26
Figure 21. Wheel saw teeth wear versus cutting distance in 18-in.-thick PCC. 27
Figure 22. Pavement saw-cutting process (Air Force Civil Engineer Center 2016). 28
Figure 23. Caterpillar 75148-1 prototype cutting bits before cutting and after 102 ft of cutting. 29
Figure 24. Inconsistent wear of Kennametal RP15 teeth on Caterpillar SW360B wheel saw. 29
Figure 25. SS3600 diamond blade attachment mounted on a Caterpillar 279C XPS CTL. 31
Figure 26. Sludge splattering the windshield of the Caterpillar 279C XPS CTL during cutting. 32
Figure 27. SS3600 diamond blade attachment with a 36-in.-diam blade on a Caterpillar 299D XPS CTL. 32
Figure 28. 42-in.-diam diamond-tipped saw blade. 34
Figure 29. Average saw-cutting rates for the diamond blade saw attachments. 35
Figure 30. SS4800HF diamond-tipped saw blade attachment. 36
Figure 31. Caterpillar 299D XPS with SS4800HF attachment. 37

Tables

Table 1. Nuclear density gauge results for crushed limestone base material. 8
Table 2. Average 28-day laboratory PCC data. 13
Table 3. Caterpillar CTL specifications. 15
Table 4. Caterpillar SW45, SW360B, and SW460B wheel saw specifications. 17
Table 5. Cuts, Inc. diamond blade saw attachment specifications. 19
Table 6. PCC saw-cutting test matrix. 24
Table 7. Wheel saw saw-cutting production rate results in 18-in.-thick PCC. 25
Table 8. Saw-cutting rates and teeth wear in 18-in.-thick PCC. 28
Table 9. Diamond-tipped saw blade attachment production results. 30

Preface

This study was conducted for the U.S. Air Force's Civil Engineer Modernization Program sponsored by Headquarters, Air Combat Command in Langley Air Force Base, VA. Headquarters, U.S. Air Force Civil Engineer Center (AFCEC) located in Tyndall Air Force Base, FL, provided funding for the research project described in this report, and Dr. Craig Rutland, AFCEC, provided guidance during the project.

The work was performed by the Airfields and Pavements Branch (APB) of the Engineering Systems and Materials Division (ESMD) with quality control testing provided by the U.S. Army Engineer Research and Development Center's (ERDC's) Materials Testing Center within the Geotechnical and Structures Laboratory (GSL). Mr. Jeb S. Tingle was the ERDC Airfield Damage Repair program manager. At the time of publication, Dr. Timothy W. Rushing was Chief, APB; Dr. G. William McMahon was Chief, ESMD; and Mr. Nicholas Boone was the Technical Director for Force Projection and Maneuver Support. The Deputy Director of ERDC-GSL was Dr. William P. Grogan, and the Director was Mr. Bartley P. Durst.

COL Bryan S. Green was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
gallons per minute	6.309019 E-05	cubic meters per second
inches	0.0254	meters
mils	0.0254	millimeters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
pounds (mass) per square yard	0.542492	kilograms per square meter
revolutions per minute	0.10471975	radians per second
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

1 Introduction

1.1 Background

The next generation of airfield damage repair (ADR) is focusing on lighter and leaner efforts for bomb-crater repairs. The Rapid Airfield Damage Recovery (RADR) Program was established to develop equipment, materials, and methods that addresses base recovery after an attack. RADR encompasses more than simply repairing the damaged pavement and includes seven general phases:

1. Identification of damage sustained to the airfield operating surfaces
2. Selection of minimum pavement surface areas required to support aircraft operations including the minimum operating strip (MOS) and minimum aircraft operating surface (MAOS)
3. Clearance of unexploded ordnance (UXO) from the MOS/MAOS
4. Repair of damaged pavement within the selected MOS/MAOS
5. Installation of aircraft arresting systems
6. Application of airfield markings and paint striping
7. Restoration of airfield lighting.

All seven phases must be completed within 8 hr after recovery has commenced. While each phase is critical to the safe launch and recovery of aircraft, the most time consuming phase is the repair of the damaged pavement within the MOS/MAOS (crater repair phase), particularly if the repair scenario requires the completion of a large number (up to 120) of small (8.5 by 8.5 ft) crater repairs. Regardless of the number of required repairs, the repairs must be completed within 3 (objective) to 6.5 hr (threshold) after an attack. The crater repair phase can be divided into eight general steps or tasks:

1. On-ground crater assessment
2. Initial debris removal
3. Material hauling
4. Upheaved pavement marking
5. Saw cutting
6. Excavating
7. Backfilling
8. Capping

After the on-ground crater assessment, each task is executed by separate teams, each of which should ideally take a similar amount of time for optimal efficiency and a continuous work flow. If one task requires a longer length of time, then the teams performing the subsequent tasks will be required to wait, thus slowing the entire ADR process. The research described in this report focuses on saw cutting, which is typically the most time-consuming task.

Research and development activities have evaluated a number of new equipment solutions to expedite the repair process including wheel saws for cutting upheaved pavement around a bomb crater. Results combined from previous demonstrations (Priddy et al. 2013a; Priddy et al. 2013b) and evaluations (Bell et al. 2015; Bell et al. 2014; Edwards et al. 2015; Bell et al. 2013; Edwards et al. 2013) were used to create the techniques, tactics, and procedures (TTPs) manual describing the processes and requirements of crater repair (Air Force Civil Engineer Center 2016).[1] The demonstration and evaluation results indicated that saw cutting around upheaved pavement is often the slowest task of crater repair. The TTPs specify the goal for completing cutting of pavement around a small crater using two wheel saws should be 22 min or less with a rate of 1 ft/min.

The previous evaluations of saw technologies identified the Caterpillar SW345B and SW360B wheel saw attachments as the best tools for cutting portland cement concrete (PCC) in ADR scenarios (Bell et al. 2015 and Edwards et al. 2015). The saws are easily attached to Caterpillar compact track loaders (CTLs), which are used extensively throughout the crater repair process. However, sawing through thick PCC using this method has still proven to be the slowest task in the ADR crater repair process. The Caterpillar wheel saws sometimes are not able to meet the TTP goal of cutting 1 ft/min in thick PCC. Larger rock saws have been evaluated; they improve the efficiency of saw cutting and provide increased cutting depths (Bell at al. 2015). However, the machines are more cumbersome, more expensive, logistically challenging, and are not multi-purpose machines.

Currently, the next generation of RADR is focusing on lighter and leaner efforts in terms of equipment size. The lighter and leaner efforts for saw cutting include a faster return to operation objective and equipment capable of being C-130 transportable. A need exists for a saw technology

[1] Air Force Civil Engineer Center. 2016. In preparation. Airfield Damage Repair (ADR) Tactics, Techniques, and Procedures (TTPs).

similar in size to the Caterpillar SW345B and SW360B wheel saws but with the cutting efficiency of the larger rock saws.

1.2 Market research

Several types of equipment were reviewed to identify lighter and leaner saw technologies. Many options were considered during the planning of this project such as attaching a wheel saw to a backhoe. Backhoes are generally readily accessible in theater and would be convenient to use for sawing upheaved concrete. However, it was learned that the wheel saw structure is not designed for the loads a backhoe loader can generate, especially with the larger wheel saws such as the Caterpillar SW360B.

The U.S. Army Engineer Research and Development Center (ERDC) inquired with Caterpillar about modifiying the SW345B wheel saw attachment and/or 279D XPS CTL. Caterpillar did not agree to modifying this equipment but did make suggestions to evaluate some of their new concrete cutting technologies – the 299D XHP CTL and the SW460B wheel saw attachment. The Caterpillar 299D XHP is the most powerful of Caterpillar's CTL fleet and has more horsepower and weight than the 279D XPS CTL currently used as the prime mover for saw-cutting pavements. The weight of the 299D XHP is approximately 1,700 lb more than the 279D XPS CTL. There are no design changes from the 279D to 299D CTL model that would improve performance. However, the 299D XHP version (versus the 299D XPS model) has a higher horsepower and hydraulic flow, which has the potential to increase the performance of a wheel saw. The SW460B wheel saw is the same size as the SW360B model wheel saw, which is currently used in the ADR concrete repair package.

A wheel saw's conical cutting bits play a large role in the speed and durability of saw cutting through PCC. Several brands, shapes, and sizes of wheel saw cutting teeth have been evaluated by ERDC. Market research did not reveal new commercially available cutting bits for use on wheel saws for this project. However, Caterpillar recently developed "extreme duty" prototype cutting bits that were included in the evaluation for comparison against the Kennametal RP15 cutting bits currently specified for ADR.

Market research was also conducted to find a diamond-tipped saw blade attachment for use on a CTL. The search discovered a company that has manufactured a prototype diamond saw blade attachment. The equipment was included in this evaluation and is discussed in detail in this report.

Other options considered for inclusion in this evaluation but not selected included mounting a wheel saw on an excavator and concrete laser cutting. Mounting a wheel saw on an excavator would be too large for crater repair purposes, and laser cutting equipment does not have the ability to cut through thick PCC required for projected ADR scenarios.

1.3 Objective and scope

The primary objective of this project was to identify and evaluate new saw technologies and/or modify existing saw technologies (e.g., prime movers or saw attachments) and compare them to the current ADR wheel saw attachments (Caterpillar SW345B and SW360B). The evaluation included determining each selected technology's cutting rates in thick PCC, measuring the durability of the cutting mechanisms, and determining the logistical characteristics of the alternative saw technologies. These findings helped to determine which equipment is the most efficient, durable, lightest, leanest, and easiest to maneuver when cutting airfield pavement in ADR scenarios.

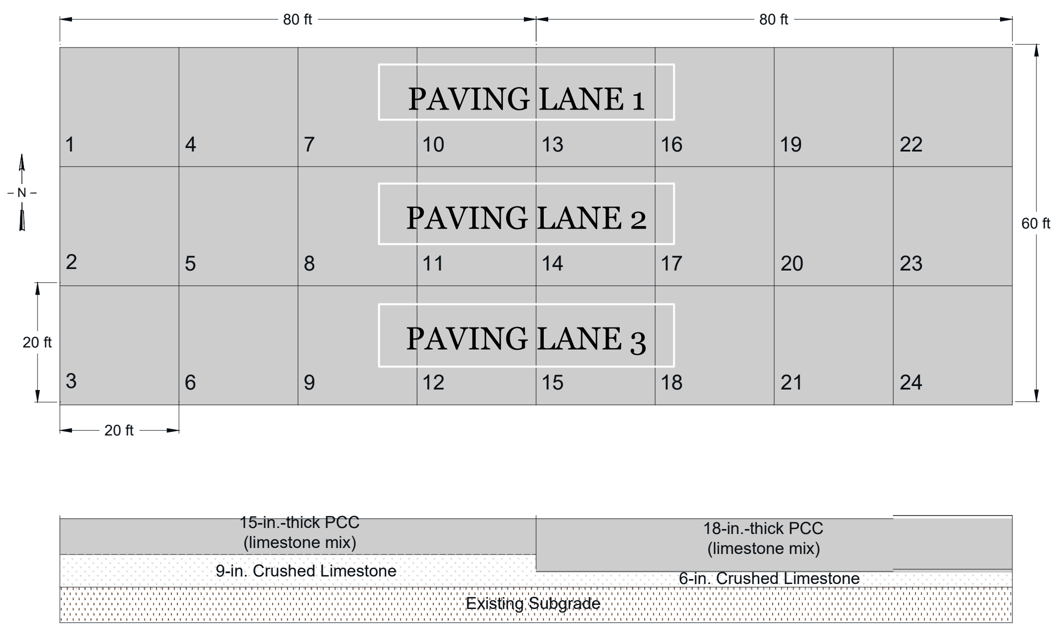
This report provides information for the following:

1. Description of test site
2. Description of evaluated equipment
3. Testing matrix and field evaluation results

2 Test Section Description and Characterization

A full-scale test section was constructed on in March 2016 and consisted of 15- and 18-in.-thick airfield designed PCC pavement to provide a testing area for evaluating a variety of concrete sawing equipment for crater repairs. Lanes 1 and 3 were constructed on one day, while Lane 2 was constructed seven days later. The test section was located on a pavement test area at ERDC's Vicksburg facility. The plan and profile views of the test section are shown in Figure 1. The slabs were numbered to identify the slab locations used for the various saw tests.

Figure 1. Plan and profile views of test section.



2.1 Test site preparation

The existing subgrade, classified by the Unified Soil Classification System as a brown clay (CL), was graded prior to construction with a 0.4 percent cross-slope to allow for drainage. The base layer was placed over the subgrade and consisted of 6 in. of compacted #610 crushed limestone (ASTM C33/C33M-16) (ASTM International 2016a) under the 18-in.-thick PCC or 9 in. of compacted #610 crushed limestone (ASTM C33/C33M-16) under the 15-in.-thick PCC. The crushed limestone was compacted to a target of 95 percent modified Proctor maximum density. A Caterpillar CP-563 vibratory smooth drum roller was used for compaction (Figure 2).

Figure 2. Compacting crushed limestone base material.

2.2 Material characterization

The limestone base layer material was characterized during construction using the Troxler nuclear density gauge (ASTM D6938) (ASTM International 2017) and the dynamic cone penetrometer (DCP) (ASTM D6951) (ASTM International 2015). DCP testing is shown in Figure 3. Figure 4 shows the nuclear density gauge being used on the base material on the southeastern portion of the test section. DCP and nuclear density measurements were taken directly before each concrete placement.

Survey data of each pavement layer were collected every 1 ft along the length of the test section in the center of each of the three paving lanes (at 10, 30, and 50 ft along the width of the section) to ensure the desired layer thicknesses were achieved. Cross-section survey data were also collected every 1 ft along the width of the test section (at 20, 60, 100, and 140 ft along the length of the test section).

Figure 3. DCP testing.

Figure 4. Measuring the density and moisture of the base layer using the nuclear density gauge.

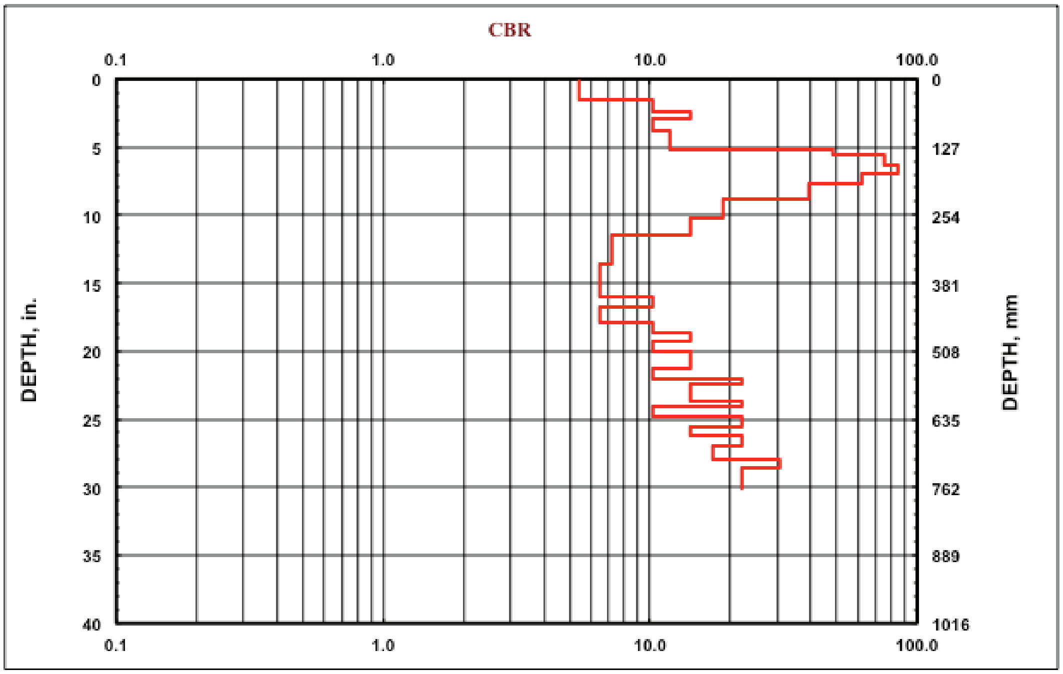
Table 1 presents the results of the nuclear density gauge tests on the limestone base. The base was tested with the nuclear density gauge at 12 different test points for a total of 24 tests. The gauge was turned 90 deg at each test location for a second measurement at the same test point. Test results for the crushed limestone showed an average dry density of 132.0 lb/ft^3 and an average moisture content of 7.0 percent.

Table 1. Nuclear density gauge results for crushed limestone base material.

Limestone Area	Test Number	Wet Density (pcf)	Moisture (pcf)	Dry Density (pcf)	Moisture (%)
Lane 1 15 in. PCC	1	143.3	8.1	135.2	6.0
		139.1	8.0	131.1	6.1
	2	137.8	7.4	130.4	5.7
		137.7	7.6	130.1	5.8
Lane 1 18 in. PCC	3	139.2	8.3	130.9	6.4
		141.6	9.0	132.6	6.8
	4	144.7	9.2	135.5	6.8
		142.0	8.1	133.9	6.0
Lane 2 15 in. PCC	5	144.3	17.7	126.6	14.0
		143.4	12.1	131.3	9.2
	6	131.6	9.6	122.0	7.9
		137.0	10.0	127.0	7.9
Lane 2 18 in. PCC	7	144.9	10.1	134.9	7.5
		144.7	9.3	135.4	6.9
	8	147.2	7.5	139.8	5.4
		145.5	8.1	137.4	5.9
Lane 3 15 in. PCC	9	142.1	6.3	135.8	4.7
		143.6	6.9	136.6	5.1
	10	145.1	8.6	136.4	6.3
		135.6	8.7	126.9	6.9
Lane 3 18 in. PCC	11	137.7	11.5	126.2	9.1
		133.8	10.8	122.9	8.8
	12	144.1	8.6	135.4	6.4
		143.5	9.4	134.1	7.0

The DCP was used to estimate the strength of the subgrade layer by testing from the top of the compacted crushed limestone base material into approximately 20 in. of the existing subgrade. The average CBR of the silty subgrade material was 15. Figure 5 presents a DCP test result showing the variable strength of the crushed limestone base layer (first 6 in.) and the strength of the silty subgrade.

Figure 5. Representative DCP result of base and subgrade materials.



The DCP was not able to accurately estimate the strength of the limestone base layer due to lack of confinement at the top of the testing layer. For a coarse-grained material such as the limestone base used in the test section, Webster et al. (1994) determined that a 5-in.-minimum penetration depth was required before the actual strength of the surface soil layer could be determined with the DCP. Thus, the DCP could not be used to accurately estimate the base's strength because the material was only 6 and 9 in. thick. The CBR of the crushed limestone material was assumed to be between 80 and 100 based on the dry density results from the nuclear density gauge on the material and previous experiences of the authors with this material.

2.3 PCC construction

The PCC pavement was constructed, on two different days during March 2016, of concrete designed to meet minimum flexural strength requirements for airfield PCC of 650 psi or 5,000 psi unconfined compressive strength (UCS). Twelve slabs were 15 in. thick, and the same number of slabs were 18 in. thick; each slab was 20 by 20 ft. The slab dimensions were in accordance with Department of Defense (DoD) maximum joint spacing specifications prescribed in UFC 3-260-02 for PCC airfield pavements greater than 12 in. thick (Headquarters, Army, Navy, Air Force 2001).

The PCC mixture was produced using a local PCC mix design capable of achieving a minimum 5,000 psi UCS after 28 days of cure that utilized limestone as the coarse aggregate. The concrete surface was constructed in a fixed-form placement and placed on grade. During placement, the concrete was consolidated with spud vibrators and struck off using a vibratory truss screed.

The PCC section was completed with a light broom finish, coated with an acrylic curing and sealing compound meeting ASTM C309-11 (ASTM International 2011) specifications, and then saw cut to provide transverse and longitudinal joints. The 15- and 18-in.-thick sections were saw cut to a depth of 3 in. after the PCC was finished. Figure 6 through Figure 10 show the PCC construction process.

A maximum slump of 7 ± 1 in. for the delivered PCC was specified to allow the PCC to be pumped. The fresh PCC temperature and air content were also recorded. The average slump for Lanes 1, 2, and 3 were 8, 7.5, and 8 in., respectively. The fresh PCC mixture temperatures for Lanes 1 and 3 averaged 66^{o}F, and the mixture temperature of Lane 2 averaged 67^{o} F. The air temperatures during the PCC placement of Lanes 1 and 3 started at about 47^{o} F and increased to 70^{o} F by the end of the pour. The air temperature during the PCC placement of Lane 2 ranged from 54 to 69^{o} F. The average air content of the PCC for all lanes was 5.2 percent.

Figure 6. Placing PCC in Lane 3.

Figure 7. Using a vibratory truss screed and placing PCC in Lane 3.

Figure 8. Finishing Lane 3 and placing and screeding PCC in Lane 1.

Figure 9. Applying curing compound to the PCC surface of Lane 3.

Figure 10. Placing and screeding PCC in Lane 2 using a pump truck.

During each placement, test specimens were prepared in accordance with ASTM C39/C39M (ASTM International 2016b) for compressive cylinders and ASTM C78/C78M (ASTM International 2016c) for flexural beams. Two sets of three beam specimens and three cylinder specimens were extracted from each paved lane for a total of 18 cylinders and 18 beams.

Laboratory test results for the cast specimens are shown in Table 2. The strengths of the PCC exceed the 5,000 psi UCS and 650 psi flexural strength requirements generally specified for PCC airfield pavements.

Table 2. Average 28-day laboratory PCC data.

PCC Area	28-day UCS (psi)	28-day Flex Strength (psi)
Lane 1	8,560	880
Lane 2	8,900	940
Lane 3	8,530	880

3 Evaluated Technologies

Various models of CTLs and types and sizes of cutting tool combinations were assessed to determine whether the saw-cutting rate in 15- and 18-in.-thick PCC could be increased to reduce the time to repair craters. Saw cutting for crater repairs is generally the slowest task in the process. Wheel saw and diamond blade CTL attachments were also evaluated. All equipment and cutting tools used in this test effort are described in this chapter.

3.1 Equipment

3.1.1 Caterpillar 279C XPS, 299D XHP, and 299D XPS compact track loaders

Compact track loaders (CTL), or skid steers, are high-flow, rubber-tracked machines with quick disconnect fittings that are used for numerous tasks in the current ADR crater repair TTPs (Figure 11). The quick disconnect feature allows attachments to be rapidly switched without the use of tools. These multi-purpose machines are employed for many of the ADR processes, including rapidly cutting around the upheaval of bomb-damaged pavement (repair area boundaries) with wheel saw attachments, breaking pavement with the hammer attachment, removing debris with bucket attachments, screeding pelletized asphalt repair caps with the asphalt screed attachment, and clearing of dust and debris with the broom attachment.

The Caterpillar 279C CTL is no longer manufactured and has been replaced with the 279D model. However, the 279C XPS model was used in this research because the machine is currently employed in the ADR crater repair kits that are deployed to various airfields around the world. The 279C XPS CTL was used as the control for this test. The Caterpillar 299D XHP and 299D XPS are larger than the 279C and 279D; however, they were included in the evaluation for their potential to increase the saw cutting rates in thick concrete because of their higher power and hydraulic flow. Specifications for the machines are shown in Table 3.

Figure 11. Caterpillar 299D XHP CTL.

Table 3. Caterpillar CTL specifications.

Parameter specifications	279C XPS	299D XHP	299D XPS
Length (in.)	116.4	123.5	125.5
Height (in.)	82.8	83.7	83.6
Width (in.)	78	78	78
Net power (hp)	82	106	95
Operating weight (lb)	9,892	11,612	11,275
Rated operating capacity at 50% tipping load (lb)	3,200	4,650	4,600
Travel speed (mph)	5.0	5.2	5.2
Tipping load (lb)	6,483	9,300	9,200
Breakout force, tilt cylinder (lb)	7,308	7,552	7,270
Maximum loader hydraulic pressure[1] (psi)	4,061	4,061	4,061
Maximum loader hydraulic flow[1] (gal/min)	32	40	32
[1]for high-flow models			

3.1.2 Caterpillar SW45, SW360B, and SW460B wheel saw attachments

The Caterpillar CTLs are equipped to operate the Caterpillar SW45, SW360B, or SW460B (Figure 12) wheel saw attachments. These wheel saw attachments have 3-in.-wide blades that produce approximately 3.5-in.-wide cuts. The SW360B and SW460B models also have blade width options of 6 and 8 in., but the cuts are too wide for the purposes of the ADR program. The SW45, which Caterpillar has replaced with a SW345B model, has an 18-in.-maximum depth cut, while the SW360B and SW460B can produce 24-in.-maximum depth cuts. Figure 13 shows a CTL with the wheel saw attached before cutting. Specifications for the SW45, SW360B, and SW460B machines are shown in Table 4.

Figure 12. Caterpillar SW460B wheel saw attachment.

Figure 13. Caterpillar 279C CTL with SW45 wheel saw attachment.

Table 4. Caterpillar SW45, SW360B, and SW460B wheel saw specifications.

Parameter Specifications	SW45	SW360B	SW460B
Overall width (in.)	71	73	73
Overall height (in.)	57	70	70
Length (in.)	78	93	93
Weight (lb)	2,295	3,009	3,009
Wheel width without teeth (in.)	3	3	3
Hydraulic flow requirement (gal/min)	24 - 42	33	40
Optimal hydraulic pressure range (psi)	2,611 - 4,351	4,000	4,000
Wheel torque at maximum pressure (ft-lb)	4,944	5,538	5,538
Wheel speed at maximum flow (rpm)	115	74	89
Number of teeth per wheel	64	70	70
Maximum depth of cut (in.)	18	24	24
Sideshift travel (in.)	26	22	22

3.1.3 Cuts, Inc. SS3600, SS3600HF, and SS4800HF diamond blade saw attachments

Cuts, Inc. developed two prototype diamond blade saw attachments (SS3600 and SS3600HF) that are compatible with the Caterpillar CTLs. Figure 14 shows the SS3600 attached to a CTL. For this evaluation, 36-, 42-, and 48-in.-diam diamond-tipped blades were used on the attachments. The diamond-tipped skid steer attachments require the use of an external water source to keep the blade from becoming overheated during operation.

Figure 14. Cuts, Inc. SS3600 diamond blade saw attachment.

After the initial testing with the SS3600 and SS3600HF attachments, Cuts, Inc. made some modifications and returned for further testing with the SS4800HF prototype unit. Some of the modifications included a larger, more powerful hydraulic motor, a redesign of the blade shaft, the relocation of the saw blade housing, and the addition of four wheels on the bottom of the unit. The wheels can be lifted and not used if necessary. Table 5 presents the specifications of the diamond blade attachments as measured in the field. The dimensions in the table are as if the blade is installed on the machine. The length and height dimensions are different when the blade is not on the machine, because the top half of the blade housing can be lifted for storage as shown with the SS4800HF in Figure 15.

Table 5. Cuts, Inc. diamond blade saw attachment specifications.

Parameter Specifications	SS3600	SS3600HF	SS4800HF
Length (in.)	66	66	66
Height (in.)	53.75	53.75	52
Width (in.)	51	51	50.25
Weight, without blade (lb)	850	850	980

Figure 15. Cuts, Inc. SS4800HF diamond blade saw attachment without the blade.

3.2 Cutting tools

Conical tools are used on the wheel saw attachments for cutting into the pavement. Various teeth are available for varying needs and jobs. Most teeth are made of steel with carbide tips. The carbide may be produced as a seat tip or an insert tip. Replacing teeth is necessary when the carbide bits become worn, particularly after cutting through PCC. A punch tool is used with a mallet and/or puller to remove the teeth, and the teeth are tapped into place with the mallet. Another option for installing teeth is to use an air hammer.

Thin diamond-tipped circular saw blades are used on the Cuts, Inc. saw attachments. Diamond-tipped saw blades come in various sizes and grades of diamonds and are used for sawing clean cuts in hard materials such as concrete or metal. A diamond-tipped saw blade is installed by raising the blade guard and inserting the blade onto the inner flange and securing the blade using an outer flange pin (arbor) and a bolt and tightening with a torque wrench. The following sections describe the cutting tools that were used in this evaluation.

3.2.1 Caterpillar prototype cutting tools (75148-1)

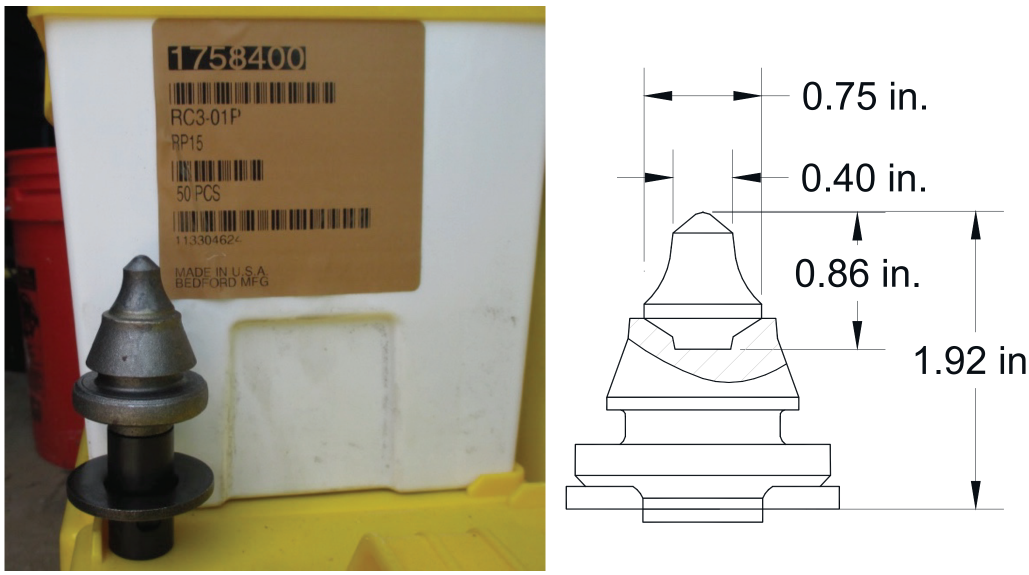
The Caterpillar 75148-1 prototype cutting tools (Figure 16) were designed for cutting concrete. The teeth are made of carbide tungsten and forged steel and consist of a 0.63-in.-diam carbide insert. The shank diameter is 0.78 in. The shank is the cylindrical shaft that is housed inside the wheel saw shoe.

Figure 16. Prototype wheel saw tooth, Caterpillar 75148-1.

3.2.2 Kennametal cutting tools (RP15)

The Kennametal RP15 teeth have a 0.76-in.-diam shank. The cutting tools are made of forged steel with tungsten carbide tips. They are equivalent to the Kennametal SM04 teeth and Sandvik F286 teeth except that the RP15 teeth have a smaller shank diameter. Common applications for these cutting tools on medium- to high-horsepower machines include hard to medium asphalt and concrete conditions. Figure 17 shows a diagram and a picture of the RP15 tooth.

Figure 17. Wheel saw tooth, Kennametal RP15.



3.2.3 Diamond saw blades

Diamond-tipped saw blades are made with a steel core (Figure 18). The diamond segments, which are welded to the core, are what is used to cut through the concrete. The depth of the diamond segments in this study were approximately 0.5 in. The blades are typically ¼ in. wide or less and can vary in diameter. For this study, the blades were about 3/16 in. wide and 36, 42, and 48 in. in diameter.

Figure 18. Diamond-tipped saw blade.

4 Field Evaluation and Results

4.1 Field evaluation

The crater repair saw technologies were evaluated from May to September 2016. Various tests were conducted on the PCC test section including the evaluation of teeth wear on each wheel saw, the evaluation of diamond wear on each diamond-tipped saw blade, and saw-cutting rates. The variables were tested by recording the time required to make a cut approximately 10 ft long inside a slab or measuring the saw blade wear or teeth wear using calipers.

All cutting events were timed to the second. Each technology was tested multiple times to obtain average results. The operators varied from inexperienced to highly trained for most equipment. In the current ADR TTPs, the goal for the saw-cutting rate is 1 ft/min (Air Force Civil Engineer Center 2016).

The saw and CTL combinations did not meet the lighter and leaner concept desired for this project as far as size is concerned. Since the equipment did not meet the size requirements, it was important for these technologies to cut as efficiently as possible, increasing the saw-cutting rates by at least 25 percent of the average saw-cutting rates of the current saw inventory for small crater repairs. The size limitations may possibly be waived in favor of a minimum 25 percent increase in cutting rates. The current average saw-cutting rate with Caterpilliar wheel saw attachments in 18 in. of limetone-mix PCC is approximately 0.80 ft/min (Bell et al. 2015). Diamond-blade saw testing at ERDC has not been as extensive as the wheel saw testing; however, the average saw-cutting rates with the FS 6600 D in 16 to 18 in. of limestone-mix PCC is approximately 0.65 ft/min during one set of tests (Edwards et al. 2013) and 1.59 ft/min during a second set of tests (Bell et al. 2014).

Six saws - the Caterpillar SW45 wheel saw attachment, the Caterpillar SW360B wheel saw attachment, the Caterpillar SW460B wheel saw attachment, the Cuts Inc. SS3600 diamond saw blade attachment, the Cuts, Inc. SS3600HF diamond saw blade attachment, and the Cuts, Inc. SS4800HF diamond saw blade attachment - were evaluated for their efficiency of cutting through thick concrete. Two types of teeth - the Caterpillar 75148-1 (prototype) and the Kennametal RP15 - were tested on the wheel saw attachments. The teeth were replaced after each test set. Three sizes of diamond blades – 36-in.-diam and 0.187 in. wide, 48-in.-diam and 0.174 in. wide, 42-in.-diam and 0.250 in. wide, 48-in.-diam and 0.220 in. wide, and 42-in.-diame and 0.200 in. wide – were alternated on the diamond blade saw attachments. Table 6 identifies the saw-cutting matrix used for the equipment assessments in the 15- and 18-in.-thick PCC.

Table 6. PCC saw-cutting test matrix.

Test No.	Crater No.	PCC Thickness (in.)	Saw Attachment	CTL Model	Saw Teeth	Saw Blade diam (in.), width (in.)
1	20	18	CAT SW460B	CAT 299D XHP	Kenn RP15	____
2	20	18	CAT SW460B	CAT 299D XHP	CAT 75148-1	____
	21	18				
3	20	18	CAT SW45	CAT 279C XPS	Kenn RP15	____
4	6	15	Cuts SS3600	279C XPS	____	36, 0.187
5	6	15	Cuts SS3600	CAT 299D XPS	____	36, 0.187
6	21	18	Cuts SS3600HF	CAT 299D XPS	____	48, 0.174
7	21	18	Cuts SS3600HF	CAT 279C XPS	____	42, 0.200
8	21	18	Cuts SS3600HF	CAT 279C XPS	____	42, 0.250
9	21	18	CAT SW360B	CAT 299D XHP	Kenn RP15	____
10	24	18	CAT SW360B	CAT 299D XHP	Kenn RP15	____
11	21	18	Cuts SS4800HF	CAT 299D XPS	____	48, 0.220
	23	18				
12	23	18	Cuts SS4800HF	CAT 299D XPS	____	42, 0.200

4.2 Wheel saw evaluation results

Each test consisted of seven to nine cuts that were each approximately 10 to 14 ft long. The cuts were timed, and the length and depth of each cut were recorded. The lengths of 10 cutting bits (teeth) were measured using calipers before cutting began, and the same 10 teeth were measured after various cuts in the PCC. Figure 19 shows the Caterpillar 299D XHP and SW460B cutting through the PCC.

4.2.1 Saw-cutting rates

The results of the saw-cutting evaluation in the 18-in.-thick PCC are presented in Table 7. The results include the average initial plunge times and overall cutting rates for each combination of technologies selected for testing. The Kennametal RP15 cutting bits were used for this evaluation, because they have proven, in recent evaluations, to be the most durable and efficient cutting tools to use in thick PCC (Edwards et al. 2015; Bell et al. 2015). Caterpillar also requested that the prototype concrete-cutting bits, part number 75148-1, be tested. They were evaluated on the SW460B attached to the 299D XHP.

Figure 19. Caterpillar 299D XHP with SW460B wheel saw attachment.

Table 7. Wheel saw saw-cutting production rate results in 18-in.-thick PCC.

Test No.	Machine	Saw	Cutting Teeth	No. of Cuts	Plunge Time (min)			Cut Rate (ft/min)		
					Min	Max	Avg.	Min	Max	Avg.
9	CAT 299D XHP	CAT SW360B	Kenn RP15	8	3	6	4.6	0.84	1.17	1.02
10	CAT 299D XHP[1]	CAT SW360B	Kenn RP15	9	3	6	4.2	0.82	1.23	0.96
1	CAT 299D XHP	CAT SW460B	Kenn RP15	7	4	10	6.7	0.44	0.86	0.67
2	CAT 299D XHP	CAT SW460B	CAT 75148-1	8	6	10	7.4	0.53	0.79	0.70
3	CAT 279C XPS	CAT SW45	Kenn RP15	8	3	5	4.1	0.53	0.86	0.72

[1]Plunge only cutting

Two tests, Tests 9 and 10, were completed using the Caterpillar 299D XHP equipped with the SW360B and Kennametal RP15 teeth. Test 9 was conducted in the traditional manner - plunge full depth through the PCC, and then cut forward. Test 10 was completed using only plunge cuts; each of these cuts in this test consisted of three or four plunge cuts before the 10-ft-long cuts were complete. The two methods of cutting had essentially the same cutting rates, 1.02 versus 0.96 ft/min. The Caterpillar 299D XHP equipped with the SW360B and Kennametal RP15 teeth was able to meet the 1 ft/min saw-cutting rate goal. The downside of the plunge only cuts was that humps of PCC would sometimes remain in the cut line. This was due to the saw's circular shape (Figure 20) and the saw sitting back as it plunges through the PCC. It is difficult for the saw spotter or operator to line up the saw properly so that there is the correct amount of overlap between the plunge cuts. Too much overlap will result in a longer cut time. Too little overlap will result in humps of PCC remaining inside the cut.

Figure 20. One plunge cut with the Caterpillar wheel saw attachment.

The saw-cutting rates of the Kennametal RP15 and Caterpillar 75148-1 teeth on the SW460B wheel saw, Tests 1 and 2, were essentially the same; however, they were not able to meet the goal of 1 ft/min. Both tests were completed using the same operator. The SW360B wheel saw cut approximately 1.5 times faster than the SW460B wheel saw.

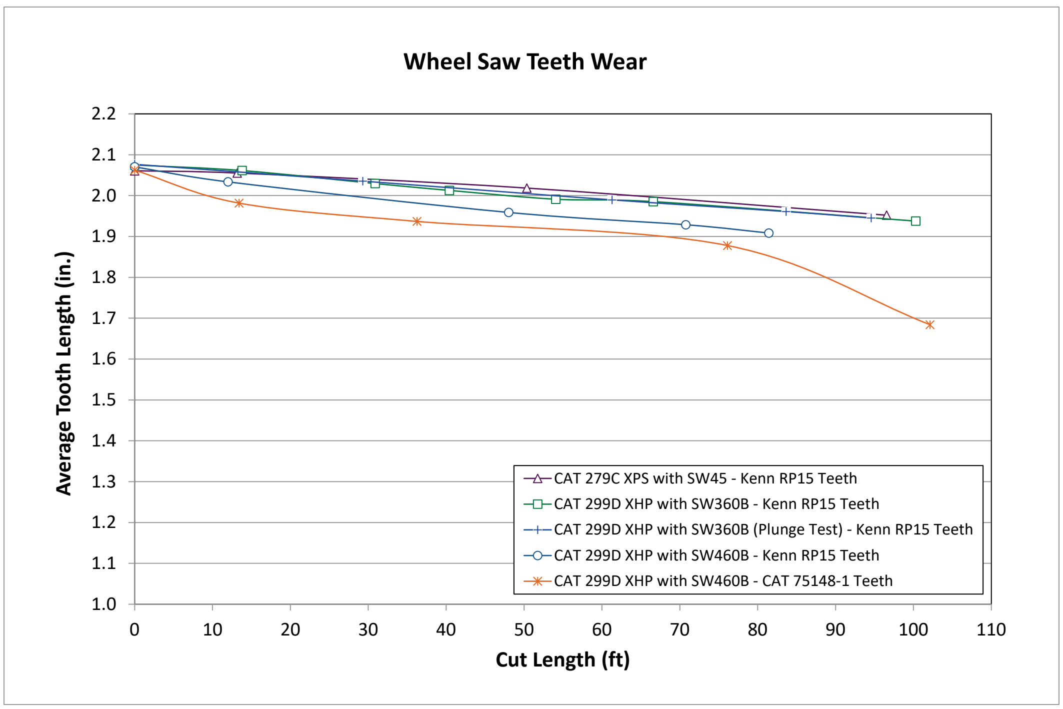
The Caterpillar 279C XPS with the SW45 wheel saw and Kennametal RP15 teeth (Test 3) was evaluated in this test section to use as the basis of comparison. The Caterpillar SW45 wheel saw attached to the 279C XPS CTL are the current technologies deployed for saw cutting in crater repair scenarios. The average saw-cutting rates were consistent with the results obtained from the 2014 saw-cutting evaluation (0.83 ft/min) in similar PCC.

4.2.2 Cutting teeth wear

Even though saw-cutting rates are a primary concern, teeth wear is also a concern for measuring the durability and efficiency of cutting. Replacing the teeth on a wheel saw can take approximately 20 min with two people. This decreases productivity and can cause the operator to lose momentum. Therefore, it is desirable that crater repairs in theater be completed without having to replace teeth during the repair process.

Figure 21 shows the teeth wear of the five tests conducted for the wheel saw evaluation. The plot shows that the Kennametal RP15 teeth on the SW360B and SW45 wheel saw attachments deteriorate at essentially the same rate. The Kennametal RP15 and Caterpillar 75148-1 teeth on the SW460B wheel saw attachment deteriorate at a faster rate, particularly with the Caterpillar 75148-1 teeth. The Kennametal RP15 teeth on the SW360B wheel saw attachments deteriorated at the essentially the same rate when the cut method was plunge cuts only or plunge, then cut forward.

Figure 21. Wheel saw teeth wear versus cutting distance in 18-in.-thick PCC.



Currently, for a typical small crater repair scenario, four wheel saws are required to saw cut around the upheaval of 18 craters approximately 8.5 by 8.5 ft as shown in Figure 22. Each wheel saw is needed to cut a total of approximately 170 ft. Table 8 presents a summary of the average saw-cutting rates and approximate extrapolated cutting lengths for teeth at 30 percent wear. The 30 percent teeth wear metric was determined in the past to be the maximum amount of wear a set of cutting teeth should have to be efficient and effective at PCC saw cutting for crater repair scenarios.

Figure 22. Pavement saw-cutting process (Air Force Civil Engineer Center 2016).

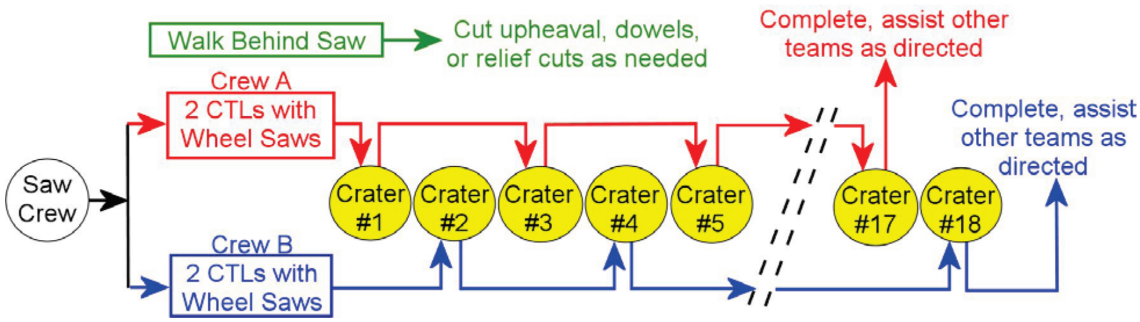


Table 8. Saw-cutting rates and teeth wear in 18-in.-thick PCC.

Test No.	Prime Mover Machine	Wheel Saw	Cutting Teeth	Avg. Saw-Cutting Rate (ft/min)	Estimated Saw-Cutting Distance At 30% Teeth Wear (ft)
9	CAT 299D XHP	CAT SW360B	Kenn RP15	1.02	515
10	CAT 299D XHP[1]	CAT SW360B	Kenn RP15	0.96	515
1	CAT 299D XHP	CAT SW460B	Kenn RP15	0.67	255
2	CAT 299D XHP	CAT SW460B	CAT 75148-1	0.70	170
3	CAT 279C XPS	CAT SW45	Kenn RP15	0.72	520

[1]Plunge only cutting

The prototype Caterpillar 75148-1 teeth were tested on the Caterpillar SW460B with the 299D XHP skid steer. When comparing the Caterpillar teeth to the Kennametal teeth used on the same equipment duo, the rates were the same; however, the teeth wear was not. The Kennametal RP15 teeth could likely handle 1.5 times more linear feet of cutting before reaching 30 percent of wear on the cutting teeth. Figure 23 shows the Caterpillar 75148-1 prototype cutting bits before cutting and after cutting 102 ft of 18-in.-thick PCC. The teeth were worn approximately 18 percent after 102 ft of cutting.

Figure 23. Caterpillar 75148-1 prototype cutting bits before cutting and after 102 ft of cutting.

Table 8 also shows that the Caterpillar SW460B wheel saw would barely be able to efficiently complete the required 340 ft of linear saw cutting in 18-in.-thick limestone-mixed PCC for small craters without having to stop and replace worn teeth. The Kennametal RP15 teeth are more durable on the Caterpillar SW360B and SW45 wheel saws and would not require replacing teeth before the required 340 ft of cutting is complete. Figure 24 shows how uneven the teeth wear can be on the wheel saws. The third cutting bit from the left is new. The other teeth, used on the same Caterpillar SW360B wheel saw, cut approximately 100 ft of 18-in.-thick PCC at the same time.

Figure 24. Inconsistent wear of Kennametal RP15 teeth on Caterpillar SW360B wheel saw.

4.3 Diamond-tipped saw blade evaluation results

The diamond-tipped saw blade attachments were evaluated on two separate occasions. After the first evaluation, the manufacturer made some modifications based on the initial test results and observations and developed another prototype diamond-tipped saw blade attachment. The results of the first set of tests with the diamond blade (Tests 4, 5, 6, 7, and 8) are in Section 5.3.1, and the results of the second set of tests with the diamond blade (Tests 11 and 12) are in Section 5.3.2. Table 9 gives the saw-cutting rate results of the diamond saw blade attachments in the 15- and 18-in.-thick PCC. Sections 5.3.1 and 5.3.2 describe the results in detail.

Table 9. Diamond-tipped saw blade attachment production results.

Test No.	Machine	Saw	Saw Blade Diam (in.), Width (in.)	No. of Cuts	Precut Time (min)			Cut Rate (ft/min)		
					Min	Max	Avg.	Min	Max	Avg.
4	CAT 279C XPS	SS3600	36, 0.187	3	1.00	1.83	1.35	1.60	1.67	1.64
5	CAT 299D XPS	SS3600	36, 0.187	2	1.85	1.95	1.90	1.41	1.50	1.46
6	CAT 299D XPS	SS3600HF	48, 0.174	2	1.43	1.62	1.53	1.00	0.82	0.91
7	CAT 279C XPS	SS3600HF	42, 0.200	1	2.00	2.00	2.00	0.78	0.78	0.78
8	CAT 279C XPS	SS3600HF	42, 0.250	1	1.43	1.43	1.43	0.87	0.87	0.87
11	CAT 299D XPS	SS4800HF	48, 0.220	4	0.60	2.50	1.31	1.45	1.56	1.52
12	CAT 299D XPS	SS4800HF	42, 0.200	3	1.38	1.55	1.45	1.41	1.63	1.52

4.3.1 Evaluation #1

The first assessment, Test 4, for this suite of testing included a 36-in.-diam diamond blade (SS3600) attached to a Caterpillar 279C XPS CTL, as shown in Figure 25. The attachment with the 36-in.-diam blade allowed for a 15- to 16-in.-depth cut. The saw blade was approximately 3/16 in. wide. For increased stability, Cuts, Inc. recommends a ¼-in.-wide saw blade for concrete cutting applications. A wider blade produces a straighter cut line; however, production is lost.

Three cuts ranging from 11.5 to 13 ft long through 15-in.-thick PCC were timed using the equipment setup previously described. The operator used two methods for cutting; (1) precut approximately 3 to 4 in. deep, then plunge full depth at the beginning of the cut and cut forward or (2) precut approximately 3 to 4 in. deep, then plunge full depth and move forward, plunge full depth and move forward, etc.

Figure 25. SS3600 diamond blade attachment mounted on a Caterpillar 279C XPS CTL.

The saw-cutting times using the 36-in.-diam blade through the 15-in.-thick PCC ranged from 1.60 to 1.67 ft/min and averaged 1.64 ft/min. The average precutting time over the 11.5- to 13-ft-long cuts was 1 min 21 sec. The setup of the attachment allowed for a large amount of concrete sludge to splatter on the windshield of the CTL during cutting (Figure 26). This could potentially hinder the sight of the CTL operator, particularly if the windshield wiper is not operational.

Test 5 used the same blade and attachment on a Caterpillar 299D XPS CTL in 15-in.-thick PCC, as shown in Figure 27. Two cuts were made using this equipment setup. Each cut was approximately 11.5 ft long.

Cut 1 was made with a 3- to 4-in. deep precut, followed by a full-depth plunge at the end of the cut, then a full-depth plunge at the beginning of the cut, then cutting full depth through the remainder of the cut. The precut time was 1 min 51 sec, and the total cut rate was 1.50 ft/min. Cut 2 was made with a 3- to 4-in.-deep precut, followed by a continuation of full-depth plunges. The precut time was 1 min 57 sec, and the total cut rate was 1.41 ft/min.

Figure 26. Sludge splattering the windshield of the Caterpillar 279C XPS CTL during cutting.

Figure 27. SS3600 diamond blade attachment with a 36-in.-diam blade on a Caterpillar 299D XPS CTL.

Test 6 included a 48-in.-diam diamond blade on the SS3600HF attachment mounted to a Caterpillar 299D XPS CTL. The 48-in.-diam blade can cut 18 to 20 in. deep. The 299D XPS CTL has a high flow option; however, the attachment was not compatible to run in high flow on this machine. The saw blade was approximately 0.174 in. wide. Again, for increased stability, Cuts, Inc. recommends a ¼-in.-wide saw blade for concrete cutting applications.

Two cuts were made in the 18-in.-thick PCC using this equipment setup. Due to the larger blade and the increased PCC thickness, each cut was precut twice using the 48-in.-diam blade before plunging the blade full depth. Precuts are not normally made using a 48-in.-diam saw blade. Typically, a smaller blade, such as a 36-in.-diam blade, is used to make a precut, then a larger blade would follow to complete the deeper cut.

Cuts 1 and 2 were 10 and 11 ft long, respectively. For Cut 1, the operator finished the first precut in 1 min and 37 sec and completed the second defined precut in 46 sec. For Cut 2, the first precut was completed in 1 min 26 sec, and the second defined precut was completed in 35 sec. The average total cut rate for this equipment was 0.91 ft/min. The cut depths were approximately 19 in.

Test 7 included one cut with the a 42-in.-diam saw blade on the SS3600HF attachment mounted to a Caterpillar 279C XPS CTL. For this cut, only one precut was made using the 42-in.-diam saw blade. The precut took 2 min to cut through a 10-ft-long line. After the precut, the operator plunged the 42-in.-diam saw blade full depth, moved forward, and plunged the blade again. This method was repeated through the remainder of the precut line for a total saw-cut rate of 0.78 ft/min. It took approximately 25 sec for the saw to plunge full depth (approximately 19 in.).

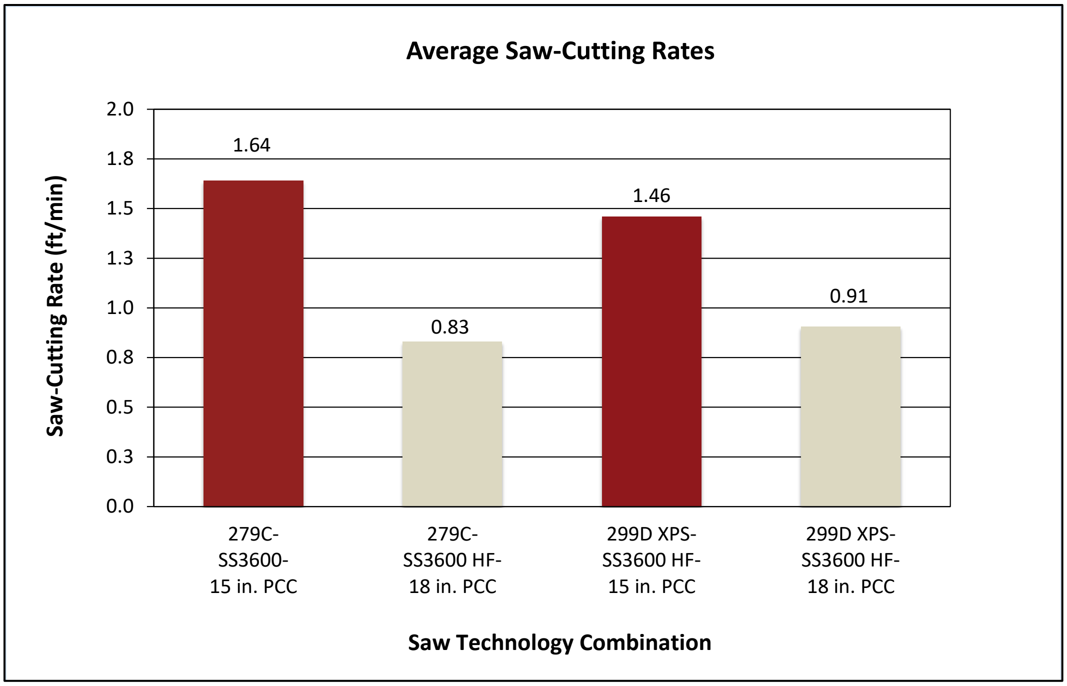
For Test 8, a 0.250-in.-wide and 42-in.-diam blade was put on the SS3600HF (Figure 28). The attachment was mounted to a Caterpillar 279C XPS CTL. Two precuts were made in one 11-ft-long cut. The first precut took 1 min 26 sec. The second defined precut time was not recorded. The total saw-cutting rate was 0.87 ft/min.

Figure 28. 42-in.-diam diamond-tipped saw blade.

Figure 29 shows the average saw-cutting rates of the four evaluated saw technology combinations from Evaluation #1. The average saw-cutting rates include the precut times. The maroon bars represent the average saw-cutting rates in the 15-in.-thick PCC, and the tan bars represent the average saw-cutting rates in the 18-in.-thick PCC.

The 36-in.-diam saw blade in the 15-in.-thick PCC (1.55 ft/min) was almost twice as fast as the 42- or 48-in.-diam blades in the 18-in.-thick PCC (0.87 ft/min). It is likely that the saw-cutting rates achieved with the 42- or 48-in.-diam blades would have been faster if the high flow option on the CTL had been compatible with the SS3600HF attachment. The faster rate of the smaller blade shows how much easier a smaller blade is to control when cutting through thick concrete.

Figure 29. Average saw-cutting rates for the diamond blade saw attachments.



4.3.2 Evaluation #2

The purpose of this second round of testing (Tests 11 and 12) was to evaluate the diamond-tipped saw blade attachment modified by Cuts, Inc. The modified unit, labeled as SS4800HF, is shown in Figure 30. The modifications were based mainly on the concrete saw-cutting testing conducted at ERDC in June 2016 (Evaluation #1). Some of the modifications to the attachment included a larger, more powerful hydraulic motor, the addition of four wheels on the bottom of the unit, a redesign of the blade shaft, and the relocation of the saw blade housing. A 42-in.-diam saw blade on the modified attachment has the ability to cut 20 to 21 in. deep. Cuts, Inc. also used an external 100-gal water tank during this test to approximate how much water is used when cutting. All cuts were made using a Caterpillar 299D XPS CTL as the prime mover, operated in high flow.

Test 11 included four timed cuts using a 48-in.-diam blade housed in the modified attachment. The diamond-tipped saw blade was 0.22 in. wide, and the approximate depth of the diamond tips before cutting was 0.45 in.; the depths of the diamond tips on the blades from Evaluation #1 were not measured. The four 11- to 15-ft-long cuts were made in 18-in.-thick PCC. The precut times ranged from 36 sec to over 2 min. The saw-cutting rates ranged from 1.45 to 1.56 ft/min and averaged 1.52 ft/min. The heights of the diamond tips on the saw blade decreased approximately 7 percent (from 0.45 to 0.42 in.) after 57.5 ft of cutting through 18-in.-thick PCC.

Figure 30. SS4800HF diamond-tipped saw blade attachment.

Test 12 included three times cuts using a 42-in.-diam blade with a 0.20-in. width (Figure 31). The intial diamond-tipped depth was approximately 0.49 in. The average precut time was 1 min 27 sec. The three 10- to 13-ft-long cuts ranged from 1.41 to 1.63 ft/min in the 18-in.-thick PCC. The average saw-cutting rate was 1.52 ft/min, which was the same average rate measured with the 42-in.-diam, 0.22-in.-wide diamond saw blade. The height of the diamond tips on the saw blade decreased approximately 18 percent (from 0.49 to 0.42 in.) after 35 ft of cutting through 18-in.-thick PCC.

The modifications made to the diamond-blade skid steer attachment and the ability for the attachment to operate on a CTL in high flow resulted in an average concrete saw-cutting rate almost twice as fast the results from the Evaluation #1 (0.87 ft/min versus 1.52 ft/min). With the limited collected data, it seems as though the thicker 0.22-in.-wide saw blade was more durable than the 0.20-in.-wide blade, although their production rates were the same. Also, saw cutting in the 18-in.-thick concrete used 100 gal of water after approximately 70 linear feet of cutting.

Figure 31. Caterpillar 299D XPS with SS4800HF attachment.

4.4 Saw evaluation summary

The current crater repair process uses four wheel saws per crater repair team with a walk-behind saw for use as a backup. Each crater repair team is responsible for 18 craters. Two wheel saws work simultaneously on a crater at the same time that two wheel saws are working simultaneously on an adjacent crater, as shown in Figure 22. The saws continue in a leap-frog pattern until the saw-cutting process for the 18 craters is completed.

The current equipment set includes four Caterpillar SW45 (or SW345B) wheel saw attachments with four Caterpillar 279C (or 279D) XPS CTLs. The SW345B wheel saw attachment is the current model that replaced the SW45, which is no longer manufactured. The 279D XPS CTL is the current model that replaced the 279C XPS, which is no longer manufactured. The Caterpillar SW360B is also included in the current crater repair equipment set as a larger saw that can cut approximately 23 in. deep.

This research looked into the possibilities of using lighter and leaner equipment for saw-cutting around upheaved pavement in crater repair scenarios. Market research, however, did not reveal lighter and leaner saw equipment that had the potential to cut through thick PCC. Nonetheless, slightly larger and more powerful versions of the current saw cutting equipment were tested with the hope that they would achieve faster saw-cutting rates. The Caterpillar 299D XHP CTL with a SW360B and SW460B wheel saws were compared to the Caterpillar 279C XPS CTL with a SW45 wheel saw. The 299D XHP CTL weighs approximately 2,000 lb more and is approximately 5 in. longer than the 279D XPS and 279C XPS CTLs. The SW460B weighs approximately 700 lb more and is approximately 15 in. longer than the SW45 wheel saw. The SW360B weighs approximately 1,000 lb more and is approximately 15 in. longer than the SW45 wheel saw. Table 3 and Table 4 give more detailed specifications of the Caterpillar equipment.

The larger, more powerful 299D XHP CTL with the SW360B wheel saw resulted in a rate approximately 40 percent faster compared to the smaller CTL, which results in a total time savings of about 1 hr per 18 craters. Using the SW460B wheel saw on the 299D XHP CTL did not increase the saw-cutting rate. The teeth wear rate was also the highest with the SW460B wheel saw.

Also, based on the results of this evaluation, the Cuts, Inc. SS4800HF diamond blade attachment can cut craters in half the amount of time as the Caterpillar SW45 wheel saw attachment on the Caterpillar 279C XPS CTL. However, the diamond blade attachment relies on a water source and produces an approximate 0.25-in.-wide cut. The excavation process, which occurs after cutting, relies on the approximately 3.5-in.-wide cut of the wheel saw attachments to be able to place the bucket's teeth inside the cut for ease of PCC removal. A wheel saw attachment is necessary for at least part of the concrete saw-cutting process of each crater.

Currently, a Husqvarna FS 6600 D walk-behind wheel saw is used in the crater repair process for backup and when dowels are encountered. The Cuts, Inc. SS4800HF diamond-tipped saw blade attachment for CTLs, which uses the same type of saw blades as the Husqvarna FS 6600 D walk-behind saw, has shown to be about as easy to operate as a wheel saw and much faster. Also, the Husqvarna FS 6600 D walk-behind saw weighs about 900 lb more than the Cuts, Inc. SS4800HF attachment.

Now that a diamond-tipped saw blade can be used on an attachment for CTLs, it may be beneficial to combine both types of saw-cutting attachments for optimal performance of crater repairs. Further research needs to be completed to determine how many cuts per crater would be the most efficient with each wheel saw and diamond-blade attachment.

5 Conclusions and Recommendations

ERDC performed full-scale field evaluations of wheel saw and diamond-tipped blade attachments to identify production rates of sawing around small craters for repair purposes. The study included the evaluation of Caterpillar SW45, SW360B, and SW460B wheel saw attachments and Cuts, Inc. SS3600, SS3600HF, and SS4800HF diamond blade saw attachments. The wheel saws produce approximately 3-in.-wide cuts, while the diamond-tipped saw blades produce approximately 0.25-in.-wide cuts. Both types of attachments were operated on Caterpillar CTLs. The following sections present the conclusions and recommendations resulting from the study.

5.1 Conclusions

- Market research was unable to identify wheel saws that were lighter and leaner than the Caterpillar SW345B and SW360B and capable of cutting through 18-in.-thick PCC.
- The Caterpillar SW45 wheel saw with the Caterpillar 279C XPS CTL was used as the control for this research. The larger SW360B wheel saw on the same CTL gives the same production as the SW345B wheel saw, which is equivalent to the SW45 wheel saw. The Caterpillar SW360B wheel saw on the larger, more powerful 299D XHP CTL was 0.30 ft/min faster (approximately 40 percent) than the traditional SW45 wheel saw on the 279C XPS CTL. The Caterpillar 299D XHP CTL weighs approximately 2,000 lb more and is approximately 5 in. longer than the 279D XPS CTL.
- For the wheel saws, cutting by plunging the wheel saw full depth through the PCC then moving forward is a better method than cutting the concrete by conducting a series of continued full-depth plunge cuts. It is easier for the wheel saw operator to plunge full depth once and move forward, and the method results in increased durability of the cutting teeth.
- Although their saw-cutting rates were similar, the Kennametal RP15 teeth on the Caterpillar SW460B wheel saw was almost twice as durable as the prototype Caterpillar 75148-1 teeth on the same wheel saw. Both wheel saws used the Caterpillar 299D XHP CTL as the prime mover.

- The Kennametal RP15 cutting teeth on the Caterpillar SW460B wheel saw wore at a faster rate than on the Caterpillar SW360B wheel saw. Both saws were operated using a Caterpillar 299D XHP CTL.
- The prototype Caterpillar 75148-1 cutting teeth are not durable enough for thick PCC cutting.
- The 42- and 48-in.diam diamond-tipped saw blades on the Cuts, Inc. prototype SS4800HF attachment were able to surpass the saw-cutting goal of 1 ft/min by approximately 50 percent with an average saw-cutting rate of 1.52 ft/min. The SS4800HF attachment was operated with a Caterpillar 299D XPS CTL.
- Three additional inches of PCC thickness had a large impact on saw-cutting production rates for the diamond-tipped saw blade attachments. The 36-in.-diam diamond-tipped saw blade cut through 15-in.-thick PCC almost twice as fast as the 42- and 48-in.-diam diamond-tipped saw blades cut through 18-in.-thick PCC. The smaller blade, although lacking depth versatility, was easier to control in the thick PCC.
- The Cuts, Inc. diamond blade saw attachments are lighter and leaner than the current Caterpillar wheel saws used for crater repair; however, diamond-tipped saw blades cannot complete the crater repair saw-cutting job alone. The excavation process relies on the wider cut of the wheel saws so that the excavator's bucket teeth can reach in and grab the PCC for removal. At least one out of the four cuts required for each crater repair would need to be completed using a wheel saw.
- The Cuts, Inc. diamond saw blade attachments rely on a water source for cutting through the PCC. Approximately 100 gal of water is required per 70 ft of cutting through 18-in.-thick PCC using the SS4800HF attachment.

5.1 Recommendations

- It is recommended to conduct side-by-side testing of the Husqvarna FS 6600 D walk-behind saw and the Cuts, Inc. SS4800HF attachment to compare speed, maneuverability, and durability.
- It is not recommended to use the Caterpillar SW460B wheel saw attachment for crater repair purposes due to the saw's slow saw-cutting rate and its increased teeth wear.

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Appendix A: PCC Mix Design

Figure A1. PCC mix design.

SINCE 1927 MMC MATERIALS, INC.

FORM 1 - Mix Design Submittal

Project Number: ______________

Project Description: U.S.A.C.E. Paving

Constructor: DirtWorks, Inc.

Concrete Supplier: MMC Materials

Mix Number: V5045130

Specified Compressive Strength: 5000 psi

Specified Slump: 6 inches max

Specified Air Content 3-6 %

Target Air Content 4.5 %

Required Average strength, f'_{cr} *(check the appropriate box)*

[XXXX] Based on Field Experience of Trial Mixtures (Supporting data must be attached) 5000 psi

[ ] Based on Laboratory Trial Mixtures (Supporting data must be attached) ______ psi

Material Porperties and Source

Cementitious Material		Type		Source		Specific Gravity
Portland Cement		IL		Holcim		3.1
Fly Ash		C		Headwaters		2.5
GGBFS (Slag)		Grade 100		Grancem		2.69

Admixtures		Name		Supplier		Dosage, oz, cwt
AEA		AE-90		BASF		3-6%
Type F		7500		BASF		4
Type S		Z-60		BASF		5.0
Note: Dosage rate will require adjustments for field and environmental conditions.						

Aggregate Size	Type	Aggr. #	Sp. Gr. SSD	Sp. Gr. OD	Absorption, %	F.M.	DOT Source #
#57	Limestone	FMJ	2.68	2.67	0.90	6.85	
			1.00	1.00	1.00		
Sand	Natural	Green Bro	2.62	2.60	0.68	2.56	3-15-3

Water: Local Water Association

Material	Quantities lb/yd^3 SSD	Absolute Volume yd^3		Quantities lb/yd^3 Oven-Dry	Absolute Volume yd^3
Cement, lb.	461	2.38		461	2.38
Fly Ash, lb	197	1.27		197	1.27
Mix Water, lb.	250	4.01		250	4.01
Slag, lb.	0	0.00		0	0.00
Coarse Aggr., lb. 1	1750	10.48		1734	10.41
Coarse Aggr., lb. 2	0	0.00			
Fine Aggr., lb.	1250	7.65		1253	7.72
Air Content, %	4.5	1.22		4.5	1.22
Total Mass, lb.	3908	27.00		3900	27.00

Mix Design Information:

Mix Class 5000PSI

Comments:

Mix Revision Number: 0

Organization: MMC Materials

Water / cementitious material ratio: 0.38

Water - Gallons/Yard 30.0

The above mix will meet the specified strength in 28 days when tested, placed and handled in accordance with current ASTM and ACI standards and recommended practices. Please include this office on the distribution list for all concrete test reports.

Designed by: Ben Hardy Title: RQA Director Date: 3/15/2016

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14. ABSTRACT

This report presents a technical evaluation of selected saw technologies, tools, and methodologies for improving the efficiency of sawing around damaged pavement associated with crater repair. Previous evaluations of saw technologies identified the Caterpillar SW345B and SW360B wheel saw attachments as the best tools for cutting portland cement concrete for Airfield Damage Repair (ADR). However, the next generation of ADR is focusing on lighter and leaner efforts, particularly in regards to equipment size. Selected saw technologies slightly larger and heavier were included in the evaluation in hopes that the saw-cutting rates increased significantly from those of the Caterpillar SW345B and SW360B wheel saw attachments. The evaluation results of all selected saw technologies were compared to the performance of the Caterpillar SW345B and SW360B wheel saws. Results indicate the wheel saw attachments tested are not lighter, leaner, or faster than the SW345B and SW360B wheel saw attachments. The Caterpillar SW345B and SW360B wheel saws are the smallest and most efficient technologies to use for cutting PCC for ADR scenarios. The results also showed that a diamond-blade saw attachment, when compared to a walk-behind diamond-blade saw currently utilized for ADR, is more ideal for concrete crater repairs.

15. SUBJECT TERMS
Crater, Concrete, Saw cutting, ADR, Wheel saw, Diamond blade, Runways (Aeronautics), Pavements, Concrete-Maintenance and Repair, Portland cement, Sawing, Blades

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