2014-06-10

Friction Bit Joining of Dissimilar Combinations of Advanced High-Strength Steel and Aluminum Alloys

Lile P. Squires
Brigham Young University - Provo

BYU ScholarsArchive Citation

Squires, Lile P., "Friction Bit Joining of Dissimilar Combinations of Advanced High-Strength Steel and Aluminum Alloys" (2014). *All Theses and Dissertations*. 4104.
https://scholarsarchive.byu.edu/etd/4104

Friction Bit Joining of Dissimilar Combinations of Advanced High-Strength Steel and Aluminum Alloys

Lile P. Squires

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Michael P. Miles, Chair
Alan J. Boardman
Andrew R. George

School of Technology

Brigham Young University

June 2014

ABSTRACT

Friction Bit Joining of Dissimilar Combinations of
Advanced High-Strength Steel and
Aluminum Alloys

Lile Squires
School of Technology, BYU
Master of Science

Friction bit joining (FBJ) is a new method that enables lightweight metal to be joined to advanced high-strength steels. Weight reduction through the use of advanced high-strength materials is necessary in the automotive industry, as well as other markets, where weight savings are increasingly emphasized in pursuit of fuel efficiency.

The purpose of this research is twofold: (1) to understand the influence that process parameters such as bit design, material type and machine commands have on the consistency and strength of friction bit joints in dissimilar metal alloys; and (2) to pioneer machine and bit configurations that would aid commercial, automated application of the system.

Rotary broaching was established as an effective bit production method, pointing towards cold heading and other forming methods in commercial production. Bit hardness equal to the base material was found to be highly critical for strong welds. Bit geometry was found to contribute significantly as well, with weld strength increasing with larger bit shaft diameter. Solid bit heads are also desirable from both a metallurgical and industry standpoint. Cutting features are necessary for flat welds and allow multiple material types to be joined to advanced high-strength steel. Parameters for driving the bit were established and relationships identified. Greater surface area of contact between the bit and the driver was shown to aid in weld consistency.

Microstructure changes resulting from the weld process were characterized and showed a transition zone between the bit head and the bit shaft where bit hardness was significantly increased. This zone is frequently the location of fracture modes. Fatigue testing showed the ability of FBJ to resist constant stress cycles, with the joined aluminum failing prior to the FBJ fusion bond in all cases. Corrosion testing established the use of adhesive to be an effective method for reducing galvanic corrosion and also for protecting the weld from oxidation reactions.

Keywords: Lile Squires, friction bit joining, FBJ, dissimilar metals, dissimilar material joining, advanced high-strength steel, aluminum, DP980, automotive manufacturing, aerospace manufacturing, corrosion, ORNL, friction element welding

ACKNOWLEDGEMENTS

Sincerest appreciation is expressed to the many people who have contributed time and effort to the development of friction bit joining during this research. Dr. Mike Miles provided the most guidance and direction as a mentor, friend and committee chair. Coulter Woodward and Alex Avila provided significant technical assistance, as well as companionship in the excitement of discovery and advancement of the process. Their enthusiasm and expertise was critical to this work.

Particular appreciation and mention is made for collaborative efforts made by Yong Chae Lim from Oak Ridge National Laboratory for his high quality work and diligence. Professional consultation was contributed by Jon Babb, MegaStir and Trevor Reed. Undergraduate contributors include Taeseon Lee, Cory Cunningham and Aubrey Decker. Their support was equally appreciated.

Gratitude is also conveyed to my family members. My parents, siblings and wife have all provided support and encouragement throughout my graduate work. I appreciate their patience, enthusiasm and good-natured tolerance as I frequently shared research developments and technical progress with them.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

The transportation industry has recently been put under pressure to reach higher levels of fuel efficiency. In an effort to reduce greenhouse gas emissions and extend the range of existing power plants, manufacturers are looking for effective methods of reducing weight in their products. One common approach is to combine dissimilar materials in unit production in order to utilize different properties with function-specific advantages. This must be done without losing critical overall performance or safety attributes. This is a danger because traditional joining processes often fall short when employed to join materials with significantly different physical or chemical characteristics.

Current efforts to combine dissimilar metals in mixed-material applications include friction welding, diffusion bonding, self-piercing rivets, fusion welding, friction stir spot welding, adhesive bonding and friction stir welding. Each of these methods is subject to technical problems such as the formation of brittle intermetallic compounds or low mechanical strength. These drawbacks, as well as other limitations, restrict the use of these joining processes. As a result, a new solid-state joining process was recently introduced to overcome the most significant obstacles.

Friction Bit Joining (FBJ) is a new method that enables lightweight metal and nonmetal materials to be joined to advanced high-strength steels. Research carried out at BYU indicates that FBJ offers a solution to many of the challenges associated with weight reduction through the use of advanced high-strength materials. The most common challenge associated with the use of these materials is the formation of brittle intermetallic compounds when a traditional method like resistance spot welding creates mixing of the dissimilar alloys in the weld pool. Another challenge is the tendency to fracture within the heat-affected zone where softening has occurred during welding. FBJ overcomes both of these issues by utilizing a combination of low temperature solid-state bonding and plastic deformation.

FBJ is a simple process with only three stages. During the first stage, a rotating, consumable bit is driven through upper materials. A joining phase follows where the bit, through frictional heat and pressure, forms a plasticized region at the interfaces between itself and the surrounding materials. During the final stage, all rotational motion is stopped and the tool is withdrawn, leaving the consumable bit behind in a metallurgical bond with the lower material.

Prior work, though limited due to the recent introduction of FBJ by BYU, has established the potential for this process to create viable dissimilar metal joints. Still, many conditions relevant to the process were undefined and had not been studied. Process control had not yet been fully established, and processing parameters that lead to consistent, strong joints had not been identified. The aim of the current study was to evaluate relationships between process parameters and weld strength, as measured in static lap shear, and then evaluate machine configurations and consumable bit characteristics that would promote commercial, automated use of the process.

Until these problems were addressed, it would not be likely that FBJ could be seen as a viable process eligible for automated manufacturing situations. Lack of scientific research into FBJ relationships between processing parameters was a significant barrier to further development and adoption by industry.

1.1 Problem Statement

The purpose of this research is twofold. First, it is to understand the influence that processing parameters have on the consistency and strength of friction bit joints in dissimilar metal alloys such as dual phase steel and aluminum. Second, it is to pioneer machine and consumable bit configurations that would aid commercial, automated application of the system.

These two objectives will define the science behind Friction Bit Joining in such a way that FBJ will become a legitimate option for application by manufacturers in the automotive and aerospace markets, as well as other industries.

1.2 Research Questions

The questions addressed during this research include the following:

What influence do processing parameters have on the consistency and strength of friction bit joints?

- Spindle RPM
- Z-axis velocity
- Z-axis depth command

What are machine and consumable bit configurations that support commercial, automated application of the system?

- Physical bit properties and dimensions
- Bit production, machine fixtures, and clamping
- Resistance to corrosion, weld strength

1.3 **Hypotheses**

1. There is a specific combination of process parameters, bit and machine characteristics that lead to optimal joint properties.
2. Galvanic corrosion of the aluminum/steel joints will reduce joint strength if the joint is unprotected by a coating or by adhesive when subjected to a corrosive environment.
3. Applying adhesive to the joint will not significantly mitigate a drop in joint strength when the joints are subjected to a corrosive environment.

1.4 **Methodology**

1.4.1 **Materials**

Dissimilar metals that were joined were generally aluminum and steel, except for limited experiments with carbon fiber. Specifically, these materials were 1.6 mm thick AA7075-T6, 2.08 mm thick AA5754, carbon fiber and 1.2 mm thick DP980 advanced high-strength steel (AHSS). DP980 advanced high-strength steel is increasingly popular and particularly suited for use in automotive and transportation industries due to its mechanical strength, high work hardening rate, and high uniform and total elongation (Bhagavathi , 2011).

Aluminum specimens used were 7075 aluminum and 5754 aluminum, which contain manganese, iron, magnesium, silicon and aluminum (Aalco Metals Ltd. 2011). These alloys are frequently used in aerospace applications (Zhao, 2007).

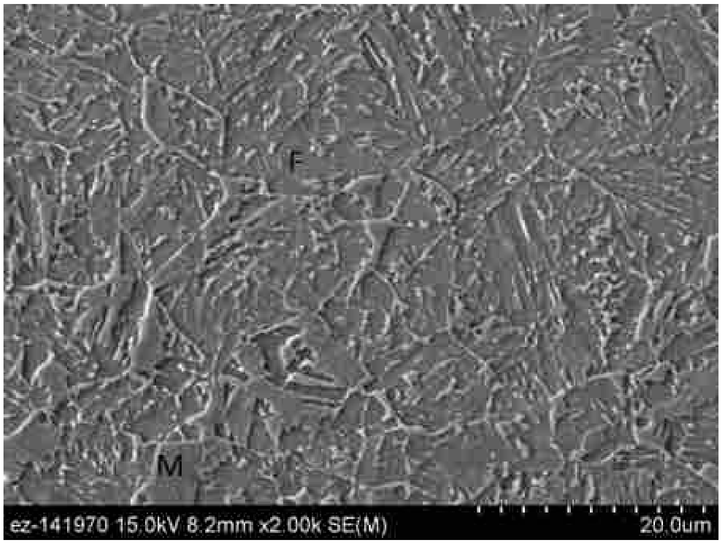


Figure 1-1: DP 980 SEM, Showing Ferrite and Martensite

Material used for bit manufacture was generally half-hard AISI 4140 alloy steel, titanium and aluminum. Bits were produced using a variety of manufacturing methods and on several machines, including plunge EDM, wire EDM, CNC lathe and CNC mill.

Dissimilar joint specimens were created using a purpose-built machine designed by MegaStir Technologies. Modifications to the original machine and fixtures were made by the Precision Machining Lab at Brigham Young University and by the FBJ research team. In all cases, DP980 was used as the bottom layer, with the aluminum alloy being placed on top. For specimens tested in the lap shear configuration, each coupon was sheared to 100 mm by 25 mm dimensions prior to use (O'Brien, 1991). Coupon overlap was 25 mm or 50 mm in all cases, with the FBJ weld located in the center of the overlap area. For cross-tension testing, coupons were sheared to 50 mm by 150 mm (O'Brien, 1991). Before use, each coupon was wiped with a clean rag to remove any oil or debris. No further cleaning action was taken and no solvents were used in order to imitate conditions common to manufacturing environments.

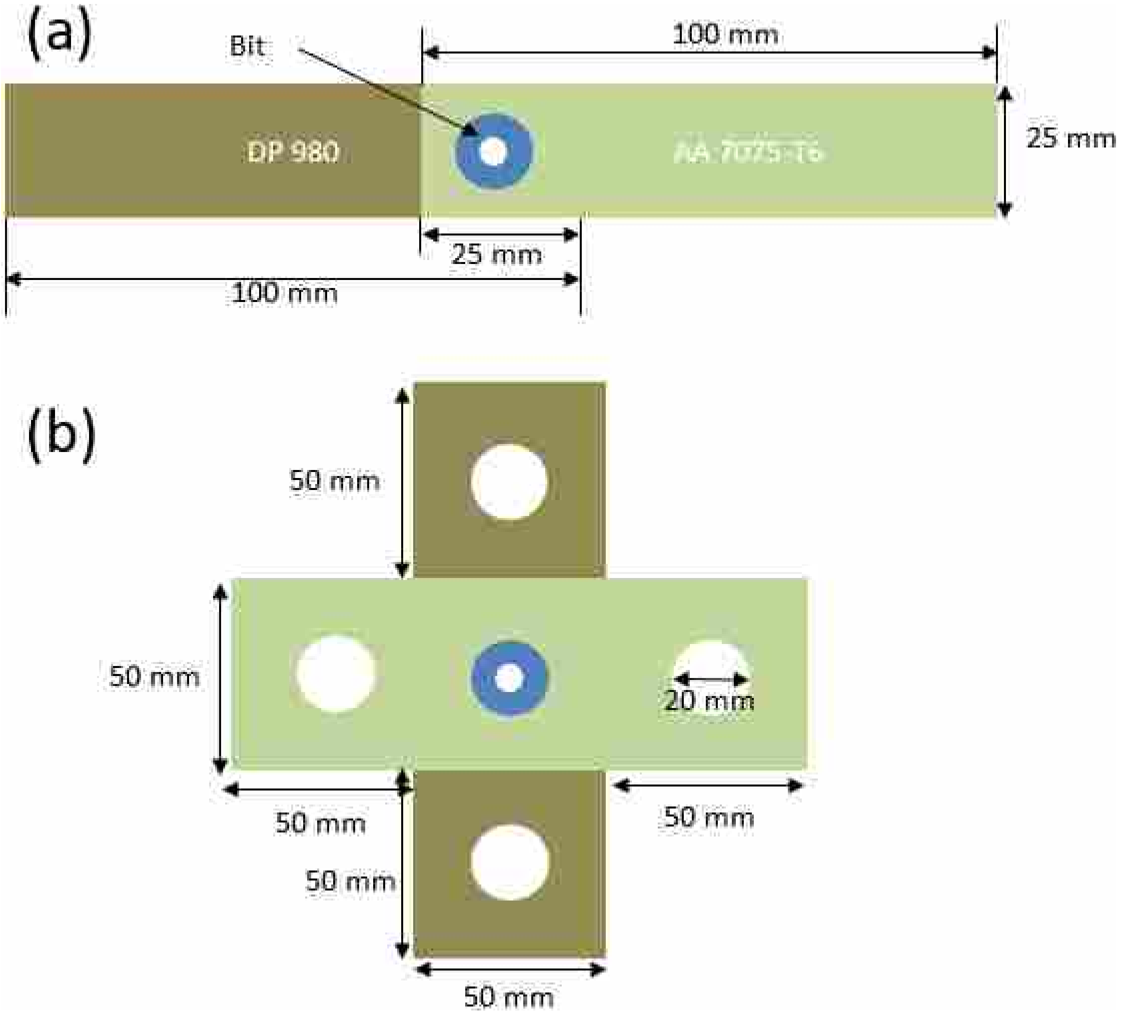


Figure 1-2: Specimen Configuration (a) Lap Shear Testing (b) Cross Tension

1.4.2 Experiments

Joint strength measured in lap shear and cross-tensional strength was tracked as independent variables were manipulated. Mechanical testing is a fast, simple method to evaluate joint strength and performance and served as an indicator of the effects of variable manipulation. Mechanical testing of specimens was done in lap shear and cross-tension configurations. For select specimens, mechanical testing preceded and was followed by accelerated corrosion testing.

Inspection of specimens was done through optical and electron microscopy. Selected specimens were cross-sectioned, then mounted and polished to allow microscope analysis and micro-hardness testing.

Through regression analysis and other statistics, relationships were identified between inputs and dependent variables. Independent variables included bit manufacturing procedure, presence of adhesive, material type, hardness and engineering design. Welding properties included clamp force, Z-travel distance, Z-velocity and RPM. Dependent variables included lap shear strength, micro-hardness, weld penetration, corrosion resistance and fusion characteristics. Development of hardware configurations was accomplished in similar fashion through manipulation of known parameters within given industry constraints as determined by MegaStir Technologies.

Using software and experimental data, FBJ was simulated in a computerized environment in order to model the behavior of the tool and specimen materials. Computerized process modeling was done using the Forge finite element software, using a Lagrangian, two-dimensional approach. The purpose of this was to aid in identifying key parameters.

1.5 **Delimitations and Assumptions**

This research does not investigate the joining of dissimilar metals other than advanced high-strength steel (AHSS) and aluminum, although conclusions may be drawn for joining other materials such as magnesium or titanium. Comparison data for other dissimilar joining processes was obtained through literature review and previous experiments on dissimilar joining methods.

1.6 Definitions of Terms

AHSS – advanced high-strength steel (steels that yield at 560 MPa or above)

DP – dual phase steel that has a ferrite and martensitic microstructure

DP980 – a high-strength dual-phase steel with an ultimate tensile strength of 980 MPa

EDM – electronic discharge machining. Two types were used during this work: wire EDM and plunge EDM.

FBJ – friction bit joining is a new joining technology that uses a consumable bit to spot-join sheet metals by drilling through the top sheet and friction-welding to the bottom sheet.

FSSW – friction stir spot welding is a solid-state welding process that uses a non-consumable tool to stir the metals to be joined together at a point.

HAZ – heat-affected zone is the area within a material that has changed properties due to welding or some other heat intensive processes.

IMC – intermetallic compound is formed when dissimilar metals diffuse together at a weld interface.

ORNL – Oak Ridge National Laboratory

RSW – resistance spot welding is a fusion-welding process that uses electrodes to clamp the sheet metals together and pass a current through them which produces the necessary welding heat.

RPM – revolutions per minute

SPR – self-piercing riveting is a cold process that uses a die set to force a rivet into sheet metal without predrilling a hole.

UTS – ultimate tensile strength

2 LITERATURE REVIEW

2.1 Introduction

Because friction bit joining is a new technology, there is a limited number of studies that focus on it specifically as a research topic. For that reason, literature was reviewed with an emphasis on current attempts to join advanced high-strength steel to aluminum, and the application within industry for a process that would effectively fill this function. FBJ combines principles and weld properties that are common to several other joining processes, such as clinching and self-piercing rivets, which are also included in this review. It is important to note however, that methods such as clinching and self-piercing rivets have limited effectiveness in joining advanced high-strength steel and aluminum alloys.

2.2 Lightweight High-Strength Material Combinations in Car Bodies

With stricter legislation on emissions, as well as pressures from the consumer market, automakers are increasingly seeking to find ways of reducing vehicle weight while also maintaining structural rigidity and strength. For this purpose, advanced high-strength steels are becoming increasingly attractive due to their low ductility and high tensile strength, and are seeing increased use in mixed-material body structures (Lai, 2007).

2.3 Traditional Methods for Dissimilar Material Joining

While the benefits of using dissimilar material combinations are clear, the greatest challenge that faces manufacturers wanting to use advanced high strength steels in their car bodies is that most available joining methods are severely limited. There are three chief methods traditionally used to join dissimilar metals. Clinching, self-piercing rivets, and hybrid spot joining (adhesive combined with a spot joint such as a resistance spot weld).

Clinching is a cold forming process that involves forming one sheet of material into another using a die. This creates a mechanical interlock between the two materials, and joint strength depends on the final geometry of the clinched joint (Hamel, 2000). Self-piercing riveting (SPR) is another cold-forming method that is common for joining dissimilar materials (Groche, 2014). Like clinching, SPR depends upon the ductile deformation of the two materials to be joined, but unlike clinching, uses a hollow rivet that is forced through the sheet metal and deformed against a die, forming a mechanical interlock. Hybrid spot joining is characterized by the use of a structural adhesive in conjunction with resistance spot welding or other method, in an effort to increase joint strength. (Bartczak, 2013).

2.4 Joining Advance High-Strength Steels to Aluminum

While several methods exist and are used in industry to join dissimilar metals, there is a severe restriction on their ability to join advanced high-strength steel to aluminum alloys. This is due to the difference in flow stress (Abe, 2006) and the tendency to develop brittle intermetallic compounds (Miles, 2009), among other challenges.

To address these concerns and improve the effectiveness of these traditional processes, recent developments have been made that reach for an ability to join advanced high strength steels and dissimilar alloys. In particular, the capabilities of clinching and SPR have increased, but they are still limited by the lack of ductility in advanced high-strength steel (Busse, 2011). Modifications to the clinching process are enabling sheet steel of up to 700 MPa to be satisfactorily joined (Mucha, 2013), while SPR has been shown to fully join aluminum sheets with steel sheets up to 590 MPa (Abe, 2009).

2.5 New Joining Method Developments

Due to the current limitations of traditional joining technologies, several new methods have been introduced, including friction bit joining, for joining aluminum to advanced high-strength steel. Solid self-piercing riveting (SSPR) uses a solid rivet that does not deform, eliminating the one of the chief problems faced by hollow rivets in SPR. Instead, the rivet is used to punch a hole in the sheets to be joined, and then with the application of additional force, the lower sheet is deformed into a groove or ring of grooves in the rivet shaft (Mucha, 2013). Resistance element welding is another new method, which uses a consumable steel weld rivet to punch through the aluminum sheet. The aluminum sheet is then placed upon the steel, which brings the weld rivet now lodged in the aluminum into contact with the steel. Electrodes are positioned and a normal resistance spot weld is made. Friction bit joining uses a consumable steel bit that pierces the aluminum sheet, and then fuses to the lower sheet using friction and pressure to generate enough heat to form a solid-state bond (Miles, 2009). FBJ is also known as friction element welding, or FEW. Current available data for these three processes shows FBJ to have the highest force-displacement properties (Meschut, 2014).

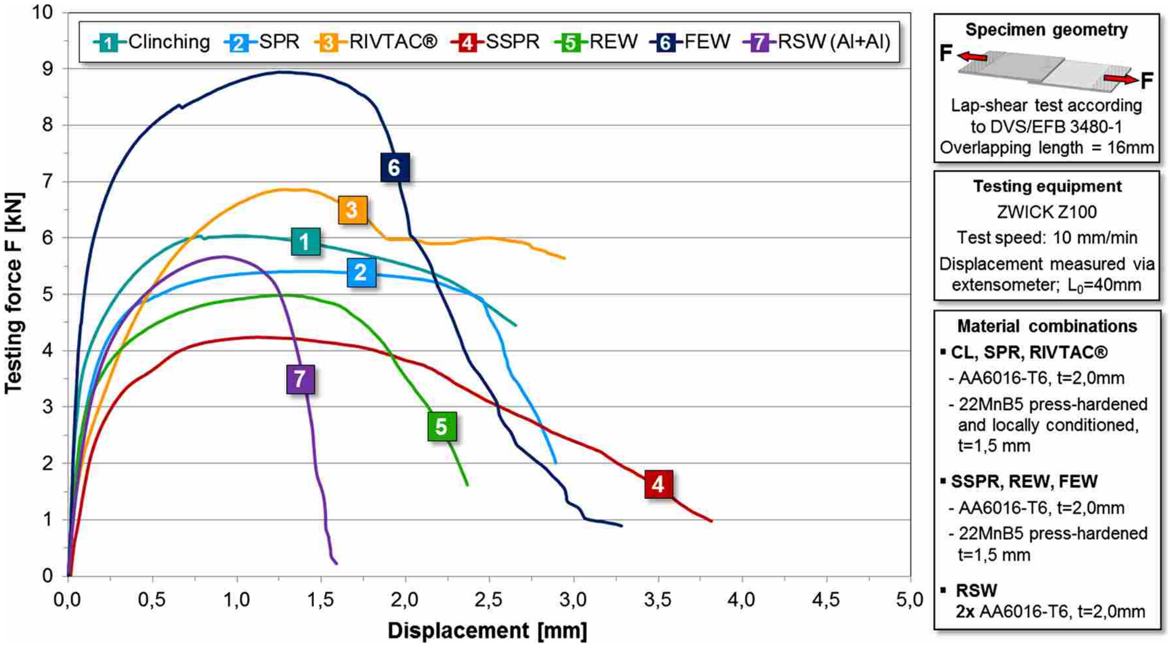


Figure 2-1: Lap-Shear Data for Different Technologies (Meschut, 2014)

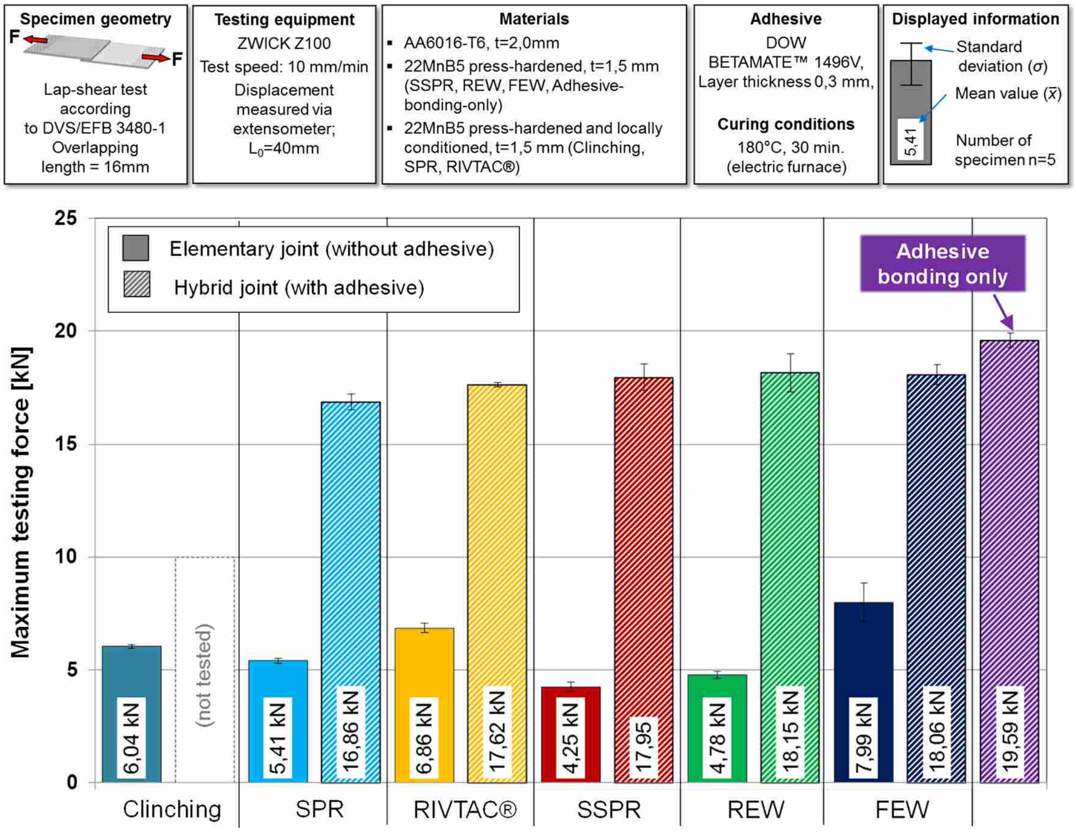


Figure 2-2: Max Shear Tensile Load for Different Technologies (Meschut, 2014)

2.6 **Direct Lap Shear Strength Comparisons**

In general, friction bit joining strengths may be compared with traditional processes only for informational purposes. It is important to note that a direct comparison with these methods is not possible, because of the material combinations that are made possible exclusively through FBJ and the new processes already discussed.

In summary, a few researchers have used solid-state and mechanical welding methods to specifically study the joining of aluminum and steel. Qie and et al. (Qiu, 2009) found a maximum lap shear strength of 6.5 kN for resistance spot welded AA5052 (1 mm thick) and austenitic stainless steel SUS304 (1 mm thick). Sun et al. (Sun, 2013) achieved 3.6 kN in lap shear while joining of AA6061-T6/mild steel (both 1 mm thick) using a flat spot friction stir welding process. . LeBozec et al. (LeBozec, 2012) used a clinching process to join AA6016 to hot dip galvanized steel, and achieved a lap shear strength of 5kN. Miles et al. (Miles, 2009) used self-piercing riveting (SPR) to join 1.6 mm high strength low alloy (HSLA) 350 and 2.0 mm AA 5754-O, which resulted in lap shear strength of ~5kN.

FBJ using 1.6 mm thick AA7075-T6 and 1.2 mm thick DP980 advanced high-strength steel (AHSS) during the research presented in this thesis resulted in lap shear strengths up to 11.75kN. While component material strengths play an important role in the overall lap shear strengths attainable, it was noted during this research that the overall joining strength of FBJ is much higher than other solid-state and mechanical welding methods for joining dissimilar metals.

3 EXPERIMENTAL DESIGN

3.1 **Summary**

Lap joints were created using a friction bit joining machine. In order to test hypotheses and answer the established research questions, variables of interest to the friction bit joining process were isolated and tested. Bit variations were produced using a CNC lathe and EDM machining. Mechanical strength was tested using Instron equipment. Inspection of specimens was conducted visually and through metallography techniques. Process parameters were simulated and manipulated in computer modeling software. Through this methodology, relationships were established between inputs and dependent variables.

Independent variables include:

- Bit manufacturing process control
- Bit material type, hardness and geometry
- Welding properties such as clamp force, Z-travel distance, Z-velocity and RPM

Dependent variables include:

- Lap shear strength and consistency
- Micro-hardness
- Weld penetration, fusion characteristics and grain structure
- Cross-tension shear strength

3.2 The FBJ Machine

The friction bit joining machine was specially built by MegaStir Technologies and is one of two in existence. It consists of a motor mounted on a frame that allows a spindle to be driven at various RPMs, maxing out at 4000 RPMs. Servo motors control movement of the spindle in the Z direction. The end of the spindle accepts a chuck that may be used to mount a variety of tool holders. A fixture below the spindle positions and secures specimens prior to the weld cycle. A brake device on the spindle allows for rapid stopping ability.

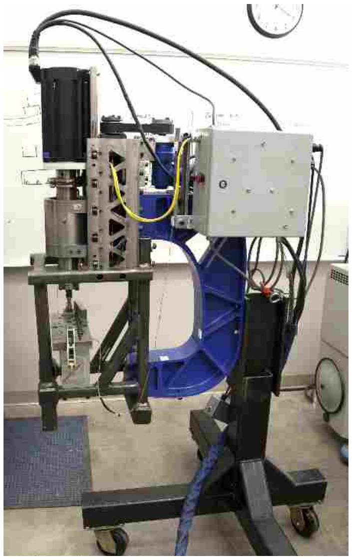


Figure 3-1: Friction Bit Machine at BYU

Sensors provide feedback and information on net Z force, Z motor torque, Z axis velocity, spindle RPM, spindle torque, weld duration and tool depth. Information about each weld cycle gathered by these sensors is recorded and made available from the software that operates the machine.

Machine control is established through this same software. Process variables directly entered include spindle RPM, Z axis velocity (in/min), Z travel command (in) and dwell time (ms). The software provides for four separate stages during the weld cycle, although for this research only two were used. Stage transitions can be position based or load based.

3.3 The FBJ Phases

During the first phase of FBJ, a consumable bit is mounted on the end of a driver in the spindle tool holder. The bit is fed at a specific RPM and Z travel speed, according to user-determined parameters, into the upper layer of material. Cutting action by the bit removes this material and exposes the underlying coupon. The second phase begins as the bit comes in contact with the bottom material during continued Z axis travel. Friction and pressure plasticize the material, whereupon spindle rotation stops and the driver is withdrawn, leaving the bit metallurgically bonded to the bottom layer material and mechanically fastening the top material layer. In the creation of this joint, no surface preparation, pilot hole, or predrilling is necessary. This process is illustrated in Figure 3-2.

The consumable bits used during this study represent one of the more definitive variables for the process. Their material properties, geometry, and interface with the driving tool were the subject of investigation, although a few characteristics were held in common for all versions.

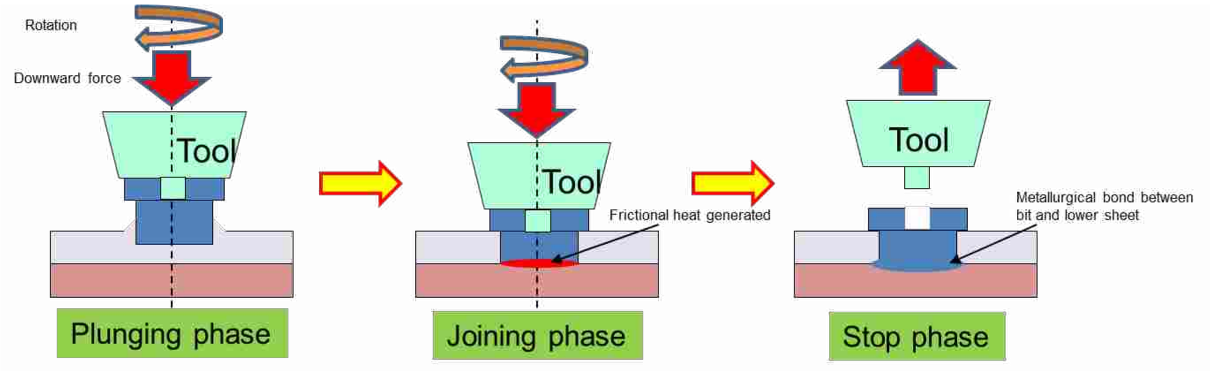


Figure 3-2: Three FBJ Phases

The generic bit design consists of a “head,” or flange portion, and a “shaft” portion. The head of the bit must incorporate geometry that enables the tool used to drive the bit during joining to engage the bit. The shaft portion of the bit must include features that create a cutting action and promote chip removal.

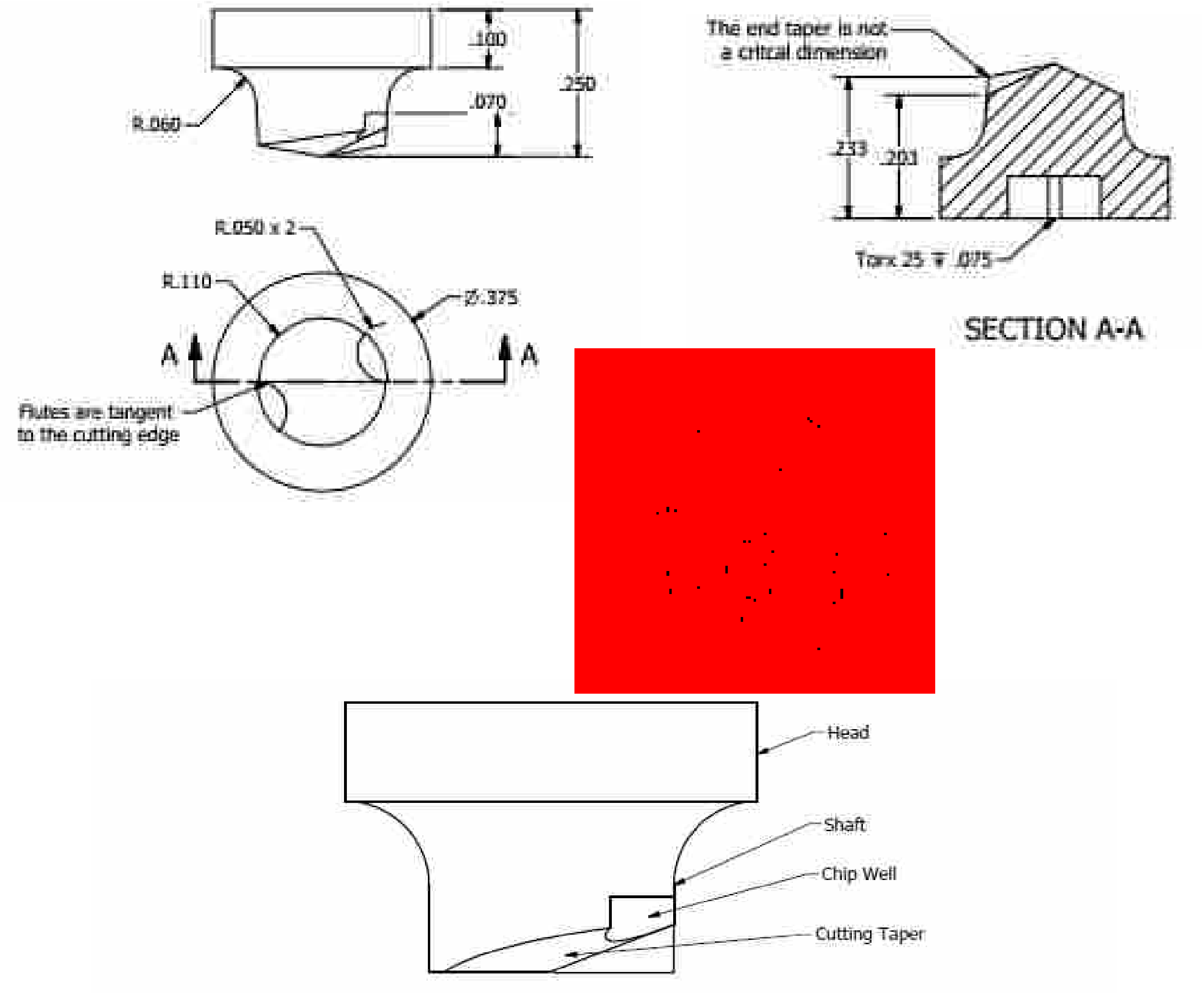


Figure 3-3: Generic Bit Design, Parts and Definitions

Figure 3-4: Okuma Space Turn CNC Lathe Used for Experimental Work

Bit profiles were created using an Okuma Space Turn LB300-M CNC lathe. Each bit had some form of profile that incorporated cutting edges and flutes for chip elimination. Each bit also had an interface through which spindle rotation was transmitted in order to drive the bit. This interface was created in the bit head using EDM procedures and rotary broaching, as well as other machining methods. Materials used were 4140 steel, D2 steel or titanium. Bit hardness was one of the experimental variables.

3.4 Data Collection

Data was automatically recorded and stored in a database by the FBJ machine software during each weld cycle. These parameters included the following:

- Z force net
- Z torque
- Z velocity
- RPM
- Weld duration
- Tool depth

To be able to compare and keep a record of welding parameters and manipulation of properties, a macro-enabled Microsoft Excel data log was developed. Each specimen that was produced on the FBJ machine was assigned an identification number and entered into this data log along with applicable conditions. These conditions included the following:

- Specimen ID number
- Experiment name
- Stage 1 and 2 spindle RPM
- Stage 1 and 2 Z velocity
- Stage 1 and 2 Z command
- Stage 1 and 2 segment dwell time
- Spindle warm-up time
- Clamp force
- Specimen overlap
- Material types used
- Material thicknesses
- Bit head and profile codes
- Bit material and hardness
- Mechanical lap shear strength
- Failure mode
- Situational notes

3.5 Failure Modes in Tensile Testing

During this research, mechanical testing was widely used to evaluate the effects of independent variables. Most often, tested specimens exhibited characteristics that were a combination of failure modes, but four main types of failure were generally seen.

Figure 3-5 Failure Modes: (Top to Bottom) Head, Material, Nugget, Interfacial

Head failure is characterized by a separation of the FBJ bit head from the bit shaft. Typically, the shaft remains bonded to the steel. The material failure mode is observed when the FBJ bit and weld remain intact, but the coupons separate when one of the materials reaches its UTS. This happens either in pure lap shear or as a result of material stretching and tearing during peeling motion. Nugget failure (also called button pullout) is a third failure mode and is recognized by the weld nugget tearing out, with the bit and coupon material otherwise intact. A pure nugget failure displays three components, which include the bit, a layer of the top material and a layer of the bottom material, all fused together. The nugget button pullout failure is the most desired failure mode for automotive applications (Chao, 2003). The final failure mode is characterized by a separation of the coupon materials at their interface. For interfacial failures, bit material is observable in both coupons.

3.6 Equipment and Testing

Ultimate tensile strength was used as a common comparator for nearly all specimens, and was obtained in static lap shear configuration using an Instron strength tester. Specimens were pulled apart at 10.16 mm/min at room temperature. Aluminum and steel shims were employed in each clamp of the Instron machine to maintain the pull direction perpendicular to the weld axis.

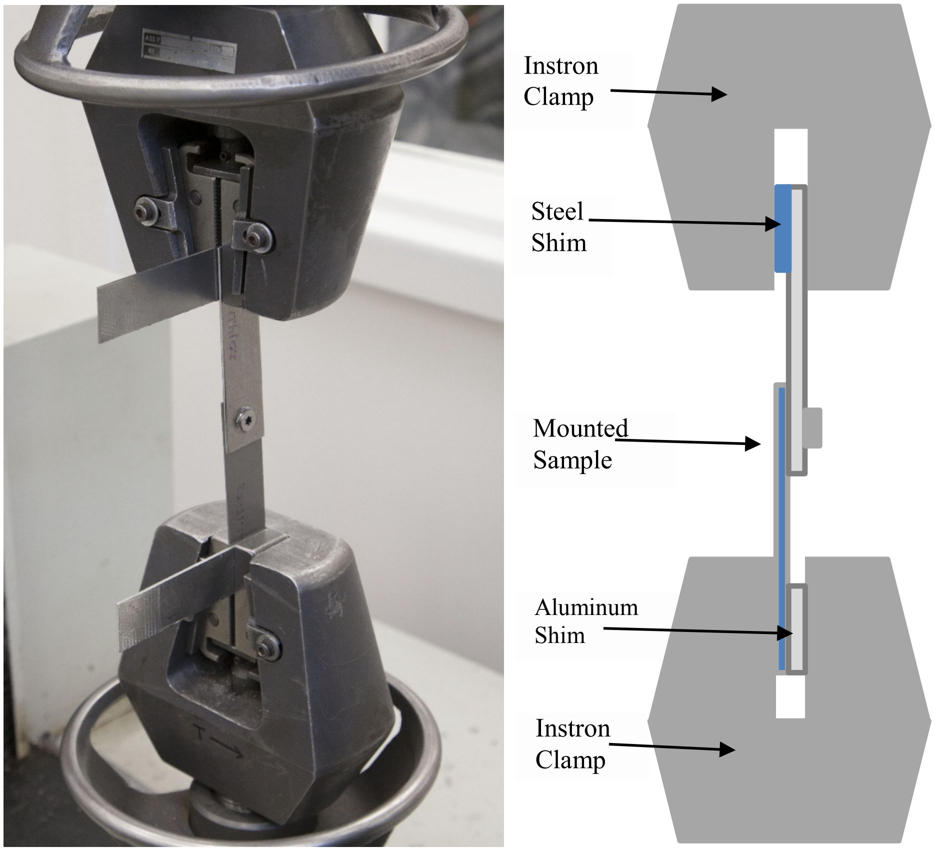


Figure 3-6: Method for Mounting Lap Shear Specimens

For cross-tension specimens, wider coupons with locating holes were used. Cross-tensional data was obtained using the same Instron strength tester as was used for lap shear testing. Fixtures used for mounting cross-tension specimens were specially fabricated, as shown in Figure 3-7.

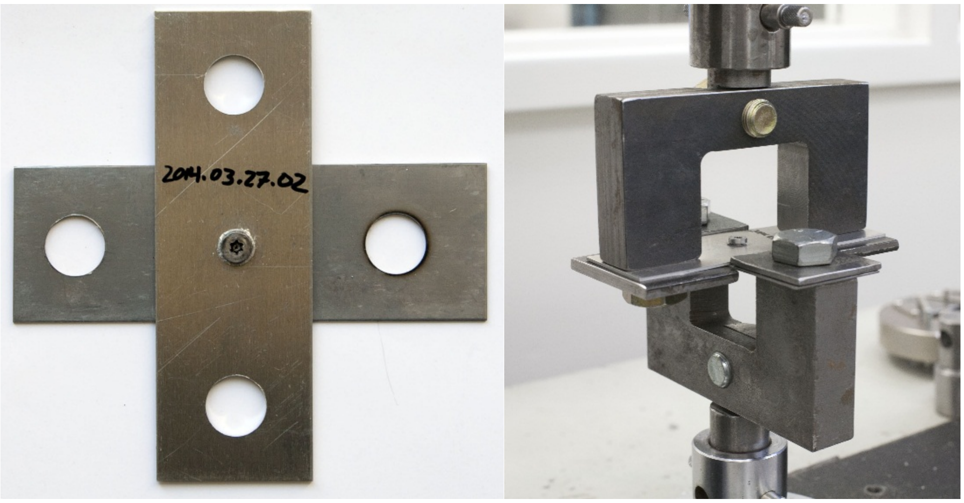


Figure 3-7: Mounting of Cross-Tension Specimens

Optical and electron microscopy examination was obtained by sectioning selected specimens. Specimens were cut in half along the short axis through the exact center of the joint.

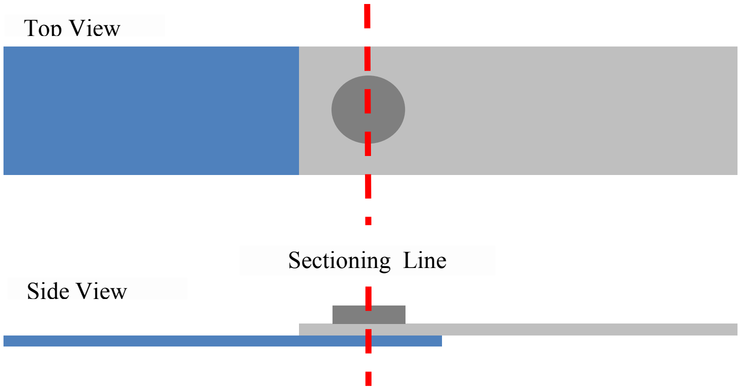


Figure 3-8: Location of Sectioning Cut Path for Lap Shear Specimens

Figure 3-9: Wire EDM Machine Used to Section Samples and Create Tooling

Sectioning was performed using a Wire EDM machine. Sectioned joints were placed in Bakelite and sanded using silicon carbide sandpaper, then polished using compounds with different-sized abrasive particles. Prior to microscope inspection, most samples were etched with a 5% Nital solution.

Data characterizing corrosion resistance was obtained using the Ford Accelerated Cyclic Corrosion Test L-467. Humidity chambers were set according to ASTM Standard E104-02 (2007). Micro-hardness data for materials used in consumable-bit production was collected using a micro-hardness tester.

4 RESEARCH RESULTS AND ANALYSIS

4.1 **Process Improvement**

In order to achieve increasingly consistent results that could be analyzed on common criteria, several aspects of FBJ research needed to be standardized immediately as this study began. Production methods and materials used for the bit were improved first, as experiments typically centered on the consumable bit and its properties. Increased bit-production capability allowed greater numbers of specimens to be made at lower cost, so a need for effective data-collection processes and informational accessibility was a second focus. The final area of standardization was machine control and fixtures.

4.1.1 **Bit Production, Materials and Methods**

Two types of aluminum sheet were used to create experimental specimens. AA7075 and AA5754 are very similar in appearance and are easily confused and interchanged in coupon form. To address this problem, all AA7075 was marked with a single purple line prior to shearing. Once sheared, all coupons with this identifying mark were stored in designated bins.

Figure 4-1: Coupon Storage

Initially, FBJ bits were produced using a complex and time-consuming combination of machines and methods that centered upon EDM capabilities. First, a raw bit profile would be turned on a CNC lathe using a pre-established program.

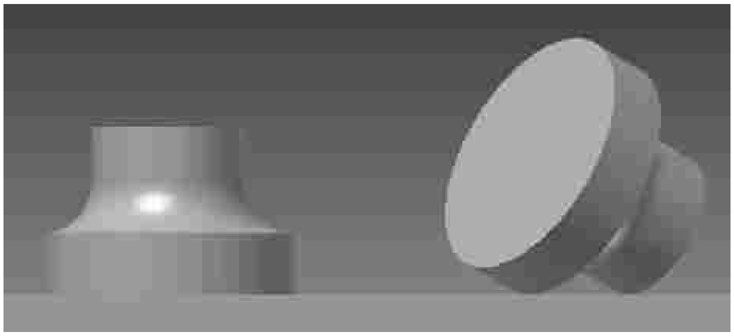


Figure 4-2: A Bit "Blank" Prior to Machining Interface Geometry

This “blank,” after having burrs removed manually, would be ready for a T-25 Torx pocket or other shape to be plunged in its head using RAM EDM. The plunging of this pocket required a graphite electrode to be fabricated. To make this electrode, a graphite cylinder was first cut from rough stock using wire EDM. The end of this graphite cylinder would then be milled to the intended pocket design shape using a CNC mill.

Figure 4-3: Graphite Cylinder Cut From a Block Using Wire EDM

This electrode would then be used in a RAM EDM machine to plunge a Torx pocket in the head of the bit blank, which would be held in a three-jaw chuck.

Figure 4-4: Graphite Electrode Positioned to Plunge a Torx Pocket in a "Blank"

Unfortunately, every use of this electrode caused deterioration and reduction of electrode dimensions. Compensation for these dimensional changes was necessary on every bit produced. By every third or fourth bit produced, maximum compensation would no longer be sufficient. After manually grinding the electrode end flat, it would then be re-machined in the CNC Mill. This process would be repeated until the electrode's total length was reduced sufficiently to require a new graphite cylinder.

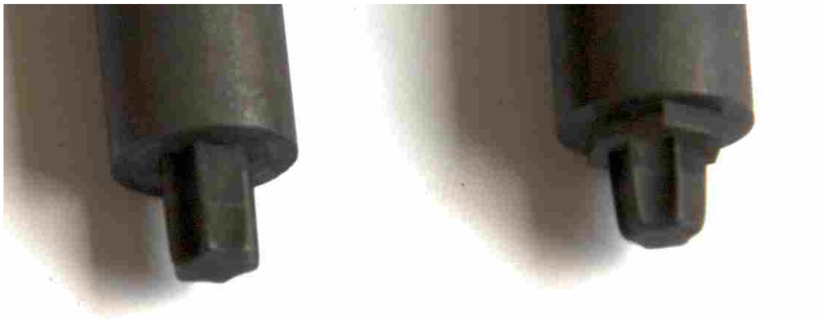


Figure 4-5: Graphite Electrodes Showing Various Degrees of Erosion

To simplify this process, as well as increase R&D production capabilities and reduce time spent on tooling, a rotary broach process was selected. This process would allow current bit designs to be perpetuated with repeatable and increased accuracy, in a two-step procedure. In the first step, the original CNC profile machining cycle was unmodified and still used to turn the bit profile. The bit blank was then placed in the CNC lathe chuck using a special fixture. This fixture was necessary to provide enough surface area for the lathe chuck to grip while holding the bit blank flush with the face of the lathe chuck jaws, and is shown in Figure 4-6. The bit shaft would be inserted in the end of the device and held in place magnetically. The edge of the blank head would be gripped by the chuck jaws along with the exterior of the fixture.

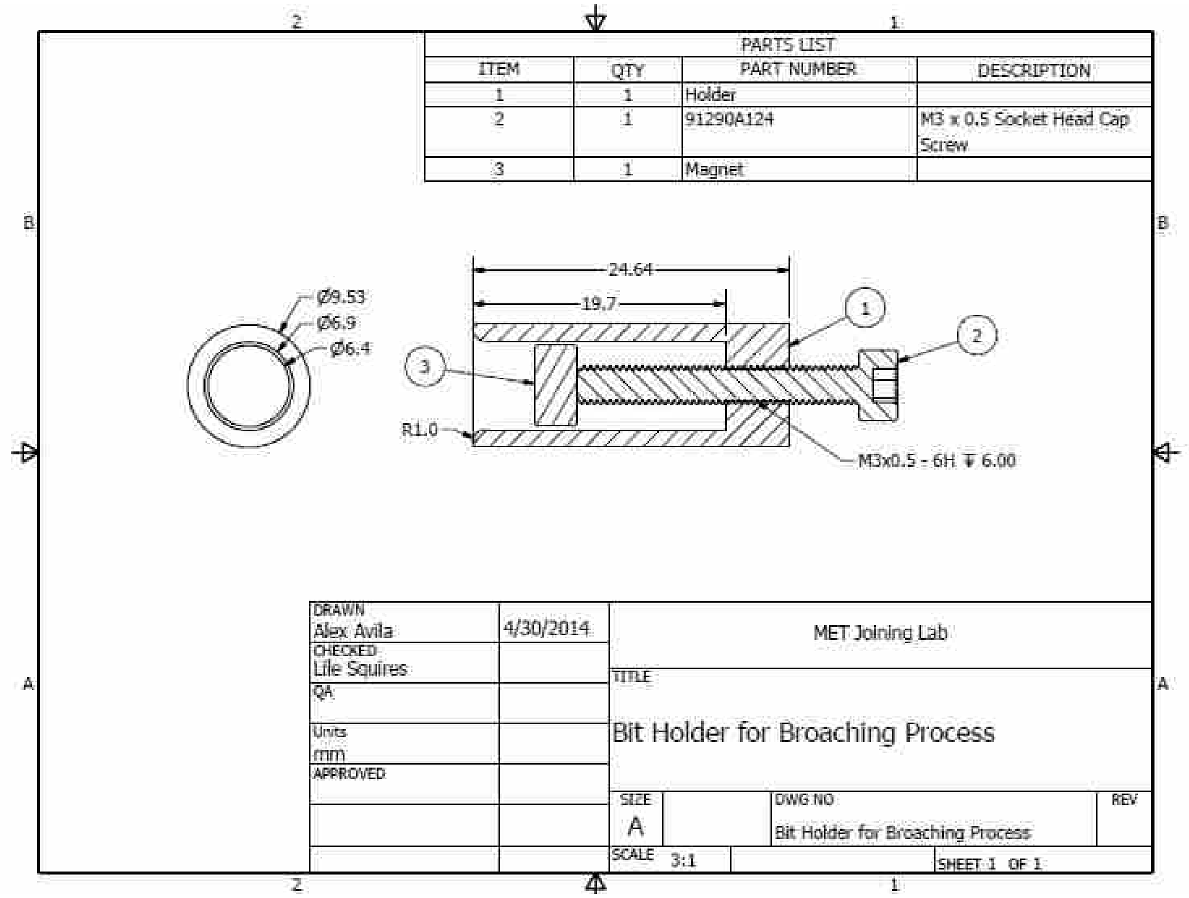


Figure 4-6: Drawing of the Fixture Developed to Hold Bit Blanks for Torx Broaching

A second cycle was introduced and programed to use a rotary broach to cut a T-25 Torx pocket in the head of the "blank." Rotary broaching uses a cutter mounted in a tool holder that spins with the lathe chuck. This tool holder has a one-degree offset, and rotation of the cutter is initiated by contact with the spinning lathe chuck. The offset relationship shown in Figure 4-8 creates a "wobble" cutting motion as the cutter is fed into a predrilled pilot hole. A step by step comparison of the EDM-based production model to the rotary broach-based model is provided in Table 4-1, with a summary of each method in Table 4-2.

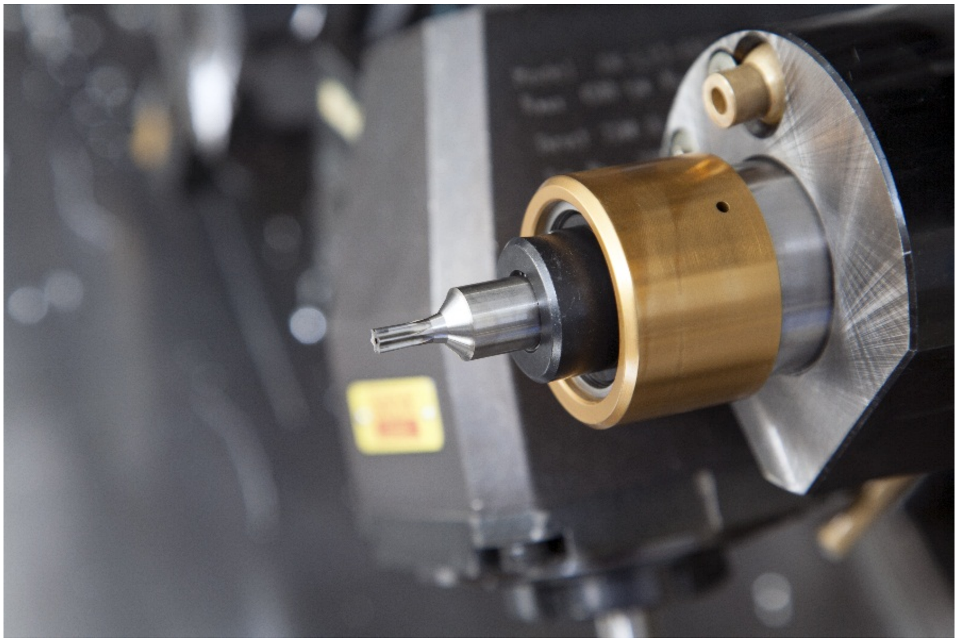


Figure 4-7: Rotary Broach Cutter and Tool Holder in the OKUMA CNC Lathe

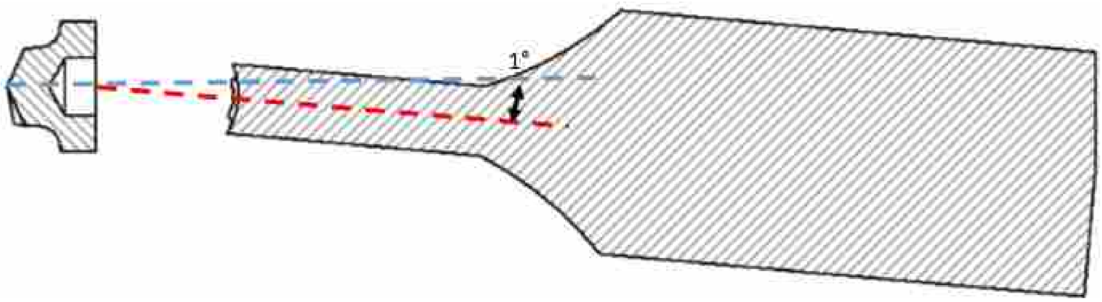


Figure 4-8: Relationship of the Torx Broach Cutter to a Predrilled Bit Blank

Table 4-1: Analysis of Bit Production Methods

Rotary Broach Procedure			EDM Procedure		
For Every:	Time (s)	Operation	For every:	Time (s)	Operation
Batch	45	Power on Okuma	Batch	45	Power on Okuma
Batch	26.9	Load Program	Batch	26.9	Load Program
1	97.9	Cut Profile	1	97.9	Cut Profile
Batch	26.9	Load Program	Batch	205.25	Walk to Grinder
1	87	Broach Torx	1	40.97	Grind Off Burr
			30	307.72	Power on Wire EDM
			30	170.68	Limit Move
			30	27.71	Load Program
			30	86.52	Thread Wire
			30	417.58	Set-Up Part
			30	4542.86	Run Part
			30	142.06	Take Down
			6	80.41	Power on Fadal
			6	12.74	Reference Return
			6	57.58	Load Program
			6	52	Load Fixture
			6	14.58	Load Part
			6	155.38	Machine Off Surface
			6	56.48	Cut Profile
			6	105.13	Take Down
			3	205.25	Walk to Grinder
			3	22.52	Grind Electrode
			Batch	107.73	Power on Plunge EDM
			Batch	98.65	Limit Move
			Batch	19.94	Load Program
			Batch	74.6	Set up fixture
			1	26.34	Load Part
			1	237.59	Column Center
			1	74.88	Touch off in Z
			1	799.18	Plunge Torx
			Batch	80	Take Down

Table 4-2: Summary of Bit Production Methods Analysis

Rotary Broach Totals					EDM Totals				
Batch Size	**Time (min)**	**min/ bit**	**Hourly Rate**	**$/bit**	**Batch Size**	**Time (min)**	**min/bit**	**Hourly Rate**	**$/bit**
1	4.73	4.73	$ 12.00	$ 0.95	1	139.87	139.87	$ 12.00	$ 27.97
10	32.46	3.25	$ 12.00	$ 0.65	10	351.69	35.17	$ 12.00	$ 7.03
25	78.69	3.15	$ 12.00	$ 0.63	25	716.60	28.66	$ 12.00	$ 5.73
50	155.73	3.11	$ 12.00	$ 0.62	50	1409.54	28.19	$ 12.00	$ 5.64

As this research was drawing to a close, about 550 specimens were documented as having used consumable bits produced through rotary broaching, excluding experimental bits and over 300 bits produced and shipped to ORNL for collaborative research. Using the data in Table 4-2, calculations were made to estimate total labor hours and manufacturing costs for producing the bits used at BYU through rotary broaching. Comparable calculations were also done to estimate the costs and hours that would have been required to produce the same number of bits using the EDM method. Calculations were done for several batch sizes, but in reality, the most common batch size during this research was a quantity of ten. For batch sizes of ten, total labor time and total production cost estimates improved by 91% by using rotary broaching (Table 4-3: Total Hours and Costs Estimated for Bits Used at BYU for This Study.

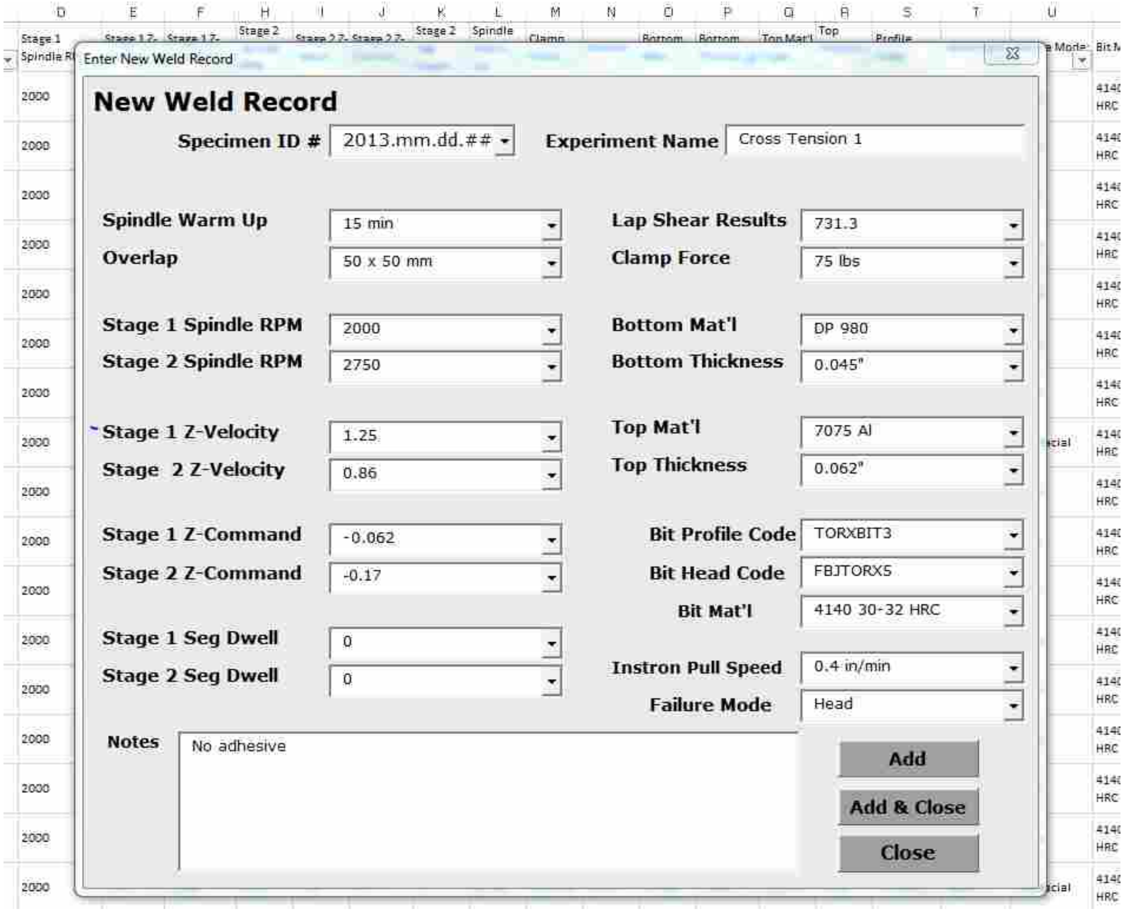
Table 4-3: Total Hours and Costs Estimated for Bits Used at BYU for This Study

Batch Size		Broach Method	EDM Method	Difference	Improvement
Batches of 1	Hours	43.36	1282.14	1238.78	**97%**
	Cost	$ 522.50	$ 15,383.50	$ 14,861.00	**97%**
Batches of 10	Hours	29.79	322.39	292.60	**91%**
	Cost	$ 357.50	$ 3,866.50	$ 3,509.00	**91%**
Batches of 25	Hours	28.88	262.72	233.84	**89%**
	Cost	$ 346.50	$ 3,151.50	$ 2,805.00	**89%**
Batches of 50	Hours	28.51	258.41	229.90	**89%**
	Cost	$ 341.00	$ 3,102.00	$ 2,761.00	**89%**

4.1.2 Data Recording

Parameters specific to each sample or experiment needed to be recorded and later accessed for analysis. Documentation of parameters and process characteristics was also found to encourage the control of a greater number of variables. However, as increasing numbers of specimens were created, large amounts of data developed.

Initially, limited characteristics for each sample where written directly on the coupons with a permanent marker. This was unsatisfactory for larger amounts of data as more variables were controlled, and made statistical and computer analysis difficult. As a result, a spreadsheet database was developed to provide quick and easy entrance of specimen data via a user form.



Enter New Weld Record

New Weld Record

Specimen ID #	2013.mm.dd.##	Experiment Name	Cross Tension 1
Spindle Warm Up	15 min	Lap Shear Results	731.3
Overlap	50 x 50 mm	Clamp Force	75 lbs
Stage 1 Spindle RPM	2000	Bottom Mat'l	DP 980
Stage 2 Spindle RPM	2750	Bottom Thickness	0.045"
Stage 1 Z-Velocity	1.25	Top Mat'l	7075 Al
Stage 2 Z-Velocity	0.86	Top Thickness	0.062"
Stage 1 Z-Command	-0.062	Bit Profile Code	TORXBIT3
Stage 2 Z-Command	-0.17	Bit Head Code	FBJTORX5
		Bit Mat'l	4140 30-32 HRC
Stage 1 Seg Dwell	0	Instron Pull Speed	0.4 in/min
Stage 2 Seg Dwell	0	Failure Mode	Head

Notes: No adhesive

Figure 4-9: Dialogue Box Used to Enter New Weld Record Data

All data entered in the user form was automatically tabled in an Excel file, where association between the physical specimen and its experimental data would be through the specimen ID number. This ID number was generated by the FBJ machine control software, and written upon the completed specimen in yyyy.mm.dd.## format.

Figure 4-10: Typical Lap Shear Specimen, With ID Number

Physical storage of coupons, while previously unorganized, was established in a specific location using divider boxes. Sorting by date in this fashion allowed samples to be easily located.

Figure 4-11: Specimen Storage of Fractured Specimens

4.1.3 **Machine Control and Fixtures**

The friction bit machine was built to perform a variety of functions for different research projects. One of these projects required a long spindle. Unfortunately, during the FBJ weld cycle, the long machine spindle was clearly seen to flex and move in directions other than along the Z axis. This unintended movement was easily observed in both the X and Y directions during the second stage of weld generation when large forces are placed on the spindle.

This displacement of the machine spindle causes the location of the final friction bit joint to move away from a centered position in the overlapping coupon area, and introduces unknown parameters to the formation of solid-state bonds. For purposes of this research, long spindle length is not necessary, so it was thought that shortening the spindle, stiffening the machine frame, and using a more solid fixture would alleviate the problem by reducing uncontrolled and non-programed movement.

To this end, modifications were modeled and analyzed by MegaStir, and quoted by the Precision Machining Laboratory. In addition to a shorter spindle and changes to the stand on which the friction bit machine is positioned, a new frame was included that would allow the friction bit machine to function in a manner similar to an ordinary drill press. Figure 4-12 shows a computer rendering of these modifications, with the stiffer frame represented in a light grey color.

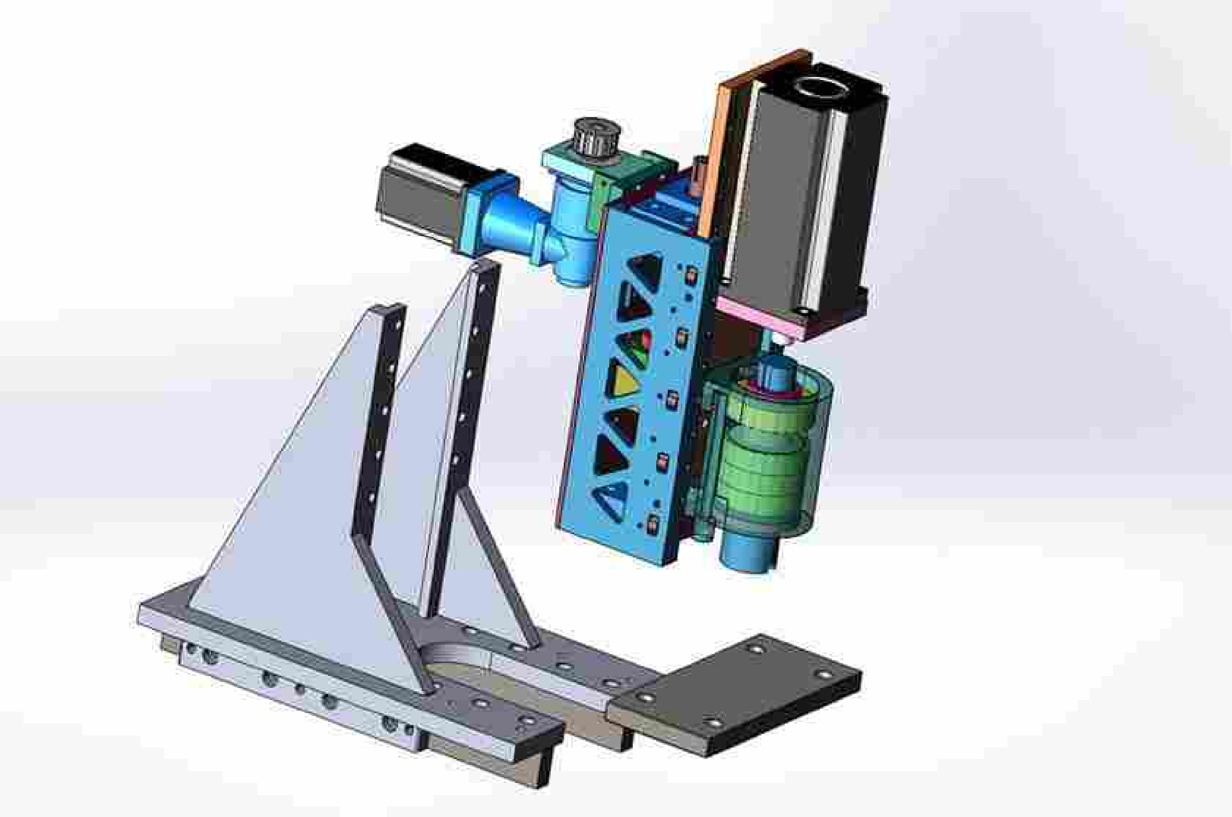


Figure 4-12: Rendering of Proposed FBJ Machine, with Modifications

A high quoted job cost by the PML (~$18,000) as well as other factors at MegaStir discouraged further action by either company. The root cause of variation was known, but unable to be resolved given the resources available. In an effort to still achieve some improvement in joint location, compensation for expected spindle displacement was designed into new locating pins. Using a profilometer for silhouette projection, average magnitude and direction of displacement from center was calculated.

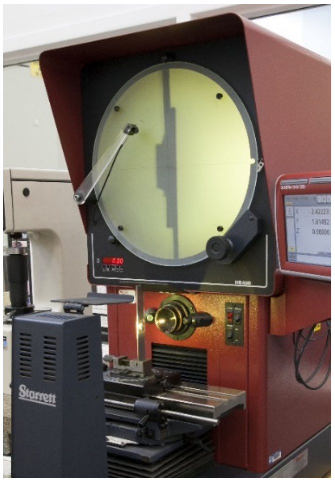


Figure 4-13: Profilometer Used to Measure Weld Location Displacement

Table 4-4: Analysis of Pin Corrections

Specimen ID	Displacement (in)	Notes
2013.2.19.05	Reference point	Original pins used (0.375" dia)
2013.2.20.00	0.01964	Intermediate pins used (0..441" dia)
2013.2.20.01	0.018735	Intermediate pins used (0..441" dia)
2013.2.20.02	0.02249	Intermediate pins used (0..441" dia)
2013.2.20.03	-0.00529	Intermediate pins used (0..441" dia)
stdev	0.0129	
avedev	0.0096	
avg	0.0203	<-- Amount added to radius of intermediate pins

Using this data, new locating pins were machined and used in the fixture. These new pins allowed consistent placement of the FBJ joint in the center of the overlapped coupon region.

After specimen coupons are placed against the locating pins prior to the weld, they must be clamped in place to prevent shifting during the weld cycle. At the outset of this study, the bar used to clamp the samples began to fatigue, losing its rigidity and ability to consistently place high pressure on the coupons immediately around the bit. As the bar lost integrity, lap strengths began to suffer. A new, thicker clamp bar was machined and used throughout all other experiments. Clamping pressure was specifically investigated as a weld parameter and it was found that in order to produce welds that did not have a bulge in the upper material, a clamp pressure of 1800 pounds was needed.

In addition to physical characteristics of the FBJ machine, it was discovered that the Z-axis velocity reading was inaccurate. While collaborating with researchers at Oak Ridge National Laboratory, a discrepancy was observed between the Z velocity programed into the FBJ machine and the real-life velocity recorded by the machine during the weld cycle. The photo-gate arrangement shown in Figure 4-14 was used to measure spindle movement. The tool driver passed through the first photo-gate and the timer started. The time was then recorded as the driver plunged past the second photo gate. It was determined that true Z-velocity could be calculated by multiplying the programed velocity by 7.1.

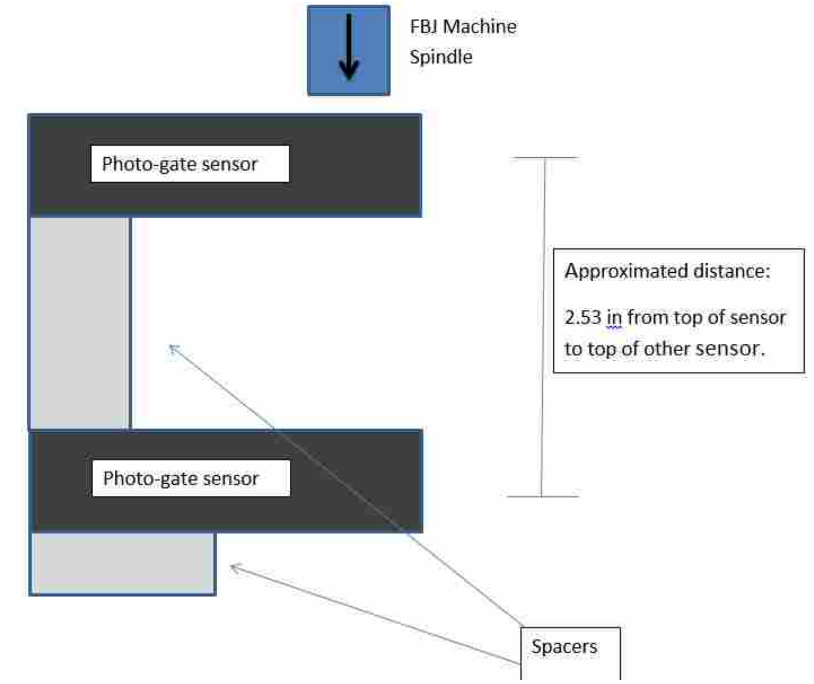


Figure 4-14: Photogate Sensor Arrangement

Table 4-5: Data From Tests of FBJ Machine Velocity in the Z- Axis

Programed Z velocity (in/min)	Actual Z Velocity (in/min)	Time (seconds)	Distance (inches)	Recorded Machine Velocity (in/min)
1.25	8.88	17.09	2.53	8.85
1.25	8.87	17.11	2.53	8.85
2.5	17.75	8.55	2.53	17.7
2.5	17.75	8.55	2.53	17.7
0.63	4.44	34.2	2.53	4.42

4.2 FBJ and Automation

In order for FBJ to be used in a commercial production setting, it must be feasible to automate the delivery of bits from a bulk location to the spindle tip. While bit design may be subject to fine-tuning over time, it was assumed that the form most suitable for eventual industry use would not be significantly different from the present bit design. Consequently, efforts were made to evaluate the current bits potential in an automated delivery system.

Several options were compared for automated bit orientation prior to transfer to the machine spindle. These options included bowl feeders, step feeders, and rotary feeders. Bowl feeders were selected due to overall advantage considering the characteristics shown in Table 4-6.

With the selection of a bowl feeder for orienting the FBJ bits, orienting geometry was prototyped to positively establish the ability of a bowl feeder to correctly and consistently orient friction bits. The geometry shown in Figure 4-15 consistently allowed only one orientation to ever make it to the end of the vibratory bowl track. Piece rate was controlled with vibratory bowl speed.

Table 4-6: Comparison of Bowl Feeding to Step and Rotary Feeding Methods

Criteria	Requirements	Bowl Feeder	Step Feeder	Rotary Feeder
Bulk loading location	*Automated*	0	0	0
Repeatable	*3 Sigma*	0	0	-
Noise		0	+	+
Cost		0	-	-
Simplicity		0	-	+
Small parts application		0	0	0
Orienting ability		0	-	-
Speed	*<45 sec/bit*	0	-	+
Gentleness		0	0	-
Safety	*Industry standard*	0	0	0
Total		**0**	**-3**	**-2**

Figure 4-15: Section of Vibratory Bowl Showing Successful Orientation Geometry

Ability to transfer bits was also established using a pneumatic mechanism that was designed to attach to the end of the vibratory bowl track. A sectioned view of this mechanism is shown in Figure 4-16. A bit enters the mechanism and rests on top of a piston (a), which is in the down position. A burst of air raises the piston, with the bit on top, until it closes off the opening through which the bit entered (b). A flange on the piston stops its upward movement. The bit is propelled out of the mechanism and into a flexible delivery hose (c), by air entering behind the bit through a 0.137” diameter hole in the top of the piston. 10 PSI was sufficient to operate the mechanism and propel the bit to the end of the attached transfer hose in a rapid manner. When the air was shut off, the piston returned to the position shown in (a). As tested, bits always reached the end of the hose in the correct orientation, with no tumbling.

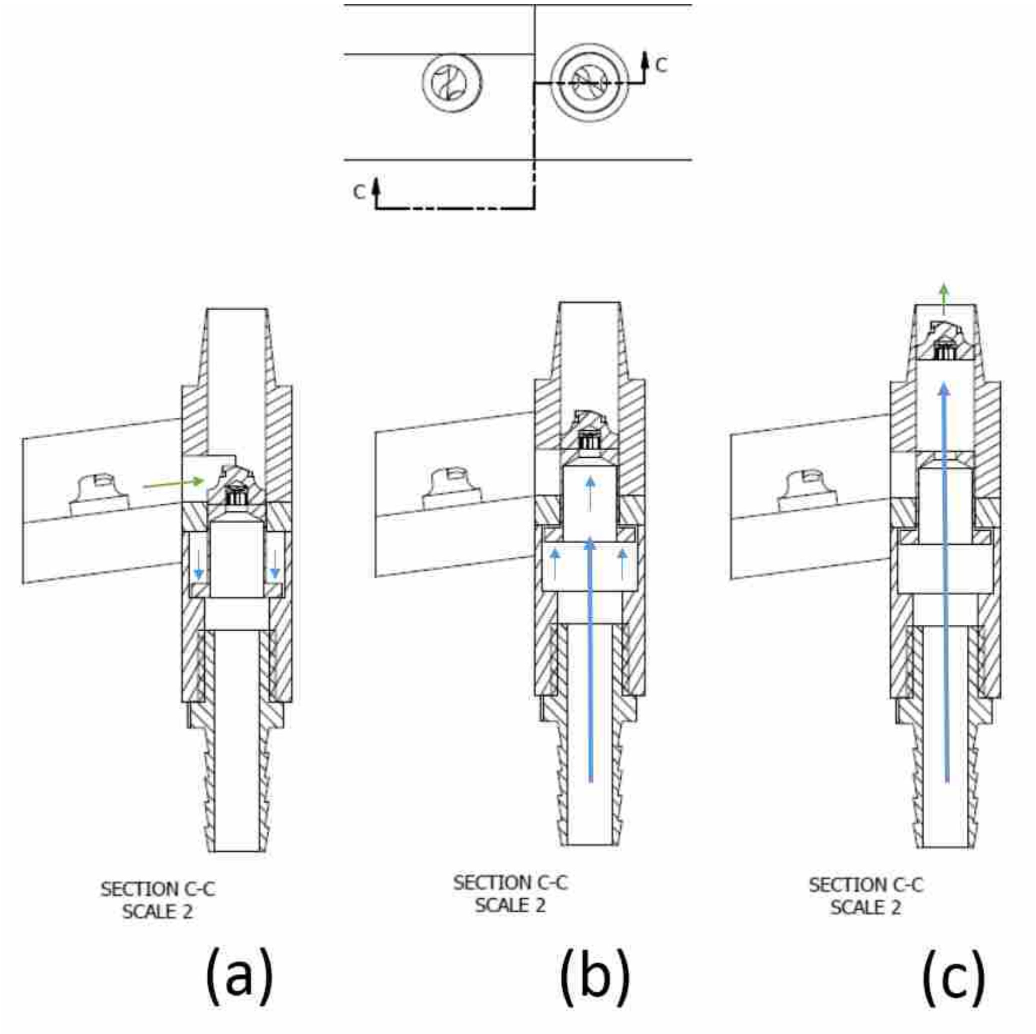


Figure 4-16: Sectioned View of the Pneumatic Bit Loading Mechanism

Automated placement of the bit onto the spindle was never fully addressed, but is theorized to function similar to standard pneumatically fed screwdrivers. The bit would travel from the bulk loading location to a mechanism on the machine spindle. This would occur pneumatically via a flexible tube, whereupon the rotating driver would engage the bit head and drive the bit to the surface of the material to be joined.

Figure 4-17: Theoretical Mechanism for Driving a Pneumatically Transferred Bit

4.3 Bit Properties and Engineering

Central to FBJ technology is the bit itself. Multiple experiments were conducted to gain an understanding of the role of the bit during joining. These tests included an investigation of the material from which bits are made, the cross sectional shape and characteristics of the bit, and head design for driver engagement.

4.3.1 **Bit Hardness**

Experiments were conducted that characterized bits made from 4140 steel with hardness between 21 and 22 HRC. Similar experiments were then conducted with bits made from 4140 steel with hardness between 30 and 32 HRC. Completed specimens were tested in static lap shear, while selected specimens were sectioned and polished prior to inspection with optical microscopy, using an optical magnification of x12.5 on an Olympus SZX12 microscope.

For the 21 to 22 HRC bits, no large cracks were commonly observed, but average lap shear was 6.165 kN. The pilot hole necessitated by the rotary broach production method was noticed to be completely filled as bit material was displaced in a ductile motion during the joining phase of the weld cycle.

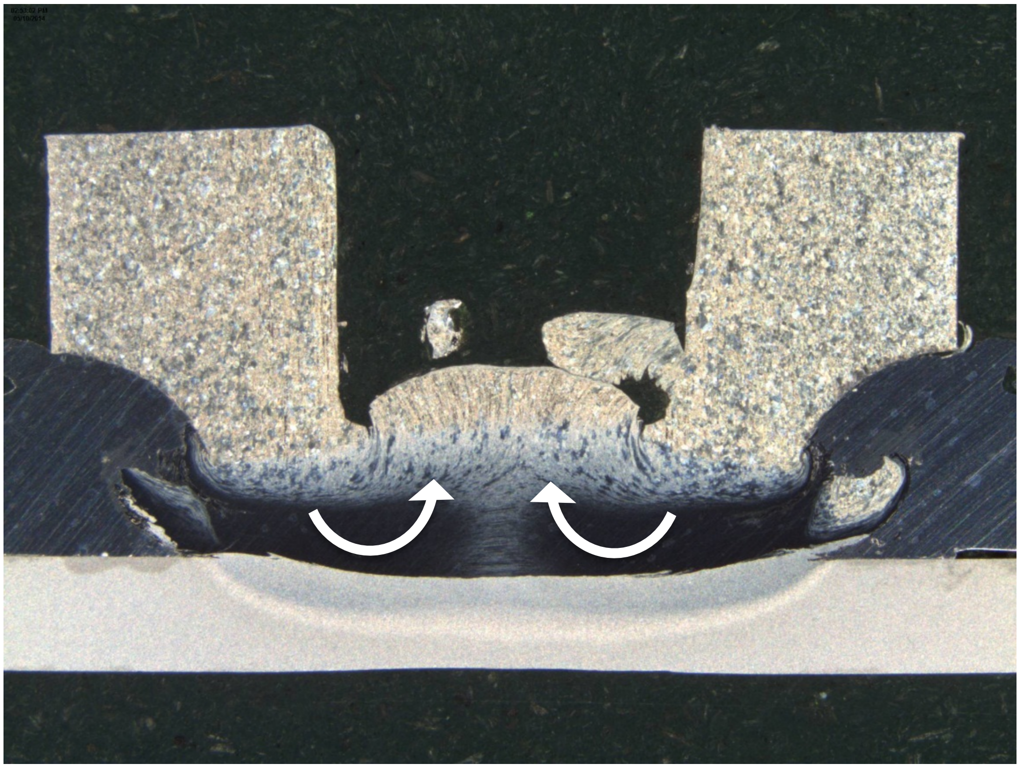


Figure 4-18: Evidence of Ductile Back-Filling into the Pilot Hole Cavity, 21-22 HRC (#2014.04.24.04)

For comparable specimens completed using bits made from 4140 steel with hardness between 30 and 32 HRC, the average lap shear was 7.668 kN, noticeably higher than the lap shear data recorded for lower hardness bits. Internal cracking was not commonly seen, but back-filling of the Torx pocket was noticeably less. Polishing and inspection of weld cross sections showed comparatively less deformation of the bit into the Torx pocket, as shown in Figure 4-19.

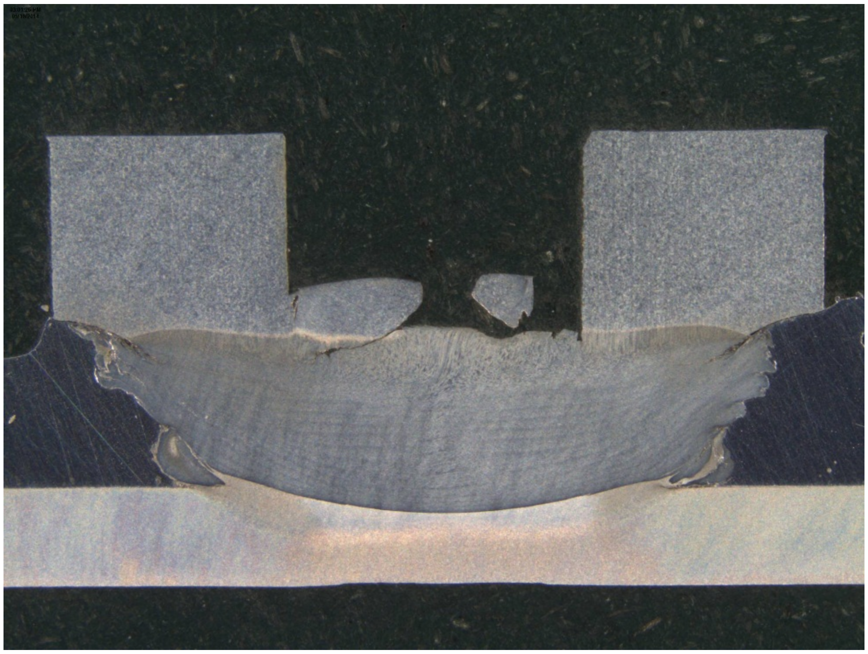


Figure 4-19: Slight Ductile Back-Filling into Pilot Hole Cavity, 30-32 HRC (#2014.04.24.03)

The DP980 used in all experiments had an average hardness of 32.9 HRC. As bit hardness in all cases was significantly harder than the aluminum, no deformation of the bit occurred during the first phase of the weld cycle. It is therefore evident from these tests that as the bit hardness approaches the hardness of the base material, higher static loads are sustained. Further analysis of these results suggested that ductile movement of bit material away from the bond zone increasingly influences loss in load capacity as frictional heat increases.

In a related study, alternative bit materials were tested. A limited number of 34-36 HRC titanium bits were produced, but broached production was difficult and prohibitive. A very slow 0.001 inch-per-revolution feed rate was necessary, along with a low 50-100 RPM until the broach was engaged (.005-.010"), and then RPM could only be increased to 700-800 RPM. Due to excessive wear on broaching tools, investigation of titanium as a potential material for FBJ was discontinued. Eventually, an alternative bit head design that circumvents the need for broach tooling was developed (Figure 4-29), and it is thought that this should allow titanium joining to be revisited.

4.3.2 Bit Profile, Shaft Diameter and Cutting Features

It was noticed in several early specimens that the upper layer of aluminum had a tendency to bulge up from the lower in the finalized joint. Cross sectioning revealed that this bulge was due to “squeeze-out” as plasticized bit material pushed outward between the coupon layers during the weld cycle.

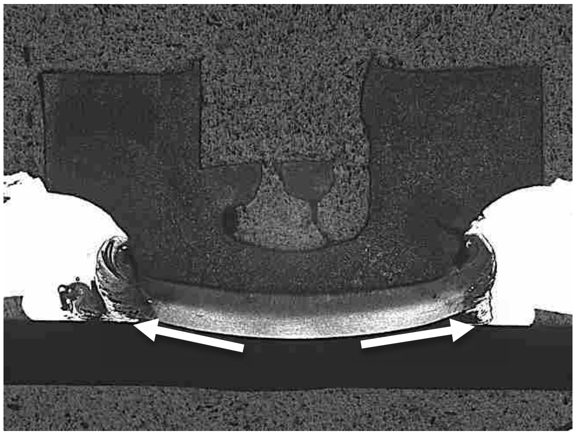


Figure 4-20: Coupon Bulge Resulting from Bit Material Between Layers (#2013.05.30.05)

A special V-shaped bit profile was created in an effort to reduce the quantity of bit material in the bond area. This bit significantly reduced the size of the cutting features and shaft volume. When this bit was tested, the resulting specimen was completely flat with no bubble. Compared with a standard bit, large amounts of aluminum chips were present on top of the specimen, surrounding the bit head. In addition, it was also noted that maximum spindle down force registered by the FBJ machine was 5.9kN. For typical procedures at the time, maximum down force was around 9.34kN. When tested in static lap shear, the V-bit registered 1.94kN, significantly less than the existing 5.8kN average for lap shear specimens being made at that time with typical bits.

Further tests of V-bits were conducted using a similar style bit. As rotary broaching was not possible for this particular profile, a shaft was left on the top of each bit that fit into the collet of the FBJ machine spindle. Due to worn tooling, a small pin was left on the end of the bit. This was not a designed feature, and was later shown to be a significant source of variation seen in lap shear test data.

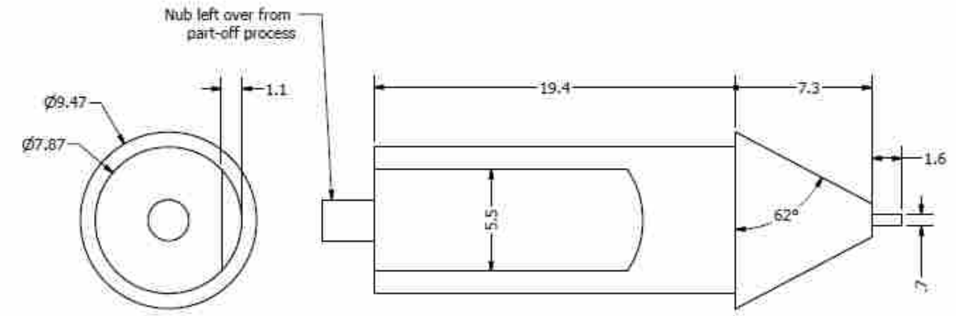


Figure 4-21: Dimensions and Features of Cone Bits

For all welds performed using these cone bits, the final joint was smooth and flat, with no bulge in the top material. Due to the V profile shape, as Z-axis tool depth increased during these tests, so did the bond area as measured by fracture diameter, so Z-axis tool depth may serve as an indicator of relative bond area size. When tested in lap shear, specimen strength increased with greater Z-axis depths. However, there appeared to be a point where joint strength peaks, and thereafter additional pressure, bit length or material, and frictional contact does nothing to increase strength. Failure mode for these bits was observed to be typified as a peeling action instead of the normal tearing mode.

Unfortunately, when these bits were produced, the use of a worn cutter insert caused a small pin to be left on the end of the bit. This pin was later proven to adversely impact the touch-off cycle in which the machine sets the Z-axis zero point prior to welding. For this reason, the data for all of the cone bit tests was relatively inconsistent. Given the doubtful authenticity of recorded parameters, a general pattern is still seen. (Figure 4-22)

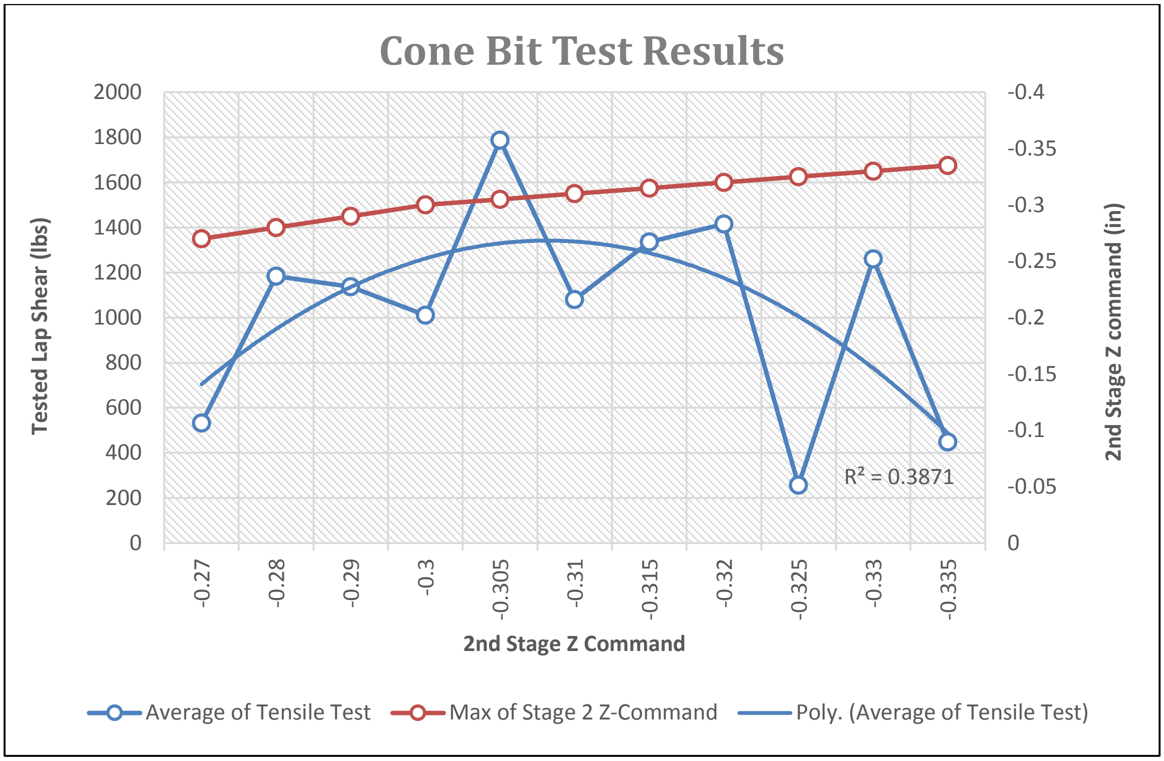


Figure 4-22: Overall Relationship between Z-axis Depth and Lap Strength, Despite "Pins"

Because of the relationship between weld strength and bond area established by the V-bits, the shaft diameter of the standard bit was specifically tested. Bits were produced with shaft diameters varying between 0.160 in and 0.260 inch. Specimens were created using 5754 AA and DP980, then tested in static lap shear. Results indicated that greater diameters for friction bit shafts lead to greater strengths, confirming the cone bit experiments. As shaft diameter approached 0.260 inches, gains in strength tapered off, with averages becoming more uniform across different bits. This also confirmed the idea that the ability of greater bit material to increase weld strength will peak and possibly diminish. All failure modes were observed to be interfacial.

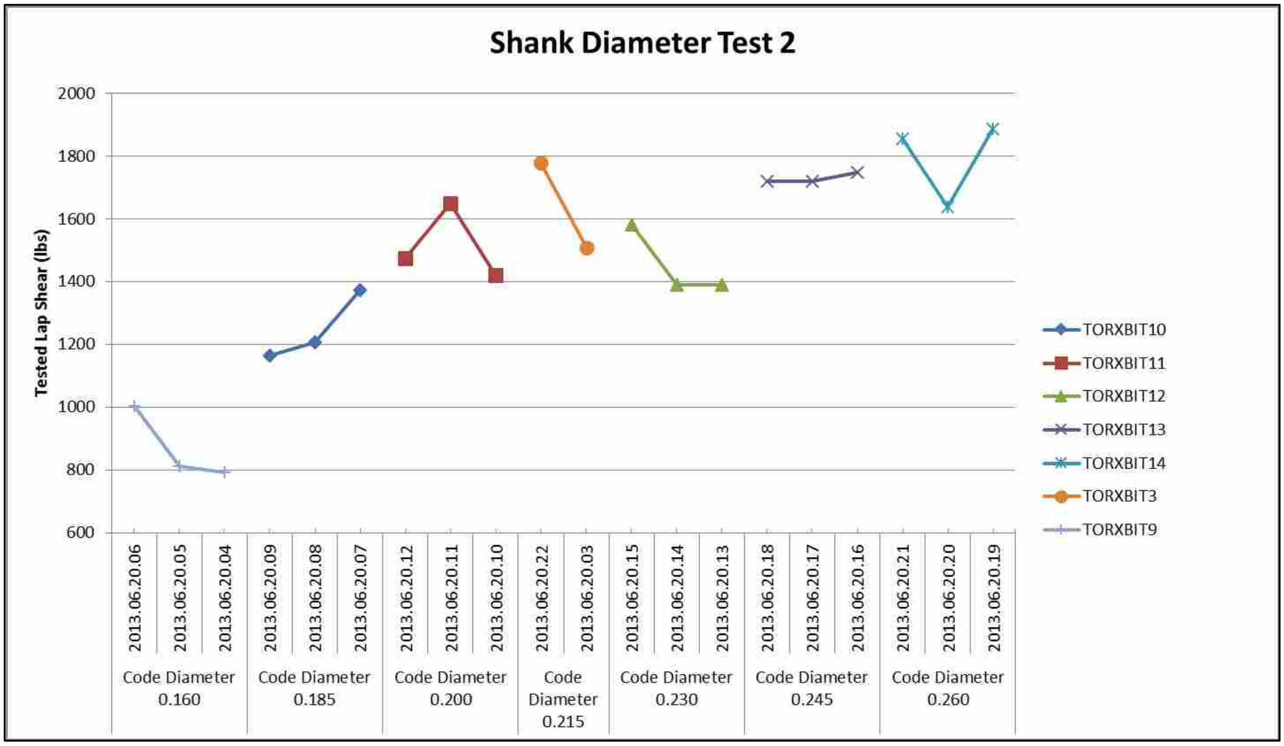


Figure 4-23: Shaft Diameter Test 2 Results

Cone style bits nearly eliminated cutting features on the bit tip, but it is important to note that the presence of cutting features on the bit shaft is significant in bit design. The purpose of cutting features, both tapered edges and chip reliefs, is to remove upper-layer material in overlapping specimens, allowing the bit to make contact with the lower-layer material to form a bond. Without cutting features on the standard bit profile, or a shape similar to the cone bit that allows the bit to pierce the overlapped specimen material, spindle Z-axis net load becomes excessive. For every case in which this was tested, Z-axis spindle load exceeded 3600 lbs. Loads above this value activate a safety mechanism that cancels the weld cycle on the BYU FBJ machine. At the same time, a related experiment showed that increasingly aggressive cutting features had the opposite impact on Z-axis spindle load. Augmented cutting ability tended to reduce spindle load, without effecting weld strength, and simultaneously improved chip removal.

4.3.3 Bit Head Dimensions and Geometry

The majority of bit heads tested during this work had internally driven Torx-style pockets. Experiments investigated bit head geometry, and included head height and the presence of a pocket when externally driven, solid bit heads were later used. The influence of each head condition was measured in lap shear strength and by observed failure mode. This data is useful in the development of FBJ bit geometry conducive to the commercial production of consumable bits.

One characteristic desirable for commercial joining methods is a low profile fastener. It was therefore deemed appropriate to investigate viability of lower-profile friction bits. Experimental bits were produced for use in testing with head heights varying between 0.025 inches and 0.100 inches. Three different profile programs were written for the CNC lathe, to produce bits identical except for their head thickness. The first, TORXBIT3, had a head thickness of 0.100 inches. The second, TORXBIT4, had a head thickness of 0.050 inches. The third program, TORXBIT15 had a head thickness of 0.075 inches. When tested, lap shear strength increased with increasing head thickness. Average lap shear for 0.100 inch heads was 2378 lbs. Average lap shear for 0.075 inch heads was 2248 lbs. Average lap shear for 0.050 inch heads was 2101 pounds.

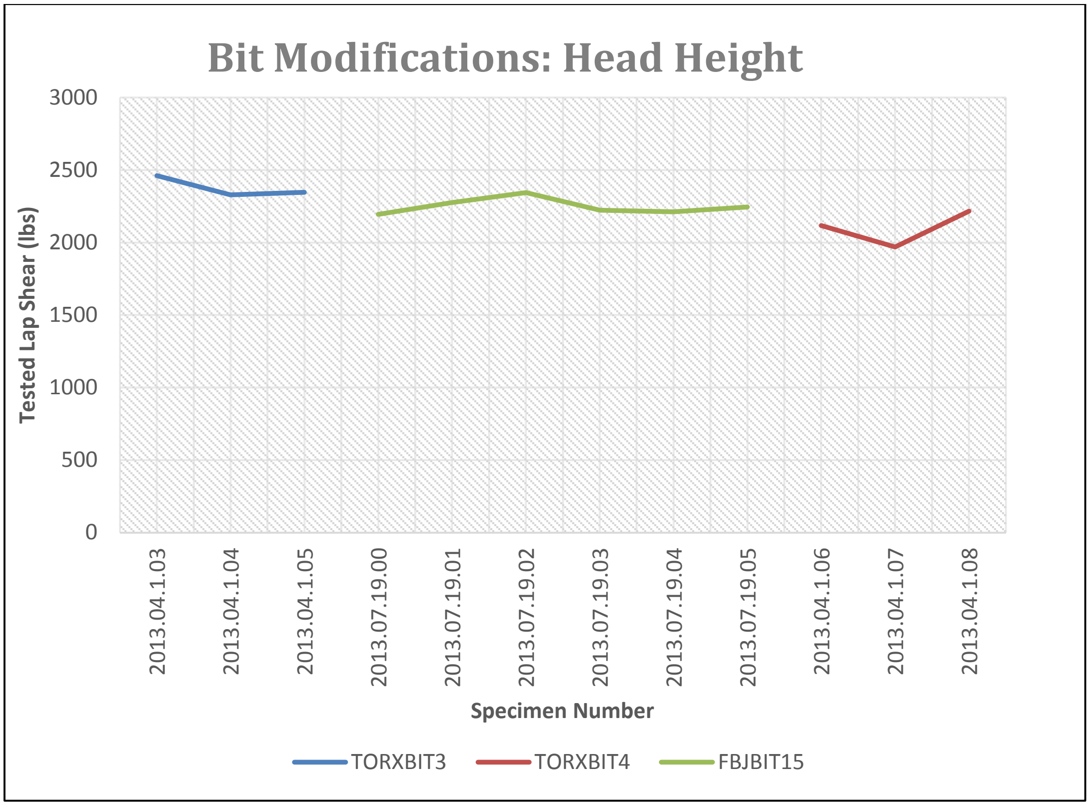


Figure 4-24: Results for Changes Made to Bit Profile Head Thickness

When head height was shortened, it was observed that the surface area for engagement between the driver and the bit was reduced (Figure 4-25). As a result, broach depth during bit production was varied from .075 inches to .100 inches, measured from the top surface of the bit blank. This allowed the impact of changing the contact area between the bit and the driver to be observed, while maintaining a constant head thickness of 0.100 inch. Lap shear testing was conducted to obtain data presented in Figure 4-26. It was found during this test that greater weld strength is obtained by using broach depths that allow more total contact between the driver and the bit. For this test, BRO3 had a broach depth and driver engagement length of 0.075 inches and an average of 2386 pounds. BRO4 had a broach depth and driver engagement length of 0.050 inch and an average of 2244 pounds.

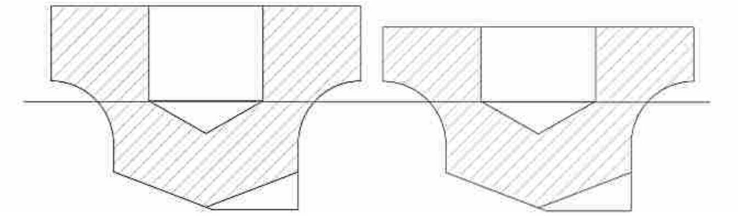


Figure 4-25: Changes to Head Thickness and Pilot Hole Depth

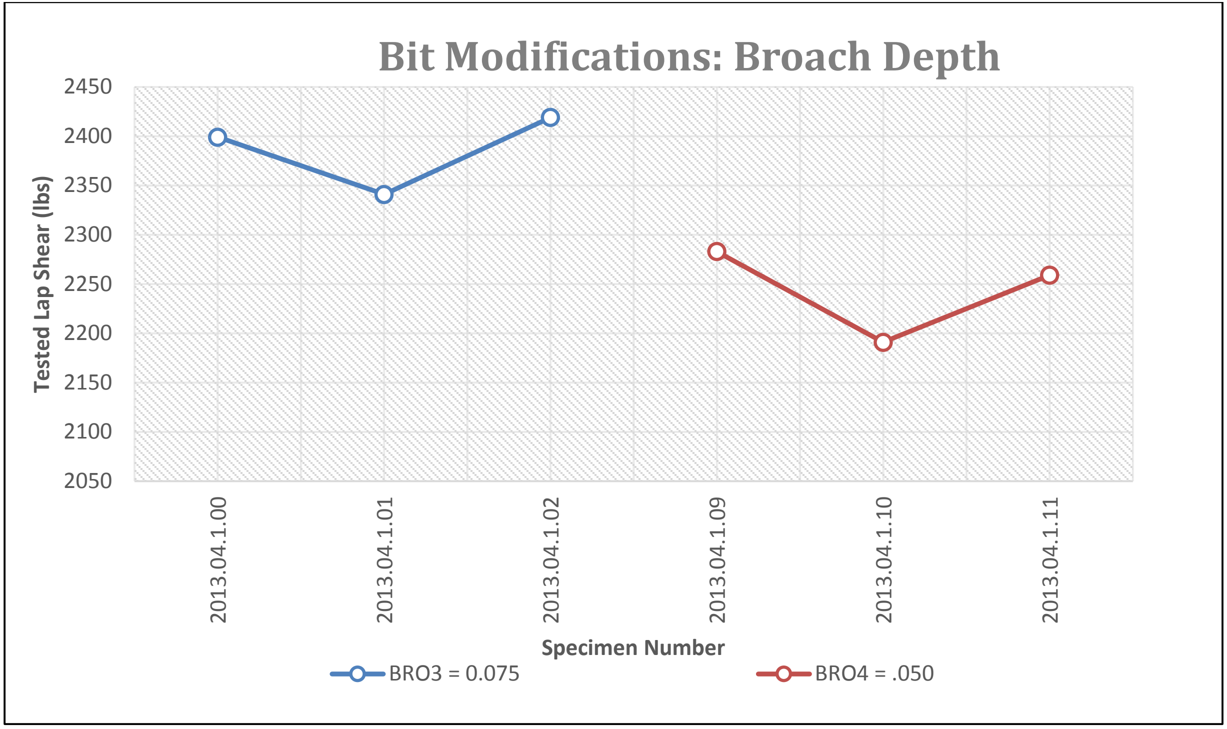


Figure 4-26: Results of Broach Depth Changes

The rotary broaching methodology requires a pilot hole to be drilled prior to the final broaching operation. It was noticed that when modifying both the broach depth and the bit head height during their respective experiments, the dimension between the interior wall of the pilot hole and the outside profile of the bit was manipulated.

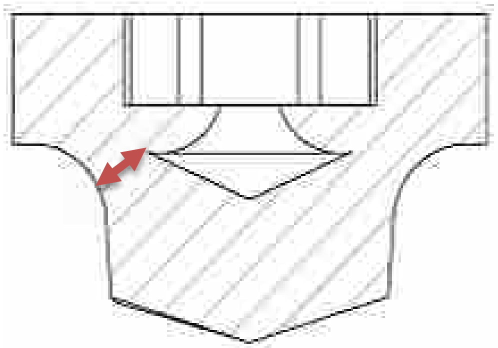


Figure 4-27: Bit Dimension Influenced by Head Height

As addressed in Section 4.3.1, ductile motion of bit material into the pilot-hole cavity influences final joint strength. The amount of bit material between the pilot-hole and the external bit profile also influences final joint strength, as indicated by head height experiments in which 0.075” broach depth and 0.075” head combinations were compared with 0.075” broach depth and 0.100” head combinations (Figure 4-28). Average lap shear for both cases was nearly identical (2248 pounds and 2255 pounds, respectively) but the second group had much less variation. This result suggests that increased bit material between the pilot-hole cavity and the outside bit profile not only reduces ductile back-filling of the pilot hole, but also reduces variation in joint strength. Additionally, it can be expected that a completely solid bit, with no internal cavity at all, would have very little variation related to ductile bit movement.

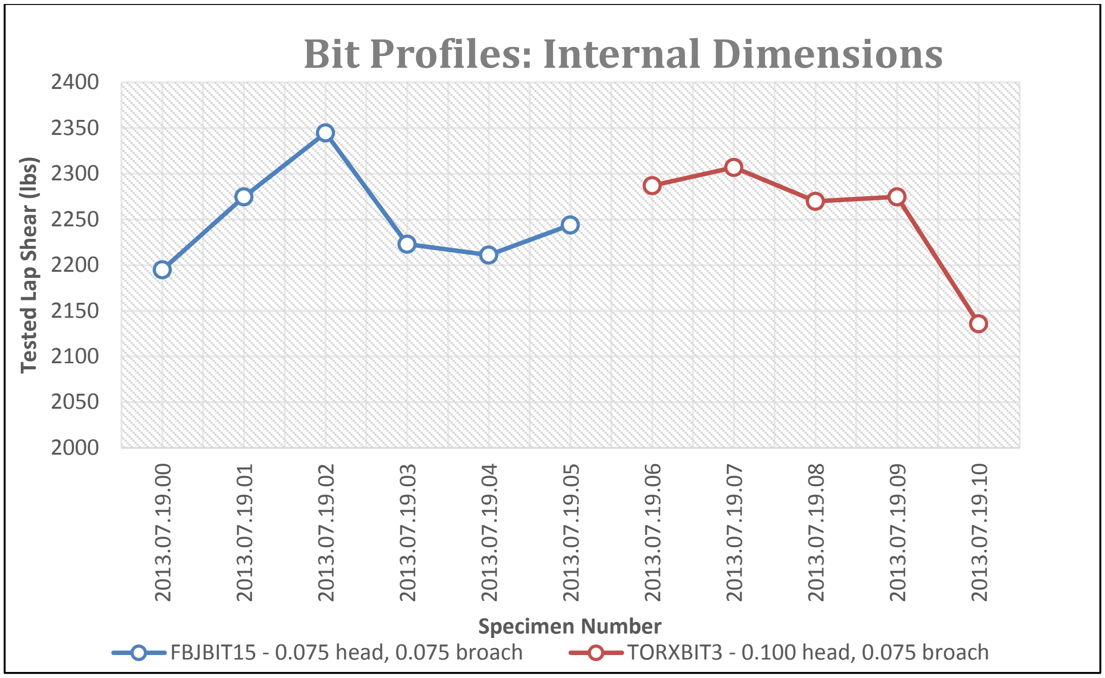


Figure 4-28: Impact of Manipulations of Bit Thickness between Pilot-Hole and Outside Bit Profile

To specifically address this pilot-hole aspect of broached bit design, the CNC code for broach 3 was modified to have a pilot hole that was 0.025" inch shallower, and designated as BRO5. For internally driven bits, reducing pilot-hole depth was seen as the only way to maximize tool engagement surface area while also maximizing the wall thickness between the internal pilot-hole the outside profile of the bit. Bits were produced using this modified broach code and the normal BIT3 0.100" head and profile. Several tests were run using these new reduced-pilot-hole bits that confirmed their effectiveness, and thereafter a BIT3-BRO5 combination became standard for bit production. At the end of this study, the overall average lap shear load for this new standard bit was calculated at 1902 lbs. The overall average for the previous BIT3-BRO3 standard production bit was 1680 lbs.

Experiments were also conducted to investigate bits with completely solid heads. The internal Torx pocket was removed, and replaced by external grooves cut radially into the periphery of the bit head. These grooves allowed the bit to couple with a specially designed driver. No modifications were made to the bit shaft or cutting features. Due to tooling constraints, a small nub was always present on the top of the solid bit, but was uninvolved with the weld process. A change in tooling would eliminate this nub.

Figure 4-29: Externally Driven Friction Bit Design

Lap shear data indicates a lower average load carried by the externally driven bits. At the same time, consistency across specimens is high, suggesting that welding process parameters could be fine-tuned to increase average lap strength (Figure 4-30). Selected externally driven bit specimens were sectioned and polished after joining in order to observe bit behavior within the joint. As is evident in Figure 4-31, ductile motion of bit material in the center of the bit is limited for solid bits. Pressure seems to be concentrated in the center of the bit, with greater heat focusing towards the outer edges of the bond. The heat affected zone appears much more uniform, with transition boundaries clearly defined.

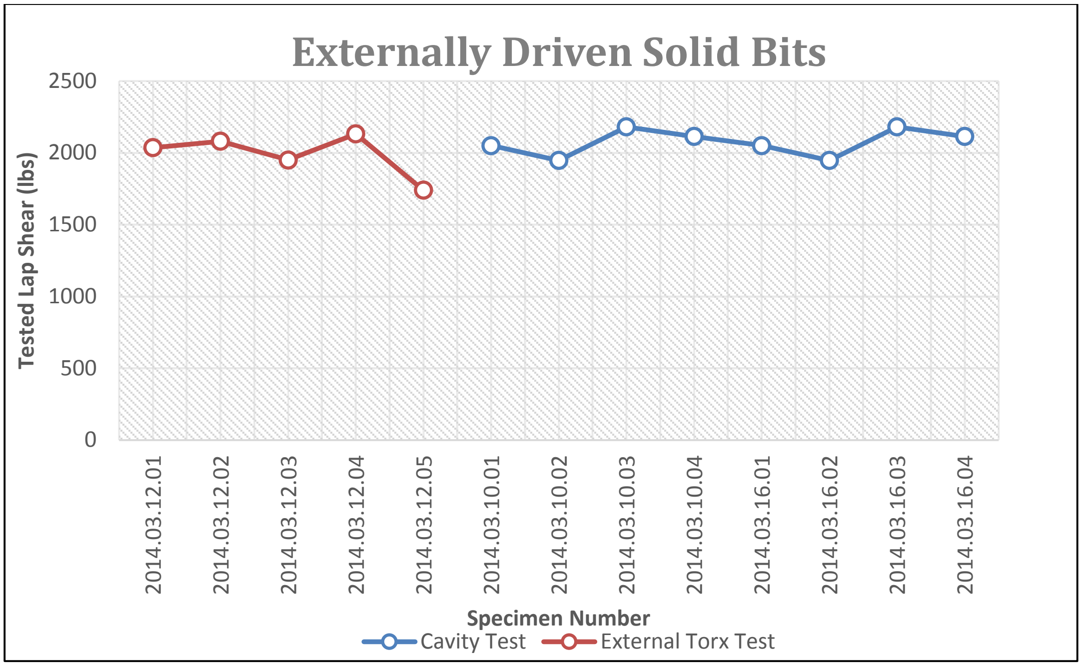


Figure 4-30: Solid, Externally Driven Bit Results

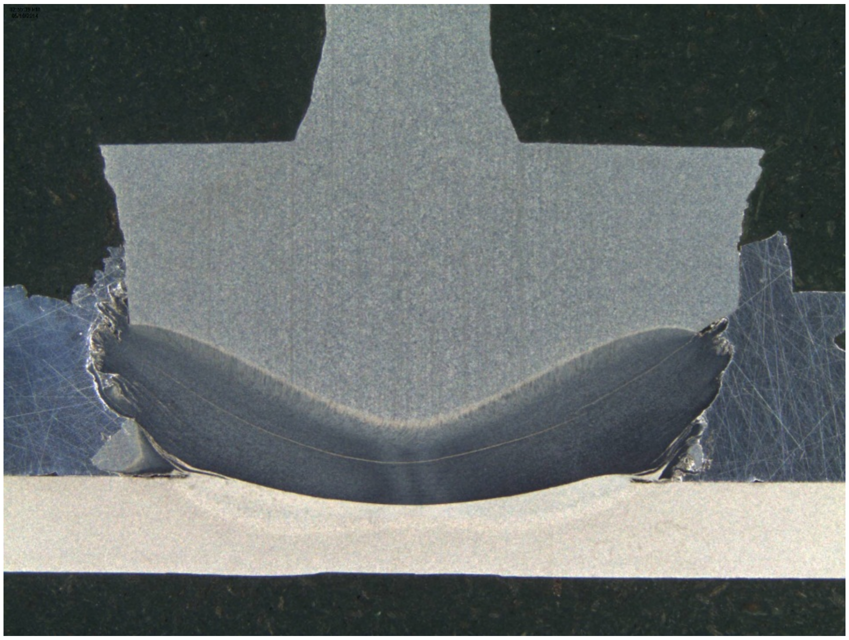


Figure 4-31: 30-32 HRC Externally Driven Solid Bit (#2014.03.14.06)

4.4 **Driving Mechanisms**

Throughout this study, several driving mechanisms were developed and employed. Initially, all force placed upon the bit was transmitted, in the Z-axis and rotationally, through a Torx T-25 driver held in a specially made tool holder. This tool holder was made by plunge EDM in a similar fashion to the original EDM style friction bits. The T-25 driver would periodically fail, either by welding itself into the specimen or by fracturing. One driver would typically survive between 10 and 15 weld cycles.

Realizing that excessive force was being placed on the driver, the tool holder was modified to remove the Z-force component from the stresses sustained by the driver. Instead of pressing down on center of the bit through the driver, the top of the bit head was brought into direct contact with the bottom of the tool holder as shown in Figure 4-32. This reduced average driver failure to one in 30 cycles.

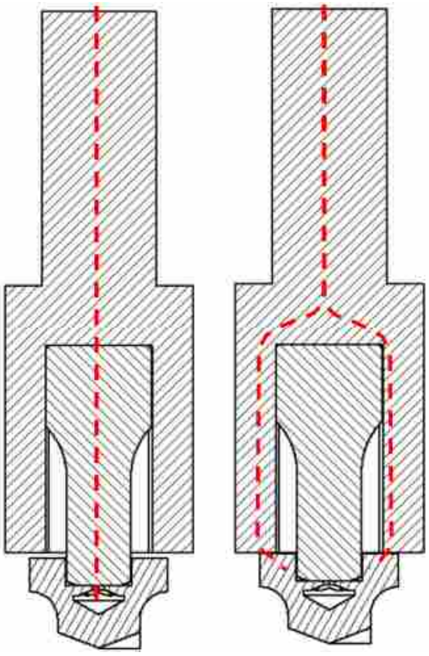


Figure 4-32: Transfer of Z-Axis Pressure to the Bit Before and After Modifications

Due to operator error or unfamiliarity with the FBJ machine, the tool holder would also frequently be destroyed. In an effort to reduce the time and effort required to create new tool holders, a commercially available option was adapted using a DeWalt magnetic tool holder typically used with hand drills. This tool holder was modified using a machine lathe in order to make it compatible with the collet of the FBJ machine.

Figure 4-33: Unmodified Magnetic Driver Holder Used to Simplify Production

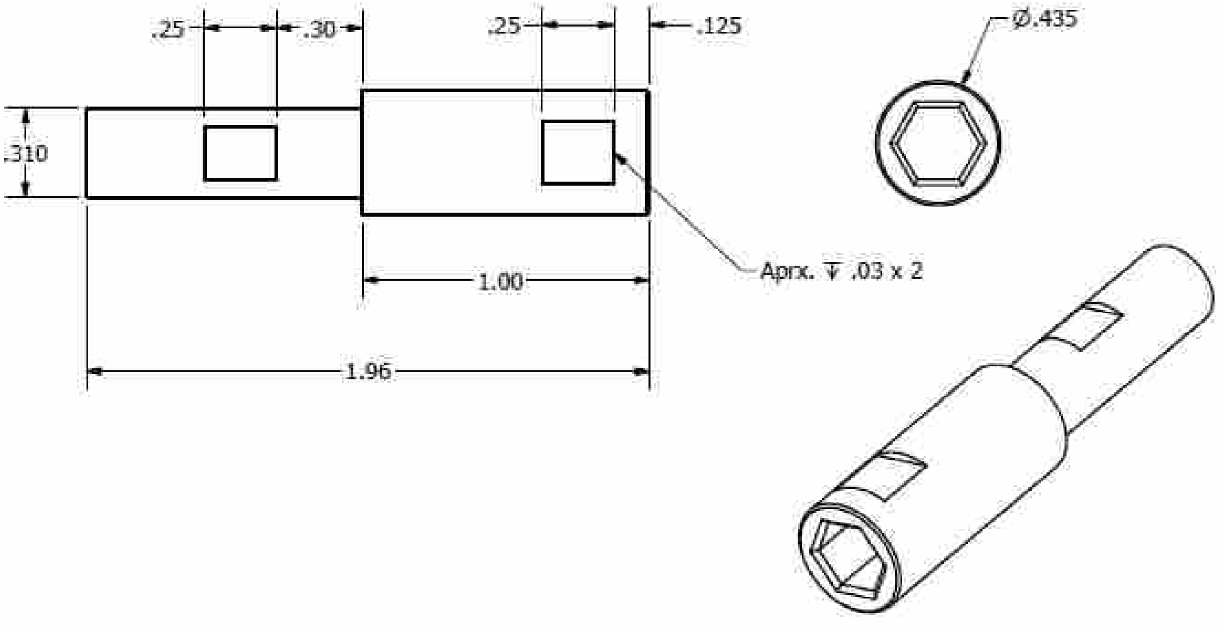


Figure 4-34: Modifications Made to the Original Tool Holder

In order to maintain pressure on the flat top of the bit head during the weld cycle, rather than on the center of the bit through the driver, a system of “caps” were designed. These caps not only transmitted Z force directly from the spindle to the bit head, but also allowed the engagement area between the bit and the Torx pocket to be easily manipulated. Less of the driver could be made to protrude from the cap by increasing the overall length of the cap.

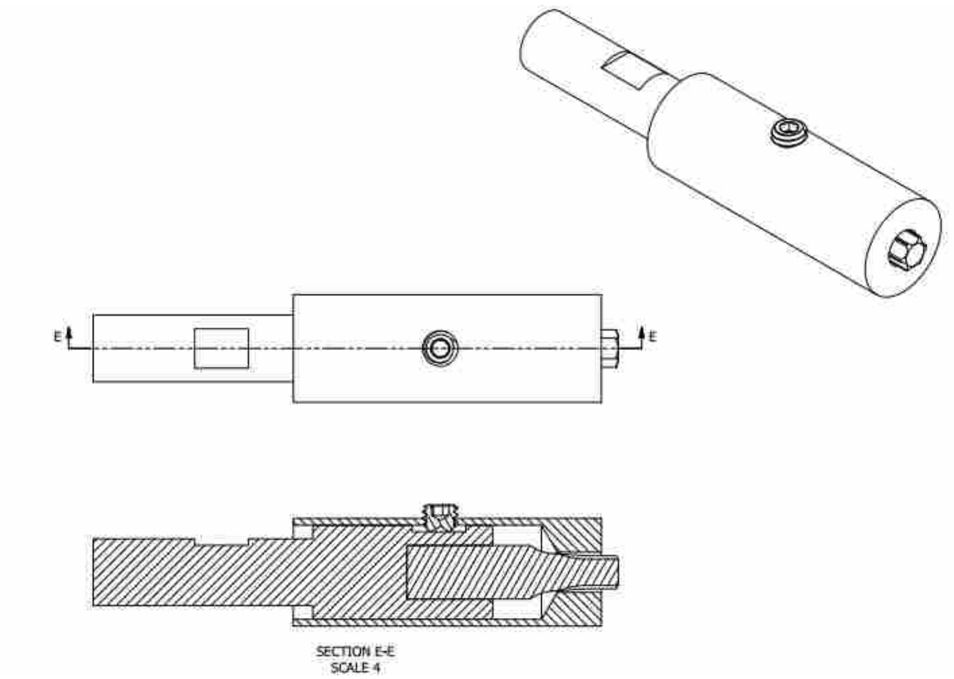


Figure 4-35: Modified Tool Holder with Bit Driver in Place and a Cap Installed

The cap system lent itself to experiments in chip removal from the final weld. A “cutter cap” was developed that incorporated cutting teeth equal in height to the bit head height. The bit, when mounted on the tool holder end, nested between these cutting teeth. During the weld cycle, as the cutting features on the bit expelled chips and debris, these teeth were found to be moderately effective in removing attached burrs.

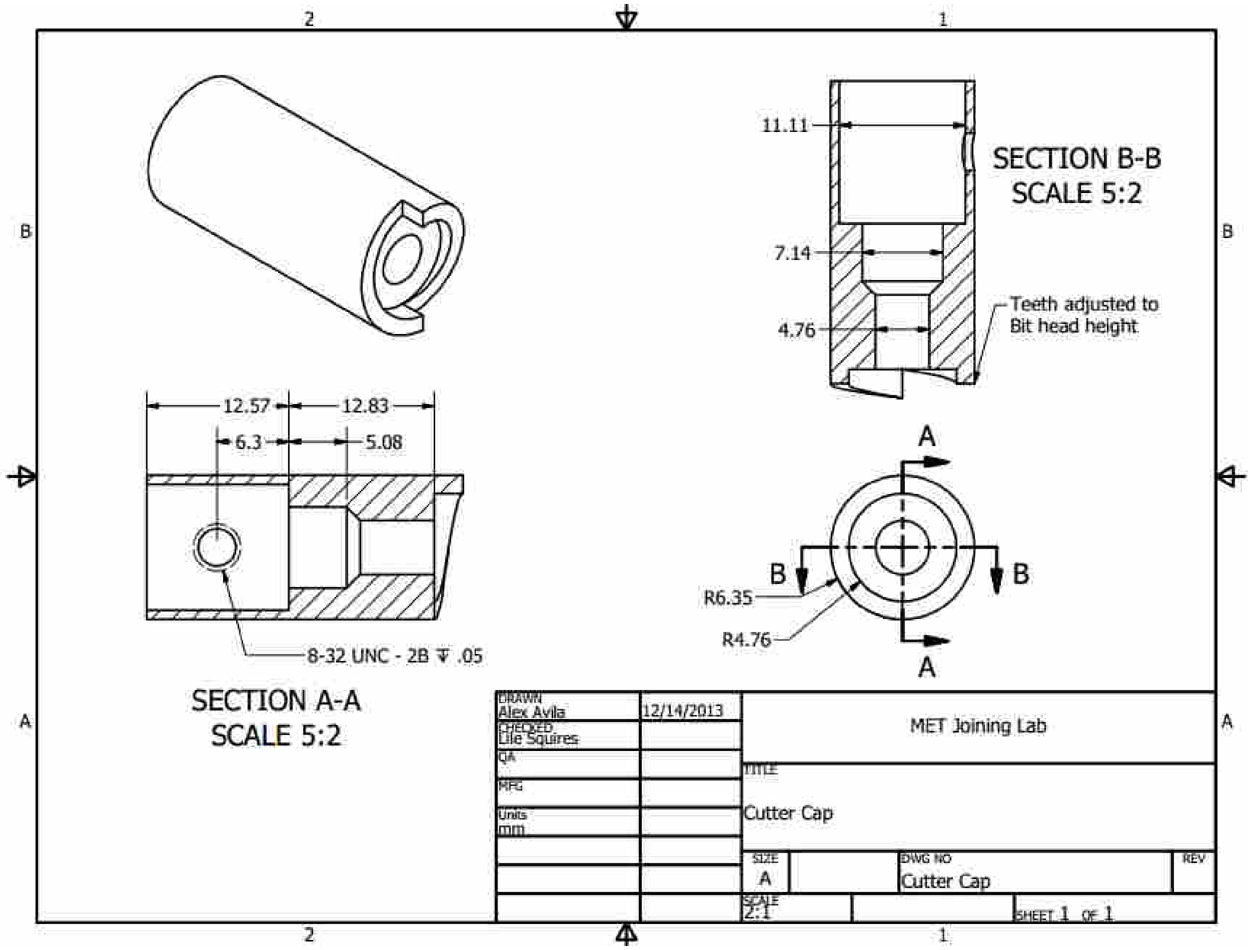


Figure 4-36: Cutter Cap System for Removing Burrs during the Weld Cycle

Each time the cutter caps were used, burrs were only partially eliminated from the final weld. The cap teeth would still be embedded in the aluminum immediately surrounding the bit when the spindle began to retract, and would leave small, sharp burrs or chips. In an effort to increase the effectiveness of the cutter caps, a momentary reverse 3rd Z-axis depth command was introduced, immediately following the 2nd Z-axis depth command. The object was to start cutter cap rotation back up as the spindle retracted, shearing off any remaining burrs. Where the typical 2nd Z-axis depth command was -0.160, the machine was programmed to reverse to a 3rd Z-axis command of -0.145. This improved the appearance of the weld, but had an adverse impact on lap shear strength as specimens were later tested. It was concluded that geometry designed into the end of the driving mechanism has the potential to effectively clean up the weld location, simultaneously with the welding action.

For experiments addressing the existence of an internal pocket as means for driving the bit during the weld cycle (Section 4.3.3), an entirely new driver was developed to eliminate the internal T-25 Torx tooling. Several different bit designs for providing external means of driving the bit were considered, but the design shown in Figure 4-29 was chosen because it was conducive to existing CNC tooling setups. This bit would interlock with the new driver through grooves cut in the periphery of the bit head (Figure 4-37). All components were quickly and easily produced on a CNC lathe, with the exception of the driver collar, which required wire EDM machining. Durability for this driving method was not sufficiently addressed, as its development was toward the end of this study. It merely illustrates one form of many possibilities for externally driving the friction bit.

Figure 4-37: Exploded Diagram of an Externally Driven Bit and Driver

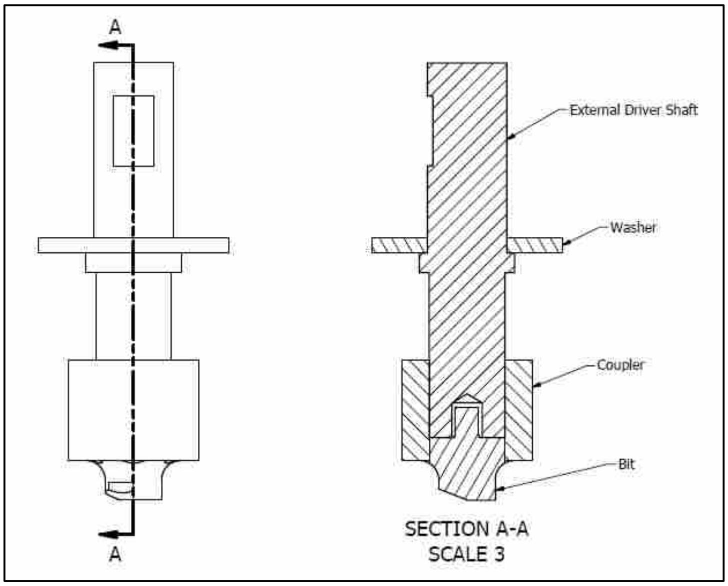


Figure 4-38: Sectioned View of an External Driver Coupled to a Solid Bit

4.5 **Processing Parameters**

Three specific parameters programmed into the FBJ machine for each cycle were evaluated to establish the significance of their impact on FBJ bond strength. They were Z-axis velocity, spindle RPM, and tool depth – also known as Z-axis command. During stage one, these three parameters do not impact weld strength, and their setting is determined by characteristics of the upper specimen material. For this research, parameter testing was confined to stage 2 settings. Clamp force was also investigated as a non-programed parameter, in order to evaluate the benefit of its control or manipulation.

Z-axis velocity is the speed with which the machine spindle moves up or down, driving the bit into the materials to be joined. This speed is programmed by the user into the machine prior to welding, as a constant value for each stage. Z-axis velocity was found to impact weld strength, with increasing Z-axis velocity leading to greater weld strengths.

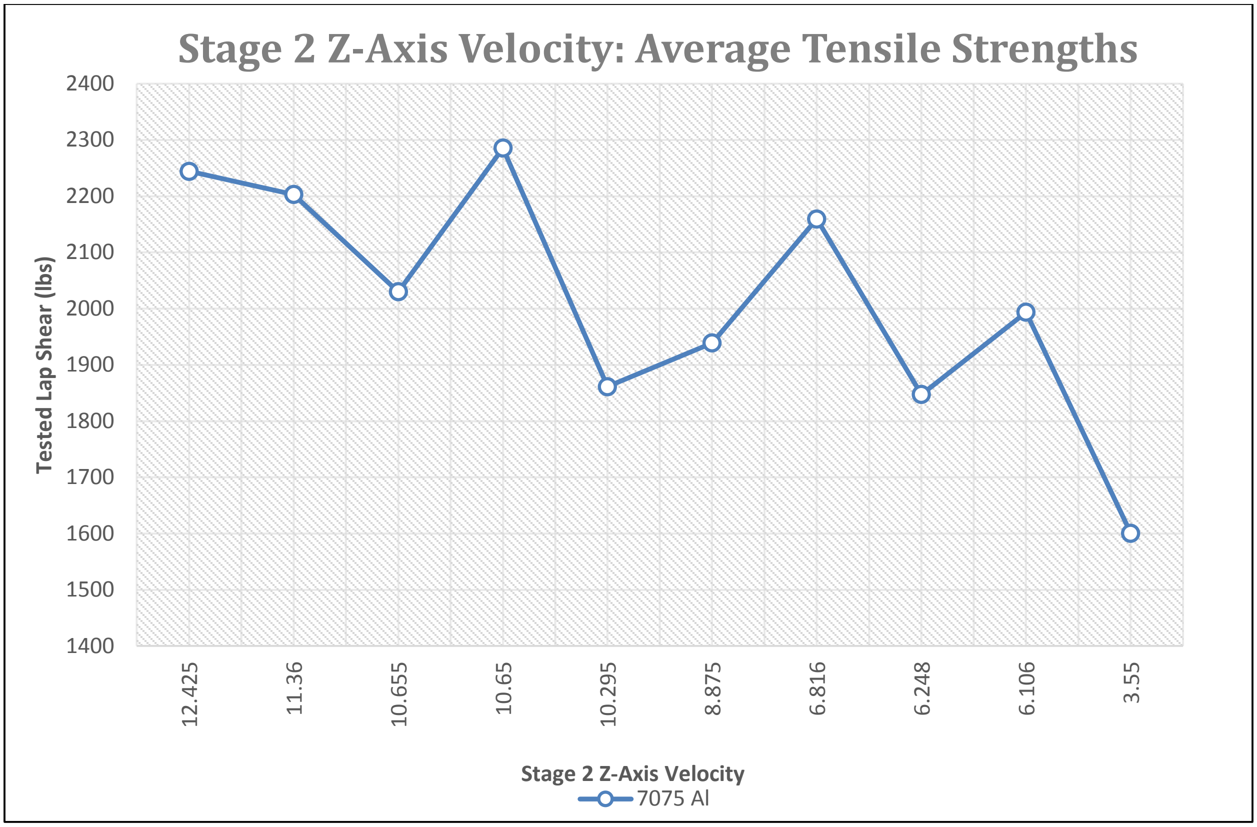


Figure 4-39: Average Tensile Strengths for Increasing Z-Axis Velocities.

RPM is the designation for the number of revolutions the spindle makes in the C-axis, or rotation around the Z-axis. This parameter is also programmed prior to an FBJ weld by the operator, as a constant value for each programed stage. It was found that average tensile strength increased as RPM was increased, until about 3250 RPM. After this point, average tensile strength was seen to decline sharply. This is thought to be a result of excessive heat generated by the high RPM, as specimens with stage 2 RPM settings over 3250 RPM were found to show increasing amounts of discoloration due to heat buildup. This would most likely impact grain structure and the solid-state bonding process.

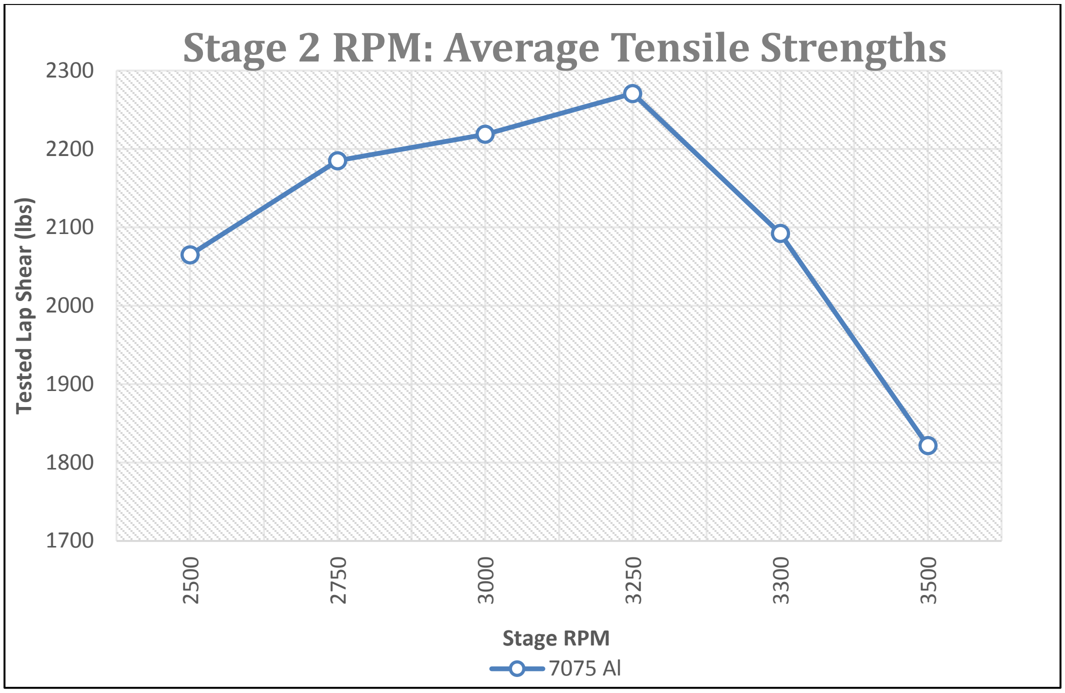


Figure 4-40: Average Tensile Strengths for Variations in Stage 2 RPM

Tool Depth or Z-axis command is the programmed value to which the spindle will move in the Z-axis direction. Each weld stage may have a different value programmed, but each stage does not add to the value before it. Tool depth is absolute rather than incremental, and is measured from the top surface of the upper material layer. The machine can set this zero value during an automatic touch-off function, or it can be set manually. For all of the experiments performed for this study, the tool depth zero was set automatically, with a bit in place on the spindle. This created a problem before bit production was improved, due to the presence of a small “pin” left on the tip of some bits. Tool depth has everything to do with weld strength, so the unnoticed presence of this “pin” on random bits would often cause the machine to set an artificially high Z-axis command zero point. Much of the weld strength variation seen during the early part of this research is attributable to this pin, as it would prevent the bit from fully reaching the intended depth. As shown in Figure 4-41, tool depth was found to be related to lap shear strength, with average lap-shear strength increasing as depth increases, then decreasing as depth settings go beyond -0.175”. After -0.175”, the bit head no longer clamps down on top of the upper specimen layer, and instead begins to penetrate into it. This reduces the strength of the coupon, and lower lap-shear strengths are obtained.

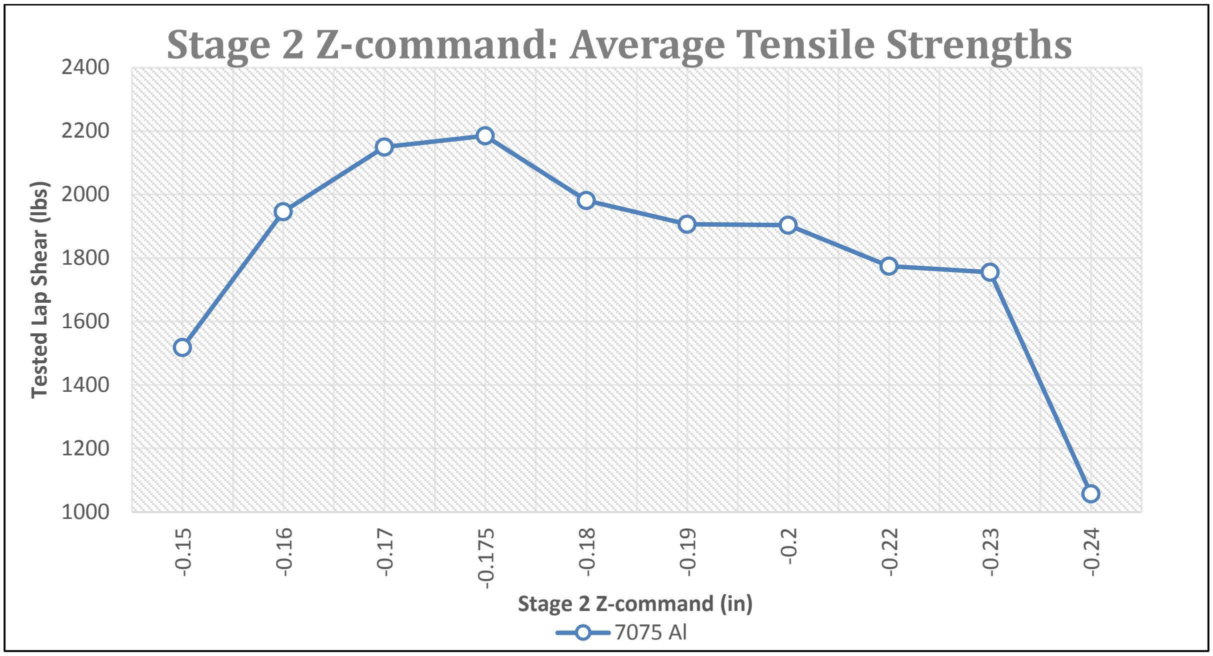


Figure 4-41: Average Lap-Shear Strengths for Increasing Stage 2 Z-Command Tool Depths

Sensors in the machine record actual velocities, RPM, and tool depths, storing them along with other machine-recorded data in a run file. When these run files are extracted and analyzed, they reveal the relationship that the three parameters have with each other during the weld cycle. It is interesting to note that while each of the parameters is input as a constant value, each parameter does not remain constant during the actual weld cycle. As the spindle encounters frictional resistance, its behavior is modified, which introduces variation. It is thought that machine modifications could be made to stiffen both the spindle and enhance the motor torque, but these modifications were not tested.

For the most part, attention was focused on processing parameters only during the first half of this study. Data was compiled from all of the early tests on parameter variations, (Figure 4-43) and a standard set of processing parameters was identified and established for general use. For tests conducted both at BYU and with collaborative laboratories, these parameters () were pursued despite improvements and modifications to welding components. Each modification or improvement to bit design or FBJ equipment would logically require tweaking of parameters to regain peak performance, but such constant adjustment of parameters was not deemed worthwhile due to the necessary time and cost of doing so. This allowed greater focus on other developments.

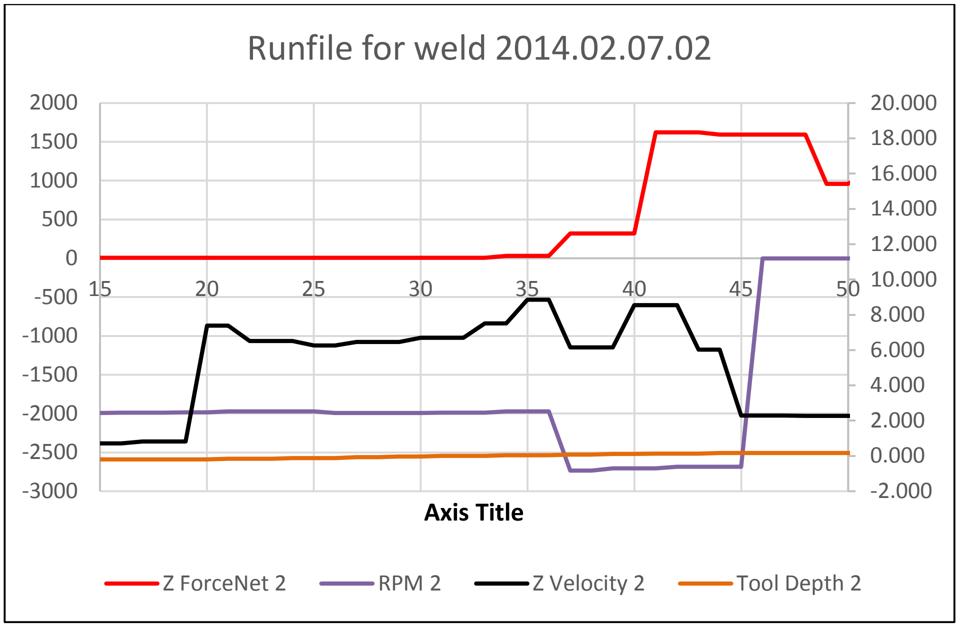


Figure 4-42: Runfile, Net Z-Force (lbs), RPM, Z-Velocity (in/min), and Tool Depth (in)

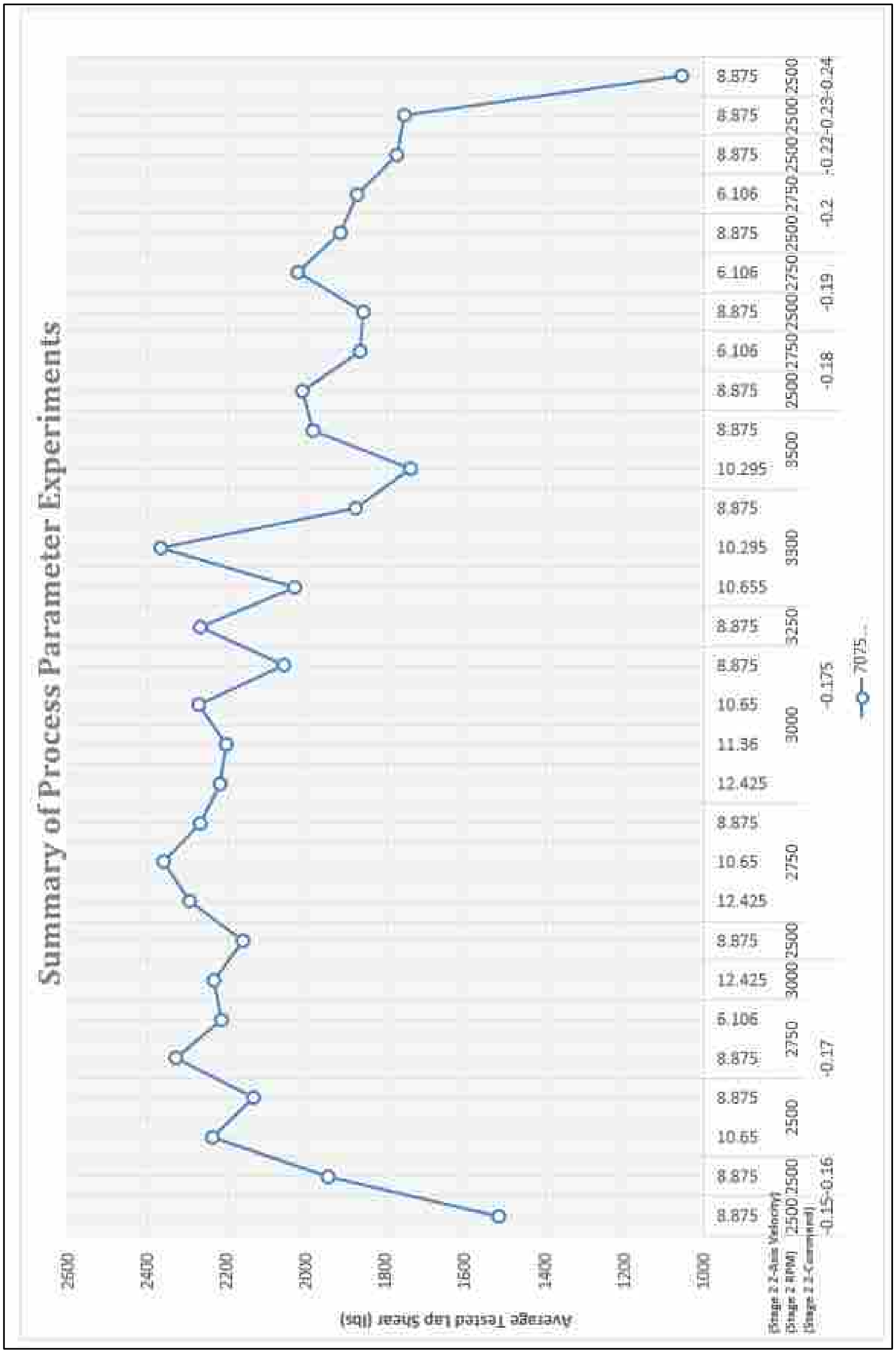


Figure 4-43: Summary of Various Z-Axis Velocity, RPM, and Z-Command Combination Strengths

Table 4-7: Standard Programed Parameters Used Throughout Testing

Parameter:	Stage 1:	Stage 2:
Spindle RPM	2000	2500
Z-Velocity (in/min)	8.875	8.875
Z-Command (in)	-0.062	-0.17
Dwell Time (ms)	0	0

4.6 FBJ and Carbon Fiber

Carbon fiber was joined to DP980 in experiments designed to evaluate the feasibility of using FBJ to join metal with non-metal material types. Two thicknesses of carbon fiber were tested. The specimens were tested in lap shear. Failure characteristics indicate that bonds are possible and easily made between steel and any other material, as long as the FBJ bit is able to penetrate the upper material. The strength of the final specimen however, is dependent on the properties of the materials that are joined. In this case, the carbon fiber was the weaker material and failure was characterized by tear-out. In all cases, the bond between the bit and the underlying steel remained undamaged.

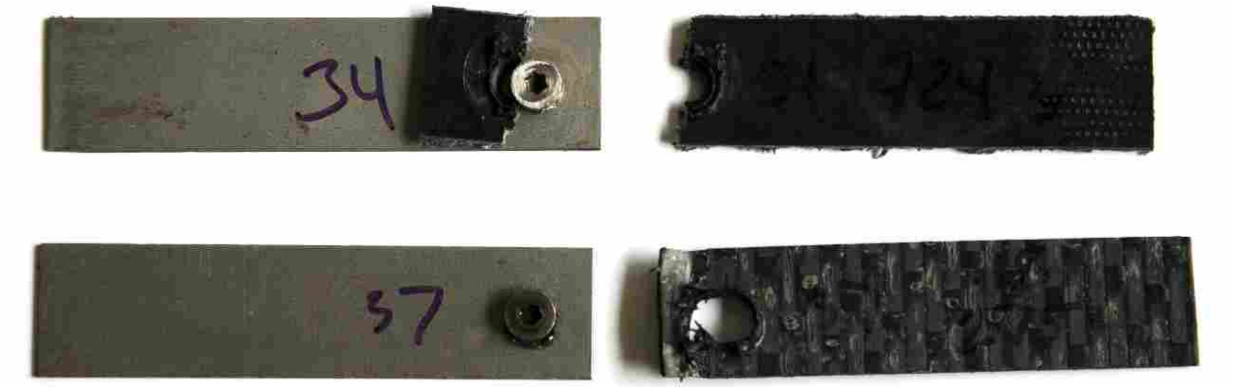


Figure 4-44: Feasibility Specimens of FBJ between DP980 (Left) and Carbon Fiber (Right)

4.7 **Microstructure**

Prior to use, FBJ bits exhibit a tempered martensite microstructure that results in 30~32 HRC hardness. Changes to this microstructure and hardness during FBJ can be explained by looking at research done on friction stir welding, as the two processes have similar dynamics during the bond phase. For friction stir welding of steel, studies have found that the maximum temperature is higher than A_3 temperature. (Lienert, 2003, Thomas, 1999) During the FBJ joining phase, a similar amount of heat is generated when the joining bit engages the DP 980 steel.

During the joining phase, significant frictional heat is generated at the tip of the bit. This results in microstructural transformation into a single phase austenite, as maximum temperatures may exceed A3 levels. In addition to changes in microstructure, a significant amount of severe plastic deformation occurs at the interface region located near the end of joining bit. The austenite microstructure then further changes into martensite as the weld cycle completes and the bit and bond area cool rapidly, therefore creating the expectation of higher hardness.

As a result of both the microstructural change and the bit deformation, the hardness value of the bit at the bond zone increases, while the bit head remains at the original hardness value. After a weld is created, the measured hardness in the bond area near the joining bit was around 60 HRC, which is two times higher than the hardness of joining bit before FBJ. This behavior is one explanation for head failures observed during lap shear tension testing, which would have occurred at the interface between the two hardness values. This also explains the failure locations observed during cross tension testing (Section 4.11), which were also head failures.

Figure 4-45 (a) shows a cross sectional image of an FBJ specimen, with a low optical image magnification. In this sectioned sample, the AISI 4140 bit is seen to join the AA7075-T6 (top layer) and DP980 (bottom layer) sheets together. Original bit joining diameter was measured at 5.56 mm, and the bond zone diameter is measured at approximately 5.35 mm. Figure 4-45 (b) shows a scanning electron micrograph (SEM) image of the interface of the bit and aluminium sheet, and the bonding interaction between the two. Figure 4-45 (v) is an SEM image of the interface between the bit and the DP 980 at the bond zone.

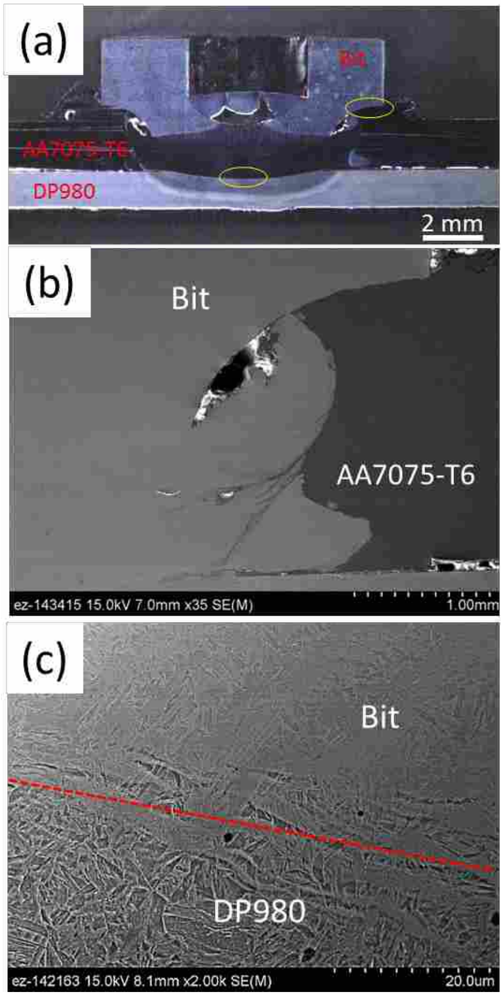


Figure 4-45: (a) Macro-Section (b) SEM at Bit Edge (c) Interface between Bit and DP980

For FBJ specimens, the metallurgical bond between the 4140 bit and DP 980 sheet is the main source of strength in the joint. For most sectioned specimens, this bond between the bit and DP 980 was consistently achieved without noticeable cracks or defects. As is evident in these figures, the lath martensite with ferrite microstructure is clearly seen in the DP 980 steel.

Figure 4-46 depicts the measured hardness profile DP980 sheet at the location of an FBJ weld. The DP 980 base metal (0.15 weight percent of carbon) is shown to have an average hardness of 30~32 HRC, which is similar to the value of the FBJ bit with its tempered martensitic structure. The hardness within joined DP 980 steel is maximized at the interface region, with a value of around 50 HRC. This value decreases slightly from the interface region toward the HAZ, and then increases again as it approaches the base metal. At the interface center (y=0.6 mm), for both DP980 steel and the FBJ bit, hardness increases up to and averages about 60 HRC, possibly due to the higher carbon content of the FBJ bit (0.38~0.43 weight percent of carbon), microstructural modifications, and plastic deformation.

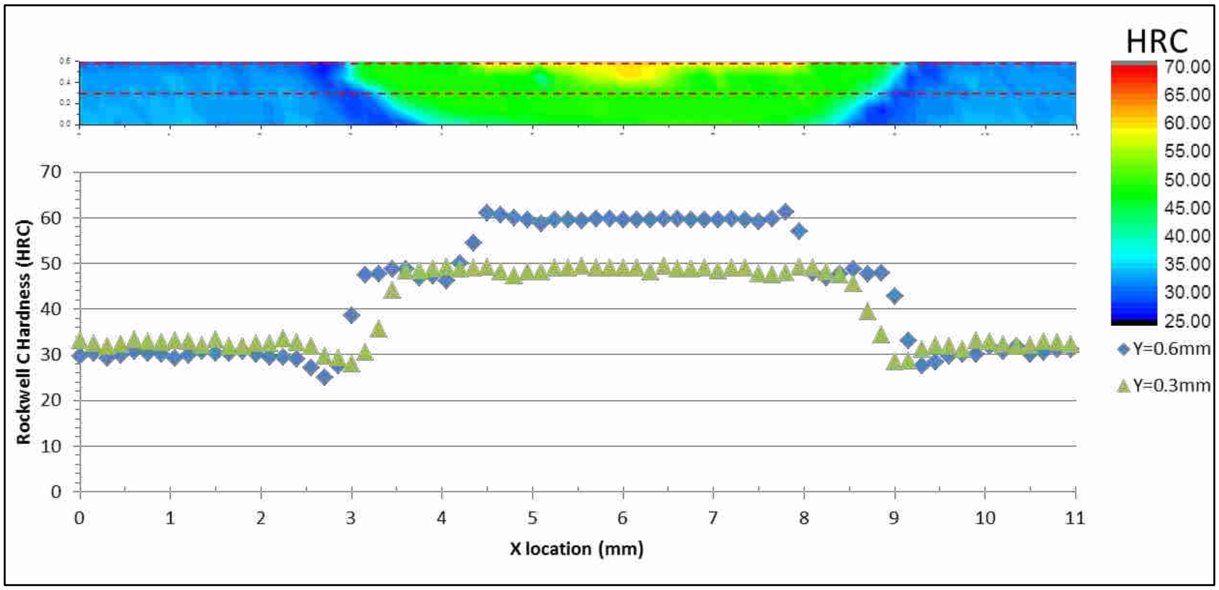


Figure 4-46: Micro-Hardness Distribution in DP980 in Immediate Region of the FBJ Weld

4.8 Fatigue Testing

As all mechanical testing had been done using static lap shear, several specimens were sent to the University of Ulsan in South Korea for cyclical fatigue testing. Five specimens were created for testing using AA-7075 aluminum and DP980 steel, while an additional five specimens were made using AA-5754 aluminum and DP980 steel. Table 4-8: Parameters Used for Fatigue Test Specimens shows the parameters used to create theses specimens, and Table 4-9 shows the performance seen for these samples. For the fatigue tests, Fmax was 2kN, Fmin was 0.2 kN, and Frequency was 10 Hz.

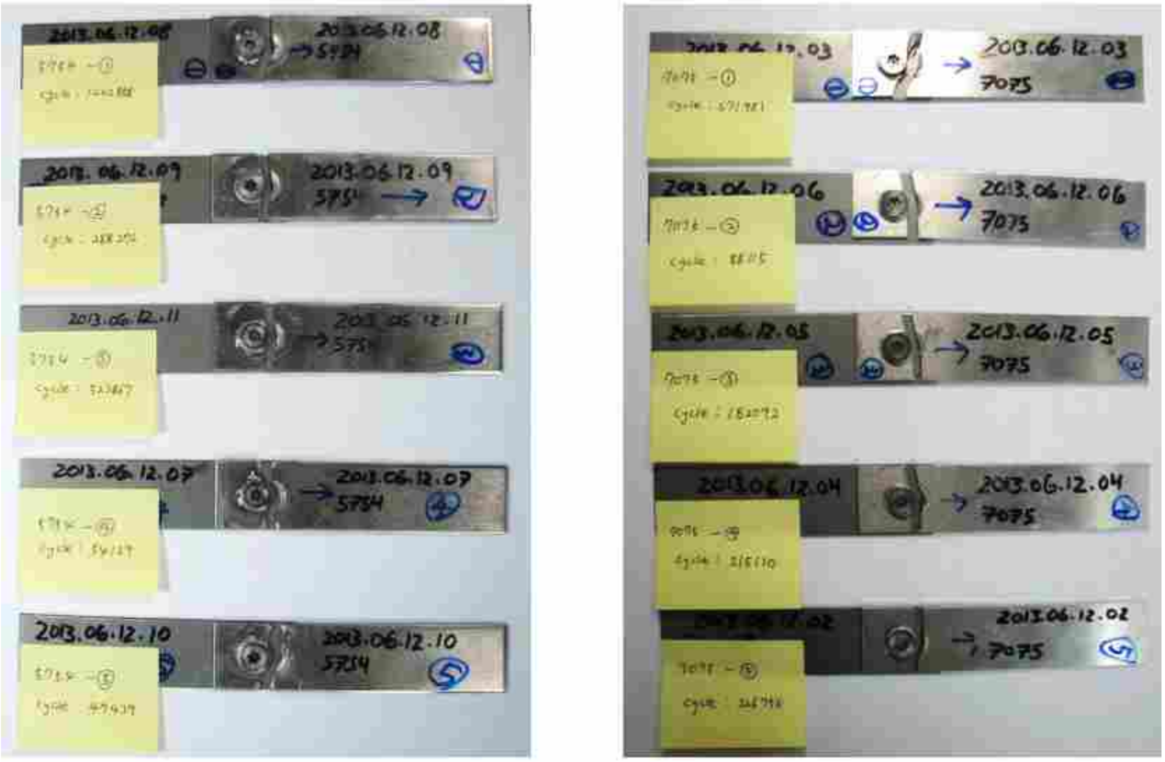
Table 4-8: Parameters Used for Fatigue Test Specimens (Korea Fatigue Test 2)

	AA-7075 (2013.06.12.02-06)		AA-5754 (2013.06.12.07-11)	
Parameter:	**Stage 1:**	**Stage 2:**	**Stage 1:**	**Stage 2:**
Spindle RPM	2000	2500	2000	2500
Z-Velocity (in/min)	8.875	8.875	8.875	8.875
Z-Command (in)	-0.062	-0.170	-0.062	-0.170
Dwell Time (ms)	0	0	0	0

Table 4-9: Fatigue Performance of Test Specimens (Korea Fatigue Test 2)

Material	Sample number	Cycles
5754	1	1,202,858
5754	2	288,276
5754	3	523,867
5754	4	54,139
5754	5	47,439
7075	1	671,981
7075	2	88,115
7075	3	182,092
7075	4	215,110
7075	5	226,756

Fatigue performance of these specimens is observed to be highly variable for the AA 5754 aluminum joints. Less variation was recorded for the AA 7075 specimens, but is still significant. Interestingly, 100% of the fatigue tested specimens exhibit the material failure mode, as seen in Figure 4-47. This mode is rarely observed during lap shear testing, and is characterized by failure within the aluminum with the FBJ bit and the weld zone still intact and undamaged.



<5754 samples> <7075 samples>

Figure 4-47: All Samples Tested in Fatigue Cycles, with Material Failure in Every Case

The fracture path for the aluminum was always in the region of the smallest cross sectional area, but closer to the edge of the FBJ bit head as shown in Figure 4-48. This is thought to be explained by the role that the bit head plays in clamping down on the aluminum, as well as the cross sectional area of the aluminum at that point. In the region of the FBJ bit, material cross section area is reduced. This makes the material more vulnerable to flexing, with pressure concentrated under the outside edge of the FBJ bit head. As the aluminum always fractured prior to a bond failure, it is evident that fatigue properties of FBJ bonds themselves are greater than the fatigue properties of the aluminum types that were used. Therefore, if fatigue loads are determined by the component materials, stronger materials must be used to focus fatigue stress on the FBJ joint itself.

Figure 4-48: Fatigue Specimens with Fractured Aluminum and FBJ Bond Intact

4.9 Adhesive Weldbonding and FBJ

Two datasets were generated to study contributions of adhesive and FBJ to overall joint strength in weld bonded specimens. FBJ-only, adhesive-only, and hybrid (FBJ-adhesive) configurations were tested. All specimens were composed of AA7075 and DP980, with Bit3 Bro5 consumable bits. Care was taken so that all conditions between the three configurations were as identical as possible.

The first dataset used a 25 mm overlap, while the second used 50 mm overlap. Adhesive thickness was varied for each dataset between 0 and 500 microns using 300 and 500 µm ZrO2 beads. Identical parameters were otherwise used for all specimens. Adhesive used was DOW epoxy based structural adhesive Betamate 4601, cured at 165-170°C, for 30 minutes after use.

Adhesive-only specimens were created exactly the same way as the hybrid specimens. Prior to lap shear testing however, the FBJ component was removed through the use of RAM EDM. This allowed hybrid and adhesive-only specimens to be as similar as possible. The specimens were flipped upside down and mounted in a fixture on the RAM EDM machine. A 3/8 in. diameter copper electrode with a flat end was used to remove the metallurgical bond from the specimens. This resulted in an adhesive-only specimen, identical to the hybrid specimens except for the absence of the metallurgical bond.

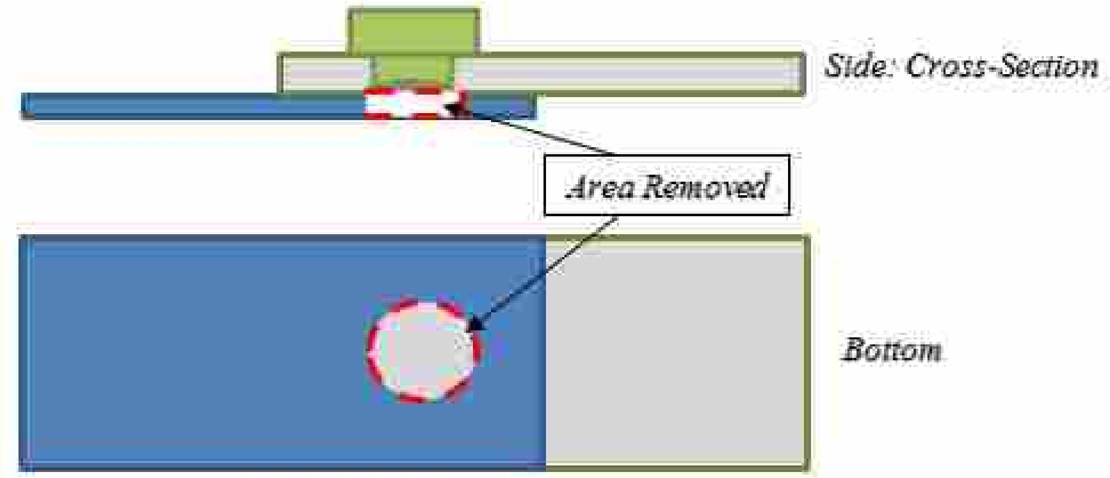


Figure 4-49: Removal of FBJ in Order to Create an Adhesive-Only Specimen

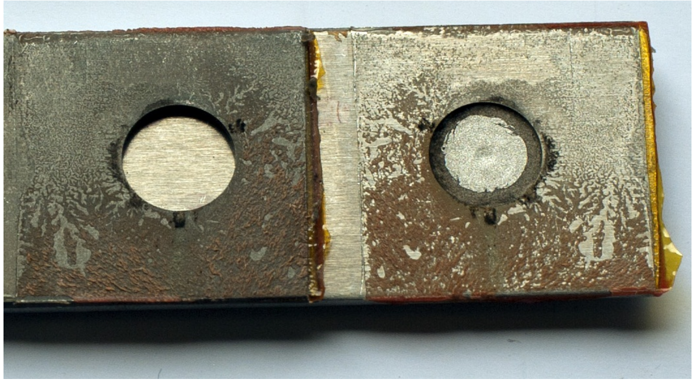


Figure 4-50: Fractured Adhesive-Only Specimen, with FBJ Removed Prior to Testing

Lap shear tests were performed at room temperature. For 25 mm overlap, the FBJ-only specimens failed at an average load of 2100 pounds. Adhesive-only specimens averaged 1700 pounds for nominal adhesive thickness, 3200 pounds for 300 microns, and 3500 pounds for 500 micron thickness. Hybrid specimens averaged 2800 pounds for nominal thickness, 3300 pounds for 300 microns, and 3400 pounds for 500 microns.

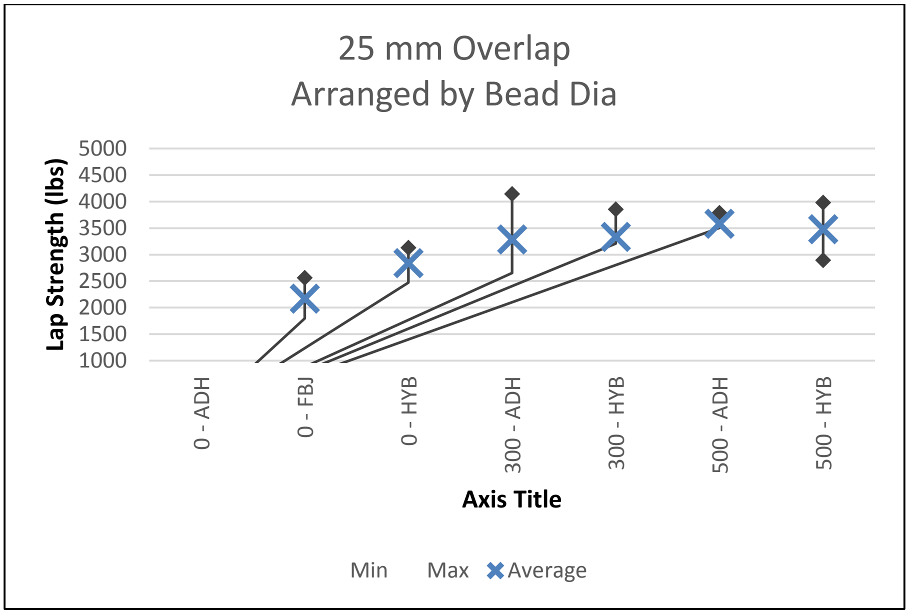


Figure 4-51: Lap-Shear Results for 25 mm Overlap Specimens

For 50 mm overlap cases, the FBJ-only specimens failed at an average load of 2200 pounds. Adhesive-only specimens averaged 3900 pounds for nominal adhesive thickness, 4500 pounds for 300 microns, and 4400 pounds for 500 micron thickness. Hybrid specimens averaged 4300 pounds for nominal thickness, 4500 pounds for 300 microns, and 4400 pounds for 500 microns.

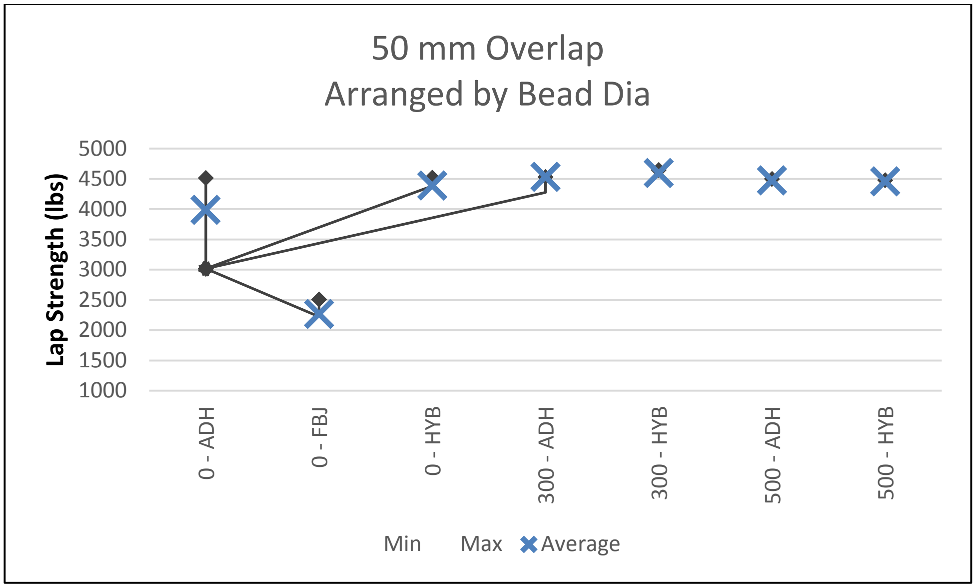


Figure 4-52: Lap Shear Results for 25 mm Overlap Specimens

In all tested 25 mm overlap specimens, the use of thicker adhesive dramatically increased strength. However, after 300 micron thickness, the effect was marginal. For 50 mm overlap specimens, failure modes were all nearly identical to each other, occurring in the aluminum across the area of the friction bit joint. For 50 mm overlap specimens involving adhesive, lap shear strength was high but almost unchanged as thickness varied. Evidently, increasing adhesive bonding area reduces the role of FBJ.

Table 4-10: Lap Shear Test Results for All Bond Area Experiments

	25mm overlap					50mm overlap		
bead thickness (microns)	Adhesive only (lbs) (EDM)	FBJ only (lbs)	Hybrid (lbs)		bead thickness (microns)	Adhesive only (lbs) (EDM)	FBJ only (lbs)	Hybrid (lbs)
0	1274	2562	3133		0	4514	2507	4251
0	1950	2305	3064		0	4426	2203	4409
0	2017	1643	2322		0	3019	2093	4518
0	1747	2170	2840	average	0	3986	2268	4393
300	2501		3059		300	4624	x	4536
300	3209		3091		300	4528	x	4608
300	4142		3852		300	4446	x	4646
300	3284		3334	average	300	4533		4597
500	3787		3980		500	4463	x	4452
500	3592		3558		500	4460	x	4479
500	3352		2893		500	4497	x	4452
500	3577		3477	average	500	4473		4461

Without a doubt, hybrid weldbond specimens of FBJ and adhesive have higher average lap shear strength than either method by itself. However, the strength relationship between the two methods is not additive for hybrid bonds.

While testing these specimens in lap shear, it was noticed that the adhesive and FBJ weld seemed to fail sequentially. At first, the adhesive shows no sign of yielding. When the adhesive bond breaks, it does so suddenly, evidently releasing all of the load it held abruptly upon the FBJ bond. In nearly every case, this load was higher than typically seen when testing specimens in lap shear. The friction bit joint resists this sudden impact long enough for either the DP980 to fail or the AL7075 to fail, either of which happens quickly. Very little bending or peeling action is observed in the coupons. These sudden applications of stress, and the higher than normal load carried by the FBJ component after adhesive failure, suggest that FBJ is impact resistant. It is also evident that all other lap shear data throughout this research is lower than it otherwise would be, due to bending and peeling in the coupons.

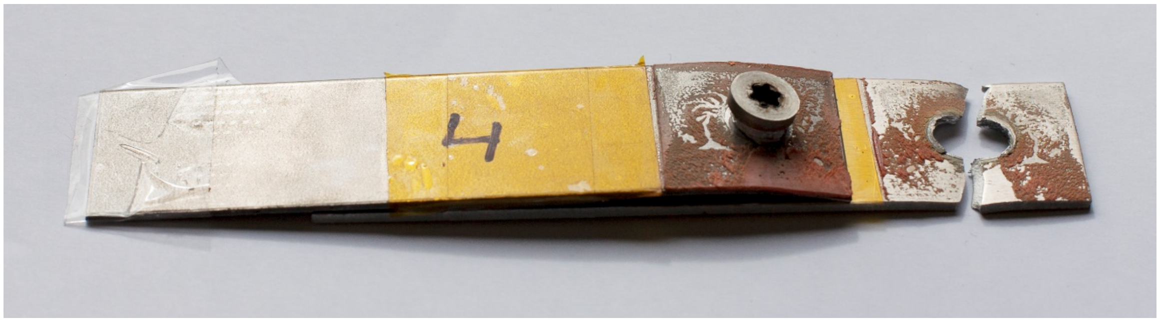


Figure 4-53: Hybrid Specimen with Aluminum Failure

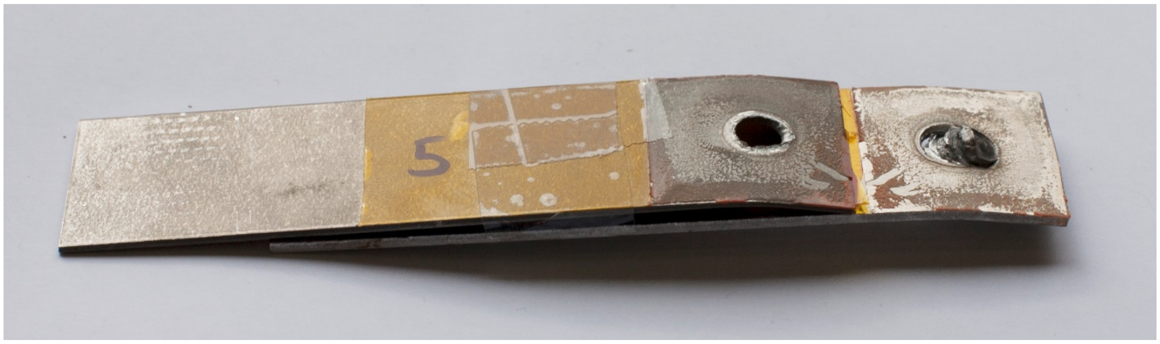


Figure 4-54: Hybrid Specimen with DP980 Pull Out – Weld Nugget Still Intact

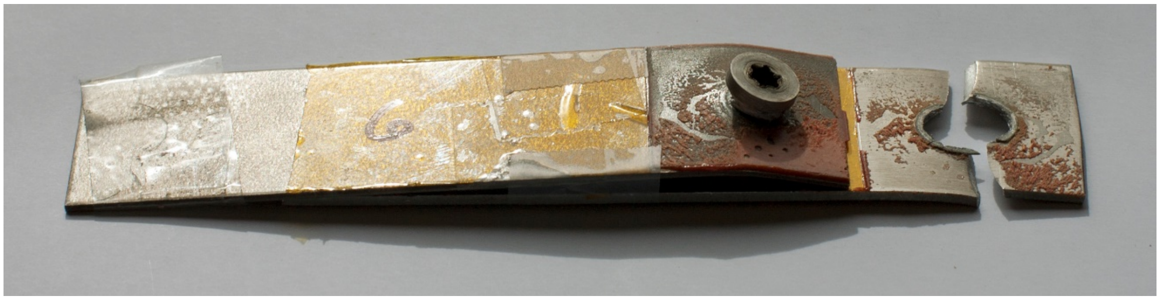


Figure 4-55: Hybrid Specimen with Aluminum Failure

4.10 **Corrosion Testing**

In a study conducted by LeBozec et al. (LeBozec, 2012) a variety of joining methods for dissimilar metals were subjected to corrosion performance and mechanical property testing. It was observed by these researchers that hybrid joints, incorporating the use of adhesive, resulted in higher strengths after being subjected to corrosive environments.

In collaboration with Oak Ridge National Laboratory, testing was done to evaluate the effects of corrosion on the mechanical behavior of joining dissimilar materials using both FBJ and adhesive-hybrid methods. Using previously determined parameters agreed upon by researchers at ORNL and BYU, two groups of specimens were produced.

Table 4-11: Parameters for Adhesive Corrosion Experiments

Parameter:	Stage 1:	Stage 2:
Spindle RPM	2000	2750
Z-Velocity (in/min)	8.875	6.106
Z-Command (in)	-0.062	-0.170
Dwell Time (ms)	0	0

The control specimens consisted only of a single friction bit joint in the center of the overlap region. The second group was characterized by a hybrid joint consisting of a friction bit joint in the center of an adhesive bond, created in similar fashion to the weldbonding process employed with resistance spot welding (Gaul, 2011). All specimens were created under conditions identical to each other.

For hybrid specimens, overlap areas were coated with a layer of Dow Betamate 4601, an epoxy based structural adhesive. An FBJ bond was created in the center of the adhesive bond, after which the hybrid samples were cured in a furnace for 30 minutes at 165 degrees Celsius. Adhesive thickness within the hybrid specimens was very thin, with no spacers used.

Corrosion and mechanical testing was completed by Oak Ridge collaborators. Corrosion testing was done using a Ford accelerated Cyclic Corrosion Test L-467. This test consisted of 30 cycles, where specimens were immersed or constantly sprayed with 0.5% NaCl solution for 15 minutes, followed by a drying period of 5 hours and 45 minutes at 25 degrees Celsius and 95% humidity. A final drying period took place at 50 degrees Celsius and 70% humidity for 18 hours. For mechanical testing, one specimen was removed after every cycle for testing in static lap shear.

Corrosion reactions on the surface of the DP980 are explained in three ways. First, with the ferrite within the DP980 acting as the anode (Sarkar, 2005, Osorio, 2009).

$$\mathrm{Fe} \rightarrow \mathrm{Fe}^{\mathbf{2+}} + \mathbf{2}\mathrm{e}^{-} \text{ (anodic)} \quad \textbf{(4-1)}$$

$$2\mathrm{H}^{+} + 2\mathrm{e}^{-} \rightarrow \mathrm{H}_2 \text{ (cathodic)} \quad \textbf{(4-2)}$$

Second, with intermediate reactions that are possible. Fe (II) hydroxide can be formed as follows (Schreiber, 2006):

$$\mathrm{Fe}{+}2\mathrm{H}_2\mathrm{O} \rightarrow \mathrm{Fe(OH)}_2{+}2\mathrm{e}^{-}{+}2\mathrm{H}^{+} \quad \textbf{(4-3)}$$

Third, Fe (II) hydroxide particles on the steel surface can be oxidized to form iron (III) oxide, Fe_2O_3:

$$\mathrm{Fe(OH)}_2 \rightarrow \mathrm{Fe}_2\mathrm{O}_3{+}\mathrm{H}_2\mathrm{O} + 2\mathrm{e}^{-} + 2\mathrm{H}^{+} \quad \textbf{(4-4)}$$

Another factor for corrosion to FBJ specimens is galvanic corrosion. This is of general concern when joining all dissimilar steel and aluminum alloys. It is one of the most common types of corrosion that occurs when two conductive materials are in contact within a corrosive medium. Aluminum is known to act as an anode when coupling with steel in chloride solutions due to having a relatively higher electrode potential than steel (David, 1999). This accelerates the corrosion of the aluminum alloy when it is brought into direct contact with the steel.

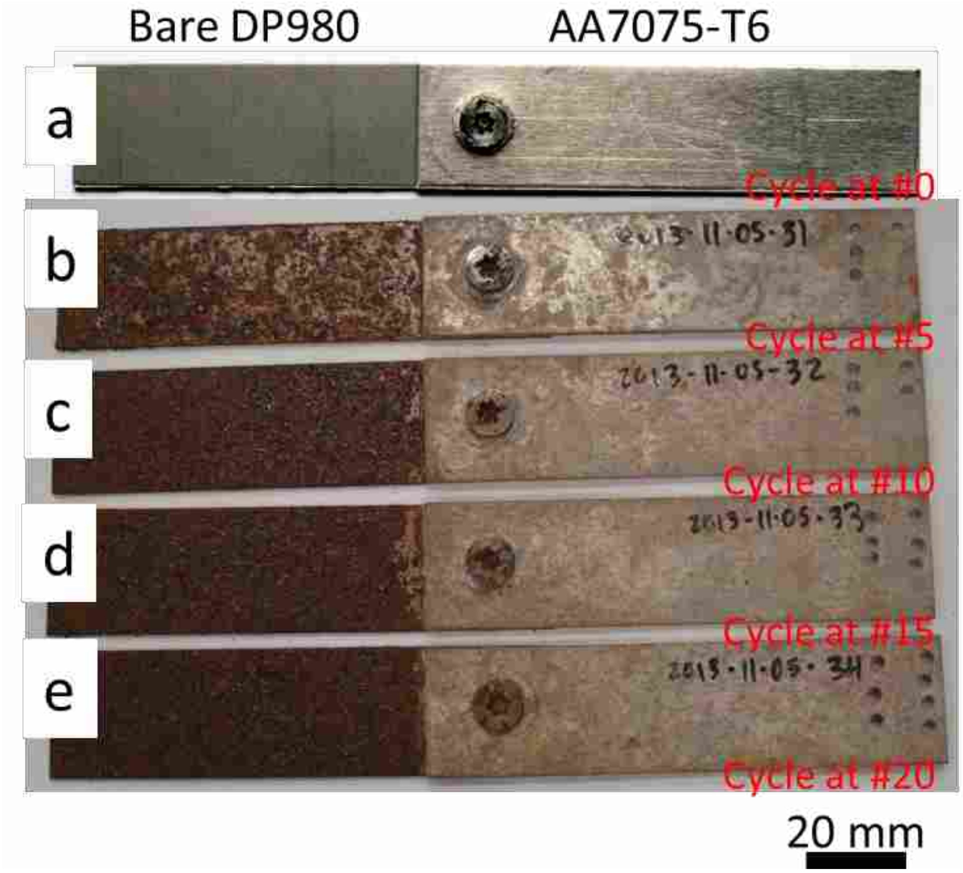


Figure 4-56: Oxidation at Various Corrosion Cycles, Steel on the Left

Throughout the corrosion test, samples were removed at periodic intervals from the corrosive environment. While all samples exhibited oxidation, no major visual difference was recorded. When tested in lap shear however, significant differences were obvious.

When tested at cycle 0, both types of specimens possessed similar strength properties. The FBJ-only specimens had only about a 7% lower lap shear strength then their hybrid equivalents, which was thought to be attributable to the uncontrolled, thin layer of adhesive used.

However, once corrosive elements were applied, differences in strength behavior between the two specimen types were quickly revealed. Figure 4-57 shows data collected for both weld types. Green shaded boxes indicate the average, maximum and minimum data points at cycle 0. For the FBJ only specimens, the lap shear failure load was initially constant until the sixth corrosion cycle. At this point, it is assumed that sufficient time had passed for corrosion to reach and begin weakening the bit and joint. With each successive tested cycle, the mechanical strength of the FBJ-only specimen decreased, with premature failures prior to reaching the final cycle. When calculated in percentages of the original strength at cycle 0, only 47% of the lap shear strength existed by cycle 24. This was in stark contrast to the behavior of the hybrid samples. For hybrid joints, over 80% of original strength was maintained throughout the entire 30 test cycles.

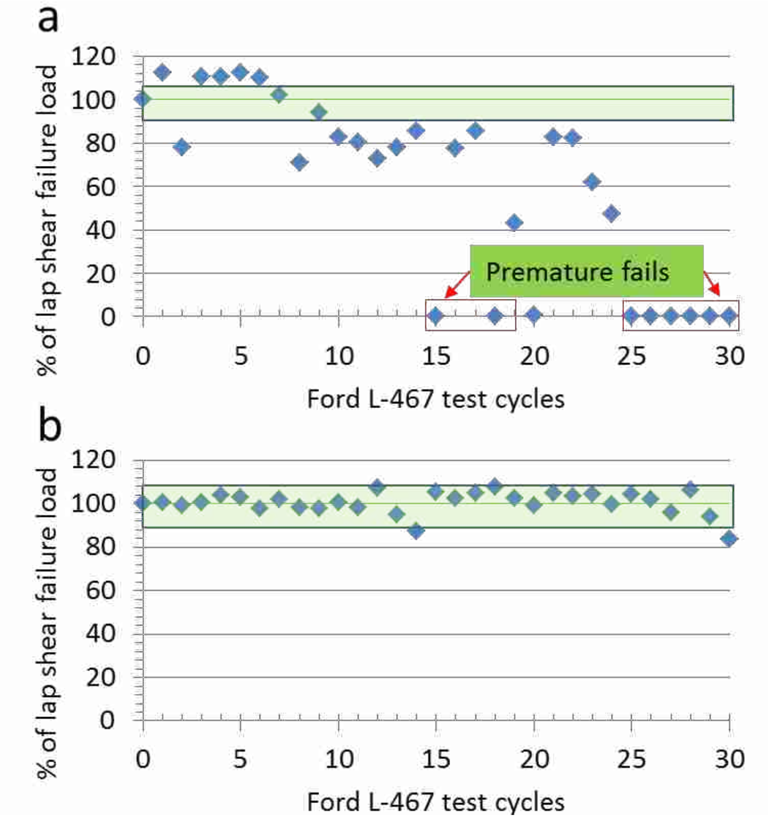


Figure 4-57: Percent of Original Strength (a) FBJ-only (b) Hybrid (adhesive + FBJ)

The failure modes observed for all corrosion tested specimens are also informative, and reveal highly consistent interfacial failure modes for the FBJ-only specimens. Figure 4-58 shows failure modes for each test, differentiated by symbols. Green boxes show the average lap shear failure load at cycle 0 with maximum and minimum errors. 28 out of 30 FBJ-only specimens had interfacial failures. On the other hand, hybrid specimens were characterized by nearly equal occurrences of interfacial (12 out of 30), head failure (9 out of 30), and material failure (9 out of 30). Hybrid specimens had no premature failures.

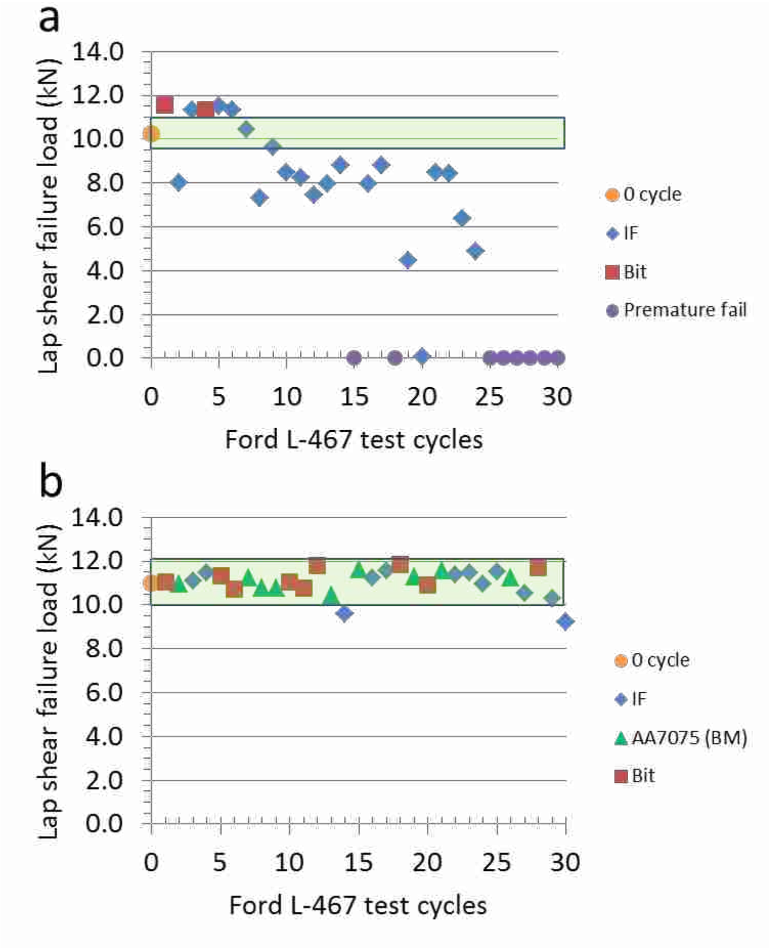


Figure 4-58: Loads Sustained by FBJ and Hybrid Specimens, (a) FBJ-Only (b) Hybrid

Until cycle 5, no significant surface corrosion was apparent on FBJ-only specimens. Thereafter, increasing amounts of iron oxide developed throughout the overlap and coupon areas. Oxidation was also increasingly observed within the bit and the bonding zone, with discoloration in both the bit and periphery as well as corrosion in the general overlapped area. In contrast, the overlap regions and bit zone for hybrid specimens show no visible evidence of corrosion at all, with no corrosion of bit, periphery of bit, or overlapped area. Figure 4-59 shows several fractured specimens from each group, with adhesive residue (light orange color) remaining on both DP980 and AA7075-T6 surfaces of the hybrid specimens.

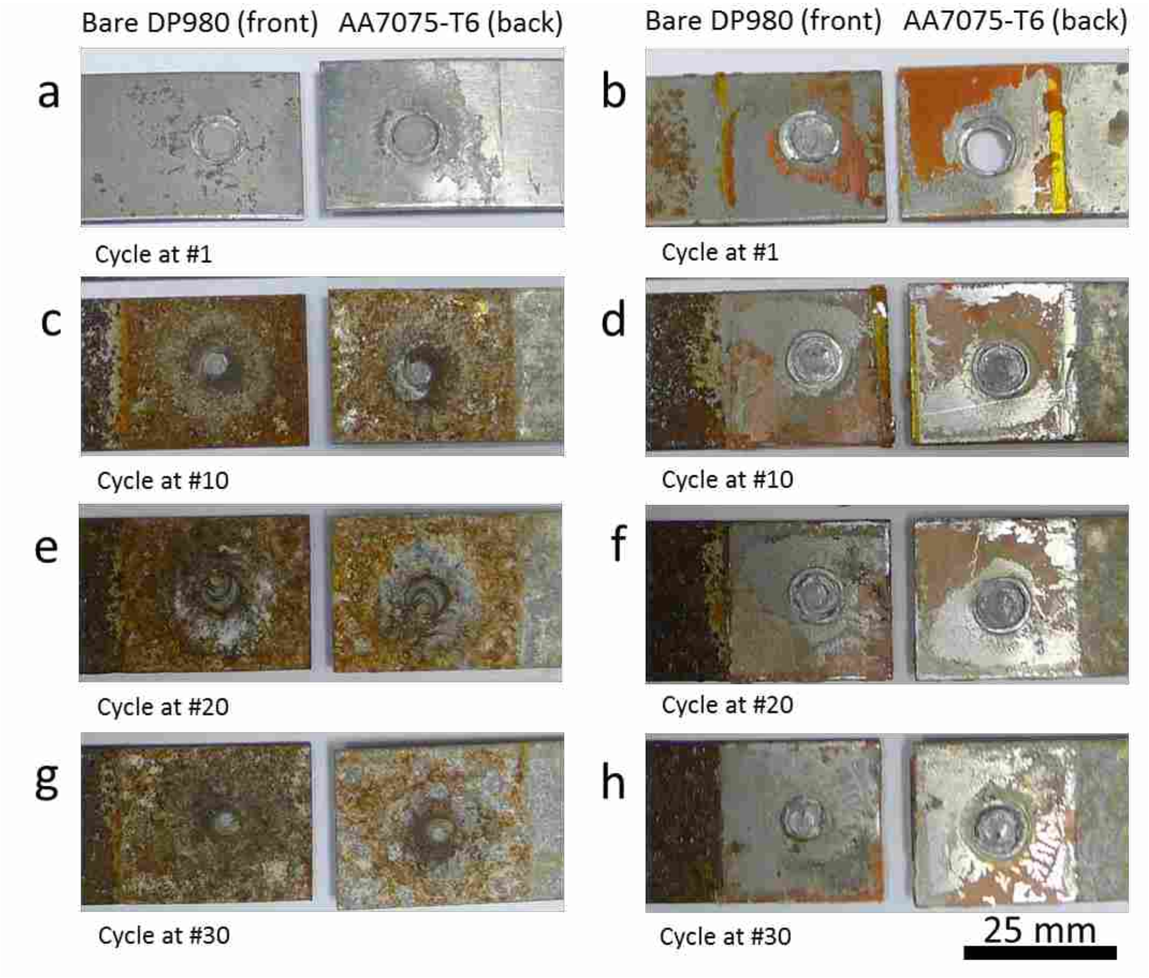


Figure 4-59: Mated Fracture Surfaces, FBJ-Only (a, c, e, g), and Hybrid (b, d, f, h)

Throughout the corrosion test, one specimen from each group was also removed every 5 cycles for metallographic examination. The FBJ-only specimen removed at cycle 15 is shown in Figure 4-60. In the low magnification image (a) a narrow gap can be seen that has developed at the interface between the bit and the steel coupon (red dashed box). A tiny gap between the bit head and the aluminum is also evident in the higher magnification image (b), and the presence of a crack at the base of the bit head in image (c), indicated by red arrows.

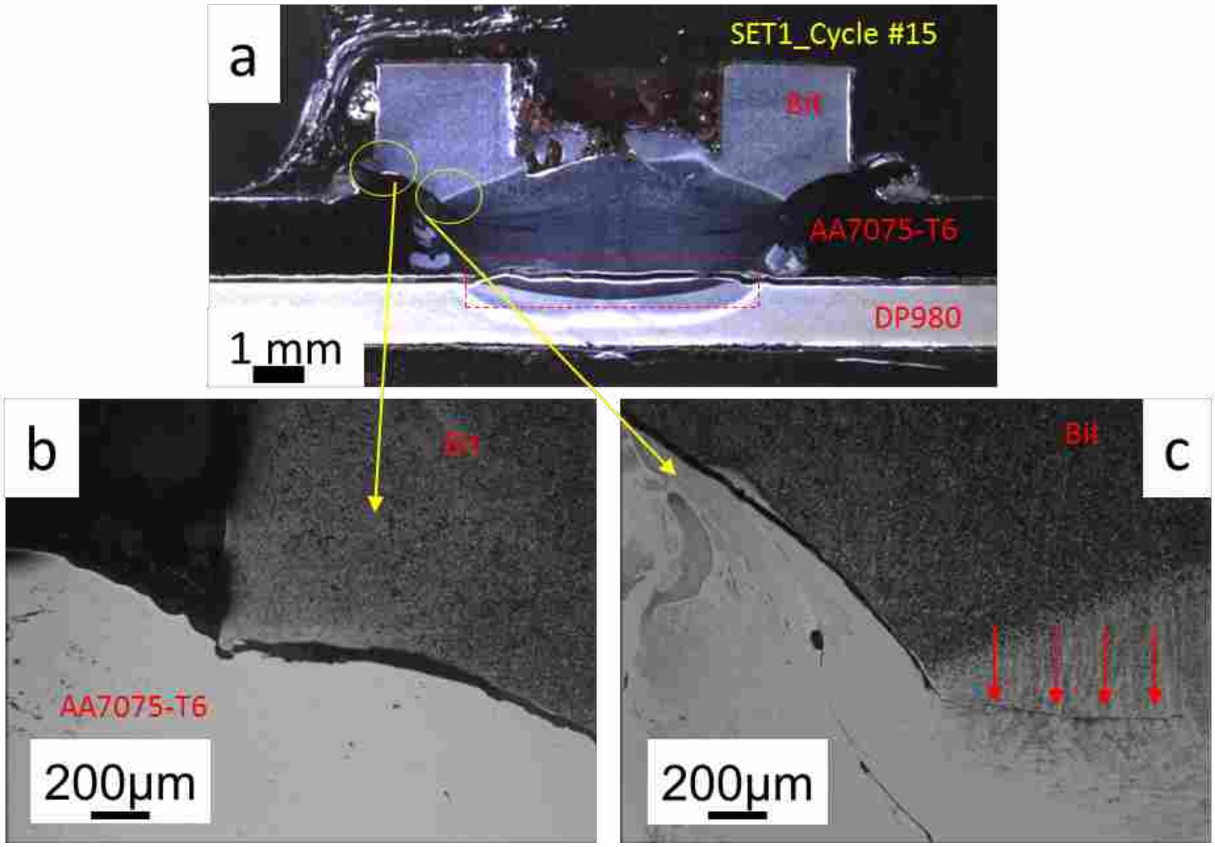


Figure 4-60: (a) FBJ-Only Specimen Removed at Cycle 15 (b) Corner of Bit Head, (c) Top of Bit Shaft

Figure 4-61 shows the image of a hybrid sample that was also removed at cycle 15 and sectioned. The low magnification image (a) reveals an absence of any gap between the bit and steel coupon. The greater magnifications in figures (b) and (c) expose a small gap between the bit head and the aluminum, similar to the one observed in the FBJ-only specimen, and a small crack at the base of the bit head, respectively. This crack is significantly smaller than the one observed in the FBJ-only specimen.

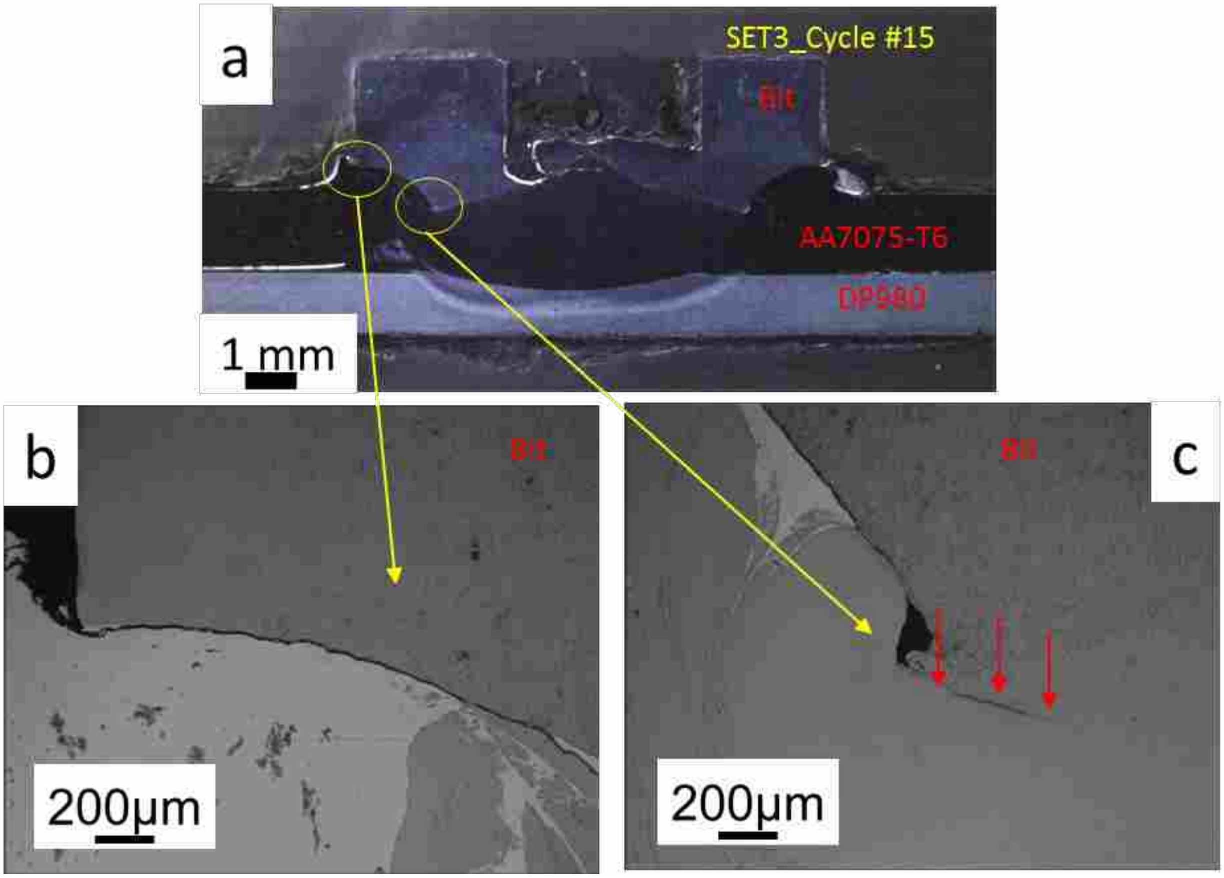


Figure 4-61: (a) Hybrid Specimen Removed at Cycle 15 (b) Edge of Bit Head (c) Top of Bit Shaft

Analysis of these images, the various failure modes, and the corrosion reactions that occur suggest two paths that corrosion may take in attacking the lap shear strength of the FBJ joint. One of these paths appears to carry the greatest impact on weld strength, yet is easily blocked through the use of adhesive. This results in substantially increased corrosion resistance

The first path is between the aluminum and steel coupons. This would explain the strength differences noted between FBJ-only and hybrid specimens. As the corrosive medium penetrates this area in the FBJ-only specimen, it has direct contact with the bond region. Weakening in this area leads to the interfacial failure mode. When this attack path is blocked and sealed by adhesive, in the case of the hybrid specimens, direct contact is no longer possible and the occurrence of interfacial failure is significantly reduced. This is indicated by the fact that 40% of hybrid specimens were characterized by interfacial failures, as opposed to 93% of FBJ-only specimens.

The second path for corrosive media to attack is located at the base of the bit head, where the bit head makes contact with the aluminum. This would explain the failure mode at that location. As galvanic corrosion creates or widens a small gap between the bit and the aluminum as shown in Figure 4-61, corrosive media gains access to any cracks existing at the base of the bit head. This is the region that is always characterized by a transition in microstructure and hardness, resulting from temperatures generated during the welding process. The presence of these cracks has yet to be controlled or studied at length, but as greater cracks are present, lower strengths are seen.

Nine of the hybrid specimens failed in a third failure mode, where the aluminum itself fractured. This material failure mode was only observed for hybrid specimens. It is assumed that this is due to higher lap shear loads capable of being sustained by the combination of adhesive and FBJ.

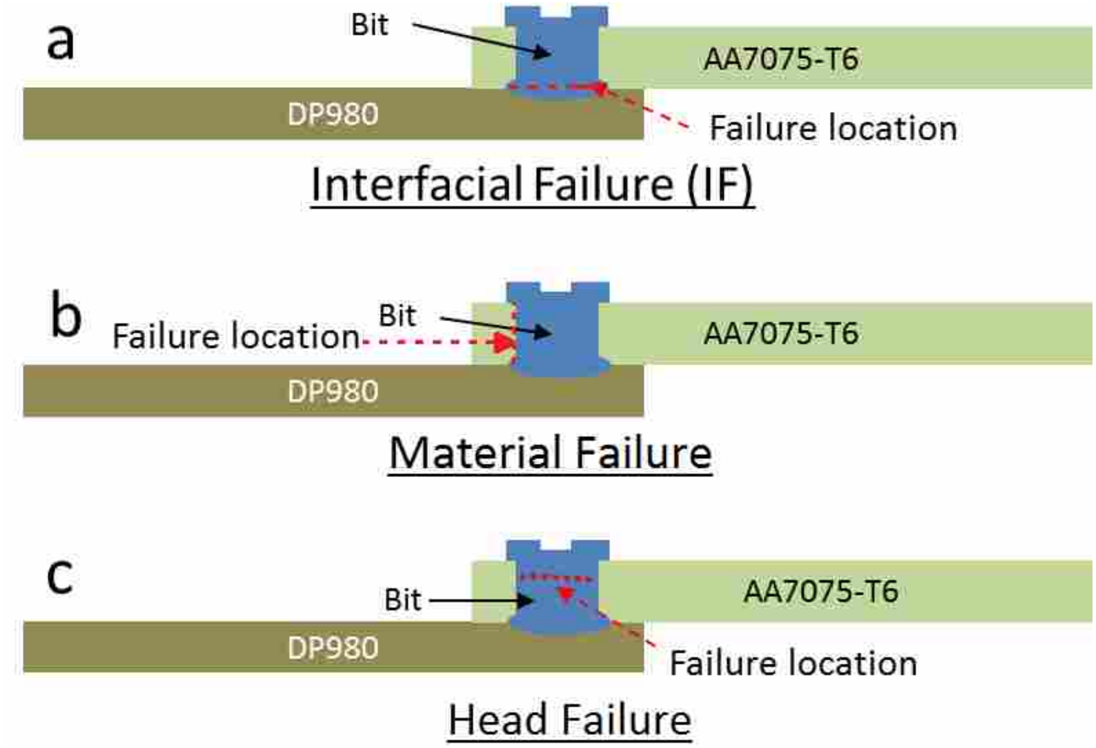


Figure 4-62: Corrosion Failure Modes (a) Interfacial (b) Material (c) Head

An alternative way of addressing corrosion reactions is to use coated DP980. Several experiments were conducted using zinc coated DP980. For these specimens, it was immediately apparent that different processing parameters would be necessary. The settings proven to yield high lap shear strengths for uncoated DP980 did not provide comparable results when coated DP980 was used. Observation of the weld cycle showed a hesitation in the Z-axis motion of the machine spindle prior to the execution of the second stage commands, which would have been at the location of the zinc coating. In the end, testing was not extensive due to problems with zinc adhesion to the DP980, but despite this challenge, the welding parameters shown in Table 4-12: Parameters for Coated DP980 were developed. These parameters consistently provided lap shears averaging at 2159 pounds, which is comparable to uncoated DP980 specimens.

Table 4-12: Parameters for Coated DP980

Parameter:	Stage 1:	Stage 2:
Spindle RPM	2000	2750
Z-Velocity (in/min)	8.875	6.816
Z-Command (in)	-0.1	-0.2
Dwell Time (ms)	0	0

The nature of these parameters is informative when compared with previous settings. In order to achieve normal lap shear loads, two changes could be made to the standard parameters. The first method was to increase the programed RPM during the first stage. Lap shear loads over 1800 lbs were obtained when the first stage RPM was 2500 or higher. The second method was to slow the programmed first stage Z command. Lap shear loads over 1800 lbs were only obtained when the first stage Z velocity was below the typical 8.875 setting. Both of these methods essentially accomplished the same thing. Increasing RPM or decreasing Z velocity effectively brought additional friction and heat to bear on the galvanic coating. Increasing the frictional heat in this manner at the galvanized layer served to remove the coating. Once that coating was removed, typical settings could be used thereafter, and the FBJ process could continue normally with predictable results.

Because the FBJ joint is unaffected by coatings once they are removed from the immediate area of the bond, it stands to reason that any coating could be used – corrosion prevention is not limited to the use of zinc. Polymers or any other coating might also be used. The type of coating is not important, as long as welding parameters can be modified sufficiently to allow the removal of the coating prior to the second programmed machine stage.

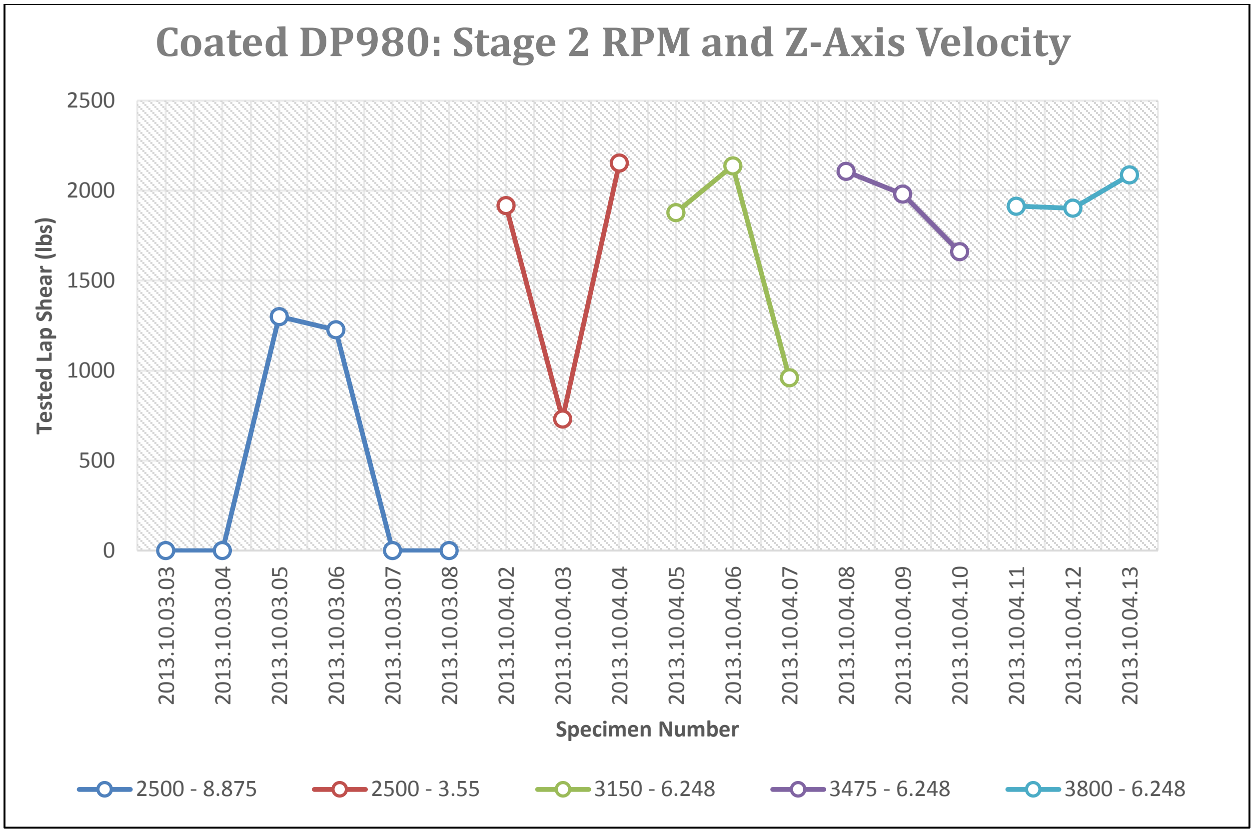


Figure 4-63: Results for Modifications to 2nd Stage RPM and Z-Axis Velocity

4.11 Cross Tension Testing

In addition to mechanical strengths obtained for FBJ through static lap shear, a few cross tension specimens were produced and tested. Cross tensional specimens used the same processing parameters as typical lap shear specimens, with a single friction bit joint placed in the center of the overlapping region. The same testing parameters were used, on the same Instron equipment. However, cross tension specimen configuration was altered to consist of larger coupons in order to facilitate mechanical testing. A typical specimen is shown in Figure 4-64.

Figure 4-64: Typical Arrangement of Cross Tension Test Coupons

Using AA 7075, The average tensile strength for five cross tension experiments was found to be 2.88 kN. This is 15.2% higher than a comparable cross tension average strength of 2.5 kN obtained through spot joining 1.8 mm thick AA5754 to 1.4 mm thick DP980 using similar bit material, by Miles et al. (Miles, 2009) Increased lap strength for the present study may be attributable to material differences and improvements made to bit design. Another possible explanation may be the use of different welding process parameters between the two studies.

Four out of these five cross-tensional specimens exhibited head failures. Each of these specimens were characterized by violent fracture of the bit head, which left the shaft of the bit still attached as shown in Figure 4-66. These results can be explained by cross tension forces being placed directly upon the interface between the bit head and shaft, where bit hardness and microstructure differences exist.

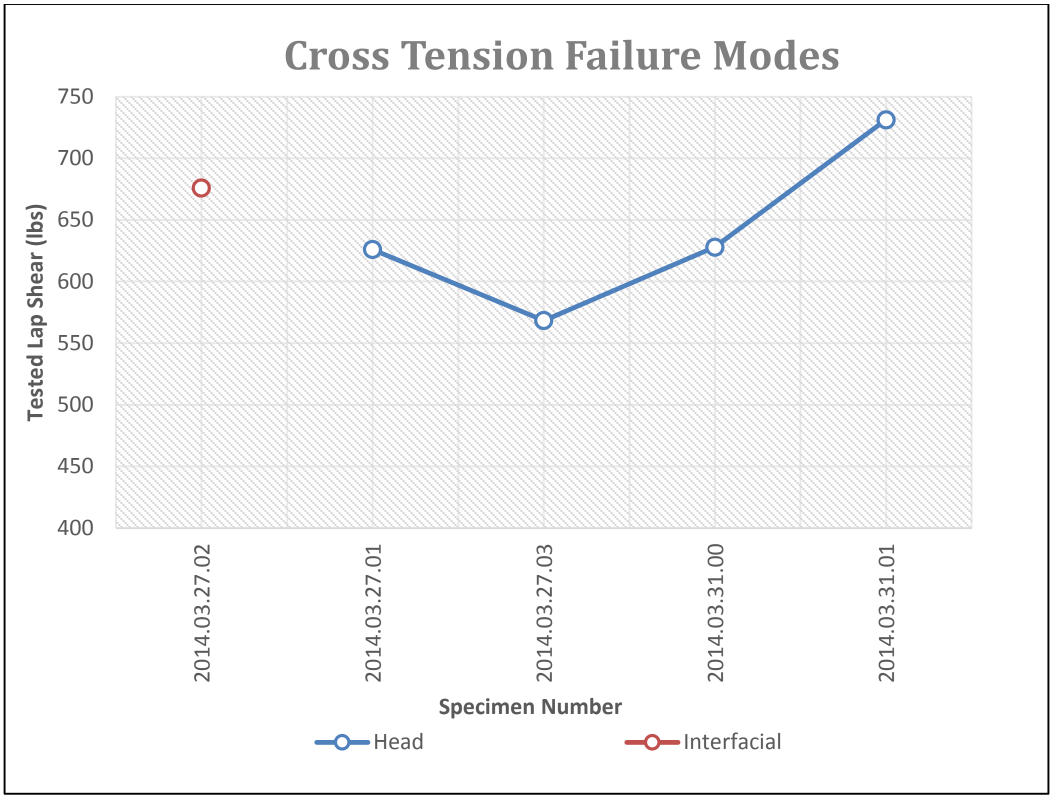


Figure 4-65: Cross Tension Failure Modes and Lap Shear Data

Figure 4-66: Specimen Tested in Cross Tension, Exhibiting Bit Head Failure

4.12 **Computer Simulation**

Efforts were made to simulate the FBJ process using computer software. A computer simulation of the process would be advantageous for gathering information about bit deformation, development of grain structure, and temperature changes throughout the weld cycle. Time required for the “fine-tuning” of optimal bit and process parameters would thus be substantially reduced.

Several broached bits were produced, and welded directly to DP980 using standard weld parameters. No aluminum was used, and the bits had no cutting features (similar to Figure 4-2, but with the bit head broached), in order to closely match the bit and welded surface to be used in the Forge finite element software. Selected specimens were sectioned according to standard procedure, and then mounted, polished and photographed using microscope imaging (Figure 4-67). Computer model settings, materials and other parameters were manipulated to imitate the behavior of the real-life specimen and tool material. Using Forge finite element software, a lagrangian, 2 dimensional approach was taken, ultimately producing a weld with a final cross section similar to the sectioned specimen.

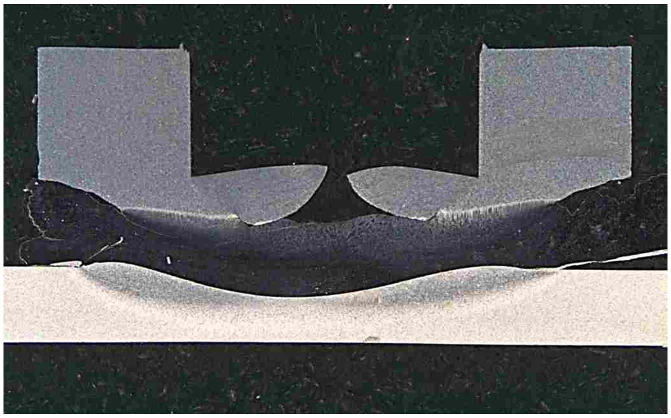


Figure 4-67: Bit with No Cutting Geometry or Chip Wells, Welded without Aluminum

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Friction bit joining is a new innovative process that has a proven ability to join advanced high-strength steels to aluminum alloys. This is done through a combination of low temperature solid-state bonding and ductile deformation of a consumable bit. This is a robust process that can be used to easily join a variety of materials under a variety of conditions. FBJ will find application within the transportation industry as the use of mixed-material structures becomes more popular for reducing weight while maintaining or increasing structural strength and rigidity.

The intent of this study was to understand the influence that processing parameters and machine design characteristics have on the strength and consistency of FBJ welds, and to investigate options for making the process more fit for use within industry. Therefore, the hypothesis that formed the basis for this work are concluded as follows:

1. There is a specific combination of process parameters, bit and machine characteristics that lead to optimal joint properties.

This hypothesis is not rejected, as peak lap shear strengths were obtained through the manipulation of machine parameters, machine configuration, and bit characteristics. Once the relationships between weld strengths and the programmed parameters of Z-axis velocity, RPM and Z-axis command were understood, the optimal joint properties could be maintained. For changes in joined material type, bit material type, bit design, clamp force, machine modification, or other parameters that caused variation in weld strength, it was found that manipulations of programmed controls could re-establish peak weld strengths.

In general, for the standard bit used during this research, it was found that increasing programmed Z-axis velocity lead to greater weld strengths. Average tensile strength also increased as RPM increased, until about 3250 RPM. After this point, average tensile strength was seen to decline sharply. Average lap-shear strength was concluded to increase as depth command increased, then decrease as depth was set beyond -0.175".

For machine parameters and process configurations, it was found that bit hardness must be relatively equal to the hardness of the steel, as ductile movement of bit material away from the bond zone increasingly influences loss in load capacity. Tests with solid bits indicated their superiority in this respect. As a result of microstructural change and bit deformation, hardness values of the bit at the bond zone double, while the bit head remains at the original hardness value.

The production of consumable bits has the potential to be made much cheaper and more cost effective, as shown by slight changes made to move from EDM methodology to broaching methodology, which translated into a huge cost reduction with no change to weld capabilities. Bit cutting features were found to be crucial in the creation of low profile welds and efficient chip removal. Tensile strength was shown to increase with greater bit shaft diameters and thicker, more solid bit heads. Automated application of the process was deemed feasible through successful testing of pneumatic transfer and vibratory sorting mechanisms. Survivability of bit driving mechanisms was determined to be higher as downward force was distributed across larger areas, and driver geometry was demonstrated that removed chips and burrs simultaneously with the weld cycle.

2. Galvanic corrosion of the aluminum/steel joints will reduce joint strength if the joint is unprotected by a coating or by adhesive when subjected to a corrosive environment.

This hypothesis is not rejected. When tested prior to corrosive exposure, FBJ-only specimens had a 7% lower lap shear strength than their hybrid FBJ-adhesive equivalents. After exposure to corrosive conditions, only 47% of the original lap-shear strength existed for the same FBJ-only specimens, while no significant drop in strength was observed for hybrid specimens.

3. Applying adhesive to the joint will not significantly mitigate a drop in joint strength when the joints are subjected to a corrosive environment.

This null hypothesis is rejected. For specimens that included adhesive in the local area of the joint, the weld zone was effectively insulated from corrosive attack by blocking corrosive media entrances to the weld zone. In these specimens, there was virtually no drop in joint strength over the complete course of corrosion testing.

In addition to these conclusions, it was noted that FBJ is a process that can be used to join virtually any material to advanced high-strength steel. The joining of advanced high-strength steel to carbon fiber during this study is representative of this capability, although final joint strength will always be determined by the tensile strength of the weakest material in the specimen.

5.2 **Recommendations**

To further knowledge about the process and continue advancing the science, the current FBJ machine must have some fundamental modifications. First, the FBJ machine spindle must be shortened and machine frame stiffened in order to eliminate uncontrolled movements and weld variation.

Beyond immediate machine modifications, several avenues for improvement and further study were observed. An entire study could be done just on automation… automation of bit delivery, bit loading onto the spindle, and clamping. At the very least, clamping of the materials to be welded should be incorporated into the spindle or the tool holder itself, in order to simplify and accelerate the clamping process. Bit design should trend towards external driving designs and methods, as opposed to the internal pocket style that was common for this work. Bits should be produced using a stamping, forming, or cold-heading process, to reduce costs.

In addition, it is recommended that the use of materials other than AHSS or 4140 bit steel be investigated. For example, the use of titanium bits joined to steel sheet, or titanium bits joined to titanium sheet. Often during this study, material failure was observed before failure of the FBJ element. The use of stronger materials would focus fatigue stress on the FBJ weld itself in such cases. The presence of tiny cracks at the base of the bit head, where a microstructure and hardness transition exists is also a recommend area of focus. These cracks have yet to be controlled or studied at length.

REFERENCES

Abe, Y., T. Kato, and K. Mori. "Self-Piercing Riveting of High Tensile Strength Steel and Aluminium Alloy Sheets using Conventional Rivet and Die." *Journal Material Processing Technology*, 2009: 3914-3922.

Bartczak, B., J. Mucha, and T. Trezepiecı´nski, Stress Distribution in Adhesively Bonded Joints and the Loading Capacity of Hybrid Joints of Car Body Steels for the Automotive Industry, Int. J. Adhesion Adhesives, 2013, 45, p 42–52

Bhagavathi, et al. Design, 32 433-440, 2011 *from TWI corrosion paper, Ref 15*

Busse, S., M. Merklein, K. Roll, M. Zu¨ rn, and H. Schubert, Numerical and Experimental Investigations of an Innovative Clinching Process. Proceedings of the 10th International Conference on Technology of Plasticity (ICTP), Du¨ sseldorf, 2011, p 736–741

Chao, Y.J. “Failure mode of spot welds: interfacial versus pullout,” Sci Technol. Weld. Joi. 8 (2003) 133-137.

David, J.R. Corrosion of aluminum and aluminum alloys. ASM International. Materials Park, 1999.

Gaul, H., G. Weber, in: L.F.M. da Silva, A. Pirondi, A. Öchsner (Eds.) Hybrid adhesive joints, Springer, New York, 2011, pp 1-36.

Groche, P., S. Wohletz, M. Brenneis, C. Pabst, and F. Resch, Joining by Forming—A Review on Joint Mechanisms, Applications and Future Trends, J. Mater. Process. Technol., 2014, 214, p 1062–1093

Hamel, V., J. M. Roelandt, J. N. Gacel, and F. Schmit. "Finite element modeling of clinch forming with automatic remeshing." *Computers and Structures*, 2000: 185-200.

Lai, M., R. Brun, Latest Developments in Sheet Metal Forming Technology and Materials for Automotive Application: The Use of Ultra High Strength Steels at Fiat to Reach Weight Reduction at Sustainable Costs, Key Eng. Mater., 2007, 344, p 1–8

LeBozec, N., A. LeGac, D. Thierry. “Corrosion performance and mechanical properties of joined automotive materials,” Mater. Corros. 63 (2012) 408-415.

Lienert, T.J., W.L. Stellwag, B.B. JR. Grimmett, R.W. Warke 2003. “Friction stir welding studies on mild steel - Process results, microstructures, and mechanical properties are reported,” Weld. J. 82 (2003) 1s - 9s.

Meschut, G., V. Janzen, T. Olfermann. “Innovative and Highly Productive Joining Technologies for Multi-Material Lightweight Car Body Structures” *Journal of Materials Engineering and Performance,* 2014: 1515-1523

Miles, M. P., K. Kohkonen, S. Packer, R. Steel, B. Siemssen, and Y. S. Sato. "Solid State Spot Joining of Sheet Materials using Consumable Bit." *Science and Technology of Welding & Joining*, 2009: 72-77.

Mucha, J., L. Kascak, and E. Spisak, The Experimental Analysis of Forming and Strength of Clinch Riveting Sheet Metal Joint Made of Different Materials, Advances in Mechanical Engineering, Vol 2013,ID848973

Mucha, J., The Numerical Analysis of the Effect of the Joining Process Parameters on Self-Piercing Riveting Using the Solid Rivet, Arch. Civ. Mech. Eng., 2013. doi:10.1016/j.acme.2013.11.002

O’Brien, R. L., *Welding Handbook Eighth Edition: Volume 1 Welding Technology,* American Welding Society, 1991

Osorio, W.R., L.C. Peixoto, L.R. Garcia, A. Garcia. Mater. Corros. 60 (2009) 804-812.

Qiu, R., C. Iwamoto, S. Satonaka. “Interfacial microstructure and strength of steel/aluminum alloy joints welded by resistance spot welding with cover plate,” J. Mater. Proc. Technol. 209 (2009) 4186-4193.

Sarkar, P.P., P. Kumar, M.K. Manna, P.C. Chakraborti. Mater. Lett. 59 (2005) 2488-2491.

Schreiber, A., J.W. Schultze, M.M. Lohrengel, F. Karman, E. Kalman. Electrochim. Acta 51 (2006) 2625-2630.

Standard Practice for Maintaining Constant Relative Humidity by Means of Aqueous solutions, ASTM E104 – 02, 2007

Sun, Y., F. H. Fujii, N. Takaki, Y. Okitsu. “Microstructure and mechanical properties of dissimilar Al alloy/steel joints prepared by a flat spot friction stir welding technique,” Mater. Design 47 (2013) 350-357.

Thomas, W.M., P.L. Threadgill, E.D. Nicholas. “Feasibility of friction stir welding steel,” Sci. Technol. Weld. Joi. 4 (1999) 365-372.

Zhao, Z., G.S. Frankel. Corros. “On the first breakdown in AA7075-T6,” Sci. 49 (2007) 3064-3088.

APPENDICES

APPENDIX A. FBJ WELD RECORDS

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2014.03.10.06	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT	-	4140 21-22 HRC	Not Pulled	Sectioned regular external bit
2014.03.10.05	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 21-22 HRC	Not Pulled	Sectioned externally driven but broached as well
2014.03.10.04	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 21-22 HRC	2115	externally driven but broached as well
2014.03.10.03	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button/Interfacial	4140 21-22 HRC	2181	externally driven but broached as well
2014.03.10.02	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 21-22 HRC	1948	externally driven but broached as well
2014.03.10.01	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 21-22 HRC	2051	externally driven but broached as well
2014.04.24.08	Soft Bit Test sectioning	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	sectioned
2014.04.24.07	Soft Bit Test sectioning	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	sectioned
2014.04.24.06	Soft Bit Test sectioning	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	-	4140 21-22 HRC	Not Pulled	sectioned
2014.04.24.05	Soft Bit Test sectioning	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	-	4140 21-22 HRC	Not Pulled	Poor clamping one side came up
2014.04.24.04	Soft Bit Test sectioning	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	-	4140 21-22 HRC	Not Pulled	sectioned
2014.04.24.03	Soft Bit Test sectioning	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	-	4140 30-32 HRC	Not Pulled	sectioned
2014.04.24.02	Soft Bit Test sectioning	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	-	4140 30-32 HRC	Not Pulled	Poor clamping one side came up
2014.03.31.01	Cross Tension 1	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	75 lbs.	50 x 50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 30-32 HRC	731.3	No adhesive
2014.03.31.00	Cross Tension 1	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	75 lbs.	50 x 50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 30-32 HRC	627.9	No adhesive
2014.03.27.07	Cross Tension 1	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	75 lbs.	50 x 50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 30-32 HRC	338.3	No adhesive, Operator error
2014.03.27.06	Cross Tension 1	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	75 lbs.	50 x 50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 30-32 HRC	671.9	With adhesive, no beads, cured 30 min at 170 C, FBJ fail at 670

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2014.03.27.05	Cross Tension 1	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	75 lbs.	50 x 50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 30-32 HRC	695.3	With adhesive, no beads, cured 30 min at 170 C FBJ fail at 730
2014.03.27.04	Cross Tension 1	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	75 lbs.	50 x 50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 30-32 HRC	874.9	With adhesive, no beads, cured 30 min at 170 C FBJ fail at 1044
2014.03.27.03	Cross Tension 1	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	75 lbs.	50 x 50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 30-32 HRC	568.3	No adhesive, measured shallow bit depth
2014.03.27.02	Cross Tension 1	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	75 lbs.	50 x 50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	676	No adhesive
2014.03.27.01	Cross Tension 1	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	75 lbs.	50 x 50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 30-32 HRC	626	No adhesive
2014.03.26.06	Replacement Specimens, ORNL	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	With adhesive, no beads, cured 30 min at 170 C
2014.03.26.05	Replacement Specimens, ORNL	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	With adhesive, no beads, cured 30 min at 170 C
2014.03.26.04	Replacement Specimens, ORNL	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	With adhesive, no beads, cured 30 min at 170 C
2014.03.26.03	Replacement Specimens, ORNL	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	
2014.03.26.02	Replacement Specimens, ORNL	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	
2014.03.26.01	Replacement Specimens, ORNL	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	
2014.03.16.05	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT1	-	4140 30-32 HRC	Not Pulled	External Head w/FBJTORX5 and Driver, Sectioned
2014.03.16.04	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT1	Interfacial	4140 30-32 HRC	2115	External Head w/FBJTORX5 and Driver
2014.03.16.03	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT1	Interfacial/ Button	4140 30-32 HRC	2181	External Head w/FBJTORX5 and Driver
2014.03.16.02	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT1	Interfacial	4140 30-32 HRC	1948	External Head w/FBJTORX5 and Driver
2014.03.16.01	Cavity Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT1	Interfacial	4140 30-32 HRC	2051	External Head w/FBJTORX5 and Driver
2014.03.12.05	External Torx Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT1	Interfacial	4140 30-32 HRC	1740	New External Head and Driver

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2014.03.12.04	External Torx Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT1	Interfacial	4140 30-32 HRC	2132	New External Head and Driver
2014.03.12.03	External Torx Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT1	Interfacial	4140 30-32 HRC	1951	New External Head and Driver
2014.03.12.02	External Torx Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT1	Interfacial	4140 30-32 HRC	2081	New External Head and Driver
2014.03.12.01	External Torx Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJEXT1	Interfacial	4140 30-32 HRC	2036	New External Head and Driver
2014.02.26.17	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4452	500 micron beads, cured 30 min @ 338 deg F
2014.02.26.16	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4479	500 micron beads, cured 30 min @ 338 deg F
2014.02.26.15	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4452	500 micron beads, cured 30 min @ 338 deg F
2014.02.26.14	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4463	498 micron beads, cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM. Video in Dropbox.
2014.02.26.13	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4460	499 micron beads, cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.26.12	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4497	500 micron beads, cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.26.11	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4646	300 micron beads, cured 30 min @ 338 deg F
2014.02.26.10	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4608	300 micron beads, cured 30 min @ 338 deg F
2014.02.26.09	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4536	300 micron beads, cured 30 min @ 338 deg F
2014.02.26.08	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4446	298 micron beads, cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.26.07	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	4528	299 micron beads, cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.26.06	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4624	300 micron beads, cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.26.05	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4140 30-32 HRC	4518	no beads cured 30 min @ 338 deg F

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2014.02.26.04	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4409	no beads cured 30 min @ 338 deg F
2014.02.26.03	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	4251	no beads cured 30 min @ 338 deg F
2014.02.26.02	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	4426	no beads cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.26.01	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	4514	no beads cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.26.00	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	800 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	3019	no beads cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.25.06	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4140 30-32 HRC	3113	no beads cured 30 min @ 338 deg F
2014.02.25.05	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button/Aluminum	4140 30-32 HRC	3064	no beads cured 30 min @ 338 deg F
2014.02.25.04	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4140 30-32 HRC	2322	no beads cured 30 min @ 338 deg F . Video in Dropbox.
2014.02.25.03	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	1274	no beads cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.25.02	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	1950	no beads cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.25.01	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	2017	no beads cured 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.19.16	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	3980	500 micron beads, 30 min @ 338 deg F
2014.02.19.15	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button/Aluminum	4140 30-32 HRC	3558	500 micron beads, 30 min @ 338 deg F
2014.02.19.14	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	2893	500 micron beads, 30 min @ 338 deg F. Video in Dropbox.
2014.02.19.13	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	3352	498 micron beads, 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.19.12	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	3592	499 micron beads, 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.
2014.02.19.11	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	3787	500 micron beads, 30 min @ 338 deg F. FBJ to be removed with Plunge EDM.

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2014.02.19.10	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Test piece, Clamping felt like less. 500 micron beads, 30 min @338 deg F
2014.02.19.09	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	3059	300 micron beads, 30 min @338 deg F
2014.02.19.08	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial/ Button	4140 30-32 HRC	3091	300 micron beads, 30 min @338 deg F
2014.02.19.07	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	3852	300 micron beads, 30 min @338 deg F. Video in Dropbox.
2014.02.19.06	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4140 30-32 HRC	2501	298 micron beads, 30 min @338 deg F. FBJ to be removed with Plunge EDM.
2014.02.19.05	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button/Aluminum	4140 30-32 HRC	3209	299 micron beads, 30 min @338 deg F. FBJ to be removed with Plunge EDM.
2014.02.19.04	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4140 30-32 HRC	4142	300 micron beads, 30 min @338 deg F. FBJ to be removed with Plunge EDM.
2014.02.19.03	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	850 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	2093	50mm overlap, no beads, FBJ only
2014.02.19.02	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	850 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	2203	50mm overlap, no beads, FBJ only
2014.02.19.01	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	850 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	2507	50mm overlap, no beads, FBJ only
2014.02.19.00	Bond Area Measurements 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	850 lbs.	50 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Warm-up
2014.02.07.06	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	2895	FBJ and Adhesive, cured 30 @ 166-170, 55 @ 180-185.
2014.02.07.05	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4140 30-32 HRC	2588	FBJ and Adhesive, cured 30 @ 166-170, 55 @ 180-185.
2014.02.07.04	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	3313	FBJ and Adhesive, cured 30 @ 166-170, 55 @ 180-185.
2014.02.07.03	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4140 30-32 HRC	2659	FBJ and Adhesive, cured 30 @ 166-170, 55 @ 180-185.
2014.02.07.02	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4140 30-32 HRC	2522	FBJ and Adhesive, cured 30 @ 166-170, 55 @ 180-185.
2014.01.28.05	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	1961	FBJ and Adhesive, cured 30 @ 166-170, 30 @ 180-185. FBJ to be removed with Plunge EDM.

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2014.01.28.04	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	3420	FBJ and Adhesive, cured 30 @ 166-170, 30 @ 180-185. FBJ to be removed with Plunge EDM.
2014.01.28.03	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	1851	FBJ and Adhesive, cured 30 @ 166-170, 30 @ 180-185. FBJ to be removed with Plunge EDM.
2014.01.28.02	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	2028	FBJ and Adhesive, cured 30 @ 166-170, 30 @ 180-185. FBJ to be removed with Plunge EDM.
2014.01.28.01	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	1542	FBJ and Adhesive, cured 30 @ 166-170, 30 @ 180-185. FBJ to be removed with Plunge EDM.
2014.01.28.00	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	-	4140 30-32 HRC	Not Pulled	Machine Warm-up Specimen
2014.01.23.AD	Bond Area Measurements	-	-	-	-	-	-	-	-	-	Unknown	-	DP 980	0.045"	7075 Al	0.062"	-	-	-	-	3894	Adhesive only, no beads. c-clamped for curing.
2014.01.23.AC	Bond Area Measurements	-	-	-	-	-	-	-	-	-	Unknown	-	DP 980	0.045"	5754 Al	0.062"	-	-	-	-	1704	Adhesive only, no beads. c-clamped for curing. Did not recognize use of 5754
2014.01.23.AB	Bond Area Measurements	-	-	-	-	-	-	-	-	-	Unknown	-	DP 980	0.045"	5754 Al	0.062"	-	-	-	-	1804	Adhesive only, no beads. c-clamped for curing. Did not recognize use of 5754
2014.01.23.AA	Bond Area Measurements	-	-	-	-	-	-	-	-	-	Unknown	-	DP 980	0.045"	7075 Al	0.062"	-	-	-	-	4616	Adhesive only, no beads. c-clamped for curing
2014.01.16.01	Computer Simulation	2000	8.88	-0.108	0	-	-	-	-	15 min	2000 lbs.	25 mm	DP 980	0.045"	-	-	TORXPROF	FBJTORX5	-	4143 30-32 HRC	Not Pulled	Aluminum Delete for calibrating computer model
2014.01.16.00	Computer Simulation	2500	8.88	-0.108	0	-	-	-	-	15 min	2000 lbs.	25 mm	DP 980	0.045"	-	-	TORXPROF	FBJTORX5	-	4143 30-32 HRC	Not Pulled	Aluminum Delete for calibrating computer model
2014.01.15.03	Machine Check	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXPROF	FBJTORX5	Hand Failure	4143 30-32 HRC	Not Pulled	3700 max z force, machine stopped, no penetration
2014.01.15.02	Machine Check	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	FBJTORX5	-	4143 30-32 HRC	Not Pulled	1700 max z force
2014.01.15.01	Computer Simulation	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXPROF	FBJTORX5	-	4143 30-32 HRC	Not Pulled	For Calibrating Computer Model
2014.01.15.00	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4143 30-32 HRC	1042	For Fracture Stress Tables. Coated, FBJ only
2014.01.14.05	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4143 30-32 HRC	1854	Questionable, For Fracture Stress Tables. Coated, FBJ only
2014.01.14.04	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4143 30-32 HRC	Hand Failure	Questionable, For Fracture Stress Tables. Coated, FBJ only, poor penetration
2014.01.14.03	Computer Simulation	2000	8.88	0.083	0	2500	8.875	0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXPROF	FBJTORX5	-	4143 30-32 HRC	Not Pulled	For calibrating computer model

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2014.01.14.02	Bond Area Measurements	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4143 30-32 HRC	2325	confirmed parameters, For Fracture Stress Tables. Coated, FBJ only
2014.01.14.01	Bond Area Measurements	2000	8.88	-0.062	0	2500	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4143 30-32 HRC	Not Pulled	unusable because of rpm, For Fracture Stress Tables. Coated, FBJ only
2014.01.14.00	Bond Area Measurements	1500	8.88	-0.062	0	2500	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4143 30-32 HRC	Not Pulled	unusable because of rpm, For Fracture Stress Tables. Coated, FBJ only
2013.12.27.03	External Bit Visual Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	8 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	EXTBIT	EXTBIT	-	4143 30-32 HRC	Not Pulled	
2013.12.27.02	External Bit Visual Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	8 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	EXTBIT	EXTBIT	-	4143 30-32 HRC	Not Pulled	
2013.12.19.02	Bond Area Measurements	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4143 30-32 HRC	3070	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-185
2013.12.19.01	Bond Area Measurements	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4142 30-32 HRC	3015	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-185
2013.12.19.00	Bond Area Measurements	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4141 30-32 HRC	3093	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-185
2013.11.22.07	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	600 lbs.	25 mm	DP 980	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	1215	
2013.11.22.06	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	800 lbs.	25 mm	DP 980	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	1283	
2013.11.22.05	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	1000 lbs.	25 mm	DP 980	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	1293	
2013.11.22.04	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	1200 lbs.	25 mm	DP 980	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	1395	
2013.11.22.03	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	1400 lbs.	25 mm	DP 980	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	1397	
2013.11.22.02	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	1600 lbs.	25 mm	DP 980	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	1403	
2013.11.22.01	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	1800 lbs.	25 mm	DP 980	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	1237	
2013.11.22.00	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	1342	
2013.11.19.AF	Adhesive Corrosion test	-	-	-	0	-	-	-	0	-	-	-	DP 980 Coated	0.038"	7075 Al	0.062"	-	-	-	-	1462	Coated, Adhesive only

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.11.19.AE	Adhesive Corrosion test	-	-	-	0	-	-	-	0	-	-	-	DP 980 Coated	0.038"	7075 Al	0.062"	-	-	-	-	1305	Coated, Adhesive only
2013.11.19.AD	Adhesive Corrosion test	-	-	-	0	-	-	-	0	-	-	-	DP 980 Coated	0.038"	7075 Al	0.062"	-	-	-	-	2391	Coated, Adhesive only
2013.11.19.AC	Adhesive Corrosion test	-	-	-	0	-	-	-	0	-	-	-	DP 980	0.045"	7075 Al	0.062"	-	-	-	-	3094	Bare, Adhesive only
2013.11.19.AB	Adhesive Corrosion test	-	-	-	0	-	-	-	0	-	-	-	DP 980	0.045"	7075 Al	0.062"	-	-	-	-	2702	Bare, Adhesive only
2013.11.19.AA	Adhesive Corrosion test	-	-	-	0	-	-	-	0	-	-	-	DP 980	0.045"	7075 Al	0.062"	-	-	-	-	2859	Bare, Adhesive only
2013.11.19.16	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	600 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	238	Will redo to see why irregularity
2013.11.19.15	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	800 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4141 30-32 HRC	1161	no notes
2013.11.19.14	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	1000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	669	Will redo to see why irregularity
2013.11.19.13	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	1200 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	1608	no notes
2013.11.19.12	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	1400 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4141 30-32 HRC	1676	no notes
2013.11.19.11	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	1600 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	257	Will redo to see why irregularity
2013.11.19.10	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	1800 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 30-32 HRC	1400	no notes
2013.11.19.09	Clamp Force Test	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4141 30-32 HRC	1183	no notes
2013.11.19.08	Adhesive Corrosion test	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button Pull	4140 30-32 HRC	2059	Coated, FBJ & Adhesive
2013.11.19.07	Adhesive Corrosion test	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button Pull	4140 30-32 HRC	2439	Coated, FBJ & Adhesive
2013.11.19.06	Adhesive Corrosion test	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	600 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	1646	Coated, FBJ & Adhesive, z command failure, bit did not penetrate coating
2013.11.19.05	Adhesive Corrosion test	2500	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	3942	Bare, FBJ & Adhesive
2013.11.19.04	Adhesive Corrosion test	2500	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	3136	Bare, FBJ & Adhesive
2013.11.19.03	Adhesive Corrosion test	2500	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 30-32 HRC	3232	Bare, FBJ & Adhesive

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.11.05.44	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-185
2013.11.05.43	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-185
2013.11.05.42	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-185
2013.11.05.41	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-185
2013.11.05.40	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-185
2013.11.05.39	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-185
2013.11.05.38	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-186
2013.11.05.37	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-187
2013.11.05.36	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-188
2013.11.05.35	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-189
2013.11.05.34	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-190
2013.11.05.33	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-191
2013.11.05.32	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-192
2013.11.05.31	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-193
2013.11.05.30	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-194
2013.11.05.29	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-195
2013.11.05.28	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-196

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.11.05.27	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-197
2013.11.05.26	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-198
2013.11.05.25	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-199
2013.11.05.24	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-200
2013.11.05.23	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-201
2013.11.05.22	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-202
2013.11.05.21	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-203
2013.11.05.20	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-204
2013.11.05.19	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-205
2013.11.05.18	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-206
2013.11.05.17	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-207
2013.11.05.16	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-208
2013.11.05.15	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-209
2013.11.05.14	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-210
2013.11.05.13	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-211
2013.11.05.12	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-212
2013.11.05.11	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-213

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.11.05.10	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-214
2013.11.05.09	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-215
2013.11.05.08	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-216
2013.11.05.07	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-217
2013.11.05.06	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-218
2013.11.05.05	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-219
2013.11.05.04	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-220
2013.11.05.03	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-221
2013.11.05.02	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-222
2013.11.05.01	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-223
2013.11.05.00	Corrosion Test Samples 2	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980, with Adhesive, cured 30 minutes at 166-170 C, then 30 min @ 180-224
2013.10.31.44	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.43	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	2330	Un-coated DP980 1
2013.10.31.42	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.41	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.40	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.39	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.10.31.38	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.37	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.36	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	1957	Un-coated DP980 1
2013.10.31.35	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.34	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.33	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.32	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.31	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.30	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.29	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.28	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.27	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.26	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.25	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.24	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.23	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.22	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.10.31.21	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	2067	Un-coated DP980 1
2013.10.31.20	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	1910	Un-coated DP980 1, Aubrey
2013.10.31.19	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.18	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.17	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.16	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.15	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.14	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.13	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.12	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.11	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.10	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.09	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.08	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.07	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.06	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.05	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	2240	Un-coated DP980 1

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.10.31.04	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.03	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.02	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.01	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.31.00	Corrosion Test Samples	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	-	4140 30-32 HRC	Not Pulled	Un-coated DP980 1
2013.10.30.08	Optimal Z Plunge, Yong Based	2000	8.88	-0.062	0	2750	6.106	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	1861	Corrosion test prep, using Yongs settings except for Z command
2013.10.30.07	Optimal Z Plunge, Yong Based	2000	8.88	-0.062	0	2750	6.106	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Aluminum	4140 30-32 HRC	1885	Corrosion test prep, using Yongs settings except for Z command
2013.10.30.06	Optimal Z Plunge, Yong Based	2000	8.88	-0.062	0	2750	6.106	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button	4140 30-32 HRC	2089	Corrosion test prep, using Yongs settings except for Z command
2013.10.30.05	Optimal Z Plunge, Yong Based	2000	8.88	-0.062	0	2750	6.106	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	1956	Corrosion test prep, using Yongs settings except for Z command
2013.10.30.04	Optimal Z Plunge, Yong Based	2000	8.88	-0.062	0	2750	6.106	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	1807	Corrosion test prep, using Yongs settings except for Z command
2013.10.30.03	Optimal Z Plunge, Yong Based	2000	8.88	-0.062	0	2750	6.106	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	1923	Corrosion test prep, using Yongs settings except for Z command
2013.10.30.02	Optimal Z Plunge, Yong Based	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 30-32 HRC	2145	Corrosion test prep, using Yongs settings except for Z command
2013.10.30.01	Optimal Z Plunge, Yong Based	2000	8.88	-0.062	0	2750	6.106	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button Pull	4140 30-32 HRC	2283	Corrosion test prep, using Yongs settings except for Z command
2013.10.24.27	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	12.43	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2234	
2013.10.24.26	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	12.43	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2270	
2013.10.24.25	Nugget Failure Seek 2	2000	8.88	-0.062	0	3300	10.66	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2030	
2013.10.24.24	Nugget Failure Seek 2	2000	8.88	-0.062	0	3500	10.3	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1837	

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.10.24.23	Nugget Failure Seek 2	2000	8.88	-0.062	0	3500	10.3	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1641	
2013.10.24.22	Nugget Failure Seek 2	2000	8.88	-0.062	0	3300	10.3	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial/ Button	4140 28-30 HRC	2368	
2013.10.24.21	Nugget Failure Seek 2	2000	8.88	-0.062	0	3150	10.3	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1599	
2013.10.24.20	Nugget Failure Seek 2	2000	8.88	-0.062	0	2500	8.875	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2160	
2013.10.24.19	Nugget Failure Seek 2	2000	8.88	-0.062	0	3300	8.875	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1879	
2013.10.24.18	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	8.875	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2058	
2013.10.24.17	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	11.36	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Button	4140 28-30 HRC	2203	
2013.10.24.16	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	12.43	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Button	4140 28-30 HRC	2283	
2013.10.24.15	Nugget Failure Seek 2	2000	8.88	-0.062	0	2750	8.875	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial/ Button	4140 28-30 HRC	2270	
2013.10.24.14	Nugget Failure Seek 2	2000	8.88	-0.062	0	3500	8.875	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1987	
2013.10.24.13	Nugget Failure Seek 2	2000	8.88	-0.062	0	3250	8.875	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Weld/Button	4140 28-30 HRC	2271	
2013.10.24.12	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	10.65	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial/ Button	4140 28-30 HRC	2373	
2013.10.24.11	Nugget Failure Seek 2	2000	8.88	-0.062	0	2750	10.65	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	2455	
2013.10.24.10	Nugget Failure Seek 2	2000	8.88	-0.062	0	2750	12.43	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial/ Button	4140 28-30 HRC	2307	
2013.10.24.09	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	12.43	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Button	4140 28-30 HRC	2333	
2013.10.24.08	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	12.43	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head/Interfacial	4140 28-30 HRC	2203	
2013.10.24.07	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	12.43	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head/Interfacial	4140 28-30 HRC	2201	

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.10.24.06	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	12.43	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head/Interfacial	4140 28-30 HRC	2028	
2013.10.24.05	Nugget Failure Seek 2	2000	8.88	-0.062	0	2750	12.43	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2196	
2013.10.24.04	Nugget Failure Seek 2	2000	8.88	-0.062	0	2750	12.43	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head/Interfacial	4140 28-30 HRC	2389	
2013.10.24.03	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	10.65	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head/Interfacial	4140 28-30 HRC	2281	
2013.10.24.02	Nugget Failure Seek 2	2000	8.88	-0.062	0	3000	10.65	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head/Interfacial	4140 28-30 HRC	2160	
2013.10.24.01	Nugget Failure Seek 2	2000	8.88	-0.062	0	2750	10.65	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head/Button	4140 28-30 HRC	2380	
2013.10.24.00	Nugget Failure Seek 2	2000	8.88	-0.062	0	2750	10.65	-0.175	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head/Interfacial	4140 28-30 HRC	2252	
2013.10.11.07	Galvanized Button Pull Seek	2000	8.88	-0.1	0	2750	6.816	-0.21	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Head/Interfacial	4140 28-30 HRC	2279	According to Yongs parameters: 6.75 in/min, Max Capture 2636
2013.10.11.06	Galvanized Button Pull Seek	2000	8.88	-0.1	0	2750	6.816	-0.2	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Head/Interfacial	4140 28-30 HRC	2150	According to Yongs parameters: 6.75 in/min, Max Capture 3127
2013.10.11.05	Galvanized Button Pull Seek	2000	8.88	-0.1	0	2750	6.816	-0.2	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1993	According to Yongs parameters: 6.75 in/min, Max Capture 2846
2013.10.11.04	Galvanized Button Pull Seek	2000	8.88	-0.1	0	2750	6.816	-0.19	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Head Failure	4140 28-30 HRC	1907	According to Yongs parameters: 6.75 in/min, Max Capture 2602, Same effect as #00 pushed driver up.
2013.10.11.03	Galvanized Button Pull Seek	2000	8.88	-0.1	0	2750	6.816	-0.18	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Head Failure	4140 28-30 HRC	2315	According to Yongs parameters: 6.75 in/min, Max Capture 3009
2013.10.11.02	Galvanized Button Pull Seek	2000	8.88	-0.1	0	2750	6.816	-0.18	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	2287	According to Yongs parameters: 6.75 in/min, Max Capture 3191
2013.10.11.01	Galvanized Button Pull Seek	2000	8.88	-0.1	0	2750	6.816	-0.18	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	2109	According to Yongs parameters: 6.75 in/min, Reset Driver
2013.10.11.00	Galvanized Button Pull Seek	2000	8.88	-0.1	0	2750	6.816	-0.18	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2236	According to Yongs parameters: 6.75 in/min, driver pushed out of position
2013.10.04.13	Galvanized DP980	2000	8.88	-0.062	0	3800	6.248	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	2087	Decreased velocity, increased RPM 3rd time Max capture 2640
2013.10.04.12	Galvanized DP980	2000	8.88	-0.062	0	3800	6.248	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1902	Decreased velocity, increased RPM 3rd time Max capture 2545

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.10.04.11	Galvanized DP980	2000	8.88	-0.062	0	3800	6.248	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1914	Decreased velocity, increased RPM 3rd time
2013.10.04.10	Galvanized DP980	2000	8.88	-0.062	0	3475	6.248	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1660	Decreased velocity, increased RPM again, Max capture 2600, rough dp980
2013.10.04.09	Galvanized DP980	2000	8.88	-0.062	0	3475	6.248	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1980	Decreased velocity, increased RPM again, Max capture 3116
2013.10.04.08	Galvanized DP980	2000	8.88	-0.062	0	3475	6.248	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	2107	Decreased velocity, increased RPM again, Max capture 3037
2013.10.04.07	Galvanized DP980	2000	8.88	-0.062	0	3150	6.248	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	960	Decreased velocity, increased RPM, Max capture less than 3000
2013.10.04.06	Galvanized DP980	2000	8.88	-0.062	0	3150	6.248	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	2138	Decreased velocity, increased RPM, Max capture less than 3000
2013.10.04.05	Galvanized DP980	2000	8.88	-0.062	0	3150	6.248	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1878	Decreased velocity, increased RPM, Max capture less than 3000
2013.10.04.04	Galvanized DP980	2000	8.88	-0.062	0	2500	3.55	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial/ Button	4140 28-30 HRC	2154	Decreased Velocity. 3.5 in/min
2013.10.04.03	Galvanized DP980	2000	8.88	-0.062	0	2500	3.55	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	731	Decreased Velocity. 3.5 in/min, reset driver, 2312 max capture
2013.10.04.02	Galvanized DP980	2000	8.88	-0.062	0	2500	3.55	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1917	3.5 in/min, driver problems pushed up into magnet, 2427 max capture
2013.10.03.08	Galvanized DP980	2000	8.88	-0.1	1000	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Hand Failure	4140 28-30 HRC	0	Dwell, 1st stage, increased 1st stage Z command
2013.10.03.07	Galvanized DP980	2000	8.88	-0.062	1000	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Hand Failure	4140 28-30 HRC	0	Dwell time on 1st stage
2013.10.03.06	Galvanized DP980	2000	8.88	-0.062	0	2500	8.875	-0.17	1000	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1226	Dwell time on 2nd stage
2013.10.03.06	Galvanized DP980	2000	8.88	-0.062	0	2500	8.875	-0.17	1000	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1226	Dwell time
2013.10.03.05	Galvanized DP980	2000	8.88	-0.062	0	2500	8.875	-0.17	100	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1300	Dwell time on 2nd stage
2013.10.03.04	Galvanized DP980	2000	8.88	-0.062	0	2500	8.875	-0.17	10	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Hand Failure	4140 28-30 HRC	0	Dwell time on 2nd stage
2013.10.03.03	Galvanized DP980	2000	8.88	-0.062	5	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Hand Failure	4140 28-30 HRC	0	Dwell time 1st stage

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.10.03.02	Galvanized DP980	2000	8.88	-0.062	0	3800	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	2337	High RPM
2013.10.03.01	Galvanized DP980	2000	8.88	-0.062	0	3500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	976	Increased 2nd RPM
2013.10.03.00	Galvanized DP980	2000	8.88	-0.062	0	3000	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980 Coated	0.038"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Hand Failure	4140 28-30 HRC	0	Increased 2nd RPM
2013.09.17.07	Nugget Failure Seek	2000	8.88	-0.062	0	2500	10.65	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Button	4140 28-30 HRC	2271	
2013.09.17.06	Nugget Failure Seek	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Button	4140 28-30 HRC	2285	
2013.09.17.05	Nugget Failure Seek	2000	8.88	-0.062	0	2500	10.65	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Button	4140 28-30 HRC	2209	
2013.09.17.04	Nugget Failure Seek	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	2303	
2013.09.17.03	Nugget Failure Seek	2000	8.88	-0.062	0	2500	10.65	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Button	4140 28-30 HRC	2156	
2013.09.17.02	Nugget Failure Seek	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Button	4140 28-30 HRC	2317	
2013.09.17.01	Nugget Failure Seek	2000	8.88	-0.062	0	2500	10.65	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	2318	
2013.09.17.00	Nugget Failure Seek	2000	8.88	-0.062	0	2750	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Button	4140 28-30 HRC	2416	
2013.09.13.06	Nugget Failure Seek	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Button	4140 28-30 HRC	2126	
2013.09.13.05	Nugget Failure Seek	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Button	4140 28-30 HRC	2247	
2013.09.13.03	Nugget Failure Seek	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2113	
2013.09.13.02	Nugget Failure Seek	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	2290	
2013.09.13.01	Nugget Failure Seek	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2358	
2013.09.13.00	Nugget Failure Seek	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Interfacial	4140 28-30 HRC	1996	tool put in

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.08.09.05	Reverse 3rd Z-command Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTRX5	Head	4140 28-30 HRC	1860	3rd Z-command -0.55
2013.08.09.04	Reverse 3rd Z-command Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTRX5	Interfacial	4140 28-30 HRC	2051	3rd Z-command -0.55
2013.08.09.03	Reverse 3rd Z-command Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTRX5	Interfacial	4140 28-30 HRC	2217	3rd Z-command -0.55, didn't appear to have cut as deep (the teeth)
2013.08.09.02	Reverse 3rd Z-command Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTRX5	Head	4140 28-30 HRC	2078	3rd Z-command -0.55
2013.08.09.01	Reverse 3rd Z-command Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTRX5	Head	4140 28-30 HRC	1843	3rd Z-command -0.55
2013.08.09.00	Reverse 3rd Z-command Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTRX5	Interfacial	4140 28-30 HRC	1608	3rd Z-command -0.55 Tool with cutter teeth, put in, Instron slipped at first
2013.07.31.04	Capless driver	2000	8.88	-0.062	0	2500	8.875	-0.15	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Not Pulled	4140 28-30 HRC	Not Pulled	The bit went in askew but was stopped before welding to the steal.
2013.07.31.04	Capless test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTRX5	Not pulled	4140 28-30 HRC	Not Pulled	The bit was placed on the torx driver without a cap. The set up was too unstable and the bit ground into the aluminum sideways. No permanent damage done.
2013.07.30.06	Sectioning at Different depths	2000	8.88	-0.062	0	2500	8.875	-0.15	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	no notes
2013.07.30.05	Sectioning at Different depths	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Third Z command -0.155
2013.07.30.04	Sectioning at Different depths	2000	8.88	-0.062	0	2500	8.875	-0.15	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Aluminum wasn't clamped to steel properly, redo as 07.30.06
2013.07.30.03	Sectioning at Different depths	2000	8.88	-0.062	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	no notes
2013.07.30.02	Sectioning at Different depths	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	no notes
2013.07.30.01	Sectioning at Different depths	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	no notes
2013.07.30.00	Sectioning at Different depths	2000	8.88	-0.062	0	2500	8.875	-0.16	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	no notes
2013.07.20.03	Nugget Failure Seek	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Button Pull	4140 28-30 HRC	2266	no notes

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.07.20.02	Nugget Failure Seek	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial/ Head	4140 28-30 HRC	1661	no notes
2013.07.20.01	Nugget Failure Seek	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial/ Head	4140 28-30 HRC	2203	Cap with no teeth
2013.07.20.00	Nugget Failure Seek	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head	4140 28-30 HRC	1710	Tool was replaced, Cap with no teeth
2013.07.19.14	.075 head test with cutter cap	2000	8.88	-0.062	0	2500	8.875	-0.16	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTORX5	Not Pulled	4140 28-30 HRC	Not Pulled	Cutter Cap with Shallow head bit, 3rd Z command -0.145, Aluminum flashing removed
2013.07.19.13	.075 head test with cutter cap	2000	8.88	-0.062	0	2500	8.875	-0.16	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTORX5	Not Pulled	4140 28-30 HRC	Not Pulled	Cutter Cap with Shallow head bit, 3rd Z command -0.145, Aluminum flashing removed
2013.07.19.12	.075 head test with cutter cap	2000	8.88	-0.062	0	2500	8.875	-0.16	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTORX5	Not Pulled	4140 28-30 HRC	Not Pulled	Cutter Cap with Shallow head bit
2013.07.19.11	.075 head test with cutter cap	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTORX5	Not Pulled	4140 28-30 HRC	Not Pulled	Cutter Cap with Shallow head bit
2013.07.19.10	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 28-30 HRC	2136	0.100 head, 0.075 broach
2013.07.19.09	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button Pull	4140 28-30 HRC	2275	0.100 head, 0.075 broach
2013.07.19.08	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button Pull	4140 28-30 HRC	2270	0.100 head, 0.075 broach
2013.07.19.07	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button Pull	4140 28-30 HRC	2307	0.100 head, 0.075 broach
2013.07.19.06	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Button Pull	4140 28-30 HRC	2287	0.100 head, 0.075 broach
2013.07.19.05	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTORX5	Button Pull	4140 28-30 HRC	2244	0.075 head, 0.075 broach
2013.07.19.04	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTORX5	Button Pull	4140 28-30 HRC	2211	0.075 head, 0.075 broach
2013.07.19.03	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTORX5	Interfacial	4140 28-30 HRC	2223	0.075 head, 0.075 broach
2013.07.19.02	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTORX5	Button Pull	4140 28-30 HRC	2345	0.075 head, 0.075 broach
2013.07.19.01	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTORX5	Interfacial	4140 28-30 HRC	2275	0.075 head, 0.075 broach

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.07.19.00	.075 head test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	FBJBIT15	FBJTORX5	Button Pull	4140 28-30 HRC	2195	0.075 head, 0.075 broach
2013.07.17.06	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1343	secondary weld
2013.07.17.05	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1297	secondary weld
2013.07.17.04	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Head	4140 28-30 HRC	1328	secondary weld
2013.07.17.03	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1430	secondary weld
2013.07.17.02	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Head	4140 28-30 HRC	1283	Tool intentionally removed and replaced prior to weld
2013.07.17.01	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1311	Tool intentionally removed and replaced prior to weld
2013.07.17.00	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1290	Tool intentionally removed and replaced prior to weld
2013.07.12.10	Pilot Hole reduction test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 28-30 HRC	2306	no notes
2013.07.12.09	Pilot Hole reduction test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 28-30 HRC	2144	no notes
2013.07.12.08	Pilot Hole reduction test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Interfacial	4140 28-30 HRC	2162	no notes
2013.07.12.07	Pilot Hole reduction test	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	FBJTORX5	Head	4140 28-30 HRC	2161	Accidently ran second z command -.18 and tool was removed and replaced
2013.07.12.04	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1170	Tool intentionally removed and replaced prior to weld
2013.07.12.03	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Head	4140 28-30 HRC	1254	secondary weld
2013.07.12.02	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1297	secondary weld
2013.07.12.01	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 2	Interfacial	4140 28-30 HRC	1373	Wrong head profile used, consequences unknown
2013.07.12.00	Tool Compression Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1187	Tool intentionally removed and replaced prior to weld

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.07.09.00	FBJ Demonstration	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1390	no notes
2013.06.27.02	Cutter Cap Visual Test	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 2	Not Pulled	4140 28-30 HRC	Not Pulled	spiral aluminum chip was still attached
2013.06.27.01	Cutter Cap Visual Test	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 2	Not Pulled	4140 28-30 HRC	Not Pulled	spiral aluminum chip was still attached
2013.06.27.00	Cutter Cap Visual Test	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 2	Not Pulled	4140 28-30 HRC	Not Pulled	Not much aluminum removed
2013.06.25.01	Aluminum delete	2500	8.88	-0.108	0	-	-	-	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	-	-	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	no notes
2013.06.25.00	Aluminum delete	2500	8.88	-0.108	0	-	-	-	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	-	-	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	no notes
2013.06.20.23	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1201	Code Diameter 0.215 Coupon appeared to have slipped in Instron
2013.06.20.22	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1780	Code Diameter 0.215
2013.06.20.21	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 14	TORXBRO 3	Interfacial	4140 28-30 HRC	1856	Code Diameter 0.260
2013.06.20.20	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 14	TORXBRO 3	Interfacial	4140 28-30 HRC	1637	Code Diameter 0.260
2013.06.20.19	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 14	TORXBRO 3	Interfacial	4140 28-30 HRC	1887	Code Diameter 0.260
2013.06.20.18	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 13	TORXBRO 3	Interfacial	4140 28-30 HRC	1720	Code Diameter 0.245
2013.06.20.17	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 13	TORXBRO 3	Interfacial	4140 28-30 HRC	1720	Code Diameter 0.245
2013.06.20.16	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 13	TORXBRO 3	Interfacial	4140 28-30 HRC	1748	Code Diameter 0.245
2013.06.20.15	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 12	TORXBRO 3	Interfacial	4140 28-30 HRC	1581	Code Diameter 0.230
2013.06.20.14	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 12	TORXBRO 3	Interfacial	4140 28-30 HRC	1389	Code Diameter 0.230
2013.06.20.13	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 12	TORXBRO 3	Interfacial	4140 28-30 HRC	1391	Code Diameter 0.230

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.06.20.12	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 11	TORXBRO 3	Interfacial	4140 28-30 HRC	1475	Code Diameter 0.200
2013.06.20.11	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 11	TORXBRO 3	Interfacial	4140 28-30 HRC	1650	Code Diameter 0.200
2013.06.20.10	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 11	TORXBRO 3	Interfacial	4140 28-30 HRC	1422	Code Diameter 0.200
2013.06.20.09	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 10	TORXBRO 3	Interfacial	4140 28-30 HRC	1165	Code Diameter 0.185
2013.06.20.08	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 10	TORXBRO 3	Interfacial	4140 28-30 HRC	1206	Code Diameter 0.185
2013.06.20.07	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 10	TORXBRO 3	Interfacial	4140 28-30 HRC	1374	Code Diameter 0.185
2013.06.20.06	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 9	TORXBRO 3	Interfacial	4140 28-30 HRC	1003	Code Diameter 0.160
2013.06.20.05	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 9	TORXBRO 3	Interfacial	4140 28-30 HRC	813	Code Diameter 0.160
2013.06.20.04	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 9	TORXBRO 3	Interfacial	4140 28-30 HRC	793	Code Diameter 0.160
2013.06.20.03	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1509	Code Diameter 0.215
2013.06.20.02	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap compressed Z command error
2013.06.20.00	Shank Diameter Test 2	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap compressed Z command error
2013.06.14.06	Cutter Cap Depth Test	2000	8.88	-0.062	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Used To visually notice difference in cutter cap plunge depth.
2013.06.14.05	Cutter Cap Depth Test	2000	8.88	-0.062	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Used To visually notice difference in cutter cap plunge depth.
2013.06.14.04	Cutter Cap Depth Test	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Used To visually notice difference in cutter cap plunge depth.
2013.06.14.03	Cutter Cap Depth Test	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Used To visually notice difference in cutter cap plunge depth.
2013.06.14.02	Cutter Cap Depth Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Used To visually notice difference in cutter cap plunge depth.

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.06.14.01	Cutter Cap Depth Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Used To visually notice difference in cutter cap plunge depth.
2013.06.14.00	Cutter Cap Depth Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Used To visually notice difference in cutter cap plunge depth.
2013.06.13.19	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .027	TORXBRO 3	Aluminum/ Interfacial	4140 28-30 HRC	1481	no notes
2013.06.13.18	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .027	TORXBRO 3	Interfacial	4140 28-30 HRC	1448	no notes
2013.06.13.17	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .027	TORXBRO 3	Aluminum	4140 28-30 HRC	1350	no notes
2013.06.13.16	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 7	TORXBRO 3	Aluminum	4140 28-30 HRC	1338	no notes
2013.06.13.15	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 7	TORXBRO 3	Interfacial	4140 28-30 HRC	1356	no notes
2013.06.13.14	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 7	TORXBRO 3	Interfacial	4140 28-30 HRC	1292	no notes
2013.06.13.13	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 7	TORXBRO 3	Interfacial	4140 28-30 HRC	1296	no notes
2013.06.13.12	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 7	TORXBRO 3	Interfacial	4140 28-30 HRC	1353	no notes
2013.06.13.11	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .0235	TORXBRO 3	Aluminum	4140 28-30 HRC	1508	no notes
2013.06.13.10	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .0235	TORXBRO 3	Aluminum	4140 28-30 HRC	1511	no notes
2013.06.13.09	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .0235	TORXBRO 3	Aluminum/ Interfacial	4140 28-30 HRC	1471	no notes
2013.06.13.08	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .0235	TORXBRO 3	Aluminum/ Interfacial	4140 28-30 HRC	1463	no notes
2013.06.13.07	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .0235	TORXBRO 3	Aluminum	4140 28-30 HRC	1483	no notes
2013.06.13.06	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .0195	TORXBRO 3	Interfacial	4140 28-30 HRC	1057	no notes
2013.06.13.05	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .0195	TORXBRO 3	Interfacial	4140 28-30 HRC	840	no notes

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.06.13.04	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	JENBIT D: .0195	TORXBRO 3	Interfacial	4140 28-30 HRC	985	no notes
2013.06.13.03	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 8	TORXBRO 3	Interfacial	4140 28-30 HRC	1045	no notes
2013.06.13.02	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 8	TORXBRO 3	Aluminum/ Button Pull	4140 28-30 HRC	1609	no notes
2013.06.13.01	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 8	TORXBRO 3	Aluminum/ Interfacial	4140 28-30 HRC	1576	no notes
2013.06.13.00	Shank Diameter Test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 8	TORXBRO 3	Aluminum/ Interfacial	4140 28-30 HRC	1708	no notes
2013.06.12.11	Korea Fatigue Test 2	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap tool holder system w/o cutters (bit produced separately)
2013.06.12.10	Korea Fatigue Test 2	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap tool holder system w/o cutters
2013.06.12.09	Korea Fatigue Test 2	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap tool holder system w/o cutters
2013.06.12.08	Korea Fatigue Test 2	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap tool holder system w/o cutters
2013.06.12.07	Korea Fatigue Test 2	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap tool holder system w/o cutters
2013.06.12.06	Korea Fatigue Test 2	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap tool holder system w/o cutters
2013.06.12.05	Korea Fatigue Test 2	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap tool holder system w/o cutters
2013.06.12.04	Korea Fatigue Test 2	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap tool holder system w/o cutters
2013.06.12.03	Korea Fatigue Test 2	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap tool holder system w/o cutters
2013.06.12.02	Korea Fatigue Test 2	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Not Pulled	4140 28-30 HRC	Not Pulled	Cap tool holder system w/o cutters
2013.06.12.01	Korea quality control	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2166	no notes
2013.06.12.00	Cutter Cap test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Aluminum/ Interfacial	4140 28-30 HRC	1214	Cutter Cap test, all chips removed, no damage to cutter, Cap compressed on first run through Z command error, run cycle not accurate. 06-20 Alex

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.06.11.09	Korea quality control	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1412	no notes
2013.06.11.08	Korea quality control	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Aluminum	4140 28-30 HRC	1383	no notes
2013.06.11.07	Korea quality control	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1409	no notes
2013.06.11.06	Korea quality control	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Aluminum	4140 28-30 HRC	1398	no notes
2013.06.11.05	Korea quality control	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3	Aluminum	4140 28-30 HRC	1428	no notes
2013.06.11.04	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Button Pull	4140 28-30 HRC	2067	Coupons were slightly narrower
2013.06.11.03	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2213	Coupons were slightly narrower
2013.06.11.02	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1845	Coupons were slightly narrower
2013.06.11.01	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2157	Coupons were slightly narrower
2013.06.11.00	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1898	Coupons were slightly narrower
2013.06.07.14	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2046	Coupons were slightly narrower
2013.06.07.13	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2170	Coupons were slightly narrower
2013.06.07.12	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Button Pull	4140 28-30 HRC	2060	Coupons were slightly narrower
2013.06.07.11	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Button Pull	4140 28-30 HRC	2252	Coupons were slightly narrower
2013.06.07.10	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2283	Coupons were slightly narrower
2013.06.07.09	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head	4140 28-30 HRC	1831	New Tool Holder, Coupons were slightly narrower, weld failed flush with top of Al instead of flush with steel like most
2013.06.07.08	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2126	New Tool Holder, Coupons were slightly narrower

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.06.07.07	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Head	4140 28-30 HRC	1436	New Tool Holder, Coupons were slightly narrower, Top Coupon slipped in instron, not valid
2013.06.07.06	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2183	New Tool Holder, Coupons were slightly narrower
2013.06.07.05	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.16	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2034	New Tool Holder, Coupons were slightly narrower
2013.06.07.04	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.16	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	2228	New Tool Holder, Coupons were slightly narrower
2013.06.07.03	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.16	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1932	New Tool Holder, Coupons were slightly narrower
2013.06.07.02	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.15	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1734	New Tool Holder, Coupons were slightly narrower
2013.06.07.01	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.15	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1766	New Tool Holder, Coupons were slightly narrower
2013.06.07.00	3rd Depth test	2000	8.88	-0.062	0	2500	8.875	-0.15	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3	Interfacial	4140 28-30 HRC	1757	New Tool Holder, Coupons were slightly narrower
2013.06.06.04	Soft mat'l test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140, 23-25 HRC	1250	no notes
2013.06.06.03	Soft mat'l test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140, 23-25 HRC	not pulled	no notes
2013.06.06.02	Soft mat'l test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140, 23-25 HRC	1427	no notes
2013.06.06.01	Soft mat'l test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140, 23-25 HRC	1226	no notes
2013.06.06.00	Soft mat'l test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140, 23-25 HRC	1641	no notes
2013.06.05.02	Soft mat'l test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 4	TORXBRO 3		Unknown 22-24 HRC	not pulled	Head of bit welded to the tool holder
2013.06.05.01	Soft mat'l test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 4	TORXBRO 3		Unknown 22-24 HRC	not pulled	no notes
2013.05.30.05	Profile at different depths	2000	8.88	-0.062	0	2500	8.875	-0.16	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	not pulled	no notes

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.05.30.04	Profile at different depths	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	not pulled	no notes
2013.05.30.03	Profile at different depths	2000	8.88	-0.062	0	2500	8.875	-0.14	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	not pulled	no notes
2013.05.30.02	Profile at different depths	2000	8.88	-0.062	0	2500	8.875	-0.15	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	not pulled	no notes
2013.05.30.01	Profile at different depths	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1355	no notes
2013.05.30.00	Profile at different depths	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1428	no notes
2013.05.29.06	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	1000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1378	no notes
2013.05.29.05	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1379	no notes
2013.05.29.04	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1318	no notes
2013.05.29.03	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1318	no notes
2013.05.29.02	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1457	no notes
2013.05.29.01	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1426	no notes
2013.05.28.07	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	1000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1399	no notes
2013.05.28.06	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	1000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1388	no notes
2013.05.28.05	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	1000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1248	no notes
2013.05.28.04	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1331	no notes
2013.05.28.03	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1346	no notes
2013.05.28.02	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1173	no notes

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Overlap	Bottom Mat'l	Thickness	Top Mat'l	Thickness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.05.28.01	Clamp test	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	not pulled	Bit fell off probably right after touch-off melted the tool-holder and bit
2013.05.28.00	Clamp test	2000	8.88	-0.062	0	-	-	-	0	15 min	1500 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	not pulled	Accidently only executed first z command, no bond formed
2013.05.23.01	No aluminum, for sectioning	2500	8.88	-0.135	0	-	-	0	0	15 min	1172lbs	25 mm	DP 980	0.045"	-	0	TORXBIT 4	TORXBRO 4		4140 28-30 HRC	not pulled	No aluminum, for sectioning
2013.05.23.00	No aluminum, for sectioning	2500	8.88	-0.11	0	-	-	0	0	15 min	1172lbs	25 mm	DP 980	0.045"	-	0	TORXBIT 4	TORXBRO 4		4140 28-30 HRC	not pulled	No aluminum, for sectioning
2013.05.16.14	2nd Korea fatigue test samples	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1522	no notes
2013.05.16.13	2nd Korea fatigue test samples	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1079	no notes
2013.05.16.12	2nd Korea fatigue test samples	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1417	no notes
2013.05.16.11	2nd Korea fatigue test samples	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1400	no notes
2013.05.16.10	2nd Korea fatigue test samples	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1373	no notes
2013.05.16.09	2nd Korea fatigue test samples	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1417	no notes
2013.05.16.08	2nd Korea fatigue test samples	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1150	no notes
2013.05.16.07	2nd Korea fatigue test samples	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	1632	no notes
2013.05.16.06	2nd Korea fatigue test samples	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2305	no notes
2013.05.16.05	2nd Korea fatigue test samples	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2643	no notes
2013.05.16.04	2nd Korea fatigue test samples	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2305	no notes
2013.05.16.03	2nd Korea fatigue test samples	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2562	no notes
2013.05.16.02	2nd Korea fatigue test samples	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2043	no notes

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.05.16.01	2nd Korea fatigue test samples	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2260	no notes
2013.05.16.00	2nd Korea fatigue test samples	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2189	no notes
2013.04.17.02	Flush Bits For Metallography	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 4	TORXBRO 4		4140 28-30 HRC	2204	no notes
2013.04.17.01	Flush Bits For Metallography	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 4	TORXBRO 4		4140 28-30 HRC	1604	* Poorly Aligned
2013.04.17.00	Flush Bits For Metallography	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 4	TORXBRO 4		4140 28-30 HRC	Not Pulled	no notes
2013.04.1.17	Tooth Taper Test	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 2		4140 28-30 HRC	2311	Bit2 with old tapers, vs. bit3 with new *Head fracture-entire head flew off
2013.04.1.16	Tooth Taper Test	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 2		4140 28-30 HRC	2125	Bit2 with old tapers, vs. bit3 with new
2013.04.1.15	Tooth Taper Test	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 2		4140 28-30 HRC	1842	Bit2 with old tapers, vs. bit3 with new
2013.04.1.14	Tooth Taper Test	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	2168	Bit2 with old tapers, vs. bit3 with new
2013.04.1.13	Tooth Taper Test	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1960	Bit2 with old tapers, vs. bit3 with new
2013.04.1.12	Tooth Taper Test	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	2419	Bit2 with old tapers, vs. bit3 with new *Head fracture-entire head flew off
2013.04.1.11	Driver Engagement Depth Evaluation	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 4		4140 28-30 HRC	2259	BRO4 = .050
2013.04.1.10	Driver Engagement Depth Evaluation	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 4		4140 28-30 HRC	2191	BRO4 = .050
2013.04.1.09	Driver Engagement Depth Evaluation	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 4		4140 28-30 HRC	2283	BRO4 = .050
2013.04.1.08	Code combination experiment	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 4	TORXBRO 4		4140 28-30 HRC	2217	no notes
2013.04.1.07	Code combination experiment	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 4	TORXBRO 4		4140 28-30 HRC	1969	no notes
2013.04.1.06	Code combination experiment	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 4	TORXBRO 4		4140 28-30 HRC	2117	no notes

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.04.1.05	Code combination experiment	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2346	no notes
2013.04.1.04	Code combination experiment	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2328	no notes
2013.04.1.03	Code combination experiment	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2460	no notes
2013.04.1.02	Driver Engagement Depth Evaluation	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2419	BRO3 = 0.075
2013.04.1.01	Driver Engagement Depth Evaluation	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2341	BRO3 = 0.075
2013.04.1.00	Driver Engagement Depth Evaluation	2000	8.88	-0.06	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 3	TORXBRO 3		4140 28-30 HRC	2399	BRO3 = 0.075
2013.02.19.04	5754 BEST Depth Test #2 (Valid)	2000	8.88	-0.083	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1456	no notes
2013.02.19.03	5754 BEST Depth Test #2 (Valid)	2000	8.88	-0.083	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1639	no notes
2013.02.19.02	5754 BEST Depth Test #2 (Valid)	2000	8.88	-0.083	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	2086	no notes
2013.02.19.01	5754 BEST Depth Test #2 (Valid)	2000	8.88	-0.083	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1605	no notes
2013.02.19.00	5754 BEST Depth Test #2 (Valid)	2000	8.88	-0.083	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1634	Replaced tool holder and driver prior to this specimen
2013.02.14.04	7075 BEST Depth Test (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1865	no notes
2013.02.14.03	7075 BEST Depth Test (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	2153	no notes
2013.02.14.02	7075 BEST Depth Test (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1958	no notes
2013.02.14.01	7075 BEST Depth Test (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1921	no notes
2013.02.14.00	7075 BEST Depth Test (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	2035	no notes
2013.02.13.09	5754 Depth Test #2 (Valid)	2000	8.88	-0.082	0	2500	8.875	-0.26	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1272	no notes

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.02.13.08	5754 Depth Test #2 (Valid)	2000	8.88	-0.082	0	2500	8.875	-0.25	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1389	no notes
2013.02.13.07	5754 Depth Test #2 (Valid)	2000	8.88	-0.082	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1519	no notes
2013.02.13.06	5754 Depth Test #2 (Valid)	2000	8.88	-0.082	0	2500	8.875	-0.23	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1332	no notes
2013.02.13.05	5754 Depth Test #2 (Valid)	2000	8.88	-0.082	0	2500	8.875	-0.22	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1385	no notes
2013.02.13.04	5754 Depth Test #2 (Valid)	2000	8.88	-0.082	0	2500	8.875	-0.21	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1500	no notes
2013.02.13.03	5754 Depth Test #2 (Valid)	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1605	no notes
2013.02.13.02	5754 Depth Test #2 (Valid)	2000	8.88	-0.082	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1470	no notes
2013.02.13.01	5754 Depth Test #2 (Valid)	2000	8.88	-0.082	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1391	no notes
2013.02.13.00	5754 Depth Test #2 (Valid)	2000	8.88	-0.082	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TORXBIT 1	TORXBRO 2		4140 28-30 HRC	1057	no notes
2013.02.11.12	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	2035	no notes
2013.02.11.11	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.16	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1589	no notes
2013.02.11.10	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.15	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	817	no notes
2013.02.11.09	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1057	no notes
2013.02.11.08	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.23	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1755	no notes
2013.02.11.07	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.22	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1774	no notes
2013.02.11.06	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1657	no notes
2013.02.11.05	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1797	no notes

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.02.11.04	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1497	no notes
2013.02.11.03	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1653	no notes
2013.02.11.02	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	1528	no notes
2013.02.11.01	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	2020	no notes
2013.02.11.00	7075 Depth Test #2 (Valid)	2000	8.88	-0.062	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TORXBIT 2	TORXBRO 2		4140 28-30 HRC	2118	no notes
2013.02.06.11	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	724	Unknown pin affect: touch off and z-command error by about 0.020".
2013.02.06.10	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	605	Unknown pin affect: touch off and z-command error by about 0.020".
2013.02.06.09	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.26	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	1923	Unknown pin affect: touch off and z-command error by about 0.020". Torx driver welded into joint. (too deep?)
2013.02.06.08	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.25	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	1574	Unknown pin affect: touch off and z-command error by about 0.020"
2013.02.06.07	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	1664	Unknown pin affect: touch off and z-command error by about 0.020"
2013.02.06.06	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.23	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	1635	Unknown pin affect: touch off and z-command error by about 0.020"
2013.02.06.05	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.22	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	2134	Unknown pin affect: touch off and z-command error by about 0.020"
2013.02.06.04	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.21	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	1854	Unknown pin affect: touch off and z-command error by about 0.020"
2013.02.06.03	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	2035	Unknown pin affect: touch off and z-command error by about 0.020"
2013.02.06.02	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	1992	Unknown pin affect: touch off and z-command error by about 0.020"
2013.02.06.01	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	1526	Unknown pin affect: touch off and z-command error by about 0.020"
2013.02.06.00	Depth Test #1	2000	8.88	-0.082	0	2500	8.875	-0.17	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	7075 Al	0.062"	TOROXBIT	TORXBRO 2	Pin	4140 28-30 HRC	2282	Unknown pin affect: touch off and z-command error by about 0.020". I think this specimen did not have a pin.

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.02.05.04	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	Not Pulled	Bits had Irregular pins: touch off and total Z command errors
2013.02.05.03	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	Not Pulled	Bits had Irregular pins: touch off and total Z command errors
2013.02.05.02	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	Not Pulled	Bits had Irregular pins: touch off and total Z command errors
2013.02.05.01	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	Not Pulled	Bits had Irregular pins: touch off and total Z command errors
2013.02.05.00	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1456	Bits had Irregular pins: touch off and total Z command errors
2013.02.04.05	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1406	Bits had Irregular pins: touch off and total Z command errors
2013.02.04.04	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1557	Bits had Irregular pins: touch off and total Z command errors
2013.02.04.03	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1468	Bits had Irregular pins: touch off and total Z command errors
2013.02.04.02	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1319	Bits had Irregular pins: touch off and total Z command errors, Driver Replaced after this Specimen
2013.02.04.01	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1231	Bits had Irregular pins: touch off and total Z command errors
2013.02.04.00	BEST Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1348	Bits had Irregular pins: touch off and total Z command errors
2013.02.01.10	Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.27	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1294	Bits had Irregular pins: touch off and total Z command errors
2013.02.01.09	Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.26	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1472	Bits had Irregular pins: touch off and total Z command errors
2013.02.01.08	Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.25	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1487	Bits had Irregular pins: touch off and total Z command errors
2013.02.01.07	Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.24	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1555	Bits had Irregular pins: touch off and total Z command errors
2013.02.01.06	Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.23	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1410	Bits had Irregular pins: touch off and total Z command errors
2013.02.01.05	Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.22	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1512	Bits had Irregular pins: touch off and total Z command errors

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2013.02.01.04	Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.21	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1318	Bits had Irregular pins: touch off and total Z command errors
2013.02.01.03	Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	874	Bits had Irregular pins: touch off and total Z command errors
2013.02.01.02	Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.19	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	1162	Bits had Irregular pins: touch off and total Z command errors
2013.02.01.01	Depth Test	2000	8.88	-0.083	0	2500	8.875	-0.18	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.082"	TOROXBIT	TORXBRO2	Pin	4140 28-30 HRC	Hand Failure	Bits had Irregular pins: touch off and total Z command errors
2012.XX.XX.28	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.31	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	977	no notes
2012.XX.XX.27	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.29	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1108	no notes
2012.XX.XX.26	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.33	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1267	no notes
2012.XX.XX.25	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.31	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1343	no notes
2012.XX.XX.24	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.29	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1076	no notes
2012.XX.XX.23	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.33	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1161	no notes
2012.XX.XX.22	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.31	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1035	no notes
2012.XX.XX.21	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.29	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1227	no notes
2012.XX.XX.20	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.335	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	449	no notes
2012.XX.XX.19	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.325	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	257	no notes
2012.XX.XX.18	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.315	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1336	no notes
2012.XX.XX.17	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.31	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	967	no notes
2012.XX.XX.16	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.3	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1011	no notes

Specimen ID #	Experiment Name	Stage 1				Stage 2				Warm Up	Clamp	Over-lap	Bottom Mat'l	Thick-ness	Top Mat'l	Thick-ness	Profile Code:	Head Code	Failure Mode:	Bit Mat'l:	Tensile Test	Notes
		RPM	Z-Vel	Z-Depth	Dwell	RPM	Z-Vel	Z-Depth	Dwell													
2012.XX.XX.15	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.32	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1416	no notes
2012.XX.XX.14	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.31	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	Hand Failure	no notes
2012.XX.XX.13	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.3	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	Hand Failure	no notes
2012.XX.XX.12	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.28	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1184	no notes
2012.XX.XX.11	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.33	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1355	no notes
2012.XX.XX.10	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.32	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	Hand Failure	no notes
2012.XX.XX.09	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.31	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	Hand Failure	no notes
2012.XX.XX.08	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.3	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	Hand Failure	no notes
2012.XX.XX.07	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.29	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	Hand Failure	no notes
2012.XX.XX.06	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.28	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	Hand Failure	no notes
2012.XX.XX.05	Cone Bit	no record	8.88	no record	0	no record	8.875	no record	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1282	no notes
2012.XX.XX.04	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.305	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1787	no notes
2012.XX.XX.04	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.305	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	1787	no notes
2012.XX.XX.03	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.27	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	532	no notes
2012.XX.XX.02	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.223	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	Hand Failure	no notes
2012.XX.XX.01	Cone Bit	no record	8.88	no record	0	no record	8.875	-0.2	0	15 min	2000 lbs.	25 mm	DP 980	0.045"	5754 Al	0.062"	CONEBIT	No head code		4140 28-30 HRC	Hand Failure	no notes