Undergraduate Research on Friction Stir Welding of Copper-Aluminum Join

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Abstract

The need for joining dissimilar materials is increasing rapidly in manufacturing industries. Therefore, a successful weld of dissimilar metals by Friction Stir Welding (FSW) process becomes a topic of interest for many investigators. FSW research topics have been used for Manufacturing Engineering students at Virginia State University as undergraduate research projects. The purpose of this study was to investigate intermetallic characteristics between aluminum and copper at the transition zone in the FSW process. The effects of process parameters on heat affected zone (HAZ) have been examined to find the optimal tool rotational speed, axial force, and transverse speed. A metallographic study was conducted to investigate the quality of intermetallic bonding at the interfaces. It was observed that using optimized process parameters for experimental setup resulted in a very good quality of the welds.

Introduction

Virginia State University provides research experience to undergraduate STEM students using a National Science Foundation (NSF) funded grant. The grant allows undergraduate STEM students to work on topics of interest in the summer and/or during the academic year. Selected students conduct one-on-one research with a faculty member in their area of interest in a STEM discipline and receive paid research internships. Students explore and develop basic computational skills, learn CAD, and cultivate proficiency in experimental design. More specifically, students study basic methods of research with their faculty mentor and obtain practical experience in design methodology and implementation to apply to their own projects.

In the first academic year for the incoming freshmen, faculty members select qualifying STEM students to apply and participate in a research project. During their sophomore year, the participating students learn the theoretical and practical knowledge required for their projects. They then outline the planning, objectives setting, data collecting, and analysis of their proposed project. The end result is an oral and written presentation of their conducted research.

Although Friction Stir Welding (FSW) is now an established and commercially available method for joining metals, there is a need for further improvement and investigation of new venues for research and development. Virginia State University owned a functioning FSW machine, along with material processing and testing facilities, to conduct studies on new manufacturing processes using this technology.

One of the undergraduate research projects within our department focuses on using FSW on the jointing of aluminum and copper plates. Our goal is to identify the effects of process parameters on intermetallic characteristics between aluminum and copper at the heat affected zone (HAZ) in the FSW process. Four undergraduate students were involved in different stages throughout this project. The results of these studies along with the impact on the students' learning outcomes reported in this paper.

Manufacturing Processes Course Overview

MANE students take two courses MANE 205 and 210 (three credit hours each) to learn topics on manufacturing processes in their sophomore year. The following is a short description of each course.

MANE 205-The types and properties of engineering materials including metals and polymers as employed in contemporary practice. The traditional manufacturing processing methods by which this material is shaped into products such as machining, casting, forming, and fabricating techniques. Several experiments will be conducted.

MANE 210- Modern manufacturing processes and related topics. Includes ceramics, composites, powder metallurgy, property enhancing and surface processing operations, rapid prototyping, and micro-fabricating. An introductory review of manufacturing support system including production planning and control, quality control, and measurement and inspection.

The basics of friction stir welding are discussed in MANE 210. Student participation and training is integral in developing a better understanding of the process. Therefore, MANE 210 requires students to complete an FSW lab assignment. This includes conducting experiments and analyzing the quality of the results by visual inspection.

FSW Lab Assignment

Objective
Conduct Friction Stir Welding practice and observe the effect of variation of different parameters (i.e. rotational speed, transverse speed, and axial load) on the quality of the weld.

Practical Approach
The lab assignment will be conducted in three sessions (two hours each)

Session I: Safety instruction and FSW exploration

After safety instruction, the setup process and machine operation will be demonstrated by the Lab Technician.

Session II: Machine set-up and operation practice

Practice the machine operation in normal setup and base parameters.

Session III: Conduct experiment

Operate the machine to weld the given work pieces under different parameters and observe the quality of the welded joints.

Report your observation:

Prepare a brief report (3 - 4 pages, with the pictures, tables, and appendices) that summarizes your work in the provided format.

Table 1: FSW Lab Activities by Teams

	Topics
Team I	Effect of rotational speed on quality of weld FSW machine set up and operation practice (3 samples) Data collection, interpretation, and submitting report
Team II	Effect of transverse speed on quality of weld FSW machine set up and operation practice (3 samples) Data collection, interpretation, and submitting report
Team III	Effect of axial load on quality of weld FSW machine set up and operation practice (3 samples) Data collection, interpretation, and submitting report

A selected Al-Al welded sample and a screen shot of the FSW data monitoring software are shown in Figures 1 and 2 respectively.

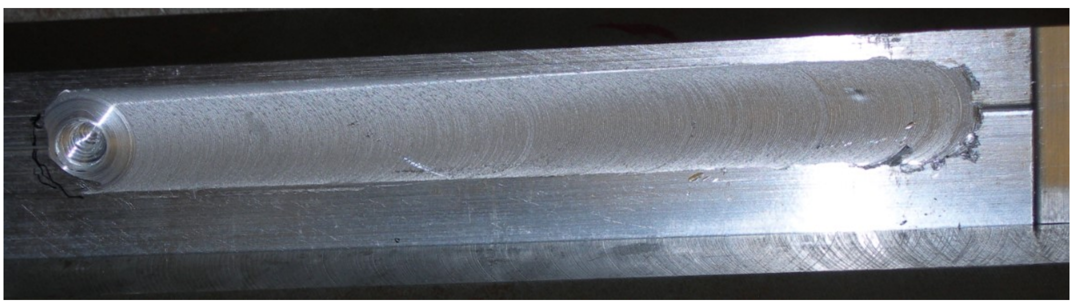

Figure 1- A Selected Sample Performed by FSW Machine

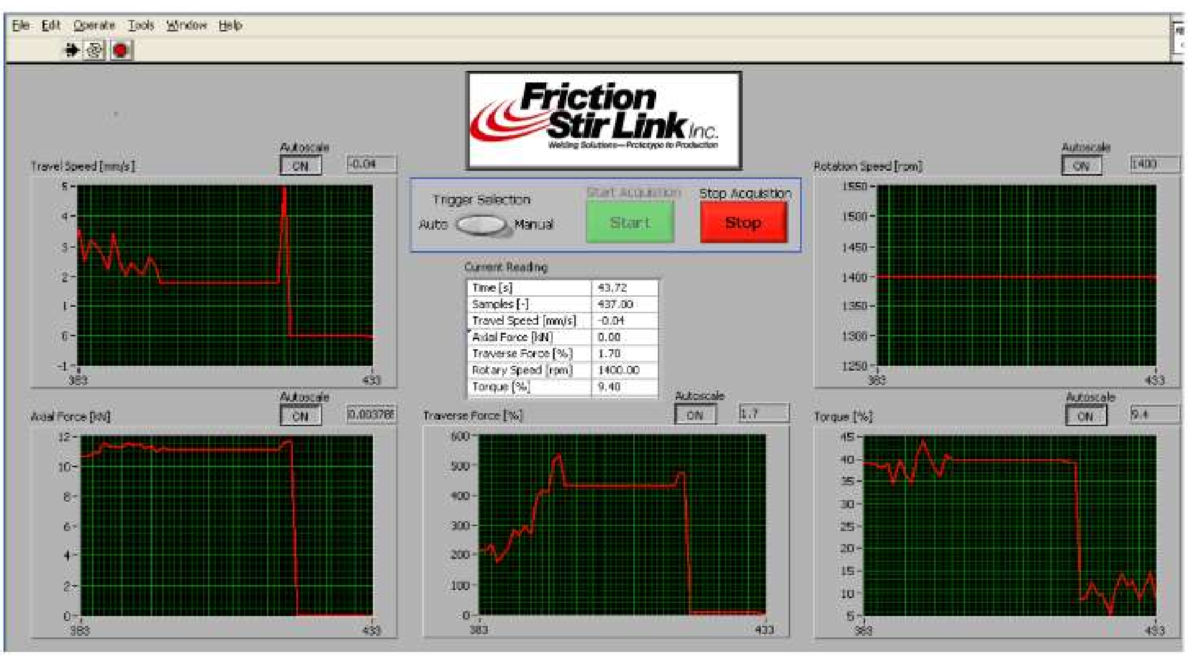

Figure 2- Screen shot of FSW data monitoring software

Undergraduate Researches on FSW

Case Study I- Mechanical Behavior of FS Welded Aluminum

The study on mechanical properties of welded aluminum plates was conducted by a team of two MANE junior students utilizing a tensile test machine to examine tensile strength and strain of the material at the HAZ.

Objectives

Tool rotational speed, transverse speed, and downward (axial) force are the most important parameters that affect weld quality. The objectives of this case study are to:

- Perform aluminum to aluminum welding using FSW technology.
- Examine the microstructural properties of the welded region using a SEM (Scanning Electron Microscope) / Nikon Microscope.
- Examine the strength of the welded region using a Tensile Test Machine and compare the results with unwelded specimens.

Procedure

Two 6061 aluminum alloy plates (6x4x ¼ in) were welded together using the FSW process. The weld was performed using tool rotational speed of 1200 rpm, the transverse speed of 4.5 mm/s, and plunging force of 5000 N. The welded plate was cut perpendicular to the welded line to produce four rectangular strips. The strips were machined using CNC mill to make identical specimens for the tensile tests. The five steps of the welded specimens' preparation and the geometric characteristics of the test specimen are shown in Figure 3.

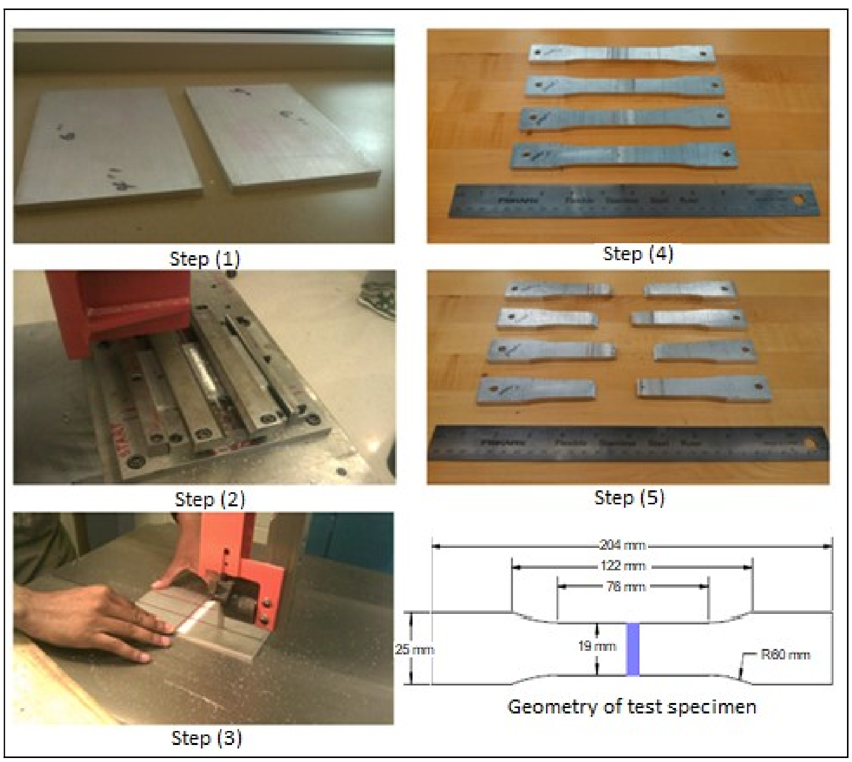

Figure 3- Procedure Steps for Tensile Test

The recorded operation parameters of the FSW machine during the Al-Al welding processes are shown in Figure 4.

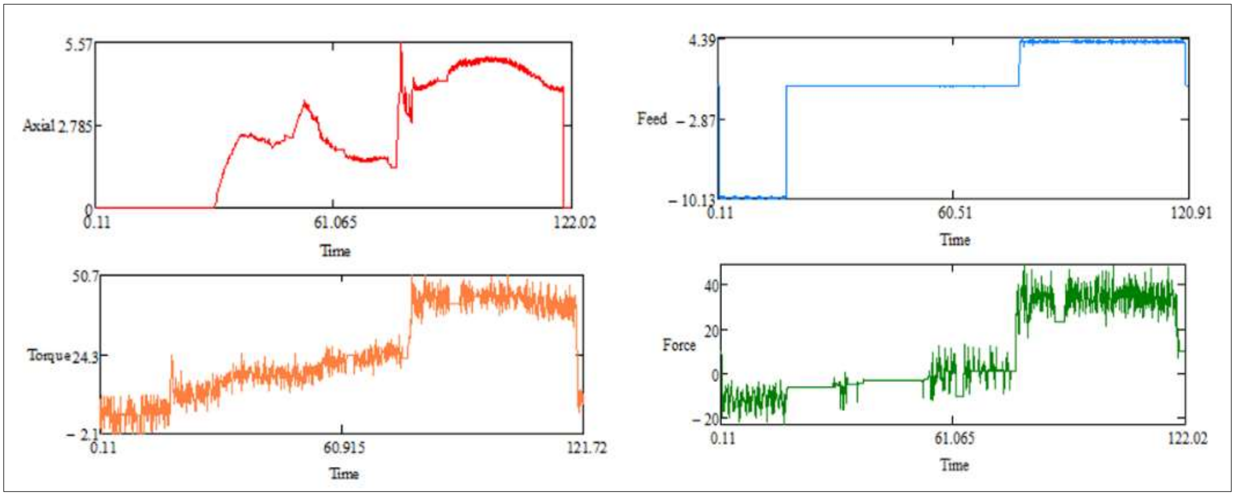

Figure 4- Variation of FSW Machine Operation Parameters During Al-Al Welding

Note that the tool rotational speed was set to 1200 RPM for both two feed rates (transverse speeds of 3.0 and 4.5 mm/s).

Tensile Test of FS Welded Specimens

Tensile Tests determine the tensile yield strength and percentage of the yield elongation of the specimens. Four Al-Al welded tensile specimens were prepared with the tensile direction perpendicular to the welding direction, such that the weld zone was in the center of the specimen. Tensile tests were performed on the four identical specimens. The obtained results of tensile test for the four FS welded aluminum specimens are shown in Table 2 and Figure 5 respectively. All of the specimen's failure happened in the vicinity of the welded region (not in HAZ). Similar studies are extended to FS welded of Al-Cu materials.

Table 2- Obtained Results of Tensile Tests

Specimen label	Max Load [N]	Load at Yield [N]	Strain at Break [mm/mm]	Time at Break [min]
Specimen 1	24,139	24,117	0.0357	0.926
Specimen 2	28,496	18,264	0.0866	2.242
Specimen 3	28,467	18,362	0.0882	2.287
Specimen 4	28,385	18,549	0.0809	2.099

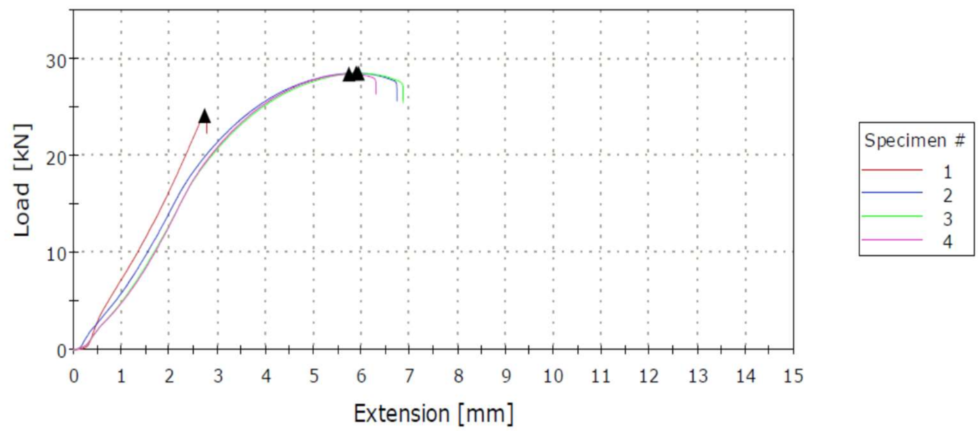

Figure 5- Tensile Test Diagrams of Al-Al welded Specimens

Case Study II- Investigation on Joint Ability of Copper and Aluminum by FSW

This study was conducted by a two-person team of MANE and MCET junior students.
This study examined the joint ability of copper and aluminum by controlling the following operation parameters: downward force, transverse speed, and rotational speed of the tool. Consequently, the study further examined the quality of copper-aluminum joints by means of metallographic investigation and identified the most effective parameters in this process.

Objectives

The objectives of this study are to:

- Gain better understanding of the FSW of joining copper and aluminum.
- Observe the quality of aluminum-copper joining in the FSW process in different zones.
- Examine copper-aluminum bonding in the solid-state joining process.
- Analyze microstructural and compositional information.

Methods/Procedure

Six 6061 aluminum alloy bars (8x1.5x 0.25 inches) were prepared to be drilled according to three designed patterns for inserting copper segments. Three pairs of aluminum bars with embedded copper segments were welded together using the FSW process. See Figure 6 for the copper inserted aluminum bar pairs (top) and frictional stir welded plates (bottom). The welds were performed using tool rotational speed of 1000 RPM and two different feed rates of 3.0 and 4.0 mm/s.

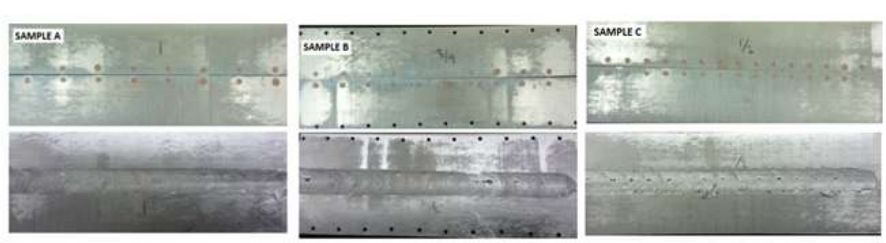

Figure 6- Copper inserted aluminum bars (top) and frictional stir welded plates (bottom)

The recorded operation parameters of the FSW machine during the Cu embedded Al welding process are shown in Figure 7.

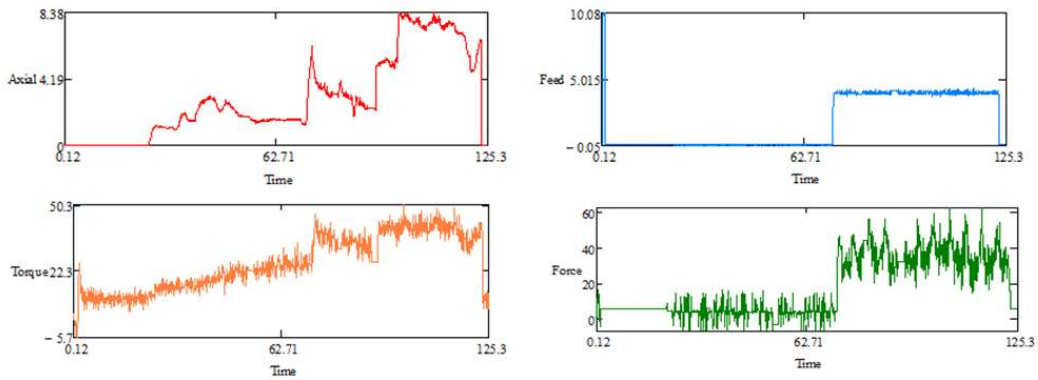

Figure 7- Variation of Machine Operation Parameters During Embedded Cu-Al Welding

Note that the tool rotational speed was set to 1000 RPM for both feed rates (transverse speeds of 3.0 and 4.0 mm/s)

The welded plates were cut at several sections for visual observations (Figure 8). Three distinguished regions as: only Al, only Cu, and mixer of Al-Cu regions were easily identified.

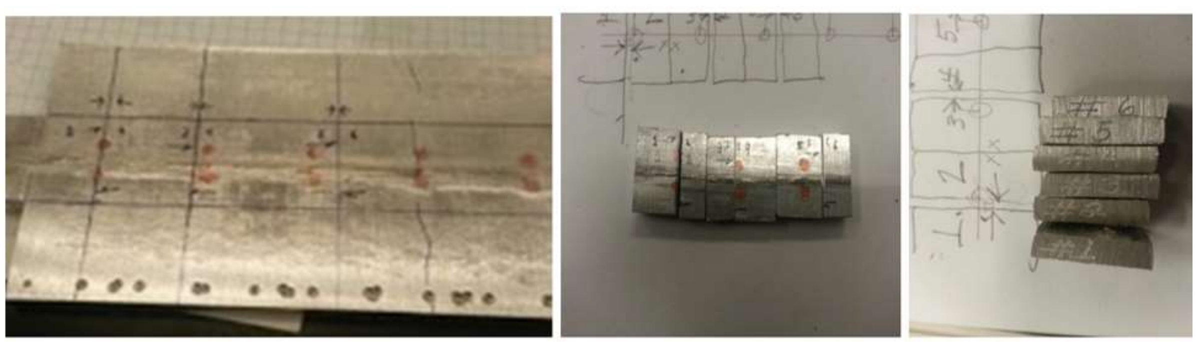

Figure 8- Cuts of Welded Plates

Several samples were cut off from the Al-Cu region and prepared for metallographic observations. Two prepared samples and some magnified microscopic images are shown in Figure 9.

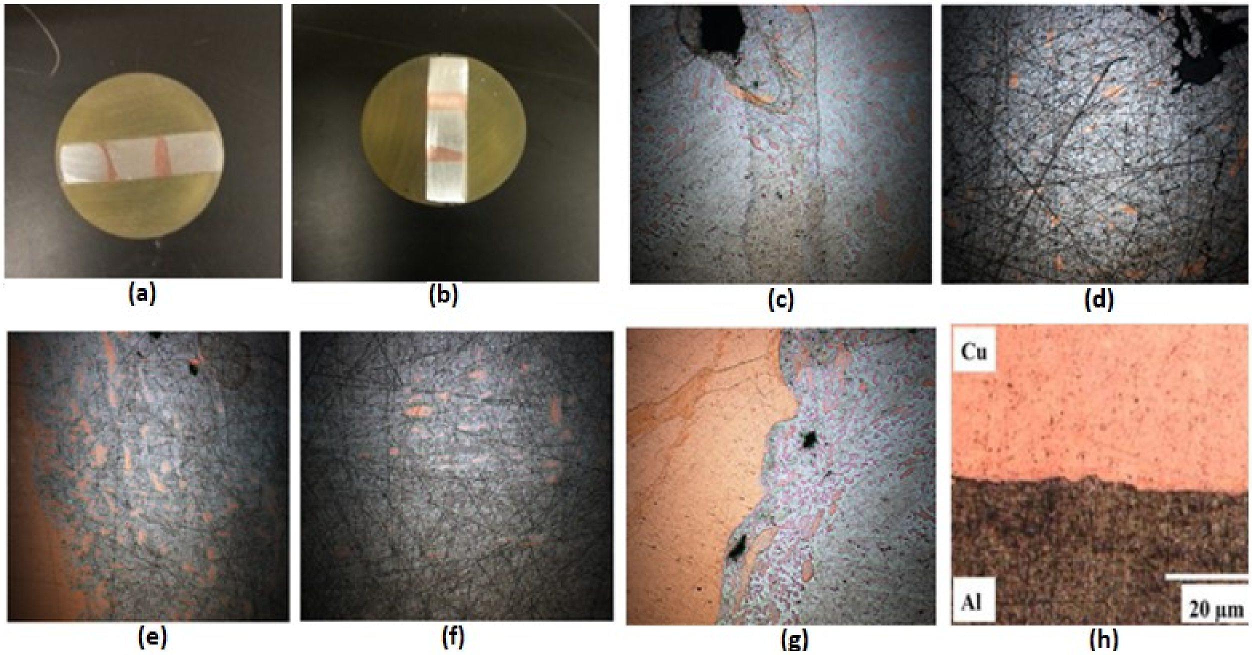

Figure 9- Selected Samples (a-b) and Microscopic Images (c-h)

The initial investigation demonstrates the joining of aluminum and copper by FSW is feasible. Results indicate a quality weld is achievable by appropriate geometric setup and optimization of transverse speed, tool rotational speed, and axial load.

Case Study III- Butt Joints of Aluminum and Copper by FSW

This study focuses on the application of FSW technology to weld aluminum and copper bars to produce a durable quality joint. For this purpose, several experiments were carried out to weld 0.125-0.25in. thick 6061 aluminum and 110 copper bars by adjusting the tool rotational speed and transverse speed in the range of 1000-1500 rpm and 0.1-0.3 in./sec, respectively. The effect of different parameters on the microstructure properties in stir zones was observed using a Nikon Microscope.

Objectives

The objectives of this study are to:

- Perform FSW to join the 6061 Al and 110 Cu bars.
- Examine the microstructural characteristics of the welded region using a Scanning Electron Microscope (SEM) and/or Nikon Microscope.
- Observe the effect of welding parameters (i.e. tool rotational speed and transverse speed) on joint quality.

Procedure

6061 aluminum alloy and multipurpose 110 copper bars with 0.125- and 0.25-inches thicknesses were selected to weld together using the FSW process. The bars were machined using CNC mill to make specimens in a specific geometrical configuration (Figure 9). Several samples from the selected sections were prepared for metallographic observations. Three of selected prepared are shown in Figure 10.

Figure 10- Procedure Steps for Al-Cu FS Welding

The experiments were performed for rotational tool speeds of the 1000-1400 rpm, transverse speeds of 3-7mm/s at 5kN plunging force. Visual investigations were conducted on prepared samples using a Nikon microscope. Selected microscopic images are shown in Figure 11. Further investigation for details is planned for future.

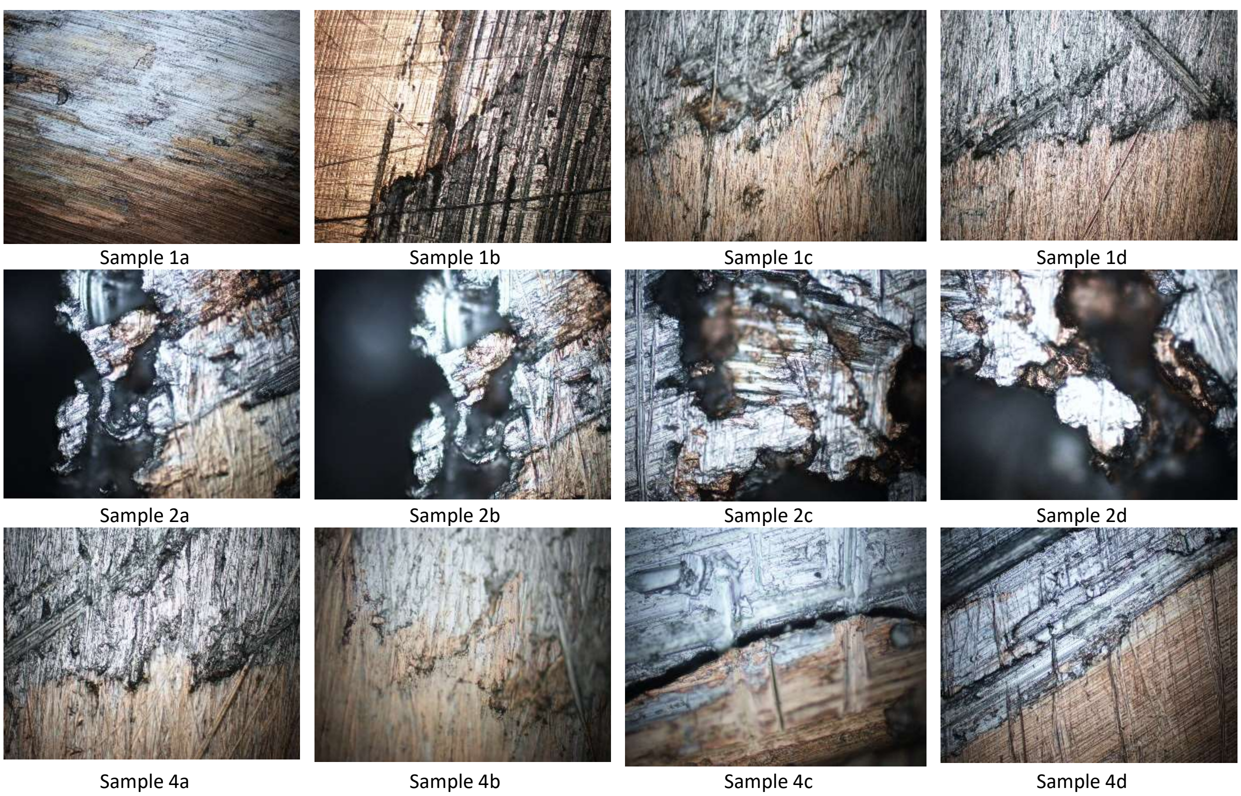

Figure 11- Selected Microscopic Images

Conclusion

During the first case study, the two junior students performed engineering research to investigate the application of the existing FSW technology and examine the mechanical properties of the material at Al-Al welded zones. They enhanced their educational knowledge of manufacturing and material processes in addition to their understanding of strength of materials. They cultivated their hands-on skills through several experimental activities, including FS welding, specimen preparation, strength testing, and data analysis.

During the second case study, intermetallic characteristics at Al-Cu welded zones were investigated. The focus of the study was to implement metallographic technique to observe the effect of copper on the quality of FS welded aluminum alloy. In this process, students also enhanced their educational knowledge of manufacturing and material processes along with their conceptual understanding of basic material science principles. The results of the study led them to determine the appropriate compositions for a quality FS weld of aluminum and copper.

During the third case study, FS welding was used to join aluminum and copper bars. The focus of the study was to investigate the effect of the FS welding parameters on the quality of the weld in different heat affected zones. Although the initial study has been conducted, more works need to be carried out to validate the expected results. Since availability of the junior and/or senior students for research work is mostly limited to the summer time, this phase of the study is still in process and more time is needed to achieve the expected goal(s).

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