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The effect of tool geometry on the micro–Friction Stir Spot Welding (mFSSW) process on fatigue strength in the result of brass with AA1100 thin plate welding

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Abstract

Micro Friction Stir Spot Welding (mFSSW) is a derivative of the Friction Stir Spot Welding (FSSW) process that can be used in thin plate welding processes. As a single spot welding process, mFSSW can be considered as an alternative to replace resistance spot welding and rivet processes. Spot welding itself is already widely used in the aerospace, railroad and automotive industries. Therefore, components that are welded using the mFSSW process need to know the strength of the connection against dynamic loads. This study aims to determine the effect of tool geometry on the fatigue strength of welded joints produced through mFSSW welding techniques on brass thin plates with Aluminum AA1100 in the form of repeated loads. In this study, the parameters were varied in the form of tool geometry, where each tool has different pin and shoulder dimensions. After being welded and confirmed to be free from cracks, the specimens will be tensile tested first to obtain parameters and fatigue tests will be carried out. During the fatigue testing process, a fracture phenomenon occurs where specimen damage begins with the formation of an initial hook-shaped crack and ends with a final fracture. The study found that a higher pin tool leads to a smaller tool diameter and smaller keyhole cross-sectional area, which results in an increase in fatigue resistance. The tool with a medium taper geometry produces the longest cycle.

Keywords: AA1100 thin plate, brass thin plate, damage analysis, fatigue test, micro-Friction Stir Spot Welding (mFSSW), tensile test, tool geometry

1. Introduction

In today's modern era, the development of manufacturing processes has advanced significantly in product design, manufacture, and maintenance. One of the commonly used manufacturing processes is welding. According to the definition of Deutche Industrie Normen (DIN), welding is the metallurgical joining of metal joints in a molten or liquid state, and hence, it is one of the most widely used manufacturing processes. This definition explains that welding involves locally joining several metals using heat energy. Aluminum is one of the metals that can be joined using this process.

Aluminum is lightweight, has high strength, corrosion resistance, and is a good conductor of electricity. However, in terms of welding, aluminum has poor properties compared to steel [1]. Welding on aluminum generally uses fusion welding methods, namely Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW), which in the results of welding with these methods are still often found defects or flaws in the weld area. Common weld defects include porosity and cracking [2].

Friction stir welding (FSW) is an innovative novel solid-state joining process invented in 1991 by The Welding Institute (TWI) in the UK. FSW utilizes friction to generate heat, which makes the surrounding material softer, and a rotating tool is then used to stir the soft material to flow and join the two pieces. As the process occurs below the melting point of the material, FSW is thus a solid-state joining process. This process results in minimum microstructural changes and better mechanical properties than welds made with conventional welding methods. FSW has been proven to be a welding technology that can produce high-quality welds for all aluminum alloys. This technology would benefit the assembly of the circuits of electronic devices and medical items micro-devices that are susceptible to overheating. Meanwhile, the technologies nowadays and in the future focusing on the micro-based technologies, mFSSW could excel in producing those.

Several studies have been conducted on the mFSSW welding process itself, particularly A. S. Baskoro, et al. have investigated the effect of welding parameters [3] and the effect of tool speed on the mFSSW welding process using AA1100 aluminum material. This study aims to determine the effect of tool geometry on the fatigue strength of welded joints produced through mFSSW welding techniques on brass thin plates with Aluminum AA1100 in the form of repeated loads.

2. Literature Review

Manuscript processing

Friction stir spot welding (FSSW) is one of the variants of friction stir welding (FSW). Recently, the FSSW method has been used as an alternative method to compete with Resistance Spot Welding (RSW), which has been widely used for decades in the automotive industry and other industries related to sheet metal fabrication [4].

FSSW is expected to be used in the automotive industry for joining aluminum sheet body parts, as it offers the same advantages as friction stir welding. The FSSW welding process typically involves three stages: plunging, stirring, and retracting. During the plunging or stabbing process, FSSW employs a tool that rotates, moves, and penetrates the overlapped material or plate to a specific depth. During the stirring stage, the tool rotates but remains stationary. Heat is generated by the friction between the tool's pin and shoulder and the surrounding material, causing it to melt. As a result of this stirring process, the melted materials from both the upper and lower sections are mixed together. After stopping the tool rotation, it is left standing for a period to permit the solidification process under the pressure of the tool shoulder and form a nugget that joins the two materials. During the final retracting stage, the tool is taken out of the material, and the joining process is completed.

FSSW Tool Geometry

The tool geometry in the FSSW process generally consists of two parts, the shoulder and the pin. The pin provides the initial heat and penetrates into the workpiece, where this part of the tool is the part that stirs the material or flows the softened material to create a bond between the two materials. Several studies have shown that pin geometry, namely pin size, pin angle, pin thread orientation, pin length and pin profile, play an important role in nugget formation [5]. While the shoulder is the part that provides heat by friction against the sample, this part also holds the hot material underneath so that it does not overflow to the side. In addition, this part also provides a vertical force to the workpiece that maintains the contact state of the tool with the workpiece.

Fatigue in the Material

Fatigue is a progressive, localized, permanent structural change that occurs in materials subjected to fluctuating stresses and strains that can lead to cracking or fracture after the number of fluctuating loads has reached the strength limit of the material. Fatigue fractures are caused by cyclic stresses, which can be axial, bending, or torsional stresses and plastic strains. The fatigue process in materials consists of four stages [6]:

1. Initial damage leading to crack nucleation and initiation
2. Small crack growth in the plastic-elastic region of the stressed area
3. Macroscopic crack growth
4. Finally, the sudden onset of fracture

3. Experiments

The research phase begins with identifying the problems that occur and then searching for and reading literature studies related to solutions to the problems that occur. The literature used can be in the form of previous research, journals and standards that will be applied to the research. The next step is to prepare materials in the form of brass thin sheets and AA1100 thin aluminum sheets with 1 x 3-inch weld specimens.

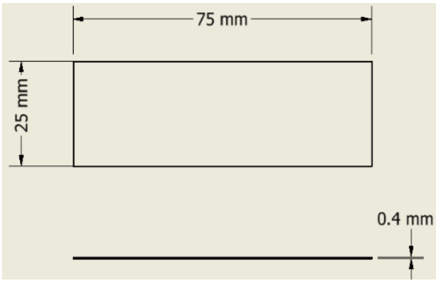

Figure 1. mFSSW specimens

Next, the specimen is welded using an EMCO CNC TU 3A machine with the tool geometry variations listed below:

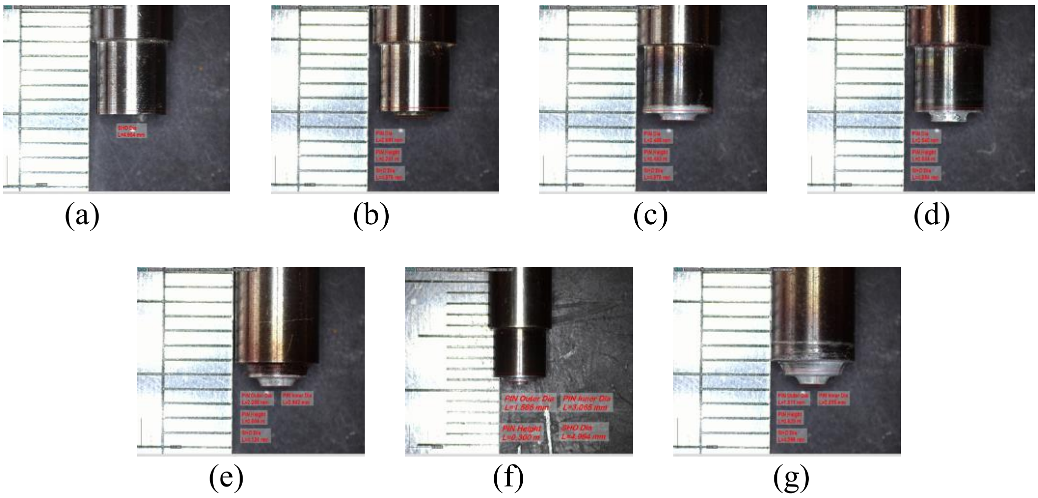

Figure 2. Tools Used in the mFSSW Process (a) Tool 1, (b) Tool 2, (c) Tool 3, (d) Tool 4, (e) Tool 5, (f) Tool 6, (g) Tool 7

Tool 1 is a variation of the probless tool, where this tool has no pin and consists only of a shoulder. For T) is a variation of the 250 shoulder tool, where this tool has a shoulder and also has a pin with a pin height of 0.251 mm. Figure 3.6 (Tool 3) is a variation of the Shoulder 450 tool, where this tool has a shoulder and a pin with a pin height of 0.453 mm. Figure 3.7 (Tool 4) is a variation of the 650 shoulder tool, where this tool has a shoulder and a pin with a pin height of 0.654 mm. Tool 5 is a variation of the small tapping tool where this tool has two pins with different pin diameters. For tool 6 is a variation of the medium tapper tool where this tool has two pins with different diameter differences. Tool 7 is a variation of the two-stage shoulder tool, which is a type of tool with a tapper but has one pin and two shoulders.

The Hungta HT-9711 Dynamic Fatigue Test Machine was used to carry out the fatigue test. This research used AWS B4.0 (Standard Methods for Mechanical Testing of Welds) [7] to determine force ratio, test load range, and frequency. The force ratio used was 0.1, the test load range was not less than 25% of the load, and the frequency value was below 170 Hz. The AWS D17.2 (Specification for Resistance Welding for Aerospace Applications) standard was also used [8]. These standard states that the minimum loading requirement for materials with ultimate tensile strength below 150 MPa is 200 N. So, if it is related to the previous standard, the test span range used is 25% to 100% of 200 N, namely 50 N to 200 N. This research used a maximum load of 200 N, a minimum load of 20 N, an amplitude of 90 N, and a pre-load of 110 N.

4. Result and Discussion

Fatigue testing was conducted on crack-free specimens with predetermined parameters resulting in the number of cycles per specimen. In order to determine the crack propagation, the friction surface of each specimen was recorded using a digital microscope during the test.

Once the specimen fractures, the fatigue testing machine automatically stops the process and the number of cycles completed during the test appears directly on the computer screen. The collected data is subsequently processed and presented in the form of tables and graphs.

The Impact of Tool Geometry on Fatigue Resistance

Mustafa Kemal Bilici [5] states that the FSSW welding tool geometry typically has two parts: the shoulder and the pin. Pin geometry, which includes pin diameter, angle, thread orientation, length, and profile, has been shown by various studies to play a crucial role in nugget formation. In this research, there are several variations used in the geometry of the mFSSW tool, including pin diameter, pin length/height and pin profile, where the pin diameter and pin length data can be seen in figure 2 while the pin profile data is obtained from the approach from the calculation of the keyhole cross-sectional area obtained from the contour measurement data of the weld results of each tool using surfcom measuring instrument. Here's an illustration of the contour measurement outcomes for the welding of tool 1:

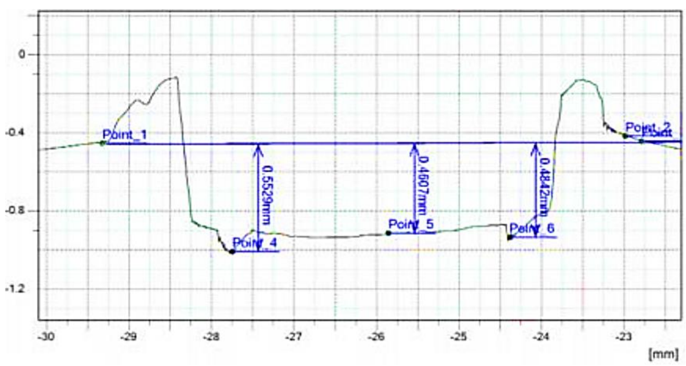

Figure 3. Contour of Weld Result Obtained with Tool 1

The Effect of the Cross-Sectional Area of the Keyhole on Fatigue Resistance

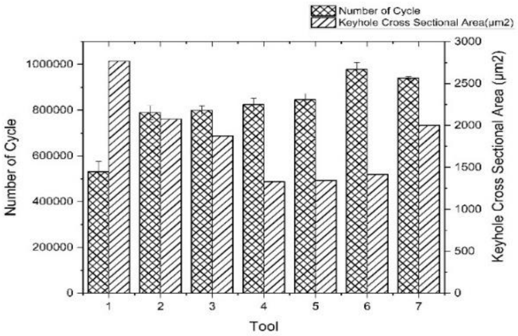

Figure 4. Keyhole cross-sectional area chart plotted against the number of cycles

From Figure 4, it can be concluded that the smaller the cross-sectional area of the keyhole in the weld, the relatively greater the fatigue strength of the tool. The keyhole cross sectional area is affected by the diameter of each tool, so based on the tool geometry shown in Figure 2, Tool 1 is the tool with the shortest number of cycles because Tool 1 has a relatively larger diameter, so the keyhole cross sectional area becomes larger.

The Influence of Pin Diameter on Fatigue Strength

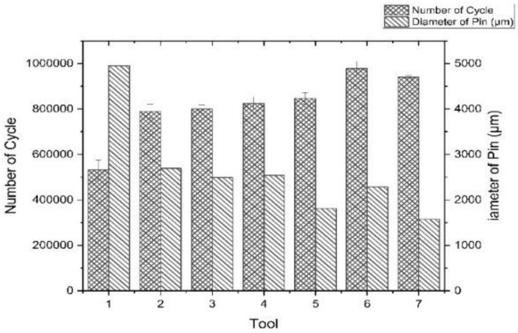

Figure 5. Chart depicting the relationship between Pin Diameter and Number of Cycles

Figure 5 suggests that increasing the pin diameter leads to a decrease in the tool's fatigue resistance. The geometry shown in Figure 2 indicates that Tool 1 has the largest diameter and produces the shortest number of cycles.

The Impact of Pin Height on Fatigue Resistance

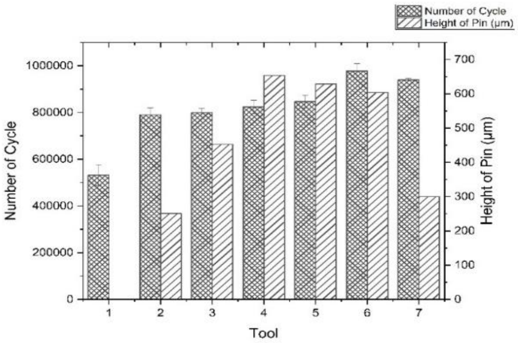

Figure 6. Chart depicting the relationship between Pin Height and Number of Cycles

According to Figure 6, the fatigue resistance of the tool increases with an in-crease in pin height. From the geometry in Figure 2, it is evident that the cyclic life of tool 1 is the shortest as it does not have a pin. This finding is directly related to tools 2, 3, 4, and 5 that have a longer pin height, resulting in a longer cyclic life.

5. Conclusion

The following conclusions can be drawn from the research carried out using data from macro tests, tensile tests, fatigue tests and the analysis of surface contour measurements:

1. The tool geometry affects the fatigue strength of the mFSSW welding process. Studies indicate that increasing the pin height on the tool improves the fatigue resistance of the welded joint. Additionally, decreasing the pin diameter and the keyhole cross-sectional area increases the fatigue strength of the welded joint.
2. The fracture phenomenon originates from the initial crack in the form of a hook, and then spreads gradually towards the stir zone area, causing crack propagation. Once the crack has propagated to the surface of the stir zone, the final fracture occurs.
3. The tool 6 medium taper geometry is used to weld the structure capable of withstanding the maximum number of cycles under fatigue loading.

6. Acknowledgement

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