E-Drill Damage Rectification Process Validation

15192 Triton Lane, Huntington Beach CA 92649 **www.ppedm.com**

Test Procedure Validation and Preliminary Results
Executive Summary

Aerospace is by its very nature a very conservative and risk adverse industry that carefully evaluates technological advances and is slow to adoption; taking cautious steps to ensure the safety of the air-vehicle and crew. Perfect Point (PPedm) has developed a revolutionary solution to one of the most basic- yet critical steps in an aerostructure life-cycle: Fastener Removal. Perfect Point has developed an EDM-based fastener removal tool called E-Drill, which removes “hard metal” fasteners in seconds, from either fastener head or collar, while cutting inside the dimensions of the fastener.

E-Drill was designed to never touch the parent material during normal fastener removal. The system contains mechanical and electronic controls to ensure concentricity on the fastener shank and cut depths that are repeatable. While these controls provide a higher level of protection from fastener removal damage than a comparable mechanical fastener removal process, if the E-Drill is not properly centered on the fastener to be removed, it can cause EDM damage to the fastener hole. This damage is limited to the interface point between the fastener head and the fastener hole and does not extend past that skin to the structure-due to electro-mechanical controls in the tool.

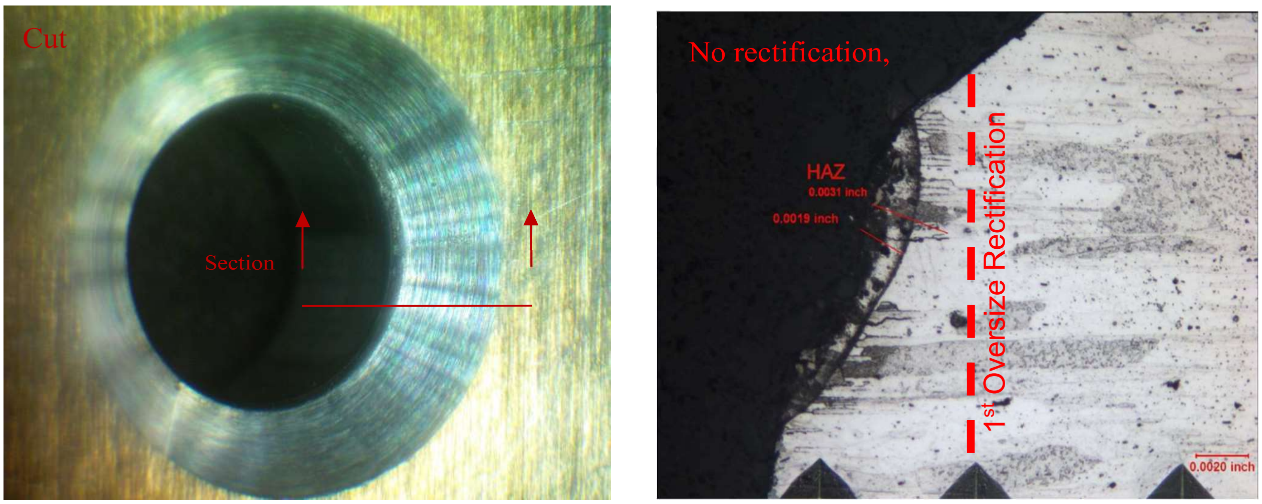
The effects of EDM on metal are well known in the industry and consist of a layer of Recast inside a Heat Affected Zone (HAZ) wherein microcracking can occur. During normal operation of the E-Drill the Recast and HAZ remains internal to the fastener and does not affect the surrounding structure. If the EDM process touches the fastener hole in the skin, then the simple industry standard disposition of going to an oversize hole returns the fastener hole to a usable condition with the same structural integrity.

PPedm designed a controlled engineering test to prove that, in the event of a fastener being hole damaged by the E-Drill, a standard oversizing engineering disposition returns the hole to the same structural integrity, comparable to that as if the damage was caused by a mechanical twist drill. Using tooling fixtures to control offset conditions and forcing fastener hole damage by the E-drill, test coupons were prepared for testing by an independent structural test lab. The purpose of the test was to 1) show that EDM damage is easily identified when it occurs 2) that EDM damage is easily rectified, 3) that EDM damage can be rectified using a standard engineering disposition of oversizing returns the material to the same structural integrity as compared to damaged caused by a twist drill.

The tests were performed using aerospace quality 7075 Aluminum coupons, which is representative of common aircraft skins. PPedm prepared the test coupons per industry specifications, made offset cuts designed to create defined degrees of damage, and then rectified the damaged holes to according to industry practices for oversizing holes.The test coupons were sent to an independent lab (Element Material Technology) where micrograph, micro hardness, and fatigue testing was completed, and certified test results were produced in an independent report which is included.

The test results concluded that a typical aircraft skin material damaged by EDM when using the E-drill during fastener removal can be rectified in accordance with standard airframe fastener oversize procedures. The damage rectification returns the structure to the same structural integrity as the parent material as illustrated in Figure 1.

Figure 1: S/N 14: .015" Offset, 7075-T7351 Aluminum, Nominal



A 1st oversize rectification removes all affected material as indicated in the above image. The total HAZ including recast is 0.0031"

While the scope of this test was to validate the test procedure and prove that EDM damage can be rectified by a simple oversize engineering disposition, it was not intended to be a comprehensive test based on statistical significant sample size. While a more extensive test could be performed to include different materials and larger sample sizes, sufficient data was collected and analyzed to substantiate our position – damage caused by E-drill can be rectified using existing engineering disposition procedures and returned to parent material structural integrity.

Other tests have been performed by agencies in the past to evaluate the E-drill, but tests were performed to demonstrate a rectification process to return the fastener hole to a useable condition that is publicly releasable. Some Customers performed their own internal test to validate the use of E-drill for their own purposes but that is proprietary data and not able to be released to the public.

The following report clearly proves that damage caused by EDM to a fastener hole can be rectified using standard engineering practices, and returns the fastener hole to the same structural integrity as compared to damage caused by a twist drill. E-drill can replace the twist drill to remove any airframe fastener **better, faster, and safer** than traditional fastener removal processes.

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Table of Contents

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Objective:

Tests were designed to prove that a fastener hole inadvertently damaged by the E-Drill EDM process (by misalignment with the fastener) can be rectified to have the same structural integrity as the hole prior to the damage. Testing has provided preliminary proof that with simple rectification processes (increasing the hole to an oversize fastener) the parent material damaged by the E-Drill electro discharge machining (EDM) process (i.e. recast and heat affected zone, or HAZ) will be removed, leaving the parent material with the same structural integrity as an undamaged hole of the same size and geometry.

Background:

Perfect Point has developed, the patented E-Drill Fastener Separation Technology (FST) solution, utilizing electro discharge machining (EDM) technology, which provides many benefits over traditional methods for fastener removal from aircraft structures using twist drills. The E-Drill uses an electrode to make a circular cut through the fastener head leaving a thin ligament of fastener material connecting the head and the fastener stem which can then be easily removed using a punch. A Deionized water system is used as both a dielectric for the EDM process and to cool the area during the cutting process. The water system flushes and vacuums during the cut process to remove debris eliminating FOD and eliminates exposure to hazardous coatings commonly found in fasteners. Use of the electrode makes the cutting process forceless and noiseless, which protects both the airframe and the operator. The E-Drill can be adapted for a wide variety of fastener removal applications including flush head, protruding head, collar locking or blind installed.

Similar to all EDM processes, an E-Drill EDM cut results in a thin layer of Recast and Heat Affected Zone (HAZ) at the cut surface. Used correctly, within ±0.009" and 2 degrees, the E-Drill makes a concentric and co-axial cut inside the fastener and does not touch the fastener hole or surrounding skin or substructure. The E-Drill FST process only cuts fastener material, which is to be discarded, so the Recast and HAZ layer is completely contained in the fastener which is discarded. In the unlikely event the EDM process does touch the aircraft skin, the recast and HAZ layer must be removed if the skin is to be reused. The rectification process is identical to rectification processes currently used to repair holes damaged by conventional drill removal techniques. Depending on the amount of damage encountered either a 1st oversize, 2nd oversize or full nominal oversize fastener would be used, and enlarging the hole is sufficient to remove all damage.

Micrographs and Micro Hardness Evaluation:

Test Overview:

7075-T7351 Aluminum samples measuring 1" x 8" x .250" were machined for a HL11V-6-8 fastener. The fastener and coupon assembly were placed into a fixture and using a fixed set of shims, the coupon was misaligned. Using fixed controller settings, a frame mounted E-Drill was used to cut the fastener. The sample is inspected both macro and micro to verify the damage. At this point the coupons were individually placed on a CNC mill and the damaged fastener hole reamed to an oversize, depending on the damage offset and test matrix. After cleaning with denatured alcohol and further inspection the samples are sent to an independent test lab for Micrographic Analysis per ASTM E3 and Micro-Hardness Validation per ASTM E384 (17).

Test Preparations:

Prior to testing all fixtures were inspected for damage, cleaned, leveled, and squared. All fixture fasteners were inspected, torqued, and replaced as needed. Before any processing coupons and fasteners were rinsed with denatured alcohol and allowed to air dry prior to assembly. Individual parts bags were prepared for the separation of each coupon and their hardware as no hardware is reused.

Alignment of the E-Drill Fixture and Coupon Fixture was checked in several ways. First with a dial indicator, a coupon was compared to the coupon fixture bore and adjustments made. This was also verified by use of a Perfect Point EDM Bomb Sight. Second a precision ground sleeve is mounted to a Vacuum Flush Head Adaptor (VFHL), to ensure concentric alignment of the E-Drill and Coupon Fixture. Third an E-Drill mounting cage is affixed to the holding frame and aligned to hold a standard production Center Grounding E-Drill. The coupon fixture assembly is then concentrically aligned to the VFHL and E-Drill assembly.

Tooling:

Coupon Fixture:

To retain a coupon in a repeatable manner a machined offset fixture was created to retain and align the coupons for processing. All test coupons are retained and located by the same fixture in the same manner throughout the process. (Figure 1) Two clamps affixed to the fixture hold down the coupon plate during E-Drill cutting to prevent unwanted movement. Both the X-axis and Y-axis have adjustable shim retainer plates to allow initial alignment of the test plate to the adaptor block bore. A true machined coupon "gage" is placed in the fixture and the hole location is verified to confirm concentricity.

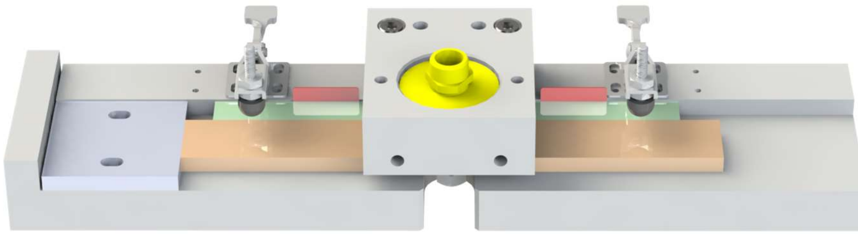


Figure 1: Coupon Fixture.

E-Drill Fixture:

An E-Drill fixture was used to ensure repeatability during the cutting cycle of the coupons and remove any inadvertent operator inputs to the test. A holding cage was constructed to retain the E-Drill and maintain alignment with the coupon fixture. (Figure 2) The cage encapsulates the main body of the E-Drill. The cage was attached directly to the internal E-Drill frame to avoid any misalignment. A guided pneumatic cylinder ensures perpendicularity and that a constant repeatable pressure was applied during the cut.

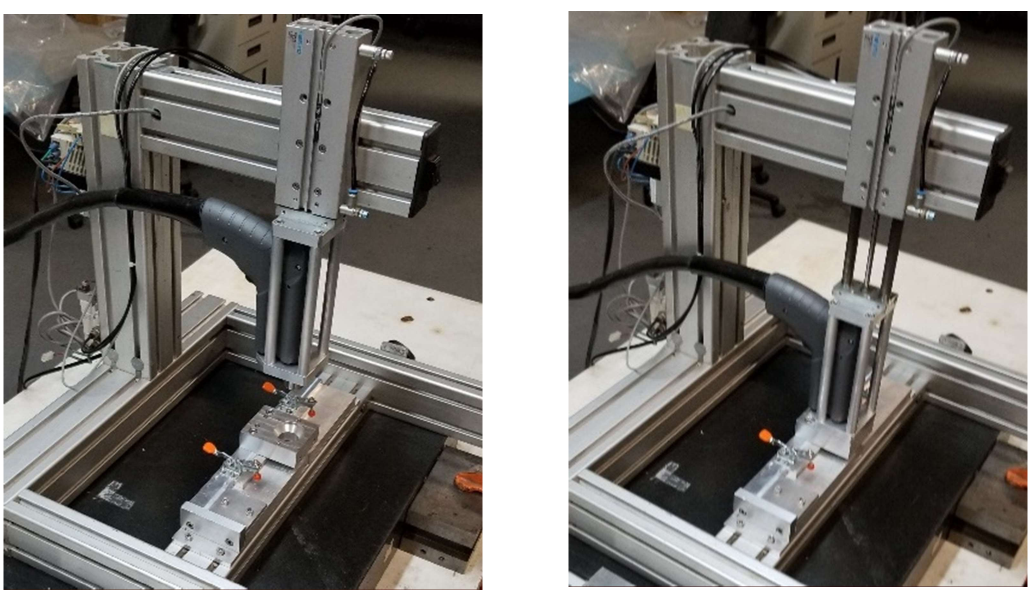


Figure 2: E-Drill Fixture in Rest and Cutting Positions.

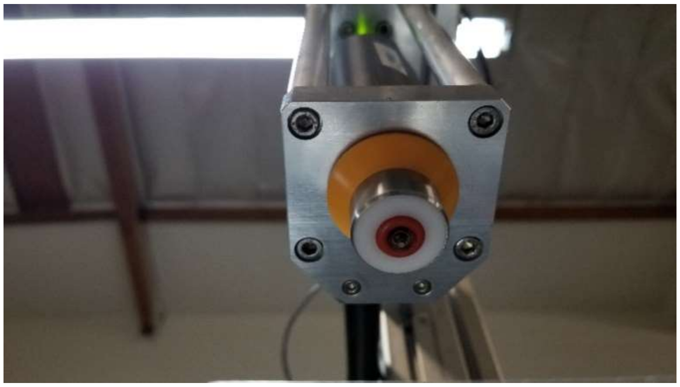


Figure 3: E-Drill Alignment Bushing.

Coupons:

The coupon plates were machined to a size of 1.000" x 8.000" with a centrally located fastener installation hole per manufacturers specification. Coupons are made from certified 7075-T7351 aluminum with a thickness of 0.250". (see exhibit C) A 3/16" nominal diameter titanium Hi-Lok HL11V-6-8 flush shear head fastener was installed in the coupon. A plastic washer was installed on the back side to prevent inadvertent coupon damage. Using a spacer and #10-32NF nut the fastener was torqued to 35-45 in-lb. per the fastener manufacturer's specification. The coupons were cut so that the material grain structure was along the X (8.00") direction.

Post EDM rectification sizing was based on fastener manufacturer's specification for a 1st or 2nd oversize fastener of the same Hi-Lok family as shown Table 1.

Table 1: Fastener Dimensions.

Pin Size Ø (in)	Shank Ø (in)	Head Ø (in)	Head Height (in)	Fillet Radius (in)	Countersink Angle (deg)	Material	Designation
3/16 (Nominal)	.1885-.1895	.2966-.3016	.045-.047	.020-.030	100	Titanium	HL11V-6-8
13/64 (1st oversize)	.2021-.2026	.2966-.3016	.0394-.0415	.020-.030	100	Titanium	HL111V-6-8
7/32 (2nd oversize)	.2177-.2182	.3253-.3303	.045-.047	.020-.030	100	Titanium	HL411V-6-8

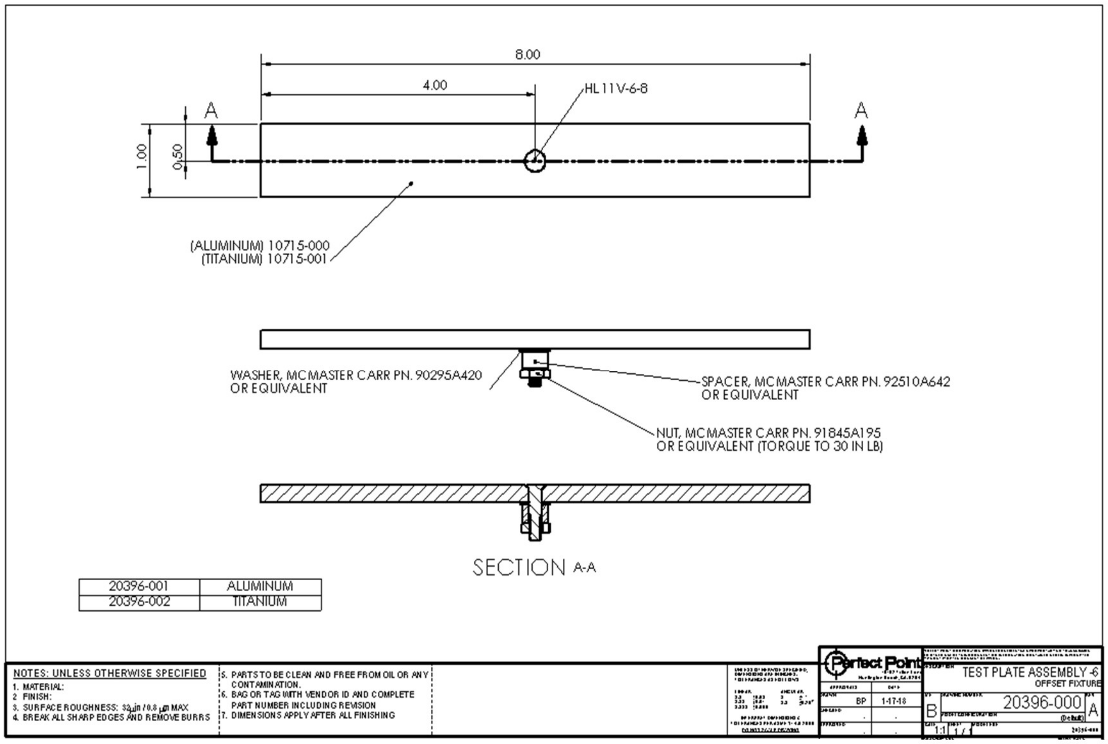


Figure 4: Test Coupon Assembly.

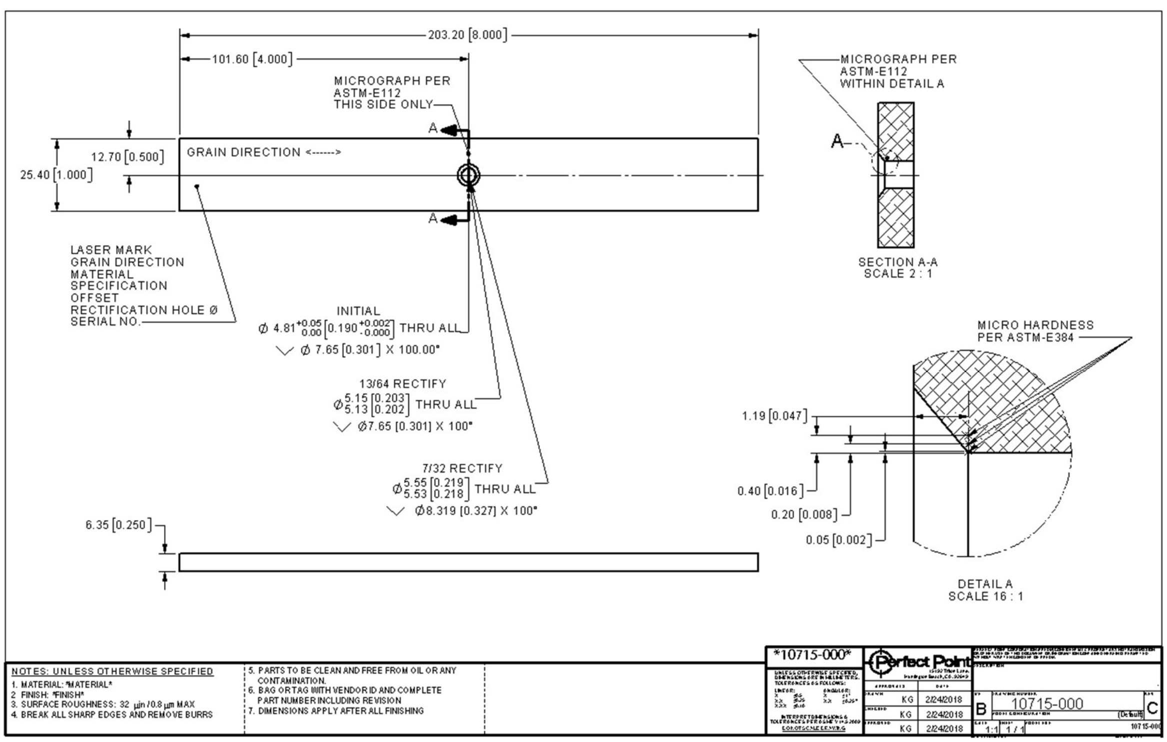


Figure 5: Coupon Independent Testing Locations.

Procedure:

Offset EDM cut:

The holding fixture was loaded with the appropriate shim to create the desired Y direction offset per Table 2. An assembled coupon was loaded into the holding fixture and clamped taking care that it was firmly in contact with both the side and end stop plates. Using the E-Drill loaded with a 206-0 (3/16 nominal, copper) electrode, measuring .156 in diameter an offset cut was created in the fastener to a depth of .061". Machine parameters were set to compensate for cutting tool and fastener material.

Table 2: Coupon Test Matrix.

S.N.	Material (type)	Operation (type)	Sample (#)	Offset (in)	Ream (in)	Rectify	Process
1	AL	E-Drill	1	0.013	0.203	1ST OS	Micrograph Micro Hardness
2	AL	E-Drill	1	0.013	0.203	1ST OS	Reserve
3	AL	E-Drill	1	0.015	0.203	1ST OS	Micrograph Micro Hardness
4	AL	E-Drill	1	0.015	0.203	1ST OS	Reserve
5	AL	E-Drill	1	0.021	0.2188	2ND OS	Micrograph Micro Hardness
6	AL	E-Drill	1	0.021	0.2188	2ND OS	Reserve
14	AL	E-Drill	1	0.015	0.1895	None	Micrograph Micro Hardness

1 coupon of each offset was submitted for lab analysis.
1 coupon of each hole size not subjected to EDM was submitted as a baseline.
1 coupon of nominal size with non-rectified EDM damage was submitted for reference.

Rectification:

Drill/ream rectification was done by use of specifically sized reamers and guide bushings, as shown in Table 2, to achieve a 1st oversize or 2nd oversize hole. The bushings were pressed in to adaptors that are tightly toleranced to fit the offset adaptor block. All reaming was done in a milling machine to allow for proper and consistent surface speed, perpendicularity, and accuracy, eliminating any variablity from the subject coupons. Depending on the amount of offset (per Table 2) either a 1st oversize or 2nd oversize fastener hole per manufacturer's specification was created concentric with the original installation hole.

External Testing:

To verify the grain structure of the material it was sectioned at the centerline of the fastener hole, creating a cross grain section. Metallurgical studies were performed on the coupons, based on ASTM standards. Post-rectification the samples were sent for third party evaluation. The tests include Micrograph (ASTM-E3) and Micro Hardness (ASTM-E384) to determine if any recast layer or heat affected zone layer formation remained post rectification on either material.

Test method:

a) Prepare sample Coupons of nominal thickness .250 and a L x W of 8.000” x 1.000”
b) Drill, Chamfer and Ream a Hole at 0.500” from top edge datum and 4.000” from the left side datum according to Table 2.
c) Place coupon in to fixture and using dial indicator ensure concentricity between hole and bushing block
d) Remove coupon and laser mark the test parameters based on Table 2.
e) Repeat step d for all coupons.
f) Using a 0206-0 electrode and .061 depth of cut, and an E-Drill adapter set up the mounted E-Drill fixture.
g) Install fastener into coupon using washer, spacer and nut. Torque to 35-45 in-lb.
h) Shim fixture to the specified offset.
i) Clamp assembled coupon into fixture against stops.
j) Using the fixtured E-Drill cut the fastener.
k) Remove the coupon and shims. Do not punch it out. Remove from the side it was installed.
l) Reattach the coupon to the fixture and place appropriate reaming bushing into adapter block.
m) Using the appropriate reamer and a milling machine rectify the hole to the specified dimension.
n) Set sample aside for step o.
o) Repeat steps g through m until all test parameters are completed.
p) Send all samples for metallurgical study.
q) If, during any portion of the testing process a unique case or condition occurs that differs from the standard cutting practices, then log the bad cut along with observations of the occurrence.

Sample Coupon Evaluation Results:

Micrographic images per ASTM-E3
Micro hardness per ASTM-E384

Evaluation testing location:
Element Materials Technology
15062 Bolsa Chica St.
Huntington Beach, CA 92649

Samples mounted and examined per drawing #10715-000 rev C (Figure 5, page 6)

Data per test reports PER083-05-24-63649-1 & PER083-05-24-63649-2 dated 5-31-2018 (See Exhibits A & B)

Lab Analysis Summary:

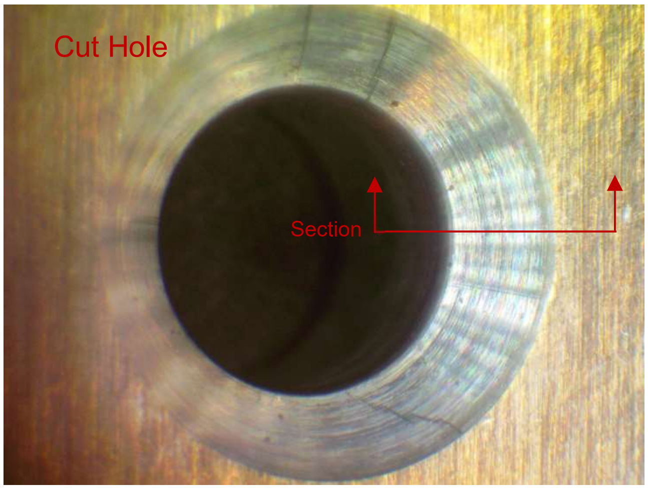
Micrographs in all rectified samples showed no evidence of Recast layer or Heat Affected Zone remaining after recommended rectification was performed. By Reaming the fastener hole to 1st or 2nd oversize depending on damage offset, see reference images S/N 1 though S/N 11, the metallurgical structure is shown to be homogeneous with no discernible variations from parent material.

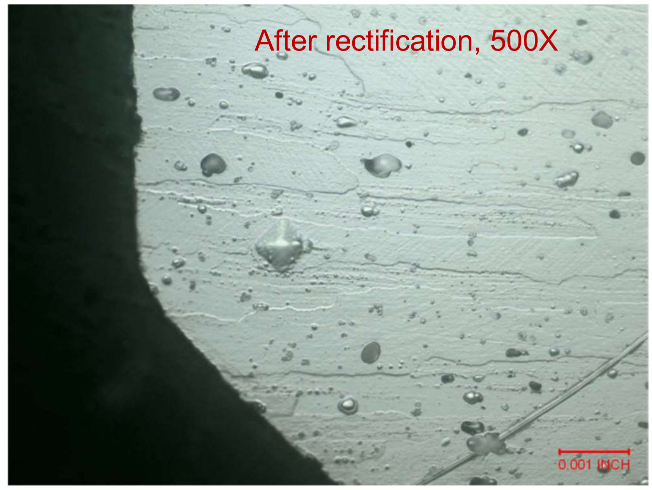
Vickers, Micro-Hardness testing on rectified samples showed no differences in tested zones adjacent to the rectified EDM event. All processed samples tested at .002", .008" and .016" from EDM rectification exhibited no adverse effects to metallic structure. The .016" test point distance is considered to be parent material and used as a baseline of material Micro-Hardness property.

The reference sample coupon that had EDM damage at a .015 offset showed a Heat Affected Zone (HAZ) of 0.0031" total including a recast layer of 0.0019". This HAZ is well within the boundary of the rectification to a 1st oversize (+.016' diameter) and will be removed with the recommended reaming process, returning the hole to full structural integrity as shown in Figure 9.

Aluminum Coupons Damaged and Rectified:

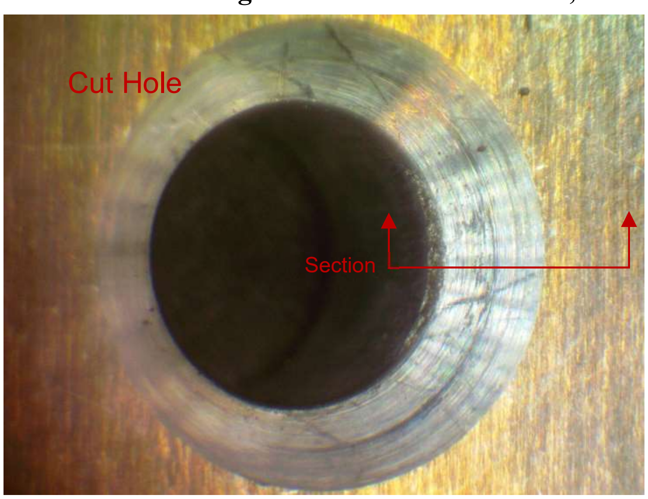
Figure 6: S/N 1: .013" Offset, 7075-T7351 Aluminum, 1st Oversize.





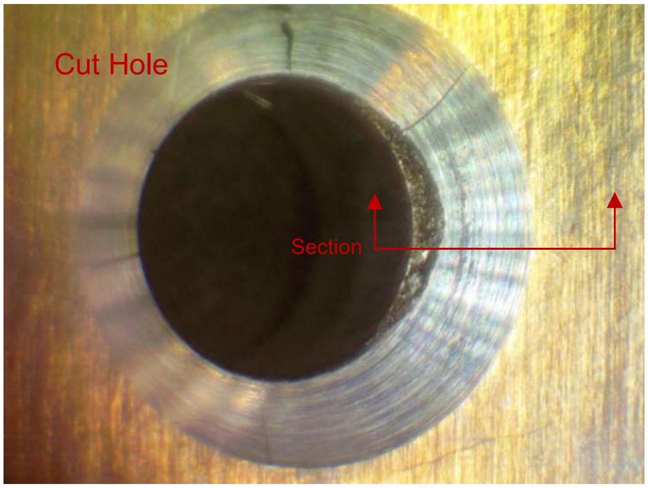
S/N 1 shows light discoloration on the cut hole (Left) with light damage. After rectification to 1st oversize the coupon section (Right) shows no Recast layer or HAZ at 500x magnification.

Figure 7: S/N 3: .015" Offset, 7075-T7351 Aluminum, 1st Oversize.



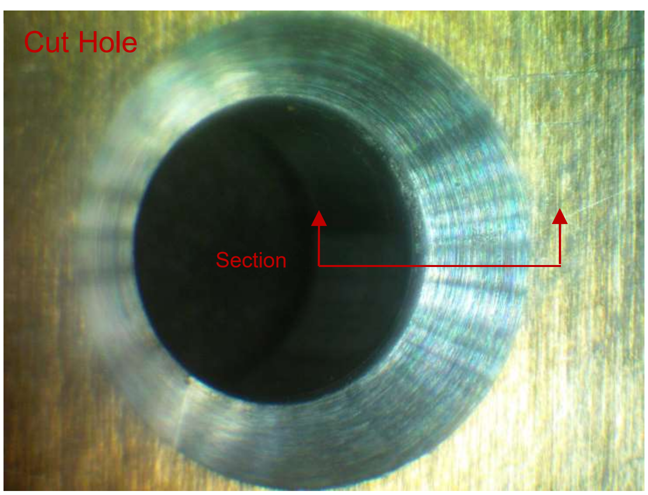
S/N 3 shows light discoloration on the cut hole (Left) with light damage. After rectification to 1st oversize the coupon section (Right) shows no Recast layer or HAZ at 500x magnification.

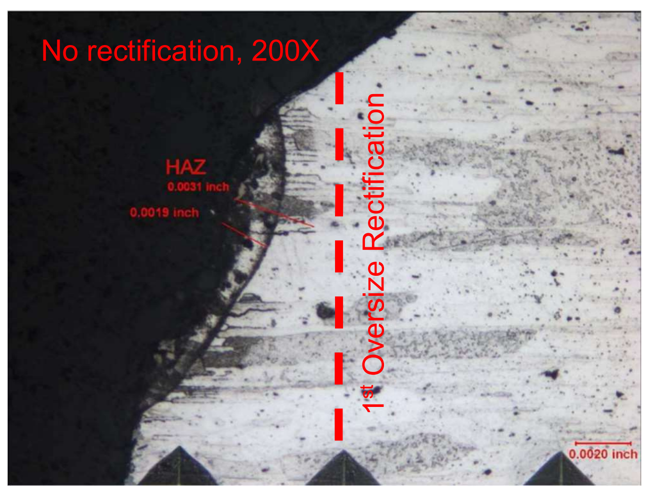
Figure 8: S/N 5: .021" Offset, 7075-T7351 Aluminum, 2nd Oversize.



S/N 5 shows light discoloration on the cut hole (Left) with moderate damage. After rectification to 2nd oversize the coupon section (Right) shows no Recast layer or HAZ at 500x magnification.

Figure 9: S/N 14: .015" Offset, 7075-T7351 Aluminum, Nominal Size.





S/N 14 shows light discoloration on the cut hole (Left) with light damage. No rectification was performed, the coupon section (Right) shows a Recast layer and HAZ at 200x magnification. A 1st oversize rectification removes all affected material as indicated in the above image. The total HAZ including recast is 0.0031". Cut geometry is detailed in Figure 10.

Figure 10: Detail image of .015" offset cut damage geometry

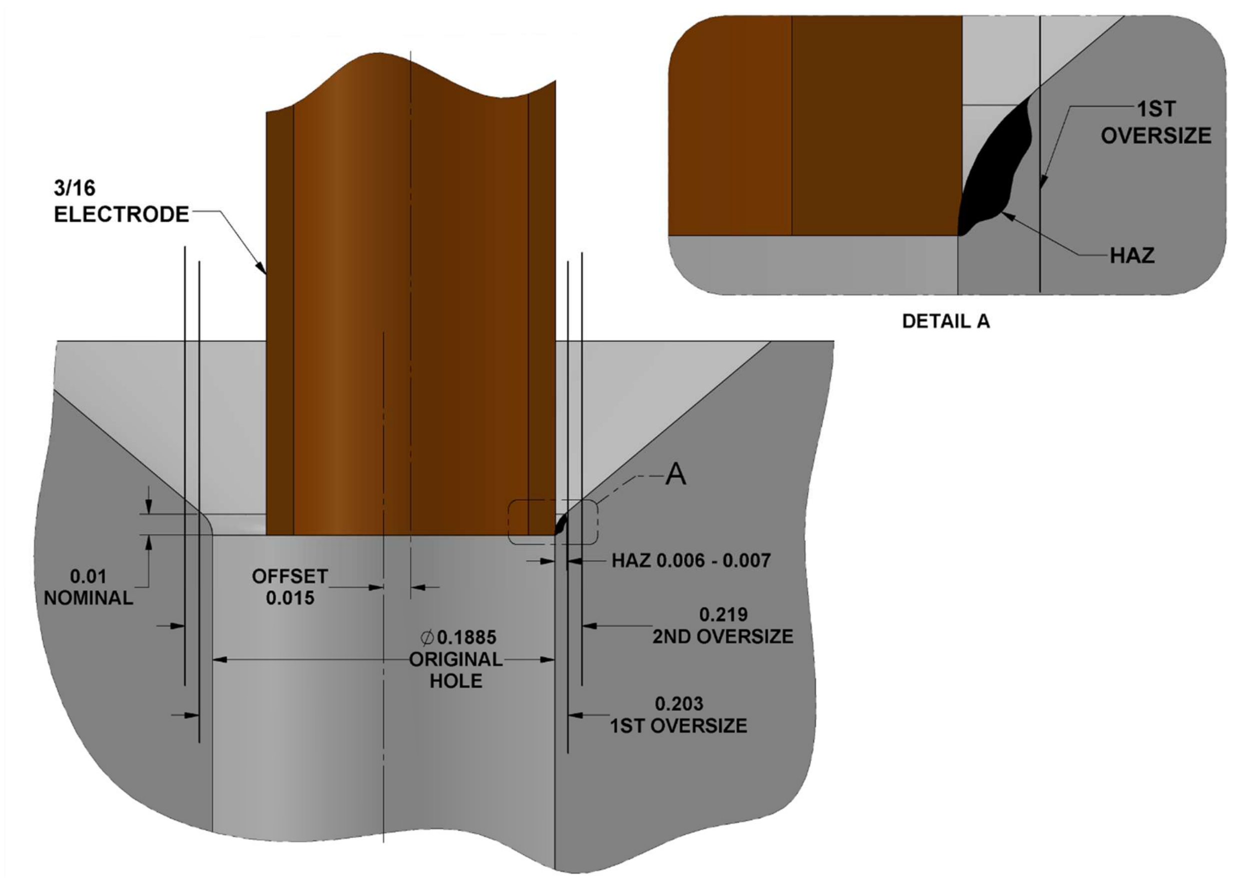


Figure 10 illustrates the rectification process for the unrectified .015" offset damage shown in Figure 9. As illustrated, a first oversize ream will eliminate all HAZ and return material to full structural integrity.

Conclusions, Micrograph and Micro-Hardness:

Based on the Element Lab test data, a fastener hole damaged by the E-Drill due to misalignment can be restored to the original structural integrity by simply drilling to the 1st or 2nd oversize fastener depending on the misalignment that has occurred. This is the same disposition used for fastener hole damage rectifications caused by a twist drill.

Based on the Element Lab test data, all evidence of EDM recast and HAZ have been removed by the recommended rectification processes. The oversize condition of the hole is equivalent to damage repair caused by conventionally drilled and removed fasteners. The condition of the hole is back to parent material state and no inherent degradation will occur.

Fatigue Testing, Low Cycle Fatigue Data

Test Overview:

Coupons prepared in the same conditions with the same offsets and processed on the same equipment were submitted for fatigue testing per ASTM-E466. Low Cycle Fatigue (LCF) studies were conducted with a range of sample coupons. A baseline (undamaged hole) for each fastener size (nominal, 1st oversize, 2nd oversize) and samples of rectified damaged holes corresponding to each offset have been tested. A baseline sample for worst case was also submitted as an un-rectified EDM damaged hole with a .015 offset cut.

Following all the same procedures as the coupons prepared for Micrograph and Micro-Hardness samples were processed for LCF testing. Table 3 shows the baseline preparation or rectification process for each EDM offset hole.

Table 3: LCF Coupon Test Matrix.

S.N.	Material (type)	Operation (type)	Sample (#)	Offset (in)	Ream (in)	Finish (Size)	Process	Notes
AL00N01	AL	E-Drill	1	NA	0.189	NOM	LCF ASTM-E466	Setup
AL00N02	AL	E-Drill	1	NA	0.189	NOM	LCF ASTM-E466	Baseline (No EDM)
AL00X02	AL	E-Drill	1	NA	0.203	1ST OS	LCF ASTM-E466	Baseline (No EDM)
AL00Y02	AL	E-Drill	1	NA	0.218	2ND OS	LCF ASTM-E466	Baseline (No EDM)
AL09N02	AL	E-Drill	1	0.009	0.189	NOM	LCF ASTM-E466	No Rectification
AL15N01	AL	E-Drill	1	NA	0.189	NOM	LCF ASTM-E466	No Rectification
AL15X01	AL	E-Drill	1	0.015	0.203	1ST OS	LCF ASTM-E466	Ream to 1st Oversize
AL21Y01	AL	E-Drill	1	0.021	0.218	2ND OS	LCF ASTM-E466	Ream to 2nd Oversize

1 coupon of each offset was submitted for LCF testing.
1 coupon of each hole size not subjected to EDM was submitted as a baseline LCF.
1 coupon of nominal size with non-rectified EDM damage was submitted for reference LCF.

Rectification:

Drill/ream rectification was done as shown in Table 3, to achieve a 1st oversize or 2nd oversize hole. All reaming was done in a CNC milling machine to allow for proper and consistent surface speed, perpendicularity, and accuracy, eliminating any variablity from the subject coupons. Depending on the amount of offset (per Table 3) either a 1st oversize or 2nd oversize fastener hole per manufacturer's specification was created concentric with the original installation hole.

External Testing:

Post-rectification the samples were sent for third party evaluation. To verify fatigue life of the material each sample coupon was prepared and mounted in a load frame and cycled at 600 cycles per minue, with a defined load of +14KSI and -14KSI full reversal stress load. All testing was performed as defined by ASTM-E466.

1 sacrificial setup piece was processed to determine load at the defined frequency and establish desired cycle count to be run for baseline samples. 1 sample of a nominally sized hole and 1 sample each of 1st oversize and 2nd oversize holes were prepared with conventional drilling and reaming techniques to be used as baseline data for fatigue life of each hole condition. Another set of sample coupons was prepared with defined EDM offset damage and rectified using the established data collected during Micrographic and Micro-Hardness testing. Rectification was done by a 1 or 2 step reaming process dependent on final hole oversizing steps defined by damage offset as shown in Table 3. An additional coupon was subjected to EDM offset damage at .015" offset and not rectified prior to fatigue testing. The unrectified coupon data is used as reference to compare against properly processed samples.

LCF Test Data Summary:

Specimen ID No.	Stress (KSI)	Freq. (CPM)	Tf (Hrs)	NF (Cycles)	Notes
AL00N01	15.26	600	1.41	50822	SACRAFICIAL SETUP PIECE
AL00N02	14.00	600	2.11	75806	NOMINAL DRILLED AND REAMED HOLE (BASELINE)
AL09N02	14.00	600	1.92	69076	NOMINAL HOLE, .009 OFFSET EDM, NO DAMAGE, NO RECTIFICATION
AL00X02	14.00	600	2.13	76590	1ST OS DRILLED AND REAMED HOLE (BASELINE)
AL15N01	14.00	600	1.48	53162	NOMINAL HOLE, .015 OFFSET EDM DAMAGE, NO RECTIFICATION
AL15X01	14.00	600	2.55	91958	1ST OS RECTIFIED, .015 OFFSET EDM DAMAGE
AL00Y02	14.00	600	1.55	55948	2ND OS DRILLED AND REAMED HOLE (BASELINE)
AL21Y01	13.99	600	2.12	76153	2ND OS RECTIFIED, .021 OFFSET EDM DAMAGE

Sample Coupon Evaluation Results: Low Cycle Fatigue

Low Cycle Fatigue Testing per ASTM-E466

Evaluation testing location:
Element Materials Technology
15062 Bolsa Chica St.
Huntington Beach, CA 92649

Data per test report PER083-05-24-65359 dated 6-22-2018 (See Appendix C)

Lab Analysis Summary:

Fatigue data showed no degradation of rectified samples (AL15X01, AL21Y01) when compared to baseline control samples prepared with only conventional tooling (drill and ream). Significant reduction in fatigue life was noted in the non-rectified EDM damaged sample (AL15N01). The reduced life of this sample was expected and understood, it is considered a reference data point.

(Note) Significant reduction in fatigue life was noted in one of the samples (AL00Y02) not exposed to EDM. Post testing examination related the cause to an improperly prepared hole exit chamfer.

Conclusion, Low Cycle Fatigue:

Evidence supports the determination that with proper rectification procedures hole quality is maintained and the material tested (7075 T7351 Aluminum) retains the structural integrity of the original mechanically generated hole.

Data collection and processing: Ken Greene, PPEDM
Bill Palleva, PPEDM

Laboratory analysis: Element Materials Technology

Appendix A: Element Test Report, AL Micrographs (post rectification)

element™

Element Materials Technology
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Huntington Beach, CA
92649-1023 USA

P 714 892 1961
F 714 892 8159
T 888 786 7555
info.hb@element.com
element.com

Contact:
Perfect Point EDM Corp.
15192 Triton Lane
HUNTINGTON BEACH, CA 92649

*****CORRECTED TEST CERTIFICATE — EAR-CONTROLLED DATA – 6/12/2018*****

Date: 5/31/2018
Purchase Order Number: 3801
Work Order Number PER083-05-24-63649-2

Description:	ALUMINUM SAMPLES
Specification:	INFORMATION ONLY
S/N:	1,3,5***

Microhardness Evaluation
S/N 1

Requirement: FOR INFO. ONLY
Load in grams: 100g
Magnification: 400X

Hardness results are readings tested in accordance with ASTM E-384 (17).

Sample	Vickers	Rockwell HRB
0.002"	153	81
0.008"	159	83
0.016"	160	83

Approximate conversion per ASTM E-140 ($12b^{E1}$)

Microhardness Evaluation
S/N 3***

Requirement: FOR INFO. ONLY
Load in grams: 100g
Magnification: 400X

Hardness results are readings tested in accordance with ASTM E-384 (17).

Sample	Vickers	Rockwell HRB
0.002"	163	84
0.008"	154	81
0.016"	150	80

Approximate conversion per ASTM E-140 ($12b^{E1}$)

Microhardness Evaluation
S/N 5

Requirement: FOR INFO. ONLY
Load in grams: 100g
Magnification: 400X

Hardness results are readings tested in accordance with ASTM E-384 (17).

Sample	Vickers	Rockwell HRB
0.002"	147	79
0.008"	150	80
0.016"	150	80

Approximate conversion per ASTM E-140 ($12b^{E1}$)

Respectfully submitted

15062 Bolsa Chica, Huntington Beach, CA 92649
(714) 892-1961 ph • (714) 892-8159 fax www.element.com

Anna Tiengthong
Anna Tiengthong
Quality Administrator

15192 Triton Lane
Huntington Beach, CA 92649
Office Tel: 714-892-3400
Hotline Tel: 714-891-6533
www.ppedm.com

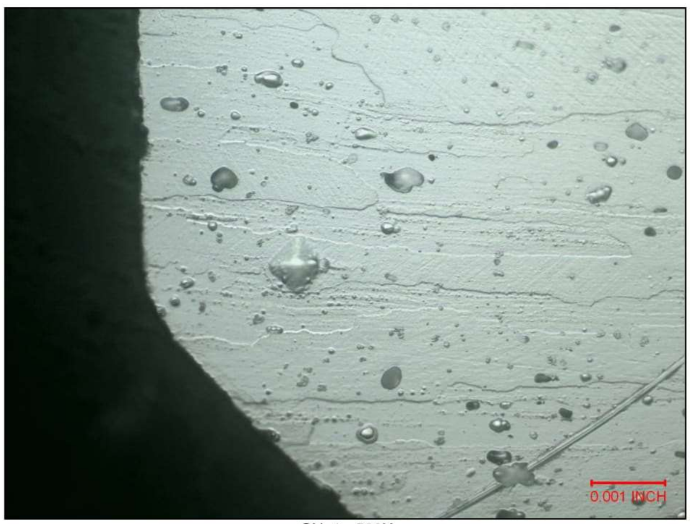
Date:	5/31/2018
P.O. No.:	3801
W/O No.:	PER083-05-24-63649-2

*****CORRECTED TEST CERTIFICATE - EAR-CONTROLLED DATA – 6/4/2018*****
EDM PROCESS EVALUATION***

Quantity Tested:	3 (S/N: 1, S/N: 3 and S/N: 5)
Requirements:	Evaluate for evidence of any remaining EDM damage.

Sectioning, mounting and polishing were performed in accordance with ASTM E3 Rev. 2011. The samples were then etched with Keller's Reagent in order to reveal the microstructure. Evaluation was performed at 200X – 500X magnification. The results are as follows.

The submitted samples for evaluation show no evidence of EDM damage.



SN: 1 - 500X

Respectfully submitted

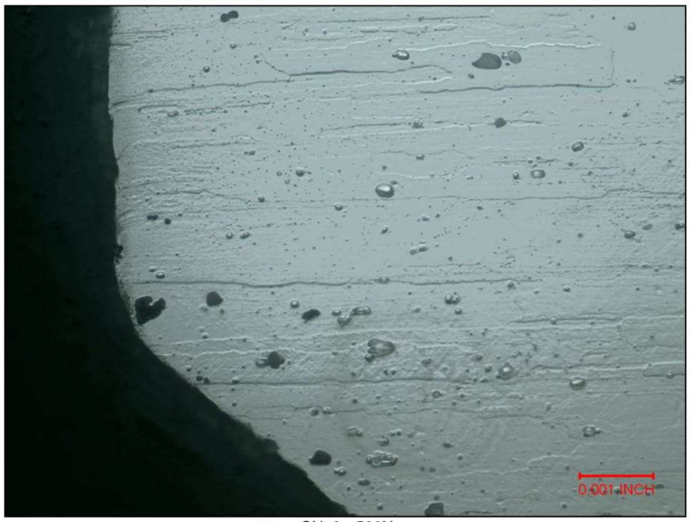
15062 Bolsa Chica, Huntington Beach, CA 92649
(714) 892-1961 ph • (714) 892-8159 fax www.element.com

Anna Tiengthong
Quality Administrator

element™

Date: 5/31/2018
P.O. No.: 3801
W/O No.: PER083-05-24-63649-2

*****CORRECTED TEST CERTIFICATE - EAR-CONTROLLED DATA – 6/4/2018*****



SN: 3 - 500X

Respectfully submitted

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(714) 892-1961 ph • (714) 892-8159 fax www.element.com

Anna Tiengthong
Quality Administrator

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Page 3 of 4

element™

Date: 5/31/2018
P.O. No.: 3801
W/O No.: PER083-05-24-63649-2

*****CORRECTED TEST CERTIFICATE - EAR-CONTROLLED DATA – 6/4/2018*****

SN: 5 - 500X

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Respectfully submitted

Anna Tiengthong
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Page 4 of 4

Appendix B: Element Test Report, Al micrographs (no rectification)

Element Materials Technology
15062 Bolsa Chica
Huntington Beach, CA
92649-1023 USA

P 714 892 1961
F 714 892 8159
T 888 786 7555
info.hb@element.com
element.com

Contact: PURCHASING/QA
Perfect Point EDM Corp.
15192 Triton Lane
HUNTINGTON BEACH, CA 92649

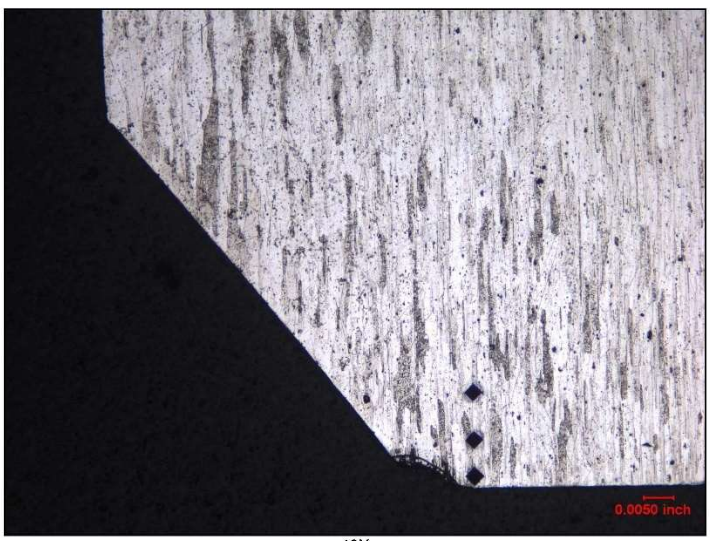
*****CORRECTED TEST CERTIFICATE — EAR-CONTROLLED DATA 6/27/2018*****

Date: 6/23/2018
Purchase Order Number: 3831
Work Order Number PER083-06-06-65359-2

Material:	ALUMINUM 7075-T7351
Drawing No.:	10715-000 REV C
Specification:	FOR INFORMATION ONLY
Description:	RECTANGULAR SAMPLE

EDM PROCESS EVALUATION

Quantity Tested: 1 (Aluminum)
Requirements: Evaluate for evidence of any remaining EDM damage.
Sectioning, mounting and polishing were performed in accordance with ASTM E3 Rev. 2011. The samples were then etched with Keller's Reagent in order to reveal the microstructure. Evaluation was performed at 200X – 500X magnification.
The results are as follows.
The submitted sample for evaluation shows evidence of existing EDM damage. (Please see attached photos).



40X

Respectfully submitted

Anna Tiengthong
Quality Administrator

15062 Bolsa Chica, Huntington Beach, CA 92649
(714) 892-1961 ph • (714) 892-8159 fax www.element.com

Date:	6/23/2018
P.O. No.:	3831
W/O No.:	PER083-06-06-65359-2

*****CORRECTED TEST CERTIFICATE - EAR-CONTROLLED DATA 6/27/2018*****

200X ***

Microhardness Evaluation
S/N 14***

Requirement: FOR INFO. ONLY
Load in grams: 500g
Magnification: 400X

Sample / Location	Vickers	Rockwell HRB
0.002"	144	78
0.008"	158	83
0.016"	162	84

Approximate conversion per ASTM E-140 (12b^{E1})

Please see attached for HCF results.
FOR INFORMATION ONLY

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Respectfully submitted

Anna Tiengthong
Quality Administrator

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Appendix C: Element Test Report, Low Cycle Fatigue Data

HIGH CYCLE FATIGUE DATA SUMMARY

Axial Stress Measurement and Control

LCF TEST VENDOR: Element Materials Technology - Huntington Beach
GE VENDOR CODE: T4707
COMPANY: Perfect Point EDM Corp. 15192 Triton Lane, Huntington Beach. CA 92649

P.O. No.: 3831
WORK ORDER No.: PER083-06-06-65359
DATE: 6/22/2018

MATERIAL: Al
WAVEFORM: Sinusoidal
SPECIMEN DESIGN: AS Supplied
TEST METHOD: ASTM E466
MATERIAL SPEC.: CUSTOMER REQUIREMENTS

Test Machine No.	Specimen ID No.	Test Temp °F	Thickness in	Width in.	Area sq./in.	Ratio R	Alt Stress (ksi)	Mean Stress (ksi)	Stress Range (ksi)	Max Stress (ksi)	Min Stress (ksi)	Nf Cycles	Test Freq. (CPM)	Tf (hours)	Comments
F016-2	AL00N01	75	0.2490	1.0000	0.2490	-1.00	15.26	0.00	30.52	15.26	-15.26	50,822	600	1.4	SF
F017-1	AL00N02	75	0.2500	1.0000	0.2500	-1.00	14.00	0.00	28.00	14.00	-14.00	75,806	600	2.1	SF
F017-2	AL00X02	75	0.2500	1.0000	0.2500	-1.00	14.00	0.00	28.00	14.00	-14.00	76,590	600	2.1	SF
F017-3	AL00Y02	75	0.2500	1.0000	0.2500	-1.00	14.00	0.00	28.00	14.00	-14.00	55,948	600	1.6	SF
F017-4	AL09N02	75	0.2500	1.0000	0.2500	-1.00	14.00	0.00	28.00	14.00	-14.00	69,076	600	1.9	SF
F017-5	AL15N01	75	0.2500	1.0000	0.2500	-1.00	14.00	0.00	28.00	14.00	-14.00	53,162	600	1.5	SF
F017-6	AL15X01	75	0.2500	1.0000	0.2500	-1.00	14.00	0.00	28.00	14.00	-14.00	91,958	600	2.6	SF
F017-7	AL21Y01	75	0.2500	1.0010	0.2503	-1.00	13.99	0.00	27.97	13.99	-13.99	76,153	600	2.1	SF

Descriptors-Fracture Location	
SF	Specimen Fracture
RS	Reduced Section
DISC	Discontinue
IG	In Grip
IT	In Threads
AR	At Radius

Specimens machined & polished at ELEMENT HUNTINGTON BEACH

APPROVED FOR RELEASE BY:

Terry Pitchford

TERRY PITCHFORD
MANAGER - DYNAMIC TESTING, Element Materials Technology-Huntington Beach

element™
15062 Bolsa Chica, Huntington Beach, CA 92649, USA
TEL.(714) 892-1961 - FAX.(714) 892-8159

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Form No. 9300007-Certificate   1 of 1   Revision 8, Issued 05/08/2018

Appendix D: Material Certification:

PERFECT POINT EDM S/O # 120632-1-1 PO # 3712

SHIP TO:
DIX METALS 800-477-4349 www.dixmetals.com
SOLD TO:
DIX METALS 800-477-4349 www.dixmetals.com

KAISER ALUMINUM
Trentwood Works - Spokane, WA 99215
Phone: (800) 367-2586

CERTIFIED TEST REPORT

Serial Number
4428589

CUSTOMER PO NUMBER:	WORK PACKAGE:	CUSTOMER PART NUMBER:	SHIP RUN/LOAD:	GOV'T CONTRACT NUMBER:	
PO0021006WC			103645/14		

KAISER ORDER NO:	LINE ITEM:	SHIP DATE:	ALLOY:	CLAD:	TEMPER:	PRODUCT DESCRIPTION:
1213253	1	6-AUG-2016	7075	BARE	T7351	Sawed Plate

WEIGHT SHIPPED:	QUANTITY:	TRUCK B/L #:	GAUGE:	DIAMETER/WIDTH:	LENGTH:
3230 LB	18 PCS EST.	2061751	0.2500 IN (6.3500 MM)	48.500 IN (1231.9 MM)	144.500 IN (3670.3 MM)

MHU 2029217: LOT 18694485: 18 pieces:

Certified Specifications

AMS 4078/RevJ
CMMP 025/RevV
AMS-QQ-A-250/12/RevA
MMS 159/RevT
ASTM B 209/Rev14

Test Code: 4297

Test Results

Lot: 18694485 Cast 225 Drop 34 Ingot 5 Melted in USA

(ASTM E8/B557)
(EN 2002-1)

	Temper	Dir / # Tests	Ultimate KSI (MPA)	Yield KSI (MPA)	Elongation %
Tensile:	T7351	LT / 2 (Min:Max)	73.5 : 74.8 (507 : 516)	62.8 : 64.0 (433 : 441)	11.3 : 11.5

(ASTM E1004)
(EN 2004-1)

Conductivity %IACS :	40.3 Min	40.3 Max
(MS/M) :	23.4 Min	23.4 Max

(ASTM E1251)

Chemistry:	SI	FE	CU	MN	MG	CR	ZN	TI	V	ZR		OTHER
Actual(wt%)	0.07	0.23	1.4	0.02	2.4	0.19	5.6	0.02	0.01	0.01	TOT	0.06

ALLOY LIMITS

7075	SI	FE	CU	MN	MG	CR	ZN	TI	V	ZR	OTHER	MAX
MIN(wt%)	0.00	0.00	1.2	0.00	2.1	0.18	5.1	0.00	0.00	0.00	EACH	0.05
MAX(wt%)	0.40	0.50	2.0	0.30	2.9	0.28	6.1	0.20	0.05	0.05	TOT	0.15

Aluminum Remainder

Page 1 of 2

PERFECT POINT EDM S/O # 120632-1-1 PO # 3712

KAISER ALUMINUM
Trentwood Works - Spokane, WA 99215
Phone: (800) 367-2586

CERTIFIED TEST REPORT

Serial Number
4428589

CERTIFICATION

Kaiser Aluminum, Trentwood Works, is ISO 9001, AS9100, and ISO 14001 certified, and hereby certifies that all material shipped under this order:

* has been inspected, tested, and found to be in conformance with the requirements of the specifications indicated herein. All test equipment and measuring devices are calibrated and certified in accordance applicable specifications. For material thicknesses outside specification limits, mechanical properties are as shown herein and chemical composition meets specification requirements. Reported elongation values have been measured as elongation at fracture.
* was melted in the United States of America or a qualifying country per DFARS 225.872-1(a), was manufactured in the United States of America, and meets the requirements of DFARS 252.225 for domestic content.
* has been thermally processed in compliance with AMS 2772, where applicable.
* is mercury free, within the limits of detection of ASTM E1215 (<1ppm).
* is in compliance with RoHS 2, European Union Directive 2011/65/EU.
* is in compliance with European Chemical Agency, ECHA, REACH regulations, (EC) No 1907/2006, and Kaiser regularly monitors these regulations for updates.
* is free of Conflict Minerals, as defined in Section 15.2 of the Dodd-Frank Act.
* is free of weld repair.
* meets the reporting requirements of EN10204, Type 3.1.

Any warranty is limited to that shown on Kaiser Aluminum's standard general terms and conditions of sale. Test reports are on file, subject to examination. Test reports shall not be reproduced except in full, without the written approval of the Kaiser Aluminum laboratory. The recording of false, fictitious or fraudulent statements or entries on the certificate may be punished as a felony under federal law.

JAMES HEMENWAY, TECHNICAL PROCESS MANAGER

Page 2 of 2