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FIREFIGHTING AND EMERGENCY RESPONSE STUDY OF ADVANCED COMPOSITES AIRCRAFT

Objective 3: Penetrating and Overhauling Wreckage

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14. ABSTRACT
The purpose of this study was to identify tools and techniques that best allow firefighters to efficiently cut and penetrate aircraft composite materials. Commercially available off the shelf tools were evaluated including carbide and diamond coated saw blades (reciprocating, circular, and hole saws), a pry axe, and a water jet cutting tool (Pyrolance). Cutting continued until the blade was too dull to cut further, as determined by the operator, or until the entire sheet of composite was consumed. The Pyrolance was evaluated for flow rate, foam quality, throw distance, maximum piercing distance between two composite panels, multiple composite panel piercing capability, and ability to extinguish hidden fires in cargo containers.

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firefighting, emergency response, advanced composites aircraft, penetrating composites, overhauling wreckage

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TABLE OF CONTENTS

Distribution A: Approved for public release; distribution unlimited.
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LIST OF FIGURES

Page

Distribution A: Approved for public release; distribution unlimited.
88ABW-2012-1278, 12 March 2012

LIST OF TABLES

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88ABW-2012-1278, 12 March 2012

FOREWORD

In 2009 the Air Force Civil Engineering Support Agency (AFCESA) commissioned the Air Force Research Laboratory, Materials and Manufacturing Directorate, Airbase Technologies Division, (AFRL/RXQ) to perform a four-pronged research and development effort to better understand and fight fires involving composites and composite aircraft. Four objectives were developed: (1) Damage Mitigation from Small Fires, (2) Firefighting Effectiveness of Technologies and Agents on Composite Aircraft Fires, (3) Penetrating and Overhauling Wreckage, and (4) Post Fire Decontamination of Personal Protective Equipment (PPE) and Equipment. This report documents experiments and findings from Objective 3 – Penetrating and Overhauling Wreckage.

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1. SUMMARY

Over the past three years, the Air Force experienced accidents involving composite aircraft including the B-1, B-2 and F-22 that required firefighter response. Lessons learned from these accidents have shown that traditional firefighting techniques used for aluminum skinned aircraft do not yield the same results for composite aircraft, which pose their own unique hazards. For example, the B-2 crash at Anderson AFB, Guam required about 10 times the amount of foam and water specified by National Fire Protection Association (NFPA) 403 Standard for Aircraft Rescue and Fire Fighting Services at Airports for an aircraft of that size (1). Complete extinguishment of the hidden fires took over six hours, which hindered continued airfield operations. A significant contributing factor was that firefighters had a very difficult time cutting and piercing the fiber composite to gain access to hidden fires with the standard tools found on Aircraft Rescue and Fire Fighting (ARFF) vehicles.

The purpose of this study was to identify tools and techniques that best allow firefighters to efficiently cut and penetrate aircraft composite materials. Commercially available off the shelf tools were evaluated, including a tool that combines features of water jet cutting and fire extinguishing, the Pyrolance. A reciprocating saw, circular saw, hole saw, pry axe and Pyrolance were used to cut or pierce carbon fiber and epoxy composite material representative of what is often used in aircraft construction. In addition to cutting relatively thin material from F-16 horizontal stabilizers, a structurally reinforced multi-layered composite door from a B-2 aircraft was also cut. Both carbide and diamond coated saw blades were assessed. Cutting continued until the blade was too dull to cut further, as determined by the operator, or until the entire sheet of composite was consumed. The time for each cut was measured. Optical image analysis was used to analyze wear on the reciprocating and circular saw blades.

The diamond coated saw blades cut more composite than the corresponding carbide blades. The diamond coated blades cost less per foot of cut, and they last longer and require less changing. Enough heat is generated when cutting carbon fiber and epoxy composite to warp the saw blades, and water should be used to constantly cool the blades during cutting, or cutting operations should be limited to one minute followed by break periods to allow the blades to cool before cutting is resumed. Water also can minimize the composite fibers dispersed into the air. A circular saw with diamond coated or carbide blades can be used to cut a structurally reinforced composite door from a B-2 aircraft; however, 12-in blades do not have sufficient radius to cut completely through the thickest sections of a B-2 door. A 6-in diameter diamond coated hole saw cut holes through 0.25-in composite in about 23 s. The blade can be used with a standard handheld drill so no special equipment is needed. A firefighter was able to cut access holes in carbon fiber and epoxy composite up to 0.13 in thick and in aluminum up to 0.05 in thick with a pry axe, though it took much longer than when using a saw. The Pyrolance is very cumbersome to use for making large area cuts, but it can be used to easily pierce a fuselage or engine nacelle and then apply water or foam to a hard to access fire. It pierced two composite panels, typical of what would be found on an aircraft, separated by 8 ft. It also penetrated five 0.153 in thick composite panels set at 1 ft intervals.

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Based on the results from the evaluations, it is recommended that ARFF units carry diamond coated reciprocating and circular saw blades, and a drill motor with a diamond coated hole saw to use in responding to emergencies involving aircraft constructed with large amounts of carbon fiber and epoxy composite material.

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2. INTRODUCTION

2.1. Background

Over the past three years, the Air Force experienced accidents involving composite aircraft including the B-1, B-2 and F-22 that required firefighter response. Lessons learned from these accidents have shown that traditional firefighting techniques used for aluminum skinned aircraft do not yield the same results for composite aircraft, which pose their own unique hazards. For example, the B-2 crash at Anderson AFB, Guam required about 10 times the amount of foam and water specified by NFPA 403 Standard for Aircraft Rescue and Fire Fighting Services at Airports for an aircraft of that size (1). Complete extinguishment of the hidden fires took over six hours, which hindered continued airfield operations. A significant contributing factor was that firefighters had a very difficult time cutting and piercing the fiber composite to gain access to hidden fires with the standard tools found on ARFF vehicles.

The purpose of this study was to identify tools and techniques that best allow firefighters to efficiently cut and penetrate aircraft composite materials. Only commercially available off the shelf tools were evaluated. Fabricators and makers of composite components commonly use diamond coated blades and saws, water jet cutters and lasers to cut composite materials. Reciprocating and circular saws and manual cutting tools are commonly carried on ARFF vehicles, and they are the primary subjects of this report. A commercially available hole saw was also evaluated as a potential addition to the ARFF inventory. A relatively recent tool that combines features of water jet cutting and fire extinguishing, the Pyrolance, is also discussed.

A reciprocating saw, circular saw, hole saw, pry axe and Pyrolance were used to cut or pierce carbon fiber and epoxy composite material representative of what is often used in aircraft construction. In addition to cutting relatively thin material indicative of aircraft fuselages, a structurally reinforced multi-layered composite door from a B-2 aircraft was also cut. Both carbide and diamond coated saw blades were assessed.

Methods and results from evaluations of reciprocating and circular saws are presented first in this report, followed by methods and results for the hole saw, the pry axe, and the Pyrolance. Conclusions and recommendations appear after results for all the tools. Detailed data from the different tests are included in appendices.

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3. RECIPROCATING SAW AND CIRCULAR SAW

3.1. Methods

Carbide and diamond tipped reciprocating saw and circular saw blades were used to cut aircraft panels made from carbon fiber and epoxy composite. Cutting speed, cumulative cut length, and blade wear were then compared, in addition to blade cost.

3.2. Materials and Equipment

The composite material used during testing consisted of F-16 horizontal stabilizers (Figure 1) provided by the F-16 System Program Office (SPO) and a door from the Spirit of Indiana B-2 aircraft (Figure 2) donated by the Advanced Composites Office (ACO), Hill AFB, Utah. Toxicity Characteristic Leaching Procedures (TCLP) tests were conducted on the horizontal stabilizer paint, and results are listed in Appendix A. Cutting an aircraft door was not included in the original test plan. The door became available during the middle of testing and provided the opportunity to cut a thicker piece of composite material.

AFRL used the composite skin of the F-16 horizontal stabilizers for testing. The stabilizers were marked for 32 cuts (Figure 1). The first 15 cuts on each F-16 stabilizer ranged in length from 63 in to 69.25 in and averaged 68 in. The remaining cuts ranged in length from 29 in to 31 in and averaged 30 in. Generally, as the cut number increased from cut 1 to cut 32 the thickness of the composite sheet also increased. A portion of the stabilizer was not used because it was being used to secure the panel to the test stand for cutting. The speed of cutting operations decreased as the material thickness increased. The reciprocating and circular saws and blades were tested on identical test articles and in identical sequence of cuts. The average thickness of the sheets is listed in Appendix B.

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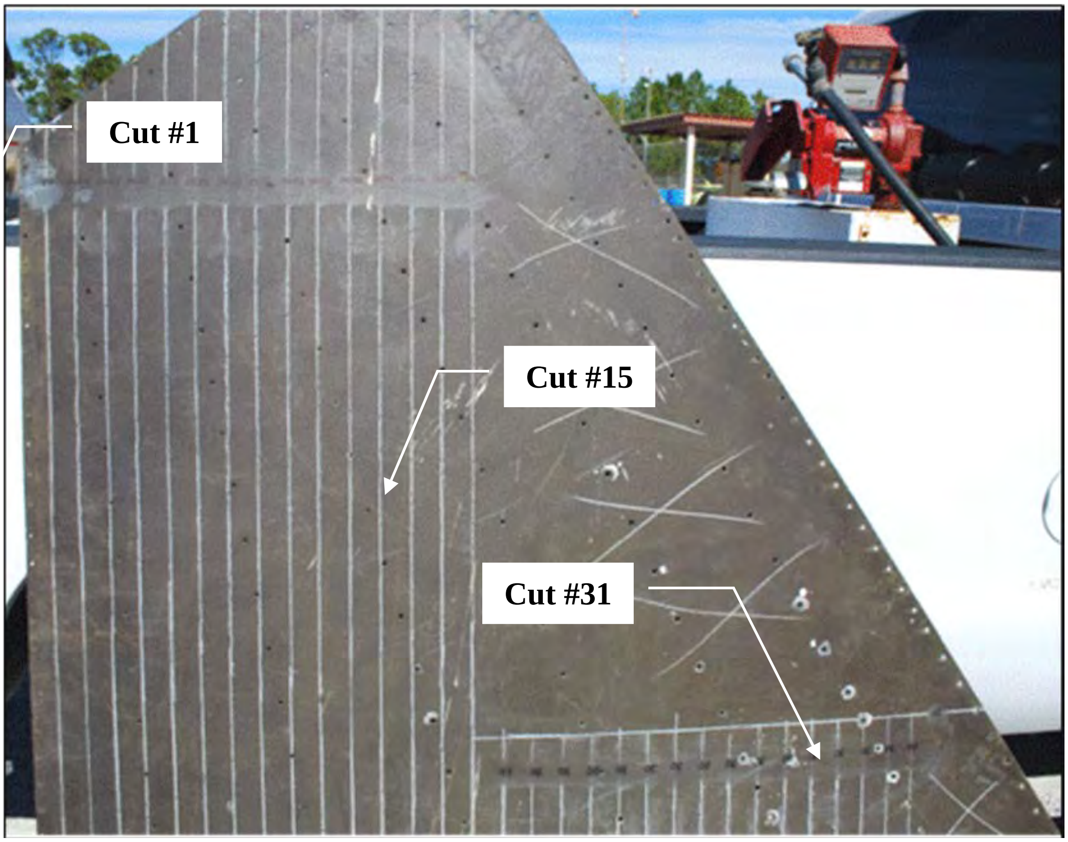

Figure 1. Composite F-16 Stabilizer

Figure 2. Composite B-2 Aircraft Door

A Hitachi 12-amp corded reciprocating saw was used as the representative saw for this portion of the testing (Figure 3). An 8-in Lenox carbide blade (Model ES-20576) and an 8-in Lenox diamond coated blade (Model ES-10833) were each tested in the same saw. Figure 4 shows a close-up of the Lenox 8-in carbide and diamond reciprocating saw blades. From the picture it is evident that the carbide saw blade had a much coarser grit than did the diamond coated blade.

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Figure 3. Hitachi Reciprocating Saw

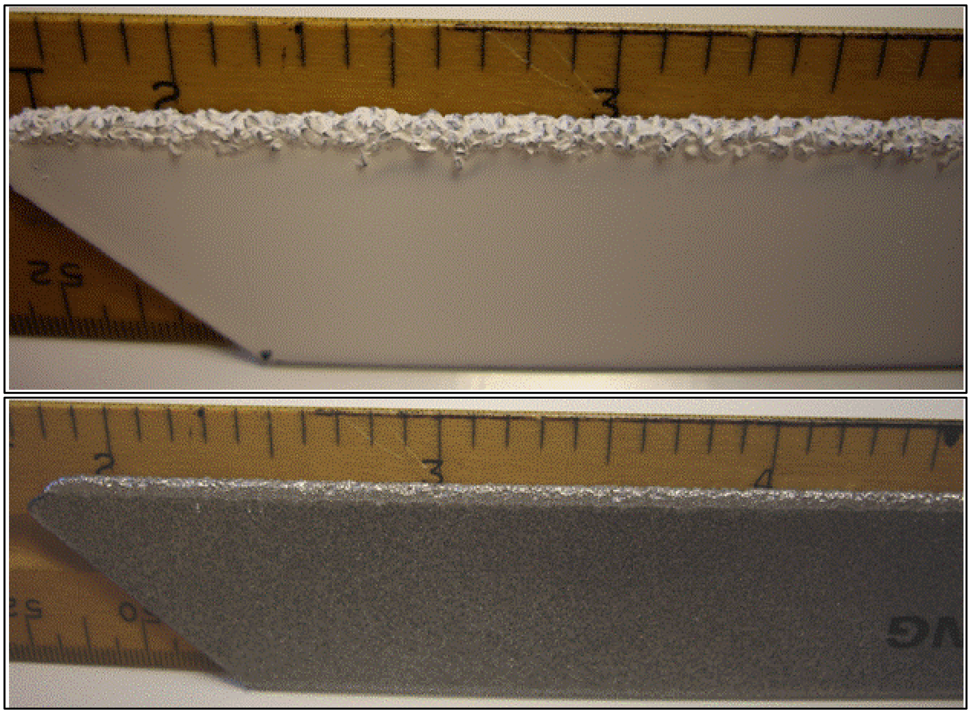

Figure 4. Close-Up of Carbide Grit (top) and Diamond Grit (bottom) Reciprocating Saw Blades before Cutting

A Partner K-12, 14-in gas powered circular saw was used as the representative saw for this portion of the testing (Figure 5). The 12-in Fire Hooks Unlimited carbide blade that came standard with the saw was used for testing as this represented a general purpose blade used by fire departments for a variety of cutting needs. The circular saw blades were purchased from a firefighting equipment supplier. The blade was constructed of 24 carbide tips on a steel body that were twice the width of the body of the blade. A MK Diamond Fire Tiger Tooth 12-in diamond coated blade was used for comparison. This blade had diamond particles directly fused to a steel core. Figure 6 shows the carbide and diamond saw blade teeth.

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Figure 5. Partner K-12 14-in Gas Powered Circular Saw

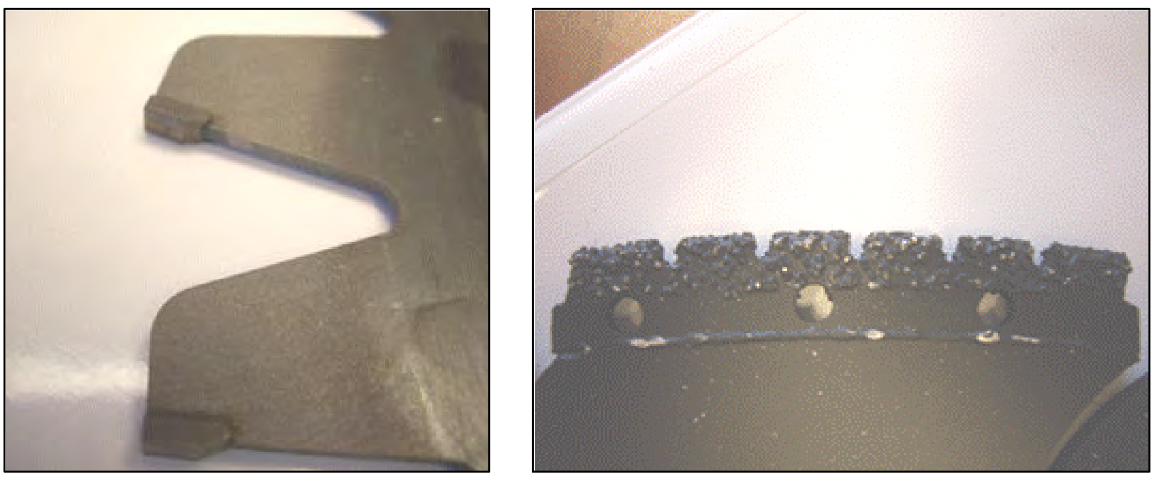

Figure 6. Close-Up of Carbide (left) and Diamond (right) Circular Saw Blades before Cutting

3.3. Procedure

A test stand was constructed from steel Unistrut® metal framing system. This apparatus could be configured to accommodate a variety of sizes of composite sheet and could be quickly reconfigured (Figure 7). The overall dimensions of the test stand were 60-in width × 86.6-in height; however the test stand could be adjusted to accommodate different sizes of composite samples. Figure 8 shows a composite sheet secured in the test stand. All cutting was conducted by the same person to provide some consistency in determining when the blade was no longer effective. The saw operator endeavored to apply a consistent force on the saw while cutting in an attempt to reduce inconsistencies in measured cutting speed. Cutting continued until blades were too dull to cut effectively, as determined by the operator, or until the entire sheet of composite was cut, so that cumulative lengths of material cut by each blade could be compared. The saw operator documented the perceived change in cutting ability after each sheet of composite. This

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cursory analysis provided a comparison on the degradation of the different blades after similar cutting conditions.

The length of each cut was measured in advance, and the cut speeds were determined by dividing the length of each cut by the time for each cut as measured from video. Cumulative cut length for each blade was determined by summing the individual cut lengths. Wear on the surfaces of the blades was measured by optical image analysis to determine a quantifiable measure of blade wear. The blades were sent to IMR Test Labs, and microscopic image analyses provided a measure of thickness of the blades before cutting and after cutting two sheets of composite. The diamond blades for the reciprocating saw and the circular saw were sharp enough after cutting two sheets of composite sample to continue cutting and so a third sheet of F-16 composite was cut with each of the diamond coated saw blades.

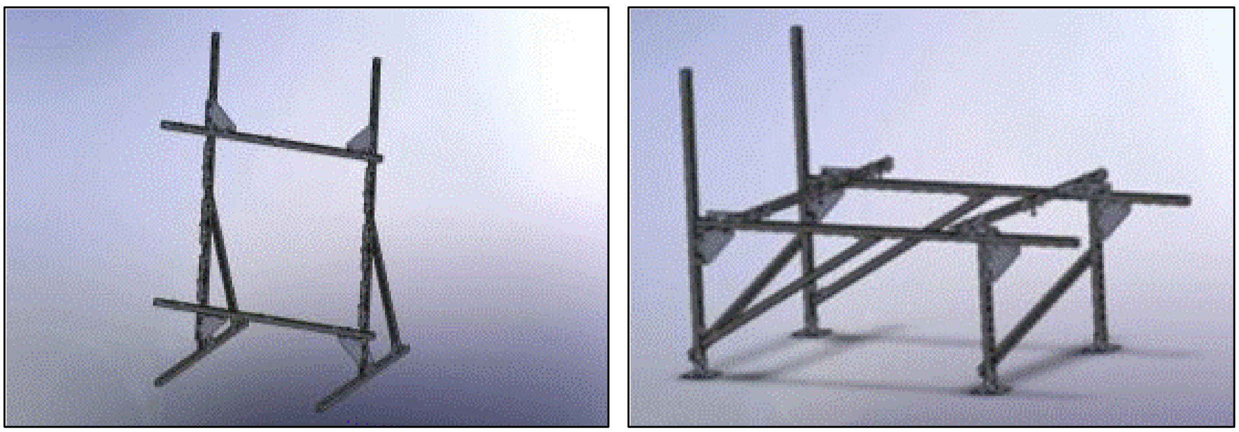

Figure 7. Test Stand in Vertical and Horizontal Orientation

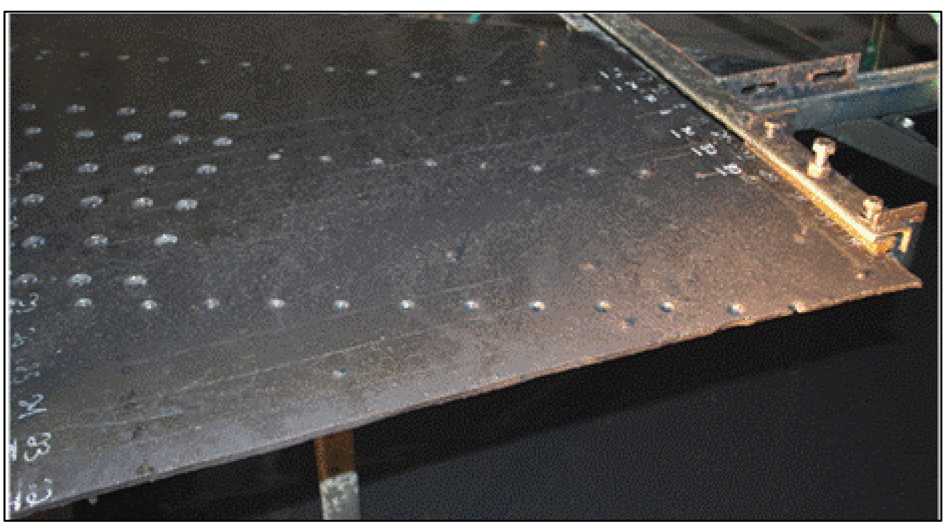

Figure 8. Composite Sheet Shown in Test Stand

The reciprocating and circular saws were used to cut strips from F-16 composite sheets along pre-measured lines. Figure 9 shows the operator cutting with the reciprocating saw, and

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Figure 10 shows the operator cutting with the circular saw. Water was used during cutting to keep the blades cool and to minimize the composite fibers dispersed into the air. The K-12 circular saw was outfitted with a water spray system that sprayed water directly onto the blade, while in the case of the reciprocating saw a hose was used to wet the sample as it was cut. The water was collected, filtered and disposed of in accordance with procedures established by AFRL. The operator wore a Tyvek suit, full-face respirator with P100 cartridge, gloves and boots during all cutting evaluations. Each F-16 stabilizer section represented 127 linear ft of composite cutting. Cutting speed was calculated for each cut by dividing the total length of the cut by the total time taken to make the cut, as determined from video records. The saw operator made an effort to apply consistent force on the saw during all cutting operations in an attempt to reduce inconsistencies in measured cutting speed.

Figure 9. Reciprocating Saw Being Used to Cut F-16 Composite Sheets

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Figure 10. Circular Saw Being Used to Cut F-16 Composite Sheets

Figure 11. Cutting B-2 Composite Door Using Circular Saw

For cutting the B-2 door, the Partner K-12 circular saw with new 12-in carbide and diamond blades was used. Each blade was used to cut 1.5 in strips of composite from the door. The door provided enough material to cut 13 strips with the carbide blade and 14 strips with the diamond blade. Because of variations in thickness of the door, the test stand could not accommodate it.

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Instead, cinder blocks were used to keep the door raised above ground and balanced so that it could be cut (Figure 11). The door appeared to be uniform in construction, however after cutting it was discovered that the side cut with the carbide blade was thicker than the side cut with the diamond blade. The blades used to cut the door were not sent to IMR Test Labs for image analysis of wear.

3.4. Results and Discussion

3.4.1. Reciprocating Saw

Figure 12 shows a comparison of the average cutting speed for both the carbide and diamond reciprocating saw blades. The graph shows the carbide blade cutting speed minus the diamond blade cutting speed, as a function of cumulative length cut. Figure 13 shows the total cumulative length of composite cut by each type of blade.

When the blades were new, the carbide blade cut faster than the diamond blade; however, after cutting 90 ft, the carbide blade had dulled to the point of being about equal in cutting speed to the diamond blade, and after that point the diamond blade cut more quickly than the carbide blade. After cutting 107 ft (cut number 24), the carbide blade was incapable of cutting through the sample at the thicker (≥ 0.25 in) end of the composite sample (appears as a gap in the data in Figure 12), though it was capable of cutting an additional 62 ft (up to cut number 11) of thinner (≤ 0.15 in) composite. Compared to the 169 ft cut by the carbide blade, the diamond blade was able to cut a total cumulative length of 382 ft of composite. The diamond blade had a consistent cutting speed through all three sheets of composite. The blade was still sharp and capable of cutting additional composite material; however, there was insufficient composite sample material to continue cutting until the diamond blade became too dull to cut further. Therefore the effective cutting length of the diamond blade was not determined.

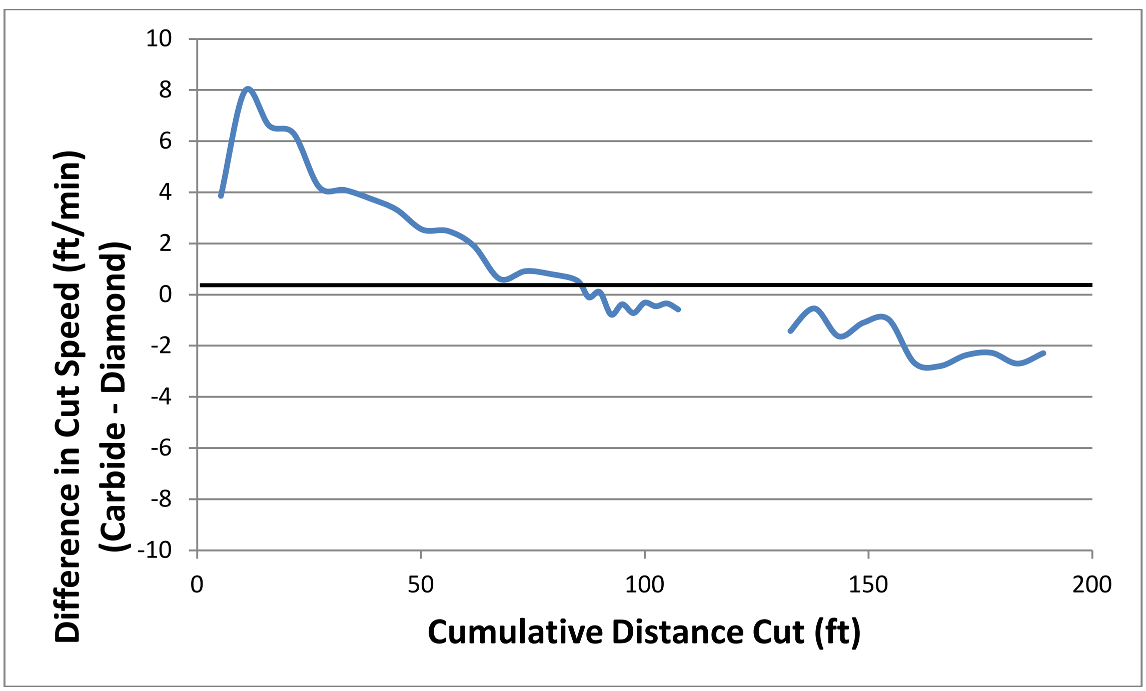

Figure 12. Difference in Reciprocating Saw Cutting Speed, Carbide Blade - Diamond Blade

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Speed of cutting decreased as the thickness of the F-16 material increased. The diamond blade cut at a consistent rate of 4 ft/min through 0.10 in thick material and 1.2 ft/min through 0.25 in thick material. For 0.10 in thick composite, the carbide blade cut at a rate of 5.6 ft/min when new and fell to 1.37 ft/min after having cut through 169 ft of composite. At 0.24 in thickness, the carbide blade cut at a rate of 0.6 ft/min and could only make one 30 in cut at this thickness. The operator noted that the diamond reciprocating saw blade made a fine cut, granulating the material, while the carbide blade initially made a more course cut. As the carbide blade tip wore down it began to make a finer cut similar to the diamond blade but at a slower speed. Operator fatigue during cutting was also directly related to the thickness of the material.

Each blade was analyzed for thickness at six different points along the length of the blade. Each blade was permanently etched with a marker at evenly space intervals and measured before cutting operations (baseline) and after cutting two composite sheets. The diamond blade was measured a third time after cutting the third composite sheet. Blade wear, measured by the change in blade thickness, showed that after 169 ft of cutting the average wear on the carbide blade was 0.191 mm, while the average for the diamond blade after cutting 254 ft of composite was 0.094 mm and after cutting 382 ft of composite was 0.128 mm. After 0.191 mm of wear, the carbide blade was too dull to cut any further, but the diamond coated blade still cut nearly as well after 0.128 mm of wear. The complete report from IMR Test Labs is located in Appendix C.

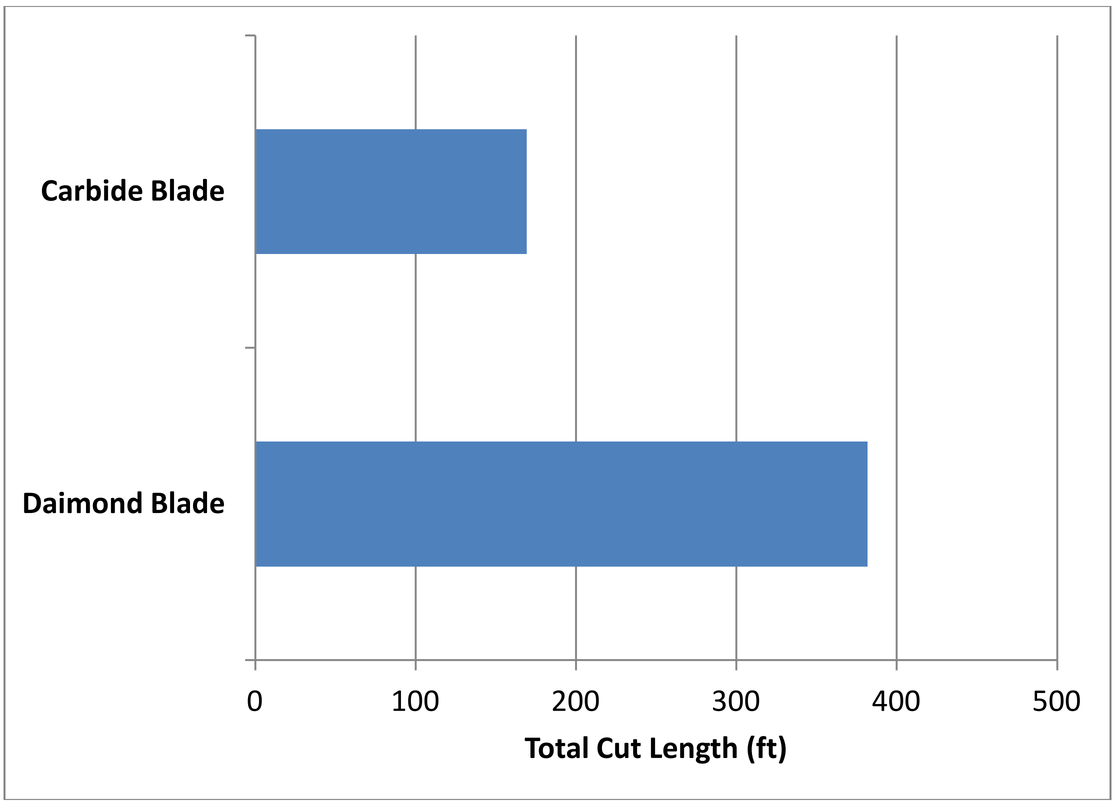

Figure 13. Comparison of Total Cut Length for Reciprocating Saw Blades

Table 1 shows the prices for the blades purchased for this study. When deciding which saw blades to purchase, durability translates into changing the blades less often, which can save

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critical time, especially in the middle of an emergency response operation. The higher cost of the diamond blades needs to be factored into the decision of whether or not the additional investment is beneficial. Blades from a single manufacturer were used for this project, which is a very small sample of blades commercially available, but a cost comparison can be made. The reciprocating saw carbide blade cut 169 ft of composite, and the diamond blade cut 382 ft of composite, but could have cut additional length. At 382 ft cut, the diamond blade was slightly more economical at $0.0293 per foot compared to the carbide blade at $0.0295 per foot. In any case, the diamond blade would not have to be changed out as frequently as a carbide blade, which would lower indirect costs as well.

Table 1. Cost Comparison of Reciprocating Saw Blades

Blade Type (reciprocating)	Blade Cost	Cost/ft	Vendor
Carbide	$4.98	$0.0295	Lenox
Diamond	$11.18	$0.0293	Lenox

3.4.2. Circular Saw

Figure 14 shows a comparison of the average cutting speed for both the carbide and diamond circular saw blades. The graph shows the carbide blade cutting speed minus diamond blade cutting speed, as a function of cumulative length cut. Figure 15 shows the total cumulative length of composite cut by each type of blade.

Up to a cumulative cut length of 255 ft (two full F-16 stabilizer sample sheets), the cutting speeds of the carbide and diamond blades were about the same, demonstrated in Figure 14 by the small and variable difference between the two cutting speeds. However, after 235 ft (cut #24 of the second sheet of F-16 stabilizer composite), the carbide blade began ripping/tearing large chunks of the composite versus clean cutting the material. The carbide blade ripped an additional 32 ft of composite, 255 ft total. The carbide blade may have been able to cut additional material, but no additional material was cut because the blade had dulled to the point of ripping rather than cutting. The diamond blade cut with consistent speed through three composite stabilizers, a cumulative total of 382 ft. The blade was still sharp and capable of cutting additional composite material; however, there was insufficient composite sample material to continue cutting until the diamond blade became too dull to cut further. Therefore the total cutting length of the diamond blade was not determined.

Speed of cutting decreased as the thickness of the F-16 material increased. The diamond blade cut at a consistent rate of 28 ft/min through 0.10 in thick material and 22 ft/min through 0.25 in thick material. For 0.10 in thick composite, the carbide blade cut at an average rate of 29 ft/min, and at 0.24 in thickness the carbide blade cut at an average rate of 16 ft/min and after 235 ft began to shred the material more than cut. The operator noted that the diamond circular saw blade made a finer cut than did the carbide blade.

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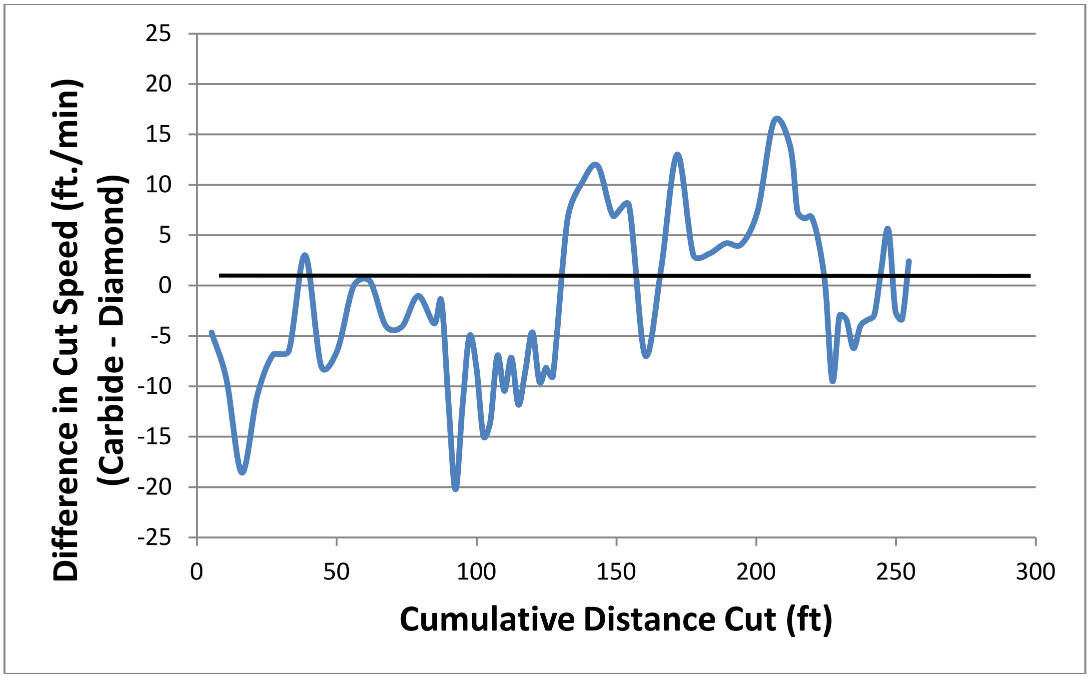

Figure 14. Difference in Circular Saw Cutting Speed, Carbide Blade - Diamond Blade

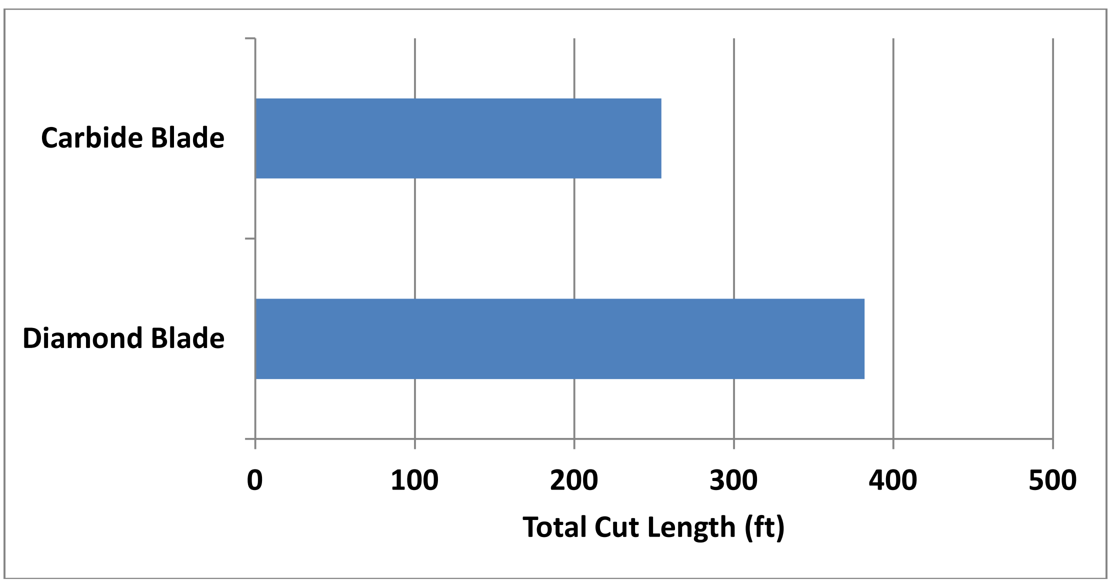

Figure 15. Comparison of Total Cut Length for Circular Saw Blades

Blade wear, measured by the change in blade tooth dimensions, showed that after 255 ft of cutting the wear on the carbide blade was about one-third more than the diamond blade after cutting 382 ft. The complete report from IMR Test Labs in Appendix C shows what dimensions were measured for each type of blade. Because the design of the two blades were distinctly different, the dimensions measured for each blade were different, which makes a direct comparison of blade wear dubious. However, based on the wear to the diamond coated blade, a rough estimate of blade life can be made. Figure 16 is a photograph of a typical set of teeth on the diamond blade, and it is apparent that diamond grit extends to about the top of the small holes, a distance of about 4 mm. If it is assumed that the blade would continue to cut effectively until the blade wore to the bottom of the v-notches, a depth of about 1.5 mm, and that the blade would continue to wear at the rate that was measured, about 0.1 mm/382 ft, then the blade should be able to cut about 5,700 ft of composite similar to the F-16 stabilizer material.

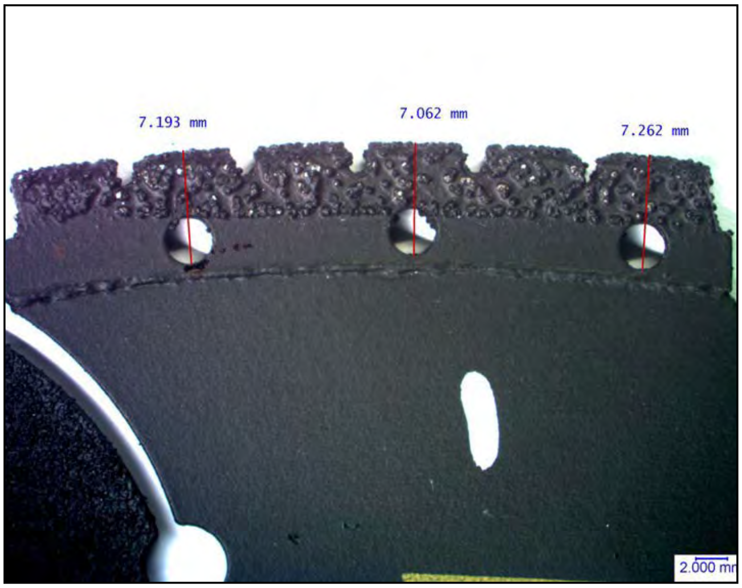

Figure 16. Diamond Coated Circular Saw Blade Teeth

Table 2 shows the prices for the blades purchased for this study (underlined), along with a range of prices found for the MK diamond Tiger Tooth blade. The circular saw carbide blade cut 255 ft of composite at a cost of $0.31/ft, and the diamond blade cut 382 ft of composite at a cost of $0.29 - $0.55/ft, depending on the cost of the blade. Since little degradation was observed in cutting speed or in cleanliness of the cut by the diamond blade after cutting 382 ft, it is highly likely that additional material could have been cut, which would lower the cost per foot. Additional F-16 stabilizer samples were not available to test the diamond blade to failure; however, based on wear estimates discussed above, the cost might be as low as 2–4 cents/ft. The time required to change blades when they become too dull to cut must also be considered, time that is particularly critical in the middle of an emergency response operation, and the diamond blade would not have to be changed as frequently as a carbide blade, potentially lowering costs as well in terms of quicker rescue and fire extinguishment times.

Table 2. Cost Comparison of Circular Saw Blades

Blade Type (circular)	Blade Cost	Cost/ft	Vendor
Carbide	$77.99	$0.31	Hooks Unlimited
Diamond	$109–202.88	$0.029–0.55	MK Diamond

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The K-12 saw was equipped with a water spray feature that sprayed water directly onto the blade while cutting. This feature was important when using both blades to cut composites for an extended period of time (greater than about one minute). Cutting the composite material generated heat sufficient to warp the blades if they were not continuously cooled during cutting. Water also reduced airborne composite fibers. The operator's protective clothing was covered in a water/composite fiber slurry after each cutting operation; however, little dust was observed in the air near the operator during cutting.

3.4.3. Circular Saw Cutting the B-2 Door

The B-2 door section was provided late in the project, and the intent was to perform a demonstration of the ability to cut a composite material component more complex than just a single thin sheet, like the F-16 stabilizer sheets. There was not enough material in one door to test the blades to failure, but there was enough to demonstrate the ability to cut reinforced composite components with the circular saw. Both of the blades cut through the composite and the metal structural reinforcements; however, it is important to note that the 12-in blades were not of sufficient diameter to cut the thickest part of the door. The door contained some internal reinforcing structures that made cutting some strips more time consuming than others, but on average the carbide blade cut at a rate of 2.6 in/s, and the diamond coated blade cut at a rate of 3.8 in/s.

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4. HOLE SAW

4.1. Methods

Hole saws are not standard equipment on ARFF vehicles but could provide an inexpensive solution for quickly cutting a hole through an aircraft to gain access for fire extinguishing. A 6-in diamond coated hole saw was used to cut aircraft panels made from carbon fiber and epoxy composite. Cutting speed, cumulative cut depth, and blade wear were measured.

4.2. Materials and Equipment

The composite material used during hole cutting consisted of F-16 horizontal stabilizers as described previously in Section 3.2.

A Treasure Hong Kong (THK) Diamond Tools 6-in diamond coated hole saw (Figure 17) was evaluated. At the time of testing, THK was the only manufacturer of diamond coated hole saw blades of this diameter and could only be purchased through an eBay vendor that imported the blades from China. An American made blade of that size was not found. The hole saw measured 6 in outside diameter and could drill to a depth of 1 ⅜ in. The hole saw had a ½ in shank to attach to a drill chuck and came with a pilot drill bit (not shown in Figure 17) coated with 50-grit diamond sand.

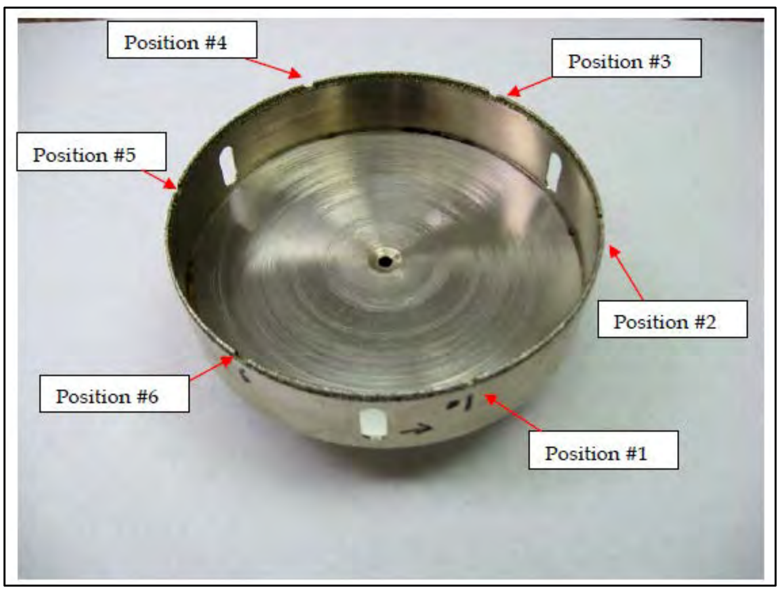

Figure 17. 6-in Diamond Coated Hole Saw

4.3. Procedure

An F-16 composite sheet was secured to the test stand and circular sections were cut with the hole saw using a DeWalt 120V, ½-in electric drill. The total number of holes, cumulative depth cut, and the speed of cutting were measured, and the blade was sent to IMR Test Labs before and after cutting to determine blade wear.

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4.4. Results and Discussion

The diamond hole saw blade completed 27 test cuts before the pilot drill bit wore out; the diamond coating on the pilot bit wore off at this point, and without a pilot bit the saw could not be held in place to start a cut. The pilot drill bit was not replaced, and testing was not continued to failure of the blade of the hole saw because of the limited supply of composite material available for this test. The total depth cut was 3.35 in, and the cutting speed was 0.0110 in/s. Image analysis showed an average decrease in thickness of 0.103 mm for the blade after cutting 3.35 in, and the depth of the notches in the blade was about 2.4 mm. This hole saw cost $48 (after completing testing, AFRL identified a United States source for the diamond hole saw blade, Broco Cutting and Welding Products, that sold a similar blade for $165), which equates to $14.33/in of cut. With another pilot bit or a better pilot bit, the blade might cut until it is worn to at least 50% of the depth of the notches, 1.2 mm. If the rate of blade wear remained constant, then the blade might have cut a total of 39 in or more, which equates to $1.23/in of cut. A lesson learned from experience during the cutting was that if dropped, this blade could easily lose its round shape, and if the blade is out of round it is difficult to control while cutting.

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5. FIREFIGHTER PRY AXE

5.1. Methods

A standard firefighter's pry axe was used to cut through aluminum and carbon fiber epoxy composite panels. These trials were conducted for information only, and the goal was to demonstrate the level of effort necessary to chop through a standard aluminum skin versus a composite skin. Information collected included time to cut, video documentation and remarks from the operator.

5.2. Materials and Equipment

A Paratech brand Pry Axe (Figure 18) was used for all cutting. The Pry Axe was 18 in long and weighed 6.6 lb. Three materials were worked: a 0.08 in thick 5052-H32 aluminum panel; a carbon fiber and epoxy composite panel of varying thickness from an F-16 horizontal stabilizer; and, 0.05 in thick aluminum aircraft engine nacelle cowling from a KC-135. The 5052-H32 aluminum used in this test was a similar type and thickness as that used for aircraft fuselages.

Figure 18. Paratech Brand Pry Axe

5.3. Procedure

The aluminum and F-16 composite sheets were secured in the test stand, which was described previously in Section 3.3. The operator used the pry axe in an attempt to cut a 12 × 12-in hole through each sheet as quickly as possible. For the KC-135 aircraft engine nacelle, the pry axe was used to cut an 8 × 18-in hole. Three attempts were made in each material to cut holes, and each trial was timed and recorded on video. The blade was sharpened after each test.

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5.4. Results and Discussion

Figure 19 shows the 0.08 in thick 5052-H32 aluminum sheets after cutting with the pry axe. With the pry axe the operator was able to cut only a few inches in the first sheet and could only make a small hole in the second sheet. The operator did not attempt a third sheet since the first two were unsuccessful. The times to make cuts 1 and 2 are shown in Table 3.

Figure 19. Pry Axe Used on 5052-H32 Aircraft Aluminum

Table 3. Results of Pry Axe Used on 5052-H32 Aircraft Aluminum.

Test	Time (s)	Remarks
1	80	Did not cut
2	65	Did not cut
3	Did not complete	None

Figure 20 shows the composite sheet with the first hole cut and shows a close up of the edge of that hole. This process was repeated two more times. The first square was cut from a section of the material that averaged 0.13 in thick, and the average thicknesses of cuts two and three were 0.07 in and 0.08 in, respectively. Results are reported in Table 4. The operator noted that the cutting edge of the pry axe, not the pry teeth or the pick, was most effective on the composite material.

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Figure 20. Pry Axe Used on F-16 Composite Skin

Table 4. Results of Pry Axe Used on Composite Sheet

Test	Thickness (in)	Time (s)	Remarks
1	0.13	326	Cutting edge works best
2	0.07	150	None
3	0.08	160	None

Figure 21 shows the operator using the cutting edge of the pry axe to cut a hole in the 0.05 in aluminum KC-135 aircraft engine nacelle cowling. Three 8 × 18-in holes were cut using this tool. Figure 22 shows the edges of the nacelle after cutting. Results are given in Table 5. The first hole took 56% longer to cut than the second and third holes, which was probably due to the operator becoming more proficient with experience.

Table 5. Results of Using Pry Axe on KC-135 Engine Nacelle Cowling

Rescue Axe Aircraft Engine Sheet		
Test	**Time (s)**	**Remarks**
1	126	None
2	81	None
3	81	None

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Figure 21. Demonstration of Pry Axe Cutting Access Hole in KC-135 Engine Nacelle Cowling

Figure 22. Edges of KC-135 Engine Nacelle Cowling after Cutting with Pry Axe

6. PYROLANCE

6.1. Methods

The Pyrolance (Figure 23) is an ultra high pressure cooling and fire fighting system that consists of a portable, high-pressure Lance and a gasoline-powered, high pressure pumping unit. The firefighter holds the Lance directly against the exterior of a structure and then activates it, piercing the structure with an ultra high pressure stream composed of water and aggregate. Once the exterior is penetrated, the stream from the Lance is changed to water mist or a water/foam combination to cool the interior of the space. AFRL previously conducted cursory evaluations of the Pyrolance capability to penetrate and cut through a variety of materials including carbon bismaleimide (BMI) composite, aircraft canopies, metal containers, armored plated steel and concrete block, all of which it was able to penetrate. The Pyrolance proved to be challenging and awkward to use for linear cutting, so was not evaluated for cutting in this test series. This test series focused on the abilities of the Pyrolance to penetrate multiple layers of composite material and to extinguish fires.

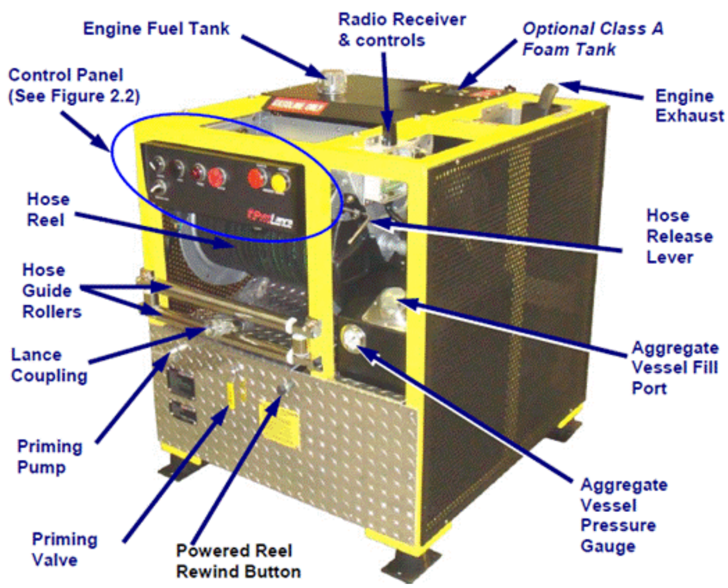

Figure 23. Pyrolance Schematic (excerpted from Pyrolance Operations Manual) (2)

The ability to pierce, cut, and apply water or AFFF make the Pyrolance a unique firefighting tool, and the purpose of this part of the project was to characterize the piercing and fire extinguishing capabilities of the Pyrolance. The Pyrolance was evaluated for flow rate, foam quality, throw distance, maximum piercing distance between two composite panels, multiple composite panel piercing capability, and ability to extinguish hidden fires in cargo containers.

Flow rate, foam quality, and maximum effective extinguishing distance (throw distance) are critical parameters in gauging fire fighting performance of a system. Flow rate was determined by measuring the volume of agent discharged over a fixed time period. Foam quality checks, expansion ratio and 25 percent drainage time, were done in accordance with NFPA 412, Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment, Section 6.3.2 (3).

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Throw distance was determined by placing a series of small pan fires at various distances and measuring the distance to the furthest pan fire extinguished.

Maximum piercing distance between two composite panels and capability to pierce multiple composite panels are important characteristics in accessing and extinguishing aircraft fires. Finding the maximum piercing distance between two composite panels was done to simulate piercing through the composite exterior of an aircraft, bridging an air gap, and then piercing an interior composite panel to reach a deep fire. This was accomplished by increasing the gap between two parallel composite panels and determining the maximum separation distance at which both panels were penetrated. The study of the capability of the Pyrolance to pierce multiple composite panels was done to simulate piercing multiple compartments inside an aircraft to reach a hidden fire. This evaluation was done by arranging multiple parallel composite panels at 12 in intervals, and then determining how many parallel panels the Pyrolance could penetrate.

Evaluations of the ability of the Pyrolance to extinguish hidden fires in cargo containers were done in accordance with Federal Aviation Administration (FAA) Aircraft Cargo Compartment Minimum Performance Standard, which establishes a minimum performance standard for testing replacement aircraft cargo compartment fire suppression systems for equivalent performance to Halon 1301 (4). The standard consists of four different tests including bulk load fire, containerized fire, surface burning and aerosol can explosion. The containerized fire test was done for this project.

6.2. Materials and Equipment

The composite material used in characterizing the Pyrolance consisted of F-16 horizontal stabilizers as described previously in Section 3.2, with the exception of evaluations to determine capability to pierce multiple composite panels. The multiple panel evaluation was conducted with carbon/epoxy composite material of 0.153 in thickness, however, unlike the F-16 stabilizer panels these samples were completely flat and of uniform thickness.

A Starrett model 799 micrometer was used to measure thickness of composite panels. A Traceable® Stopwatch model made by the Control Company was used to make all time measurements.

As mentioned previously, Pyrolance is an ultra-high-pressure system that consists of a portable, high-pressure Lance and a gasoline-powered, high-pressure pumping unit. It is a complete system built into a self-supporting frame that allows quick deployment and/or installation of the unit. System specifications are listed in Table 6. Communication between the lance and power unit was via a radio remote control system. The unit was supplied with 200 ft of high-pressure hose on a motor assisted hose reel. Penetrating was accomplished with a specially formulated aggregate called Pyroshot. Water was supplied from an external holding tank.

The Pyrolance used for this testing was modified with a feature that allowed the operator to decrease system pressure from 3500 lb/in^2 to 1500 lb/in^2 and to halt injection of garnet (aggregate PyroShot) once the water jet has penetrated the composite panel. This feature

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provides an added level of safety in the event that persons are located on the other side of the material being penetrated.

Table 6. Performance Specifications of the Pyrolance

P-1000 Unit Specifications	
Nominal Pump Flow	10 GPM (38 LPM)
Maximum Pressure	3500 PSI (241 BAR)
Engine	34 HP, Gasoline Powered
Installation Environment	Outdoor Mobile Vehicle, enclosed * or exposed * see Section 4.2 for installation requirements
Fuel Requirements	Unleaded Gasoline, 87 minimum octane
Fuel Tank Capacity	2.5 Gallons (9.5 Liters)
Remote Controls	2.4 GHz Line of site, radio frequency control
Water Inlet Pressure Limits	0 PSIG (Atmospheric Pressure) to 50 PSIG Max, (0 BAR to 3.5 BAR) *See Section 4.4.2 for further requirements*
Cutting Abrasive Requirements	Use only PyroShot Aggregate
Nozzle Diameter	0.062" (1.58mm)
Cutting Time *(per tank of Abrasive)*	Approximately 4 minutes
Overall Unit Dimensions (L x W x H)	36" x 36" x 36" (914 mm x 914 mm x 914 mm)
Hose Length	200 ft (60 m)
Power Unit Weight (Dry)	760 Lbs (345 kgs)
Lance Weight	21 lbs (10 kgs)

Information in this table was excerpted from the Pyrolance Operations Manual. (2)

6.3. Procedures

The system flow rate in piercing mode was set at the factory to 10 gal/min at 3500 psi; however, the flow rate in fire fighting mode (1500 psi) was not determined by Pyrolance prior to delivery. To confirm flow rate, the nozzle was discharged for approximately five seconds until a steady flow of 3% aqueous film forming foam (AFFF) agent was coming out of the nozzle, and then the discharge was directed into a 55 gallon drum for 30 s. The weight and volume of agent discharged were measured, and flow rate was calculated from the amount of discharge and the time elapsed. Two replicates were conducted to determine the flow rate in fire fighting mode. In conjunction with flow rate verification, discharged foam was collected in two cylinders, and 25% drainage time and expansion ratio were calculated in accordance with instructions in NFPA 412. Two replicates were done.

To ascertain the maximum fire extinguishment throw distance, a series of 12 × 18-in pans containing JP-8 were spaced at various intervals, and then the distance to the furthest pan fire extinguished was measured. All testing was conducted in the AFRL Test Range II Fire Hanger to avoid the effects of wind. The pans were 4 in deep and filled with 1 in of JP-8 floating on a 2 in layer of water (to cool the pans), which left 1 in of freeboard between the surface of the fuel and the top of the pan. The Pyrolance nozzle was clamped in a stand and positioned parallel to and 36 in above the floor. Fuel in the pans was ignited and allowed 30 s to pre-burn, and then a 6% AFFF solution (using 3% AFFF concentrate) was discharged for 60 s. After 60 s, the distance to the furthest pan fire extinguished was measured. The spacing of the pans was changed in subsequent tests to determine a more exact measure of throw distance, and then three additional

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replicates were done. In the final test, 2 ¾ in of water was topped with 1 in of JP-8 fuel to reduce the freeboard in the pan from 1 in to ¼ in. This was done to find out if the results would be different for a different freeboard; results were not different, and so additional replicates were not done. More detailed information about the procedure used for this evaluation is in Appendix D.

Finding the maximum piercing distance of the water jet stream between two F-16 composite panels was done with two composite panels secured in test stands and arranged parallel, starting at an interval of 5 ft. The lance was positioned against one composite sheet (Figure 24) and then discharged using water and garnet aggregate in piercing mode (10 gal/min and 3500 lb/in^2). Separation distance was increased and the procedure was repeated until a distance was reached at which the Pyrolance could not penetrate the second panel.

Figure 24. Setup for Two Composite Panel Penetration Evaluations

The investigation to determine how many successive composite panels the water jet stream could penetrate effectively was accomplished using eight composite panels of 0.153 in thickness secured 12 in apart in a stand specially designed for test, as shown in Figure 25. The stand was made from two pieces of 2 in thick plywood for the top and bottom, with cuts made 1 in deep every 12 in for setting the composite sheets. The Pyrolance was clamped in a stand, positioned against the first panel, and then discharged in penetration mode for 30 s. Afterward, the number of panels pierced was documented.

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Figure 25. Test Stand for Multiple Panel Composite Piercing

The Pyrolance was evaluated for its ability to suppress hidden fires by following the FAA Aircraft Cargo Compartment Minimum Performance Standard procedure for containerized fires. Boxes were stacked inside a mockup of a LD-3 container constructed of aluminum, sheet steel and Plexiglas (Figure 26). Two rectangular slots measuring12 × 3-in were cut into the LD-3 container in the center of the container front and in the center of the sloping sidewall for ventilation. Thermocouples were mounted on the four sidewalls of the container 8 in down from the top of the container and centered on the walls, one thermocouple was mounted in the center near the floor, and three thermocouples were equally spaced across the inside ceiling of the container, as shown in Figure 26. All thermocouples were 1/16 in stainless steel sheathed, K-type. The fire load consisted of 33 single-wall corrugated cardboard boxes, with nominal dimensions of 18 × 18 × 18-in. The weight per unit area of the cardboard was 16 lb/ft^2. The boxes were filled with 2.5 lb of loosely packed standard weight office paper shredded into strips. The flaps of the boxes were tucked under each other without using staples or tape. The boxes touched each other to prevent any significant air gaps between boxes (Figure 27). The boxes were conditioned to the temperature and humidity of the Fire Hangar where the tests were conducted. An ignition box, which consisted of a 7 ft length of nichrome wire wrapped around four folded (in half) paper towels, was used to start a fire inside the container by applying 115 VAC to the wire. The ignition box was located at the bottom of the container directly in front of the ventilation slot in the slanted portion of the container. Ten 1-in diameter ventilation holes were cut into the front face of the ignition box facing the ventilation slot on the LD-3 container (Figure 28).

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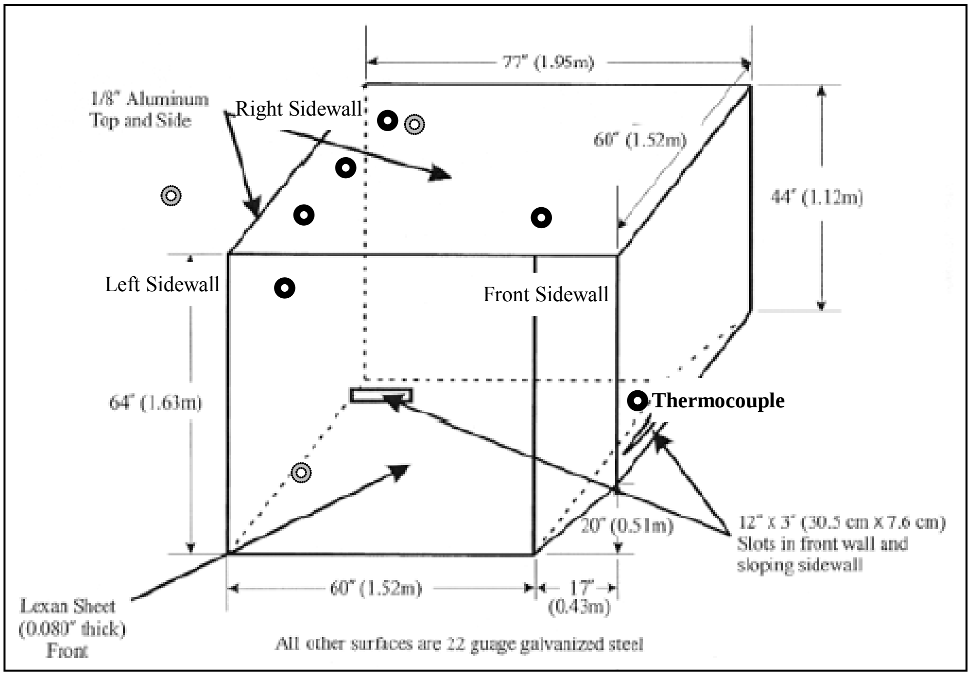

Figure 26. Diagram of an LD-3 Cargo Container

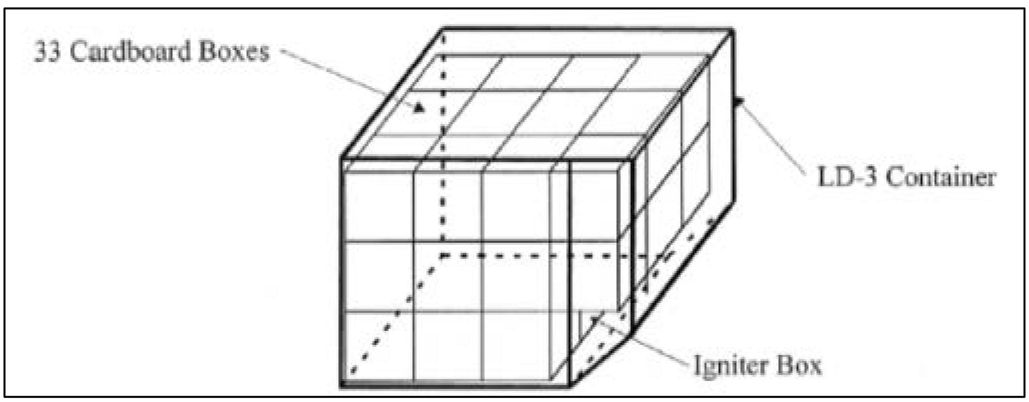

Figure 27. Setup for LD-3 Container Fire Test

The fire was started with the ignition system and allowed to burn until the ceiling temperature inside the container reached 200 °F. Agent application was started one minute later. The Pyrolance started in penetration mode using water or water/foam, depending on the test scenario, and aggregate to penetrate the cargo container exterior. Once breakthrough occurred, the aggregate was discontinued and the Pyrolance was operated in fire fighting mode (water and water/foam at 1500 psi). The Pyrolance was intended to be discharged until the water or water/foam was expended or the two interior and one ceiling thermocouples read ambient for a period of 60 s indicating fire extinguishment. Two trials were conducted. One trial was conducted using foam, and one trial was conducted using only water.

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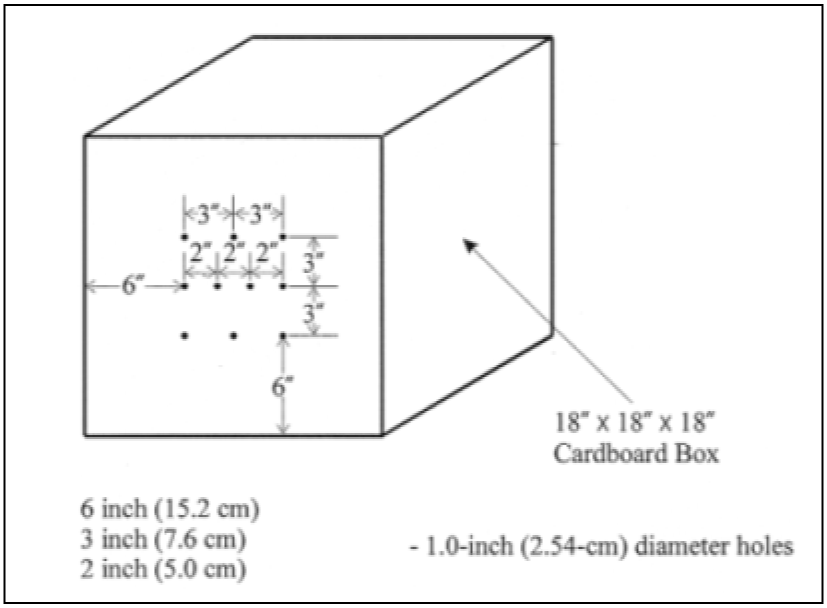

Figure 28. Ignition Box for LD-3 Container Fire

6.4. Results and Discussion

6.4.1. Pyrolance Flow Rate and Foam Characteristics

Two tests were conducted to determine the flow rate in fire fighting mode. The nozzle was discharged for approximately 5 s until a steady flow of 3% AFFF agent was coming out of the nozzle. The nozzle was then directed into a 55-gallon drum. The nozzle was removed after 30 s and the weight of the discharged agent was measured. Volume was calculated from the weight. The weight of the agent discharged in both trials was 18 lbs, which equated to a flow rate of 4.3 gal/min.

Two tests were also conducted to determine foam expansion ratio and drain time for the Pyrolance when operated in fire fighting mode. Table 7 shows the minimum expansion ratio and 25 percent drainage time requirements per NFPA 412 as well as the results of the tests conducted. NFPA 412 requires two samples per check, and since two separate checks were done there were a total of four measurements each for expansion ratio and drainage time. Expansion ratio averaged 2.9 for Test 1 and 3.0 for Test 2, and the NFPA 412 minimum is 3.0 for non-air aspirated foam. Twenty-five percent drainage time exceeded NFPA 412 minimum requirement of 1 min in all four cases.

Table 7. Pyrolance Flow Rate and Foam Quality Results

Test #	Nozzle Pressure (psi)	Flow Rate (gal/min)	NFPA Min Exp Ratio	Exp Ratio A/B	NFPA Min 25% Drain Time (min:s)	25% Drain Time A/B (min:s)
1	1500	4.3	3	2.8/2.9	1:00	4:00/3:23
2	1500	4.3	3	3.1/2.9	1:00	5:07/4:26

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6.4.2. Throw Distance

Using a set of 12 × 18-in pans containing JP-8 and positioned at different distances, it was determined that the maximum effective distance for fire extinguishment was 35 ½ ft. This result was based on three consecutive replicate test results. Appendix D is a more detailed description of the procedure and results.

6.4.3. Piercing Distance for Two Composite Panels

Figure 29 shows a piercing distance check in progress. Figure 30 shows the two panels used for determining maximum piercing distance. Six trials were completed to determine the distance, starting at 5 ft and working up to 9 ft (labeled T-1 and T-5 in Figure 30), which did not pierce the far panel. An additional test (T-6) was conducted at 8.5 ft, which also did not pierce the far panel. Therefore, the maximum distance was 8 ft. It can be seen in Figure 30 that the Pyrolance cut a small hole in the near panel and a much larger hole in the far panel as the water/aggregate stream started to disperse.

Figure 29. Testing the Effective Piercing Distance of Pyrolance

Table 8 shows the results for all six piercing tests including time to pierce the panels as well as the thickness of each sample. The thickness was consistent for the front sheets, however, the back sheets increased in thickness with each subsequent test. The Pyrolance showed a maximum piercing distance of 8 ft before the water/aggregate stream became too dispersed to be effective. Piercing both sheets took just over 20 s at a separation distance of 8 ft.

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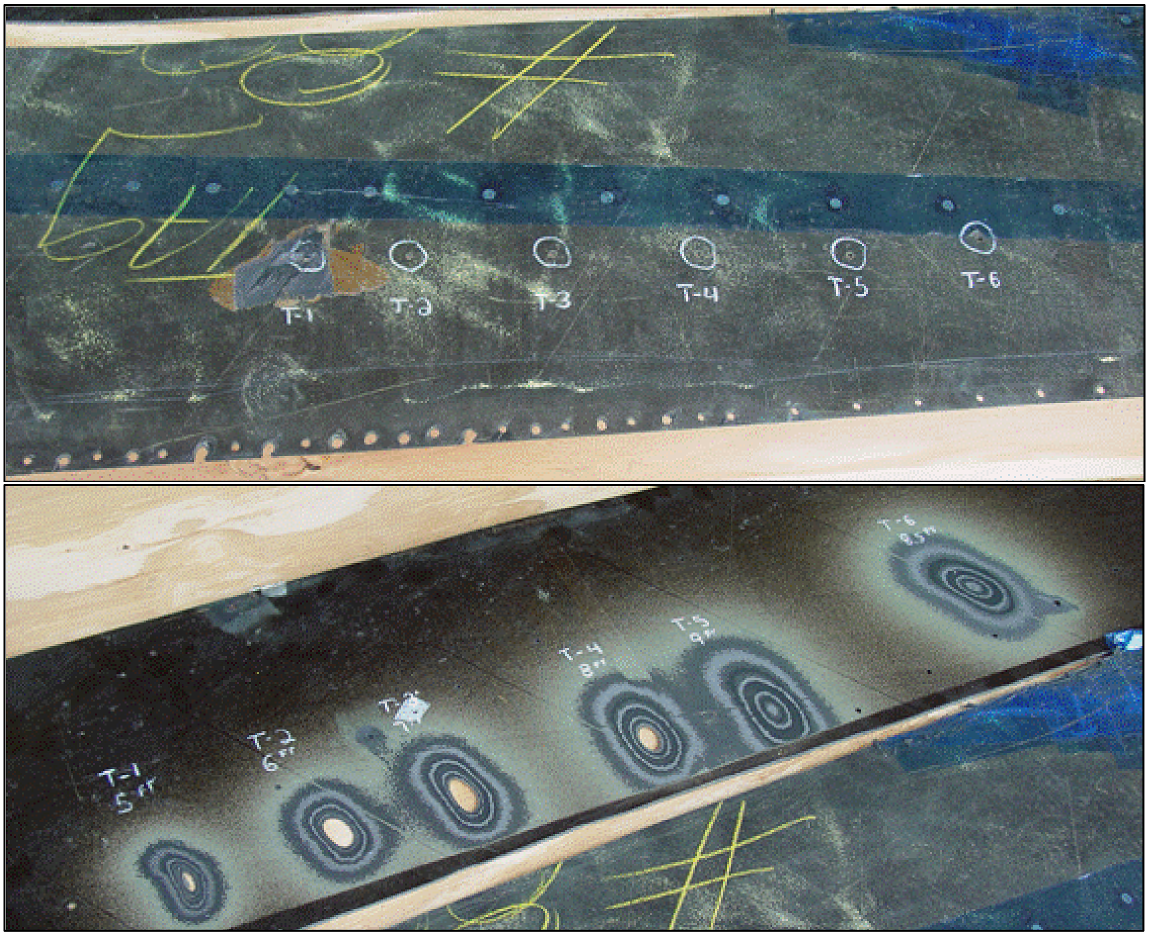

Figure 30. Panels Used for Maximum Penetration Distance Verification: (top) Near Panel; (bottom) Far Panel

Table 8. Maximum Piercing Distance Results

Test Number	Distance (ft)	Near Sheet		Far Sheet	
		Time (s)	Thickness (mm)	Time (s)	Thickness (mm)
T-1	5	3.9	1.61	3	1.9
T-2	6	0.9	1.61	5	1.98
T-3	7	1.0	1.61	11	2.11
T-4	8	0.3	1.61	20	2.32
T-5	9	0.2	1.61	70 **DNP**	2.24
T-6	8.5	0.9	1.61	64 **DNP**	2.62

DNP = Did Not Pierce

6.4.4. Multiple Panel Piercing

The Pyrolance was discharged using water and garnet aggregate in piercing mode. Five 0.153 in thick panels separated by 12 in between each panel were penetrated.

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6.4.5. Containerized Fire Suppression Test

In the first evaluation the Pyrolance was used to pierce the LD-3 container at the midpoint of the slanted side, the side of the container that is normally closest to the fuselage when loaded in an aircraft. Foam and water were used. Agent was discharged for 11 min 54 s until the water/foam tank was empty. Temperatures for each thermocouple are shown in Figure 31. As expected, the temperatures around the ignition box were highest (top left, top center and left side). The temperatures at the Left Side and Top Center increased to 312 °F and 336 °F, respectively, while the Top Left increased to 319 °F. With the exception of the Top Left thermocouple (reduced to 135-145 °F), all the other temperature measurements decreased to a range of 110-120 °F once agent was applied. While the Pyrolance decreased the temperature inside the container, it did not completely extinguish the fire and several boxes continued to smolder after the water/foam tank was empty.

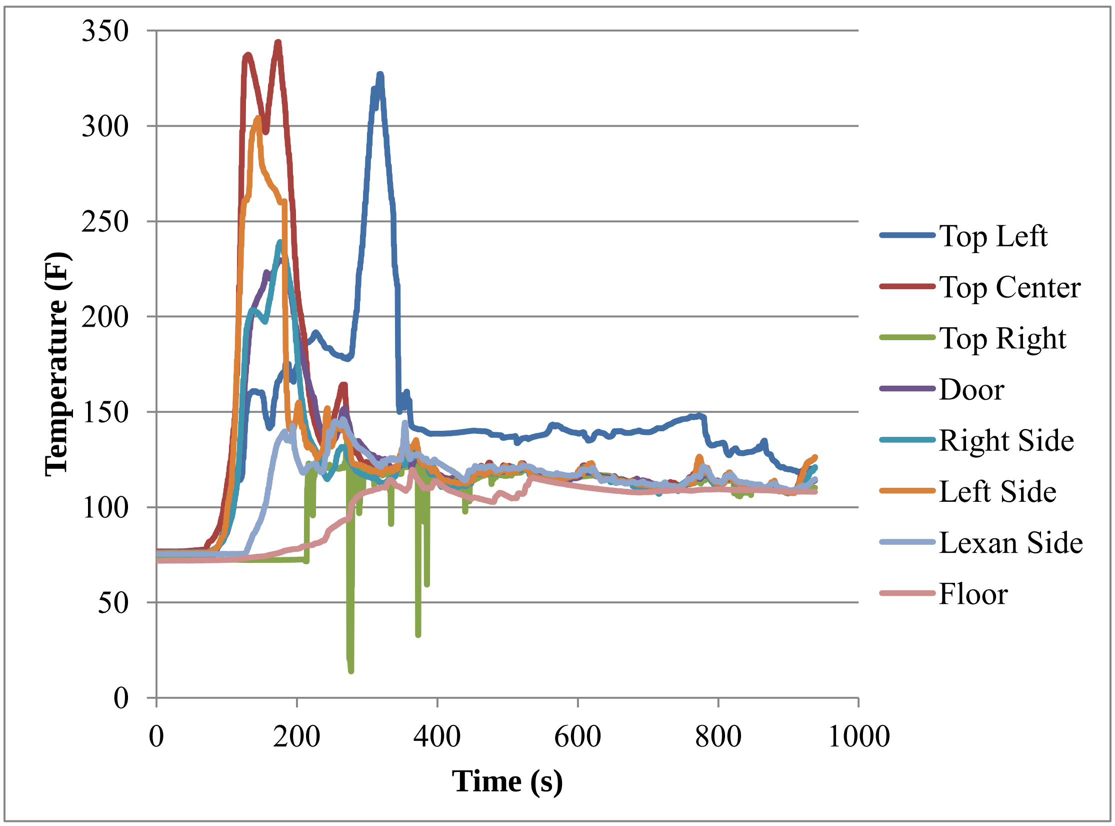

Figure 31. Temperatures during First Containerized Fire Test

A second containerized fire was conducted using the Pyrolance with water only and piercing multiple locations around the container. The operator was instructed to use his judgment and adjust the position and discharge time during testing to optimize fire fighting performance and attempt to extinguish the fire. The operator was instructed to continue discharge until the water tank was empty; however, the test was terminated when the aggregate tank became empty and no additional penetrations could be made through which water could be injected.

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The temperatures at each thermocouple location were recorded and are shown in Figure 32. The temperature measurements for the Lexan side were deleted due to the unusually high reading as a result of the thermocouple coming in contact with the melting plastic and not providing a valid measurement of the interior temperature at that location. The temperature measurements at the Top Center and Left Side increased in a similar manner to the first test, with maximum temperatures of 304 °F and 284 °F, respectively. However, unlike the first test, the Top Left temperature never exceeded 161 °F and the Right Side temperature reached a maximum of 220 °F. Also, the temperatures fluctuated for the duration of testing, suggesting that either the foam or the single, continuous application used in the first test was more effective in the fire suppression.

Video shows that the fires were diminished several times during testing however the fire was not completely extinguished. Discharge lasted approximately 8 min 22 s. The firefighter operating the Pyrolance stated that the lance was difficult to hold after several minutes due to the weight.

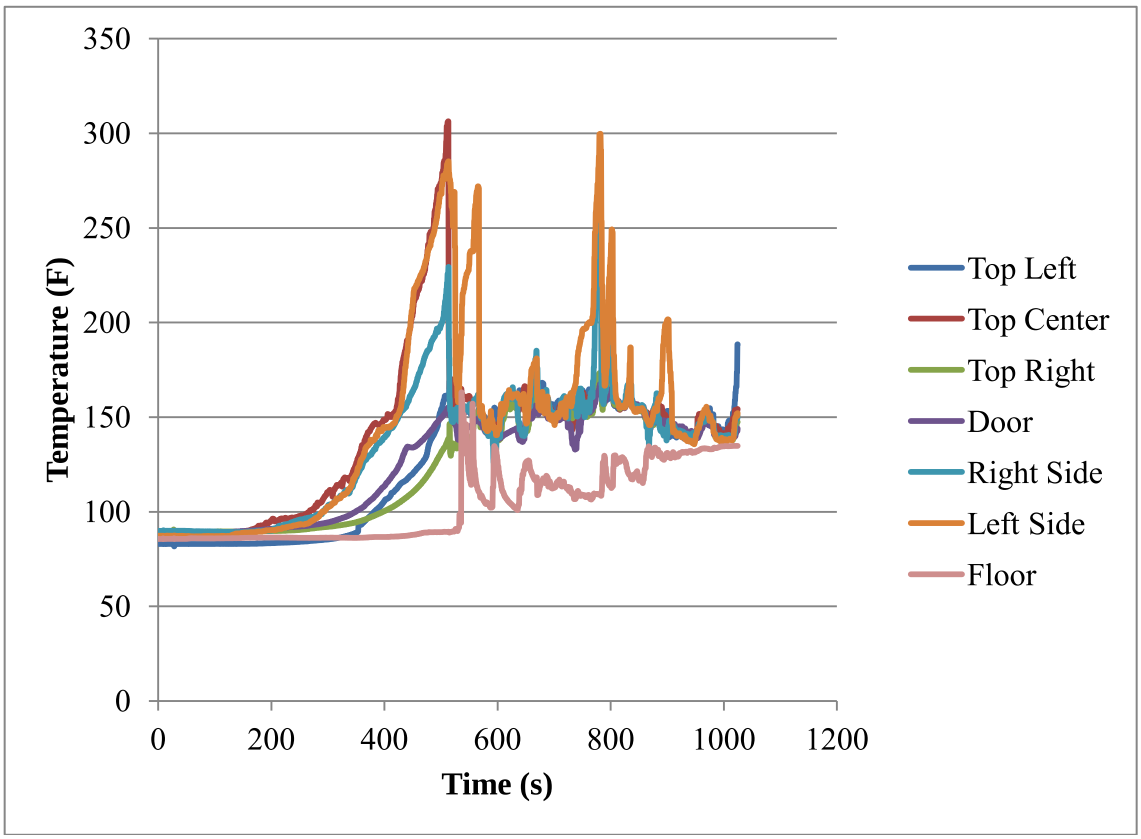

Figure 32. Temperatures during Second Containerized Fire Test

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7. CONCLUSIONS

Diamond coated reciprocating saw blades and diamond coated circular saw blades cut more carbon fiber epoxy composite than their corresponding carbide blades. Diamond coated blades cost less per foot of cut, and they last longer and require less changing, which saves time at the scene and inventory storage space. The speeds at which the saws cut decrease as the thickness of the composite increases, for both the diamond and carbide blades.

Enough heat is generated when cutting carbon fiber and epoxy composite to warp the saw blades, and water should be used to constantly cool the blades during cutting. If water is not available, cutting operations should be limited to one minute intervals with break periods to allow the blades to cool to the touch before cutting is resumed.

A circular saw, with either diamond coated or carbide blades can cut a structurally reinforced composite door from a B-2 aircraft. However, 12 in blades do not have sufficient radius to cut completely through the thickest sections of a B-2 door.

A 6-in diameter diamond coated hole saw is capable of cutting holes through 0.25 in thick composite in about 23 s. The blade can be used with a standard handheld drill so no special equipment is needed. The blade is susceptible to bending if dropped or mishandled, which can cause the blade to be out of round and make the blade difficult or impossible to use. The THK Diamond Tools 6-in diamond coated hole saw used for this work suffered from premature failure of the built-in pilot drill, which rendered the blade unusable after 3.35 in of cumulative cutting even though there was very little wear to the blade itself. Based on blade wear, it is estimated that the THK blade could have cut a total of 39 in had the pilot drill bit not failed.

Access holes can be cut in carbon fiber and epoxy composite up to 0.13 in thick and in aluminum up to 0.05 in thick with a pry axe, though it takes much longer than when using a saw. In this study, a firefighter was not able to cut 0.08 in thick 5052-H32 aluminum.

The Pyrolance is a unique combination of piercing tool and extinguisher. It is very cumbersome to use for making large area cuts, but is very easy to use to pierce a fuselage or engine nacelle and then to apply water or foam to a hard to access fire. It can pierce two composite panels, typical of what would be found on an aircraft, separated by 8 ft. It is also capable of penetrating five 0.153 in thick composite panels set at 1 ft intervals. It has a maximum effective firefighting range of 35.5 ft. Foam quality from the Pyrolance meets NFPA requirements for 25 percent drainage time, but does not meet the requirement for expansion ratio. In this study, the Pyrolance system was not able to fully extinguish fires inside an LD-3 cargo container full of cardboard and paper; however, the system did lower temperatures inside the container.

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8. RECOMMENDATIONS

ARFF units should carry diamond coated reciprocating and circular saw blades to use in responding to emergencies involving aircraft constructed with large amounts of fiber reinforced composite material. Units should consider carrying diamond coated hole saw blades and a drill motor for cutting access holes in composite material. While cutting composite material, saw blades should be cooled with water.

Additional studies should be conducted by the Air Force to investigate the effectiveness of the Pyrolance to extinguish various aircraft compartment fires using water, water/foam and heat absorbing gels (4) (5). In this study the PyroLance was evaluated primarily for its cutting and piercing capability and not for its firefighting success.

There are several recommendations for improvements to the Pyrolance.

- Based on previous studies of fighting fires with ultra high pressure technology, it is recommended that the minimum flow rate of the system in firefighting mode be at least 10 gal/min.
- Lower the weight of the lance to make the equipment easier to handle and to reduce fatigue to firefighters who use the system.
- The shoulder support for the lance rests on the gauges located on the right shoulder of the Mine Safety Appliances (MSA) self-contained breathing apparatus (SCBA). The MSA SCBA is in use throughout the Air Force, and therefore a modified shoulder support needs to be developed that will not interfere with the equipment.
- Install a power switch for the lance so that the batteries do not drain while not in use.
- Install an alternator to recharge the battery used to start the system.
- Resolve the issue with the aggregate mixing with the water when not engaged.

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9. REFERENCES

1. National Fire Protection Association. Standard for Aircraft Rescue and Fire-Fighting Services at Airports. Quincy : NFPA, 2009. NFPA 403.

2. PYROLANCE North America LLC. Operations Manual Pyrolance Model P-1000. Centennial, CO: Pyrolance, 2008.

3. National Fire Protection Association. Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment. Quincy : NFPA, 2009. NFPA 412.

4. Reinhardt, J.W., Blake, D. and T. Marker. Development of a Minimum Performance Standard for Aircraft Cargo Compartment Gaseous Suppression Systems. s.l. : Office of Aviation Research, September 2000. DOT/FAA/AR-00/28.

5. Pickett, Brent. Firefighting and Emergency Response Study of Advanced Composites Aircraft; Objective 2: Firefighting Effectiveness of Technologies and Agents on Composite Aircraft Fires. 2012. AFRL-RX-TY-TR-2011-0047; ADA554343.

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Appendix A: Toxicity Characteristic Leaching Procedures

The F-16 composite sheets were tested for any hazardous metals that might leach out as a result of cutting, requiring additional disposal considerations. The F-16 SPO informed AFRL that the paint used on the sheets contained chromium, which is classified as a hazardous heavy metal. The majority of the paint had been removed from the sheets prior to shipping to AFRL, but testing was still conducted to verify disposal procedures. Four samples were sent for testing including light paint, heavy paint both uncharred and charred. According to the Environmental Protection Agency, the TCLP limit for chromium is 5.0 mg/L. Testing showed that none of the samples exceeded the limits; however, as a precautionary measure no heavily painted stabilizer panels were cut or penetrated (Table A-1).

Table A-1. TCLP Test Results for F-16 Composite Sheets

Sample Type	Chromium (mg/L)
Light Paint, Uncharred	0.31
Heavy Paint, Uncharred	0.92
Light Paint, Charred	2.3
Heavy Paint, Charred	4.5

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Appendix B: Raw Data from Saw Performance Evaluations

F-16 stabilizer composite panels used in evaluating the reciprocating and circular saws varied in thickness. A micrometer was used to measure the average thickness across the length of each composite strip that was cut.

Table B-1. F-16 Composite Sheet Thickness

Cut Number	Average Thickness (in)	Length (in)	Cut Number	Average Thickness (in)	Length (in)
1	0.06	63	17	0.15	30
2	0.06	64.25	18	0.17	30
3	0.06	65.25	19	0.17	30
4	0.07	66.25	20	0.19	30
5	0.07	67.5	21	0.19	30
6	0.07	68.75	22	0.21	30
7	0.08	69.25	23	0.22	30
8	0.08	69.25	24	0.24	30
9	0.09	69.25	25	0.25	30
10	0.09	69.25	26	0.25	30
11	0.10	69.25	27	0.25	30
12	0.10	69.25	28	0.25	30
13	0.11	69.25	29	0.25	30
14	0.11	69.25	30	0.25	30
15	0.11	69.25	31	0.24	29
16	0.14	31	32	0.24	29

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Table B-2. Reciprocating Saw Raw Data

Cut # Sample 1	Cut Length (in)	Time of Cut, Diamond (s)	Time of Cut, Carbide (s)	Cut # Sample 2	Cut Length (in)	Time of Cut, Diamond (s)	Time of Cut, Carbide (s)	Cut # Sample 3	Cut Length (in)	Time of Cut, Diamond (s)	Time of Cut, Carbide (s)
1	63	57.46	33.71	1	63	39.19	47.61	1	63	39.14	
2	64.25	60.34	24.18	2	64.25	41.06	44.09	2	64.25	37.08	
3	65.25	57.03	26.47	3	65.25	40.24	50.37	3	65.25	43.46	
4	66.25	57.69	27.53	4	66.25	48.5	57.76	4	66.25	40.62	
5	67.5	57.25	33.40	5	67.5	50.82	59.47	5	67.5	43.52	
6	68.75	61.48	35.50	6	68.75	59	108.68	6	68.75	45.84	
7	69.25	66.65	38.69	7	69.25	63.19	128.87	7	69.25	49.08	
8	69.25	69.06	41.50	8	69.25	71.44	139.60	8	69.25	52.71	
9	69.25	75.56	48.57	9	69.25	87.9	208.08	9	69.25	61.34	
10	69.25	81.57	51.41	10	69.25	80.12	212.84	10	69.25	67.2	
11	69.25	93.16	61.56	11	69.25	94.58	252.21	11	69.25	70.46	
12	69.25	91.58	78.75	12	69.25	91.6		12	69.25	70.18	
13	69.25	98.91	78.32	13	69.25	93.81	Carbide blade could not cut additional material.	13	69.25	74.65	Carbide blade could not cut additional material.
14	69.25	103.03	83.17	14	69.25	106.5		14	69.25	88.78	
15	69.25	119.79	100.58	15	69.25	121.31		15	69.25	93.18	
16	31	48.19	49.76	16	31	63.6		16	31	44.81	
17	30	57.09	55.00	17	30	56.63		17	30	57.65	
18	30	64.54	97.16	18	30	70.11		18	30	59.77	
19	30	70.27	85.25	19	30	75.68		19	30	64.43	
20	30	76.61	121.16	20	30	97.25		20	30	80.21	
21	30	96.31	120.57	21	30	110.76		21	30	81.14	
22	30	117.75	182.72	22	30	120.68		22	30	90.43	
23	30	157.32	245.53	23	30	118.82		23	30	94.52	
24	30	126.62	247.35	24	30	122.46		24	30	108.3	
25	30	120.19	Additional cuts at this thickness could not be made with carbide blade.	25	30	132.28		25	30	119.71	
26	30	140.32		26	30	144.71		26	30	105.52	
27	30	137.59		27	30	137.9		27	30	98.52	
28	30	108.1		28	30	144.89		28	30	121.65	
29	30	116.06		29	30	133.76		29	30	102.9	
30	30	121.39		30	30	121.93		30	30	115.8	
31	29	111.62		31	29	114.66		31	29	117.14	
32	29	112.2		32	29	129.41		32	29	115.33	

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Table B-3. Circular Saw Raw Data

Cut # Sample 1	Cut Length (in)	Time of Cut, Diamond (s)	Time of Cut, Carbide (s)	Cut # Sample 2	Cut Length (in)	Time of Cut, Diamond (s)	Time of Cut, Carbide (s)	Cut # Sample 3	Cut Length (in)	Time of Cut, Diamond (s)	Time of Cut, Carbide (s)
1	63	13.08	16.22	1	63	11.37	9.18	1	63	10.52	
2	64.25	11.29	16.85	2	64.25	10.2	7.69	2	64.25	10.08	
3	65.25	8.79	17.59	3	65.25	10.81	7.76	3	65.25	11.24	
4	66.25	11.93	19.69	4	66.25	9.21	7.73	4	66.25	11.18	
5	67.5	11.15	14.43	5	67.5	8.37	6.99	5	67.5	10.05	
6	68.75	10.70	13.38	6	68.75	9.15	11.21	6	68.75	11.81	
7	69.25	14.88	13.18	7	69.25	9.22	8.83	7	69.25	13.08	
8	69.25	12.78	18.16	8	69.25	12.33	8.43	8	69.25	13.11	
9	69.25	12.78	16.75	9	69.25	9.11	8.44	9	69.25	13.08	
10	69.25	15.41	15.46	10	69.25	10.01	9.17	10	69.25	13.93	
11	69.25	17.6	17.19	11	69.25	10.4	9.24	11	69.25	11.68	Carbide blade could not cut additional material.
12	69.25	13.09	15.43	12	69.25	10.08	9.00	12	69.25	13.65	
13	69.25	14.57	17.59	13	69.25	12.97	10.12	13	69.25	10.87	
14	69.25	15.75	16.53	14	69.25	14.68	8.68	14	69.25	13.4	
15	69.25	14.87	17.75	15	69.25	16.12	9.82	15	69.25	13.34	
16	31	14.13	16.5	16	31	9.43	6.52	16	31	7.43	
17	30	6.58	13.38	17	30	6.86	5.26	17	30	7.21	
18	30	5.56	22.22	18	30	6.7	5.14	18	30	7.24	
19	30	6.82	15.07	19	30	7.6	6.22	19	30	7.49	
20	30	8.09	11.1	20	30	7.53	7.62	20	30	6.87	
21	30	6.72	10.59	21	30	6.34	10.59	21	30	8.3	
22	30	5.66	13	22	30	6.5	7.48	22	30	6.87	
23	30	6.12	13.58	23	30	6.97	8.28	23	30	8.93	
24	30	7.13	10.65	24	30	6.73	9.34	24	30	8.24	
25	30	5.88	9.97	25	30	6.71	8.18	25	30	7.11	
26	30	6.09	8.59	26	30	6.47	7.59	26	30	7.49	
27	30	6.31	12.56	27	30	6.43	7.34	27	30	7.9	
28	30	6.65	10.63	28	30	8.03	7.37	28	30	7.37	
29	30	6.41	8	29	30	7.4	5.81	29	30	7.99	
30	30	5.41	8.25	30	30	6.44	7.22	30	30	7.24	
31	29	5.75	8.5	31	29	6.03	7.00	31	29	8.84	
32	29	6.00	9.56	32	29	6.64	5.98	32	29	7.37	

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Table B-4. Hole Saw Raw Data

Cut #	Cut Depth (in)	Time of Cut (s)	Speed of Cut (in/s)
1	0.062	23	0.0027*
2	0.069	7	0.0099
3	0.073	6	0.0121
4	0.075	6	0.0125
5	0.077	6	0.0129
6	0.087	8	0.0108
7	0.089	7	0.0128
8	0.095	9	0.0106
9	0.090	8	0.0113
10	0.094	9	0.0105
11	0.099	10	0.0099
12	0.103	10	0.0103
13	0.106	10	0.0106
14	0.107	10	0.0107
15	0.113	12	0.0094
16	0.120	10	0.0120
17	0.101	10	0.0101
18	0.108	12	0.0090
19	0.119	9	0.0133
20	0.136	8	0.0170**
21	0.140	11	0.0127
22	0.157	11	0.0142
23	0.174	13	0.0134
24	0.128	13	0.0098
25	0.165	18	0.0092
26	0.209	18	0.0116
27	0.244	31	0.0079
28	0.269	34	0.0079
Total	3.35		
		Average	0.0110
		σ_s	0.0017

*This data point is an outlier. On the first cut with this device, there was a significant delay getting the pilot drill bit to bite into the material due to operator inexperience.
**This data point was also an outlier, but there is no explanation for why the speed of cut was much faster than for other penetrations. Both outlier data points were omitted in the calculation of average speed of cut and sample standard deviation.

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Appendix C: Blade Wear Data Reports

IMR Test Labs - Charleston
4500 Leeds Avenue, Suite 306, Dock 70
Charleston, SC 29405

Phone 843.740.2901 Fax 843.745.1165
Email imr@imrcharleston.com

September 04, 2009

Jennifer Schroeder
Air Force Research Lab
Fire Research Group
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32403

PO Number
KAL082009

Date Received
August 18, 2009

(1) Circular Saw Blade
NDL 18772

(1) Circular Saw Blade
CTB 113 3 / 4 - 24

(1) Hole Saw Blade P26761

(1) Reciprocating Saw Blades
Lenox Diamond 800 RDG

(1) Reciprocating Saw Blades
Lenox Iron & Abrasive 800 RG

TEST REPORT

IMR Report Number 90869

SUMMARY
Five separate saw blades were received for measurements prior to use. The blades were identified as (1) Circular Saw NDL 18772, (1) Circular Saw CTB 11 3 / 4 – 24, (1) Lenox Diamond 800RDG, (1) Lenox Iron & Abrasive 800RG and (1) Hole Saw P26761. Measurements were taken on each blade at various positions, which were documented to allow repeat measurement after use.

The results are provided on the following page(s).

Reviewed by

Charles White
Metrology Lab Manager

Reviewed by

Melissa Gainey
Lab Manager / Quality Director

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Circular Saw NDL 18772 – Before Test

Tooth #	Position # 1 (mm)	Position # 2 (mm)	Position # 3 (mm)
1	7.193	7.062	7.262
2	7.072	7.211	7.188
3	7.137	7.175	7.153
4	7.377	7.211	7.202
5	7.099	7.212	7.333
6	7.111	7.101	7.142

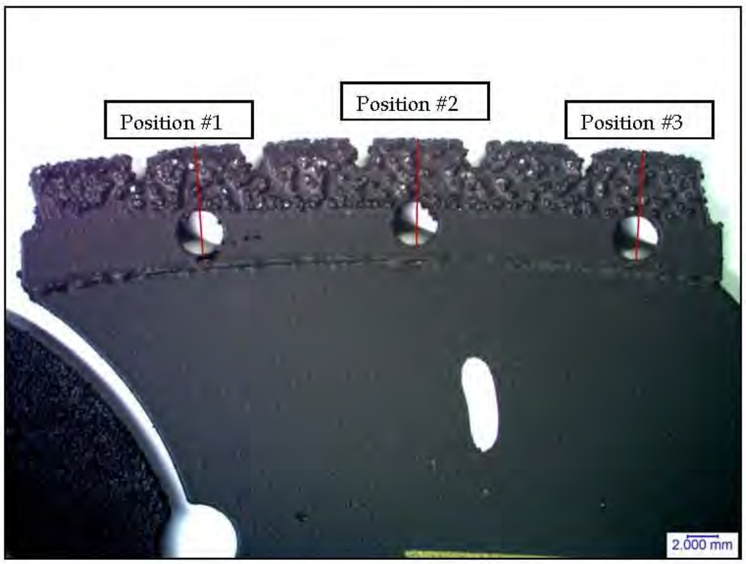

Figure 1: Macrograph of Circular Saw NDL 18772, before testing, showing position locations

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Circular Saw CTB 11 3/4 – 24 – Before Test

Tooth #	Position # 1 (mm)	Position # 2 (mm)	Position # 3 (mm)	Position # 4 (mm)
1	2.415	7.876	2.736	27.058
2	2.482	7.855	2.859	27.115
3	2.438	7.832	2.714	25.841
4	2.448	7.810	2.769	26.732
5	2.426	7.910	2.603	26.388
6	2.393	7.766	2.615	27.084

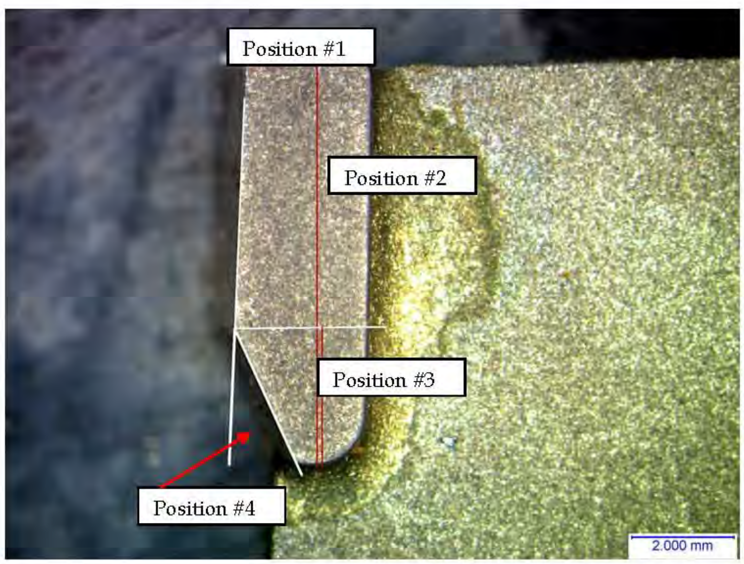

Figure 2: Macrograph of Circular Saw CTB 11 ¾-24, before testing, showing position locations

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Lenox Diamond 800RDG – Before Test

Position #	Results (mm)
1	19.530
2	19.648
3	19.532
4	19.492
5	19.488
6	19.516

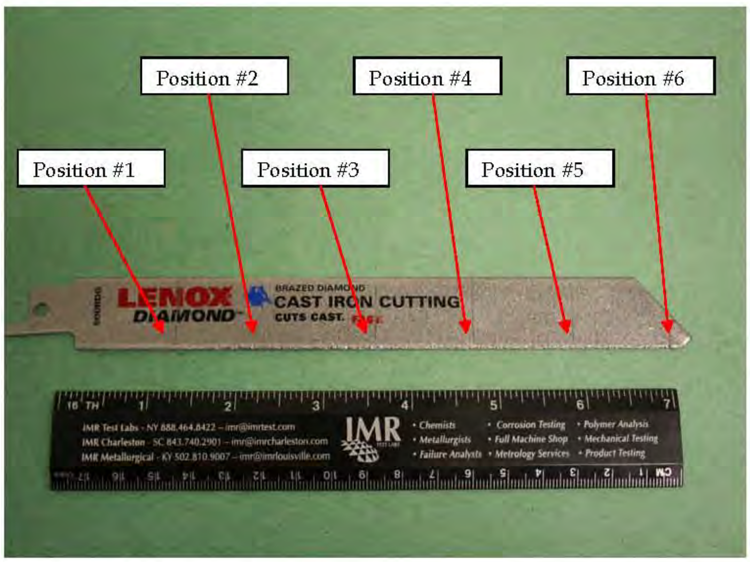

Figure 3: Macrograph of Lenox Diamond 800RDG before testing, showing position locations

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Lenox Iron & Abrasive 800RG – Before Test

Position #	Results (mm)
1	19.790
2	19.646
3	19.768
4	19.736
5	19.720
6	19.802

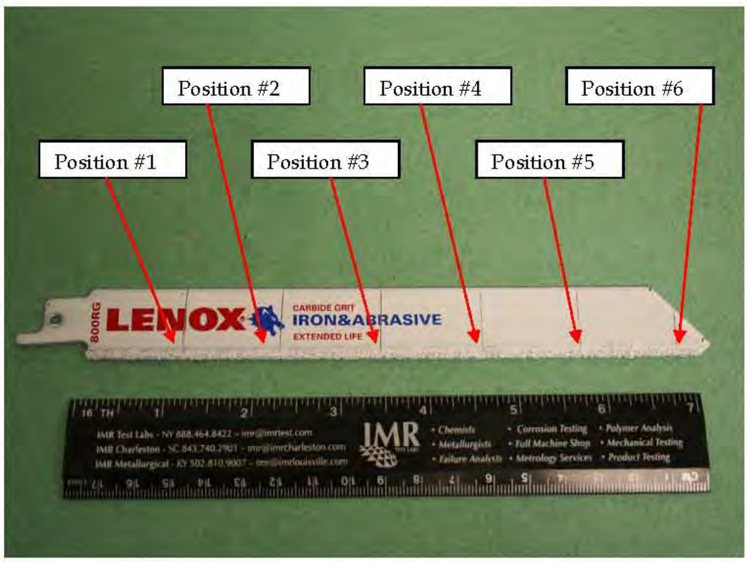

Figure 4: Macrograph of Lenox Iron & Abrasive 800RG before testing, showing position locations

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Hole Saw P26761 – Before Test

Position #	Results (mm)
1	64.826
2	64.888
3	64.934
4	64.922
5	64.966
6	65.142

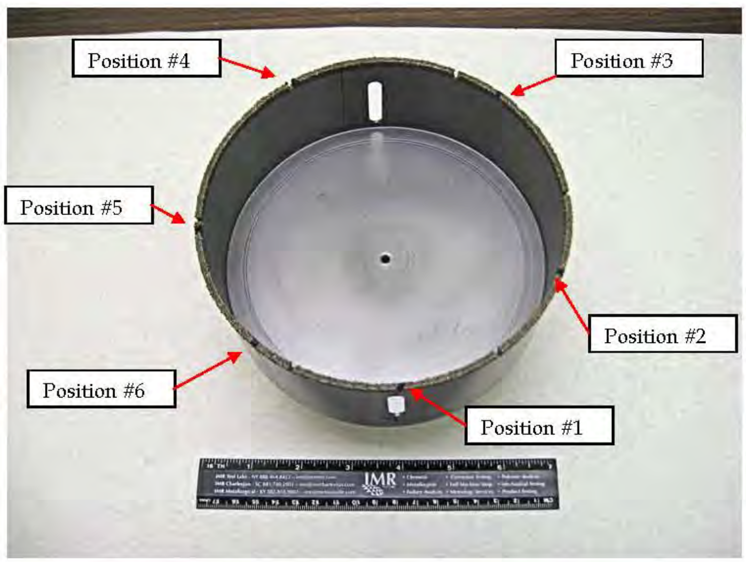

Figure 5: Macrograph of Hole Saw P26761 before testing, showing position locations

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IMR Test Labs - Charleston
4500 Leeds Avenue, Suite 306, Dock 70
Charleston, SC 29405

Phone 843.740.2901 Fax 843.745.1165
Email imr@imrcharleston.com

February 9, 2010

Jennifer Schroeder
Air Force Research Lab
Fire Research Group
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32403

PO Number
KAL012710

Date Received
February 4, 2010

Sample ID Before Test
(1) Circular Saw Blade NDL 18772 no. 2
(1) Circular Saw CTB 11 ¾- 24 no. 2
(1) Hole Saw (152 mm)

Sample I.D. After Test
(1) Lenox Diamond 800RDG
(1) Lenox Iron & Abrasive 800 RG
(1) Circular Saw NDL 18772
(1) Circular Saw CTB 11 ¾- 24.

TEST REPORT

IMR Report Number 100121

SUMMARY
Three separate saw blades were received for measurements prior to use along with four separate saw blade for after test measurements. The prior to use blades were identified as (1) Circular Saw NDL 18772 no. 2, (1) Circular Saw CTB 11 3 / 4 – 24 no. 2 and (1) Hole Saw (152 mm). The "after test" blades were identified (1) Lenox Diamond 800RDG, (1) Lenox Iron & Abrasive 800 RG, (1) Circular Saw NDL 18772 and (1) Circular Saw CTB 11 3 / 4 – 24. Measurements were taken on various blade at various positions, which were documented to allow repeat measurement after use. "Before data" for Lenox Diamond 800RDG, Lenox Iron & Abrasive 800RG, Circular Saw NDL 18772 and Circular CTB 11 ¾-24 was performed on IMR Report 90869

Reviewed by

Charles White
Senior Laboratory Specialist

Reviewed by

Melissa Gainey
Sr. Quality Specialist

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Circular Saw NDL 18772 No. 2 – Before Test

Tooth #	Position # 1 (mm)	Position # 2 (mm)	Position # 3 (mm)
1	7.196	7.063	7.196
2	7.067	7.238	6.968
3	7.121	7.177	7.120
4	7.064	6.897	7.132
5	7.231	7.118	7.080
6	7.288	7.006	7.070

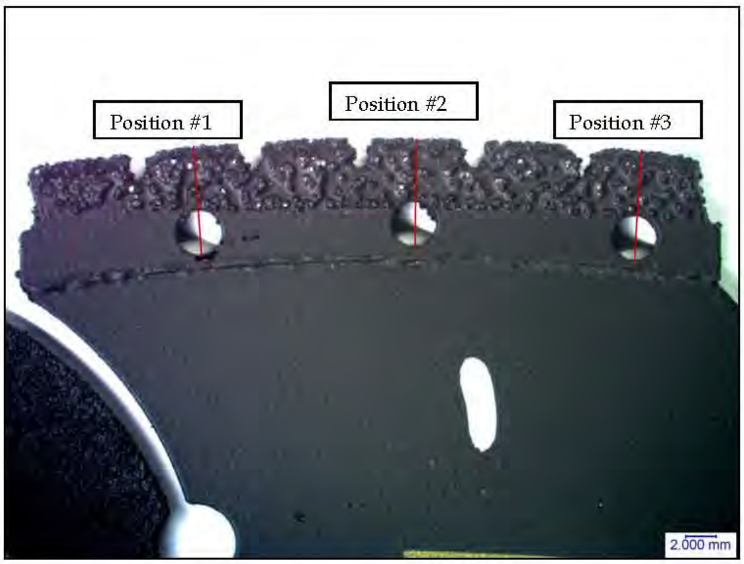

Figure 1: Macrograph of Circular Saw NDL 18772 no. 2, before testing, showing position locations

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Circular Saw CTB 11 3/4 – 24 no. 2 – Before Test

Tooth #	Position # 1 (mm)	Position # 2 (mm)	Position # 3 (mm)	Position # 4 (degree)
1	2.326	7.979	2.513	23.495
2	2.409	8.009	2.476	22.650
3	2.426	8.042	2.492	22.848
4	2.410	8.026	2.476	24.570
5	2.394	8.026	2.542	24.921
6	2.343	7.959	2.493	23.851

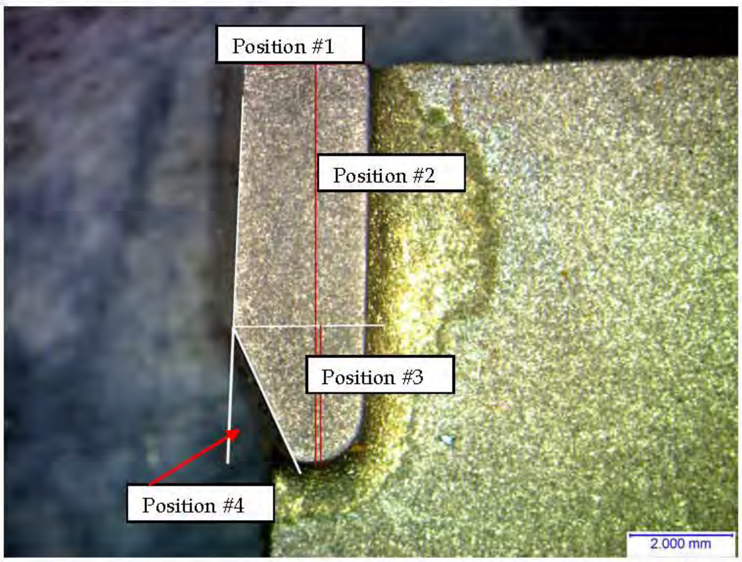

Figure 2: Macrograph of Circular Saw CTB 11 ¾-24 no. 2, before testing, showing position locations

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88ABW-2012-1278, 12 March 2012

Hole Saw 152 mm – Before Test

Position #	Results (mm)
1	35.454
2	35.592
3	35.412
4	35.788
5	35.460
6	35.620

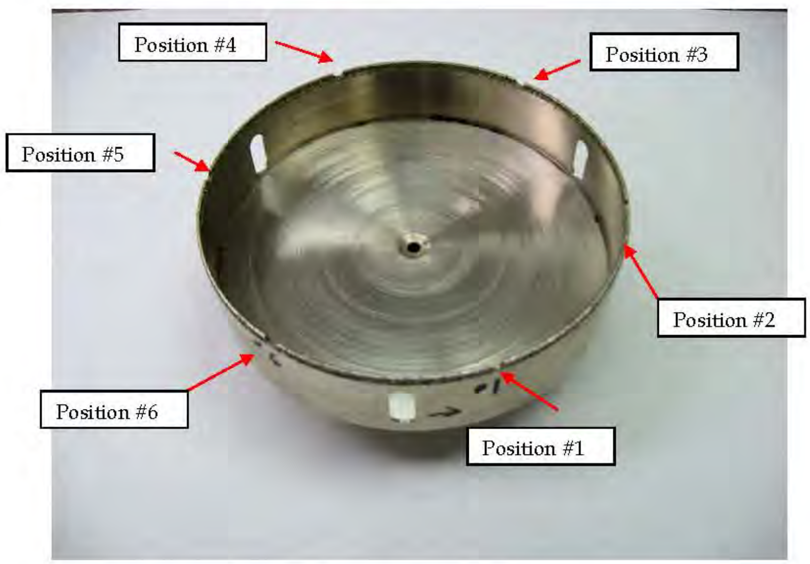

Figure 3: Macrograph of Hole Saw 152 mm before testing, showing position locations

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88ABW-2012-1278, 12 March 2012

Lenox Diamond 800RDG

Position #	Results Before Test (mm)	Results After Test (mm)
1	19.530	19.450
2	19.648	19.550
3	19.532	19.488
4	19.492	19.352
5	19.488	19.362
6	19.516	19.440

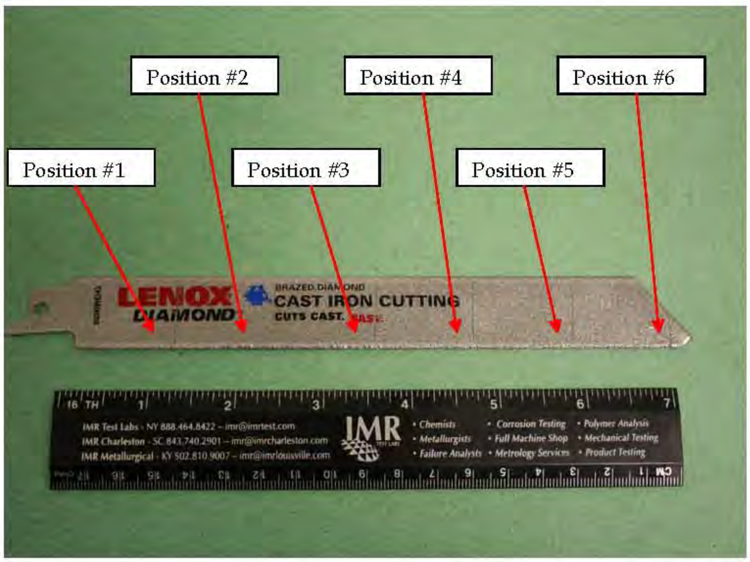

Figure 4: Macrograph of Lenox Diamond 800RDG before and after testing position locations

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Lenox Iron & Abrasive 800RG

Position #	Results Before Test (mm)	Results After Test (mm)
1	19.790	19.580
2	19.646	19.550
3	19.768	19.498
4	19.736	19.474
5	19.720	19.582
6	19.802	19.630

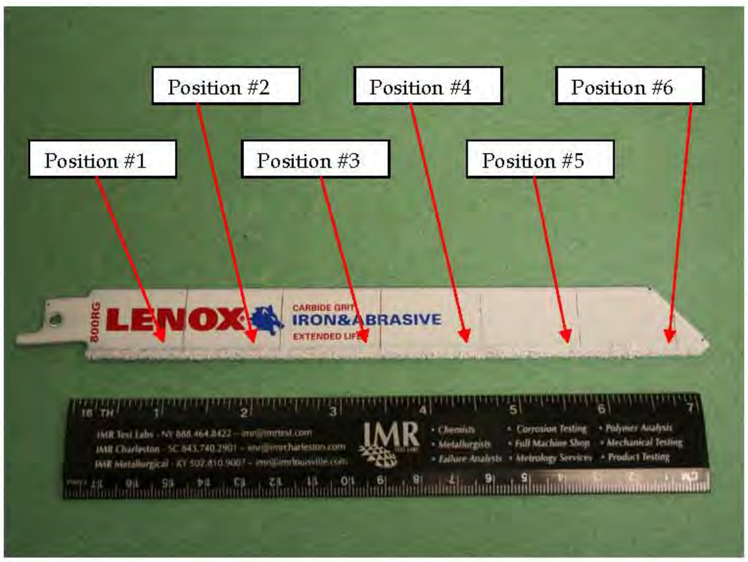

Figure 5: Macrograph of Lenox Iron & Abrasive 800RG before and After test position locations

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88ABW-2012-1278, 12 March 2012

Circular Saw NDL 18772

Tooth #	Position #1 Before Test (mm)	Position # 1 After Test (mm)	Position # 2 Before Test (mm)	Position # 2 After Test (mm)	Position # 3 Before Test (mm)	Position # 3 After Test (mm)
1	7.193	7.143	7.062	7.044	7.262	7.189
2	7.072	7.064	7.211	7.063	7.188	7.118
3	7.137	7.062	7.175	6.912	7.153	7.062
4	7.377	7.231	7.211	7.185	7.202	7.099
5	7.099	6.964	7.212	7.179	7.333	7.232
6	7.111	6.895	7.101	7.020	7.142	6.951

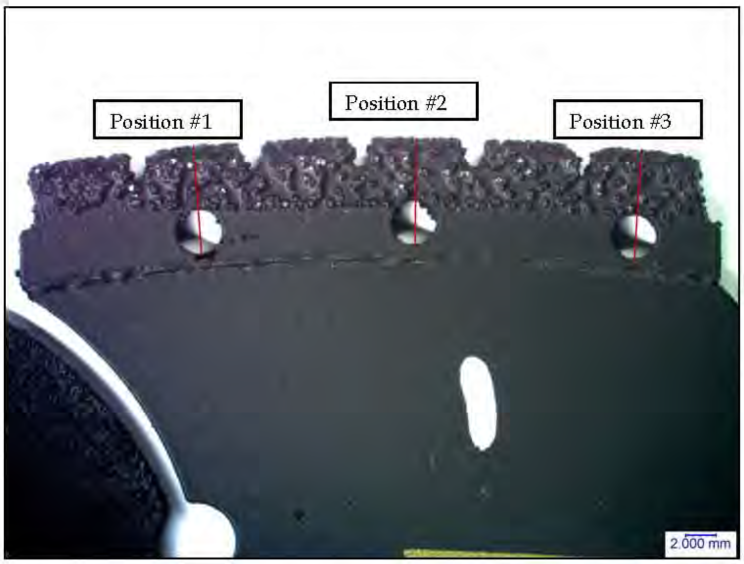

Figure 6: Macrograph of saw blade, showing before and after testing position locations

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Circular Saw CTB 11 3/4 – 24

Tooth No.	Position # 1 Before Test (mm)	Position # 1 After Test (mm)	Position # 2 Before Test (mm)	Position # 2 After Test (mm)	Position # 3 Before Test (mm)	Position # 3 After Test (mm)	Position # 4 Before Test (mm)	Position # 4 After Test (degree)
1	2.415	2.331	7.876	7.717	2.736	2.546	27.058	25.525
2	2.482	2.311	7.855	7.703	2.859	2.768	27.115	26.402
3	2.438	2.349	7.832	7.741	2.714	2.554	25.841	27.237
4	2.448	2.270	7.810	7.783	2.769	2.467	26.732	26.720
5	2.426	2.309	7.910	7.680	2.603	2.440	26.388	26.683
6	2.393	2.375	7.766	7.623	2.615	2.493	27.084	27.320

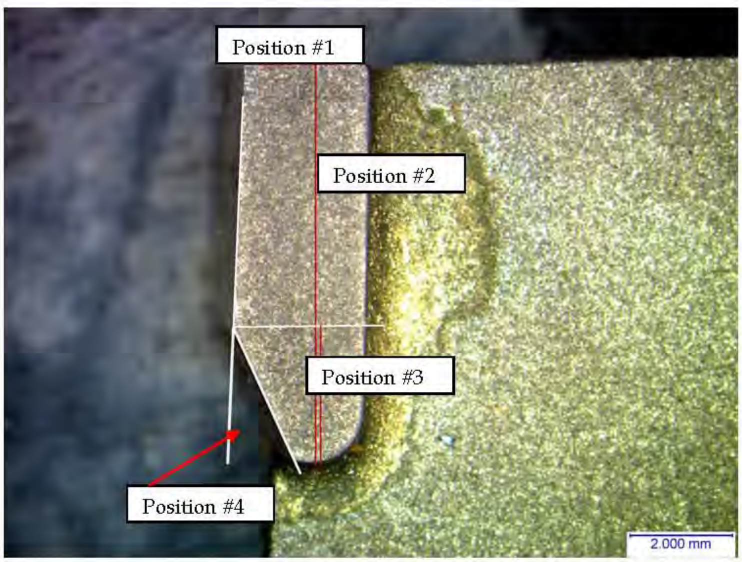

Figure 7: Macrograph of Circular Saw CTB 11 ¾-24, before and after testing position locations

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IMR Test Labs - Charleston
4500 Leeds Avenue, Suite 306, Dock 70
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Phone 843.740.2901 Fax 843.745.1165
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March 22, 2010

Jennifer Schroeder
Air Force Research Lab
Fire Research Group
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32403

PO Number
KAL031210

Date Received
March 17, 2010

Description
(1) Circular Saw NDL 18772 no. 2
(1) Circular Saw CTB 11 ¾-24 no. 2
(1) Hole Saw 152 mm

TEST REPORT

IMR Report Number 100305

SUMMARY
Three separate saw blades were received for dimensional measurements after test usage by the client. The blades were identified as (1) Circular Saw NDL 18772 no. 2, (1) Circular Saw CTB 11 3 / 4 – 24 no. 2 and (1) Hole Saw (152 mm). Prior to test usage, the same dimensional measurements were taken at the same locations on each sample and reported on IMR Report # 100121.

The results are provided on the following page(s).

Reviewed by

Charles White
Senior Laboratory Specialist

Reviewed by

Jamie Smith, CWI
Mechanical Specialist

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Circular Saw NDL 18772 No. 2

Tooth #	Position #1 (mm)		Position #2 (mm)		Position #3 (mm)	
	Before	After	Before	After	Before	After
1	7.196	7.123	7.063	7.040	7.196	7.125
2	7.067	6.958	7.238	7.040	6.968	6.800
3	7.121	7.041	7.177	6.957	7.120	6.958
4	7.064	6.958	6.897	6.792	7.132	6.970
5	7.231	7.041	7.118	7.042	7.080	6.957
6	7.288	7.124	7.006	6.792	7.070	6.875

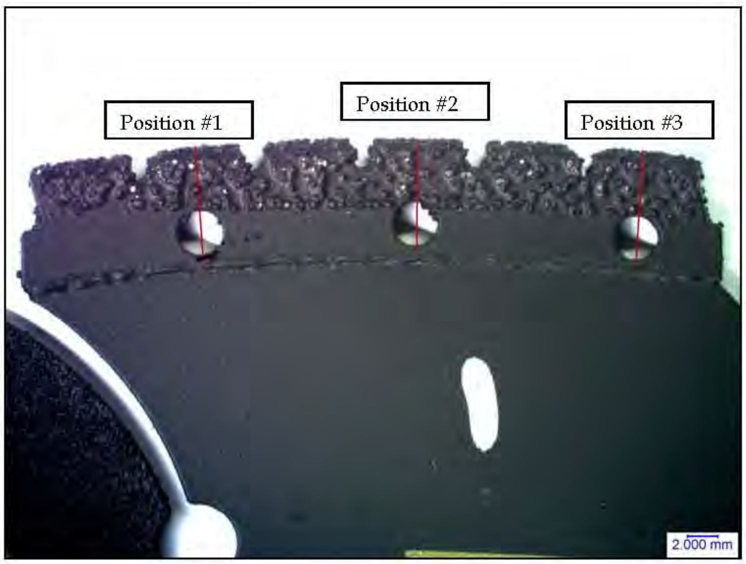

Figure 1: Macrograph of Circular Saw NDL 18772 no. 2, before testing, showing position locations

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Figure 2: Circular Saw NDL 18772 no. 2, after testing

Figure 3: Circular Saw NDL 18772 no. 2, after testing

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88ABW-2012-1278, 12 March 2012

Figure 4: Circular Saw NDL 18772 no. 2, after testing

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Circular Saw CTB 11 3/4 – 24 No. 2

Tooth No.	Position #1 (mm)		Position #2 (mm)		Position #3 (mm)		Position #4 (degree)	
	Before	After	Before	After	Before	After	Before	After
1	2.326	2.205	7.979	7.945	2.513	2.412	23.495	23.354
2	2.409	2.256	8.009	8.006	2.476	2.324	22.650	22.283
3	2.426	2.273	8.042	8.023	2.492	2.375	22.848	22.039
4	2.410	2.222	8.026	7.972	2.476	2.324	24.570	23.694
5	2.394	2.206	8.026	7.991	2.542	2.409	24.921	23.689
6	2.343	2.239	7.959	7.989	2.493	2.307	23.851	22.842

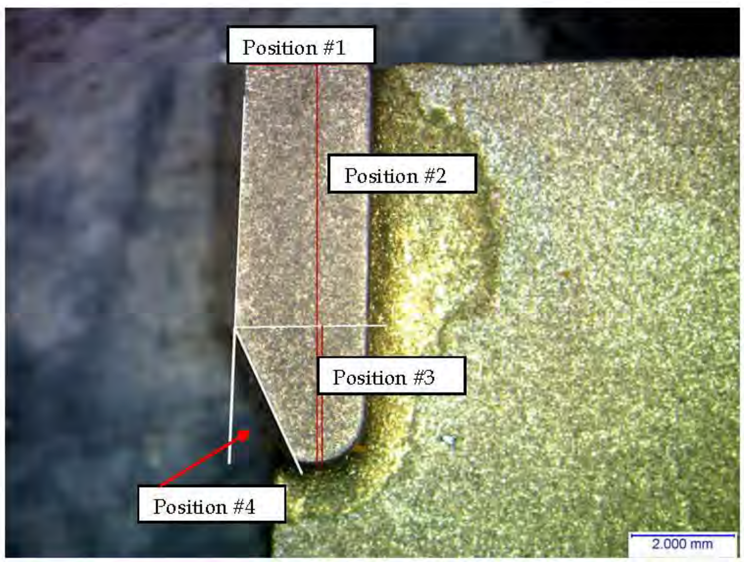

Figure 5: Macrograph of Circular Saw CTB 11 ¾-24 no. 2, before testing, showing position locations

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Figure 6: CTB 11 ¾-24 no. 2, after testing

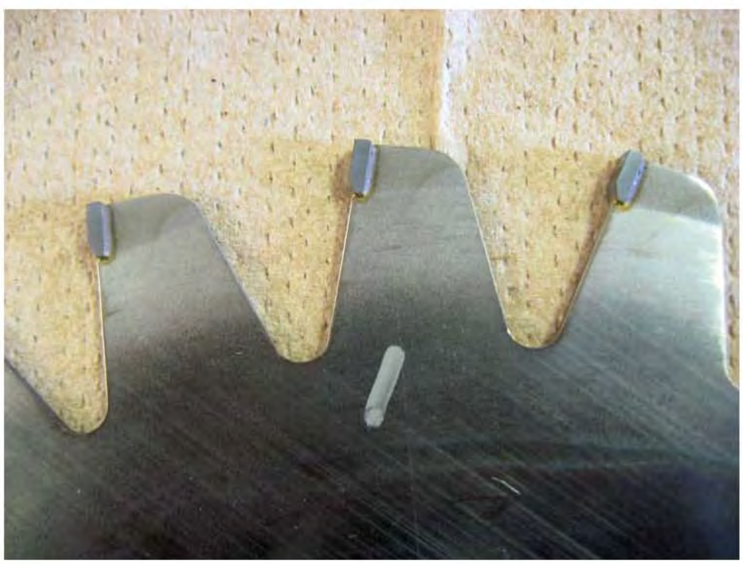

Figure 7: CTB 11 ¾-24 no. 2, after testing

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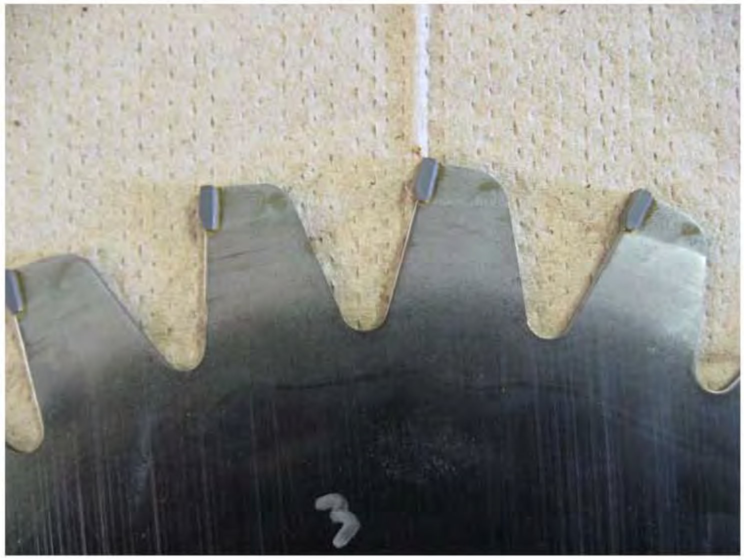

Figure 8: Circular Saw CTB 11 ¾-24 no. 2, after testing

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Hole Saw 152 mm

Position #	Before Test (mm)	After Test (mm)
1	35.454	35.426
2	35.592	35.512
3	35.412	35.380
4	35.788	35.584
5	35.460	35.370
6	35.620	35.436

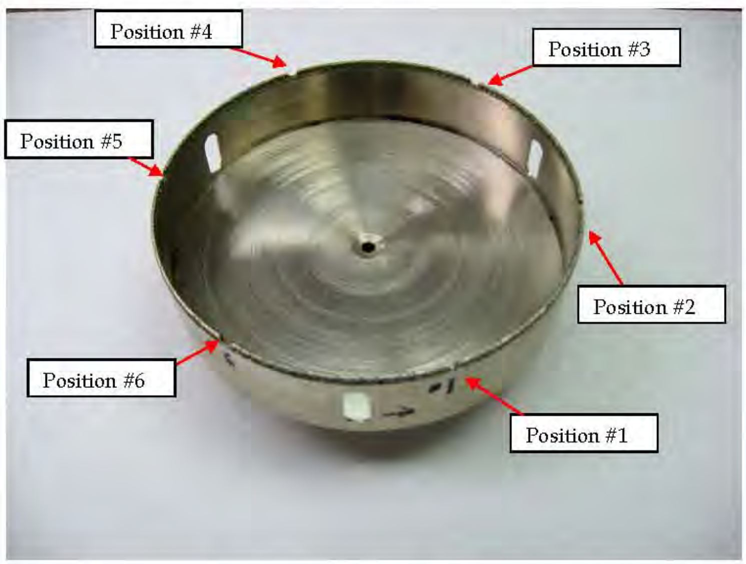

Figure 9: Macrograph of Hole Saw 152 mm before testing, showing position locations

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Figure 10: Hole Saw 152 mm after testing

Figure 11: Hole Saw 152 mm after testing

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IMR Test Labs - Charleston
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Email imr@imrcharleston.com

July 9, 2010

Jennifer Schroeder
Air Force Research Lab
Fire Research Group
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32403

PO Number
KAL062910

Date Received
July 7, 2010

Description
(1) Circular Saw NDL 18772
(1) Lenox Diamond 800RDG

TEST REPORT

IMR Report Number 100727

SUMMARY

Two separate saw blades were received for the third round of dimensional analysis after test usage by the client. The blades were identified as (1) Circular Saw NDL 18772 and (1) Lenox Diamond 800RDG. Measurements were taken on various sections of each blade at various positions, which were documented to allow repeat measurement after use.

The results are provided on the following page(s).

Reviewed by

Jamie Smith, CWI
Mechanical Specialist

Reviewed by

Charles White
Senior Laboratory Specialist

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Lenox Diamond 800RDG

Position #	Results After Test (mm)
1	19.438
2	19.448
3	19.486
4	19.348
5	19.354
6	19.364

Figure 1: Lenox Diamond 800 RDG third round of testing

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Figure 2: Lenox Diamond 800 RDG third round of testing

Figure 3: Lenox Diamond 800 RDG third round of testing

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Circular Saw NDL 18772 – After Test

Tooth #	Position # 1 (mm)	Position # 2 (mm)	Position # 3 (mm)
1	6.960	6.994	7.095
2	6.927	6.960	6.788
3	6.994	6.893	6.893
4	6.926	6.825	6.964
5	6.960	7.028	6.927
6	6.859	6.758	6.859

Figure 4: Circular Saw NDL 18772 after third round of testing

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Figure 5: Circular Saw NDL 18772 after third round of testing

Figure 6: Circular Saw NDL 18772 after third round of testing

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88ABW-2012-1278, 12 March 2012

Appendix D: Pyrolance Throw Distance Determination Data

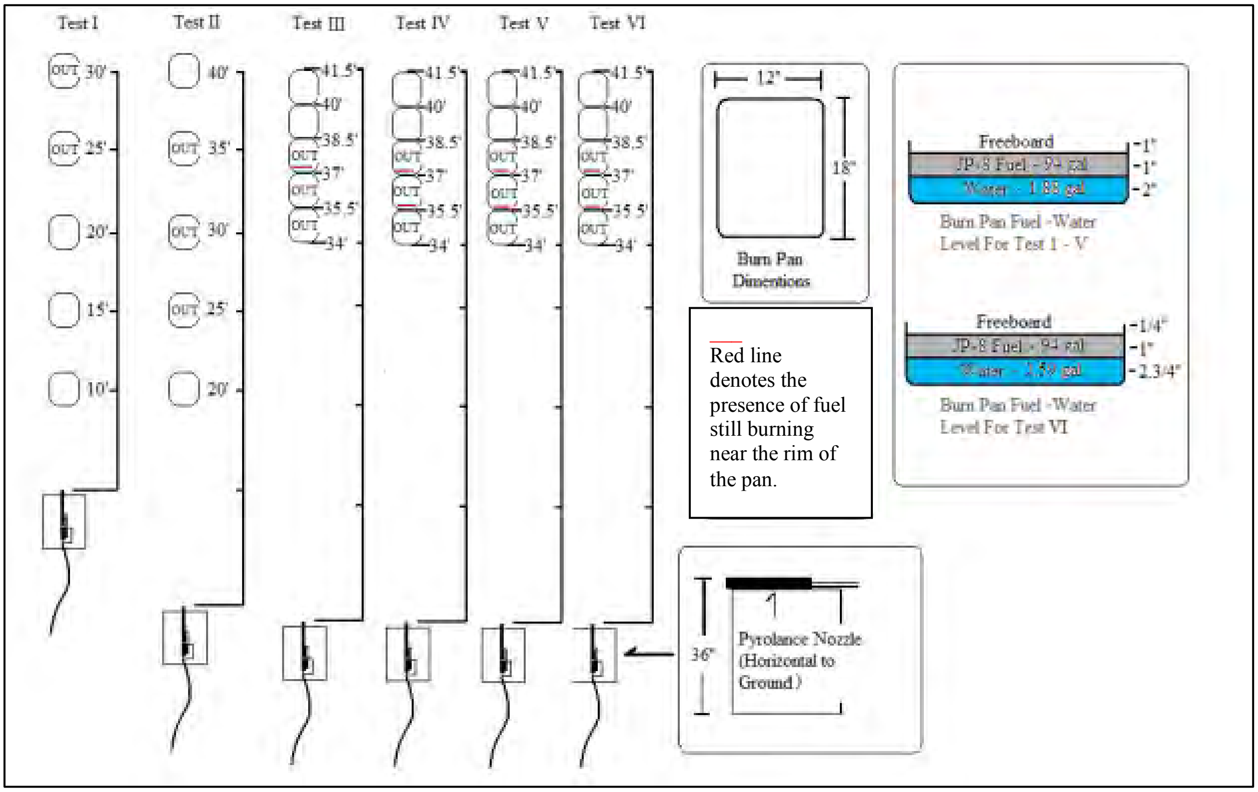

Figure D-1. Schematic of Pyrolance Throw Distance Testing

Test 1

- Five pans measuring 12-in wide × 18-in long × 4-in deep were placed 5 ft apart on center.
- The nozzle was placed horizontally 36 in off the ground and 10 ft from first pan on center.
- The pans were filled with 2 in of water and 1 in of JP-8 allowing 1 in of freeboard.
- A 30 s pre-burn was accomplished after the last pan was ignited.
- The Pyrolance water tank was pre-mixed with 47 gallons of water and 3 gallons of 3% AFFF for a 6% concentration.
- The system was discharged for 60 s and the number of pans extinguished was recorded. Any pans not extinguished during testing were extinguished with a carbon dioxide handheld fire extinguisher.
- Pans 4 and 5 were extinguished during Test 1. Pan 5 was 30 ft 9 in from nozzle tip.

Test 2

- The results from Test 1 were evaluated and the nozzle was moved back an additional 10 ft.
- The five pans were arranged at the same distances as Test 1 and the process was repeated.
- Pans 2, 3, and 4 were extinguished. Pan 4 was 35-ft 9 in from nozzle tip.

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Test 3

- The results from Test 2 were evaluated and the nozzle was moved back an additional 14 ft and placed. All five pans were spaced together to establish the maximum effective extinguishing distance ± 1 ft.
- The nozzle was placed horizontally 36 in off the ground and 34 ft from front lip of the first pan.
- Pans 1 and 2 were completely extinguished and pan 3 had some fuel near the front rim of the pan still burning. The small amount of area that remained burning in pan 3 was due to the 1 in of freeboard left in the pan reigniting the fuel. The maximum effective extinguishing distance was 37 ft.

Tests 4-6

- The results from Test 3 were evaluated and three additional tests were conducted to verify the effective extinguishment distance.
- Pan 1 was completely extinguished and pans 2 and 3 had some fuel near the front rim of the pan still burning. The maximum effective extinguishing distance was 35 ft 6 in for all three tests.

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LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

ACO	Advanced Composite Office
AFFF	aqueous film forming foam
ARFF	Aircraft Rescue and Fire Fighting
AFCESA	Air Force Civil Engineering Support Agency
AFRL	Air Force Research Laboratory
BMI	bismaleimide
FAA	Federal Aviation Administration
ft	foot; feet
ft/min	feet per minute
gal/min	gallons per minute
in	inch; inches
lb	pound(s)
lb/in^2	pounds per inch squared
min	minute(s)
MSA	Mine Safety Appliances
NFPA	National Fire Protection Association
PPE	Personal Protective Equipment
psi	pounds per square inch
RXQ	Airbase Technologies Division
s	second(s)
SCBA	Self Contained Breathing Apparatus
SPO	System Program Office
TCLP	Toxicity Characteristic Leaching Procedure
THK	Treasure Hong Kong

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