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EFFECT OF FRICTION WELDING PARAMETERS FOR ALUMINUM AND COPPER

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ABSTRACT

Friction welding is a solid-state welding technique that generates heat from friction and pressure to join two metals together. Friction welding includes various techniques, such as friction stir welding, linear friction welding, and continuous drive friction welding. This literature review examines various friction welding techniques, the welding defects that may arise among these methods, and identifies the most appropriate friction welding technique for connecting pump shafts composed of Aluminum and Copper with a circular cross-section, as fusion welding is not applicable for joining Aluminum and Copper. A primary reason is the substantial difference in melting temperature between Aluminum and Copper, approximately. 400 degrees Celsius. Based on the literature review, the outcomes of friction welding may be influenced by rotational speed, duration of pressure, axial pressure force, and the properties of the materials utilized. Employing a case study of the pump shaft, it was determined that the continuous drive friction method is the optimal technique for bonding Aluminum and Copper in the pump shaft, as the temperature distribution can be uniform across the entire weld joint surface. This situation will lead to a more uniform microstructure and weld joint quality.

KEY WORDS: *Welding parameters, dissimilar metals, welding defects, aluminum and copper joint.*

NOMENCLATURE

°c	Degrees Celcius
rpm	Revolution Per Minute
GPa	Giga Pascal
MPa	Mega Pascal
mm/min	Milimeter/Minute

1.0 INTRODUCTION

Throughout the FW process, the two metal surfaces that slide against one another generate heat that nears the melting point of the metals, with the surface of the metal nearest the friction site undergoing the largest temperature rise. FW does not need electricity or other energy sources to raise the temperature of the metal being welded. The rise in temperature happens because of the friction between the two metal surfaces or between the pin and the two metal surfaces. The fusion welding joining process is challenging for metals with significantly different melting points, like Aluminum and Copper. Consequently, FW is highly appropriate for bonding Aluminum and Copper since the joining takes place without reaching the liquid state. In FW, since the two metals do not attain the liquid state, the resulting deformation and shrinkage are quite minimal, which contributes to favorable mechanical properties in the joint outcomes. The FW welding technique offers an additional benefit, as it does not need filler metal or gas while welding. The chances of slag inclusion and porosity in FW can be reduced. FW also offers benefits from an ecological standpoint since the FW method does not generate surplus smoke or gas. Moreover, FW has the potential to lower machinery work and upkeep expenses, while enhancing capacity and decreasing tool costs. FW also possesses more precise tolerances regarding the dimensions of welded joints. While FW offers numerous benefits, it also comes with drawbacks. The drawback of the FW technique is the high cost of the FW equipment despite the low expense of the welding operation. While FW offers better dimensional accuracy, establishing the process parameters is more complex since it needs to account for time, rotational speed, feed rate, and pressure force. FW can join two distinct materials, but it is unable to bond materials that possess excessive differing traits. FW welding on various metals presents unique challenges due to variations in the metallurgical, thermal, mechanical, and physical characteristics of the two metal types. Regarding mobility, a drawback of the FW machine is that it is challenging to transport or carry.

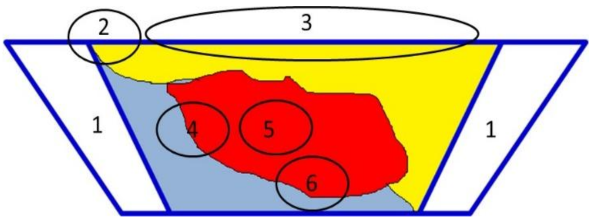
1.1 FRICTION WELDING

Given that one advantage of FW is its ability to bond various types of metals, this benefit is particularly significant in the manufacturing sector. Welding various metals is a method to combine the properties of different metals for diverse functions, aiming to achieve the required strength. Furthermore, the design and production process of parts can be executed more cost-effectively since both costly and less expensive metals can be utilized in the component. An instance is the creation of a pump shaft part that merges relatively costly Copper with relatively inexpensive Aluminum. Moreover, FW machine tools are quite affordable as well. Despite FW offering numerous benefits due to its execution in solid or semi-solid states, various welding defects may occur, including:

- Wormholes, pores and voids: These defects are likely caused by insufficient temperature and low material fluidity. This can occur in two metals that have very different melting temperatures and can occur when joining Aluminum and Copper in the case of pump shafts
- Kissing bond cracks: Caused by a lack of chemical and mechanical bonding processes, especially if the two materials have different types of bonds
- Incomplete fusion laps: Caused by the presence of dirt due to poor surface cleaning before the welding process
- Flash: Caused by excessively high temperatures
- Thinning of the material: Caused by excessive axial force
- Cracks: Caused by excessive heating and non-uniform cooling
- Insufficient penetration: Caused by too low axial force, insufficient temperature resulting in low metal fluidity, or too large a difference in thickness between the two metals.

The schematic location of some of these defects can be seen in Figure 1. Several methods are used to minimize defects in welded joints using the FW method and improve the quality of FW welding parameters. Of the many methods, the Yahya method has been applied to improve the quality of FW. For the FW optimization process, the Yahya method is used to identify the main sources of problems that can affect the quality of welded joints. Several FW methods are friction stir welding (FSW), linear friction welding (LFW) and continuous drive friction welding (CDFW).

Description:



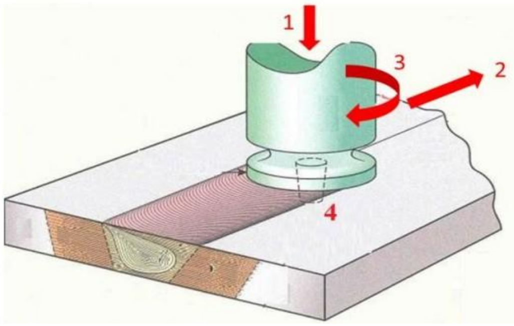
1: Heat affected zone (HAZ)
2: Flash
3: Cracks and rough surfaces
4: Hooking
5: Voids and pores
6: Lack of penetration

Figure 1. Schematic of Frequently Occurring Defect Locations in Welding Using the Friction Welding Method

1.2 FRICTION STIR WELDING

As in general FW welding, welding of different types of metals can also be done using the friction stir welding (FSW) method. FSW utilizes the friction of the rotating pin against the stationary metal material so that heat is generated and a joint is formed (Figure 2). The advantage of FSW is that porosity and cracks can be reduced. The microstructure of the FSW weld joint is smooth so that it can produce good mechanical properties in the weld joint according to the Hall-Petch equation. The FSW process is efficient so that the costs required are low and can be used to weld many types of metals. The FSW process can be carried out using a simple welding tool or can utilize a vertical milling machine that rotates the pin.

Welding that functions as a producer of frictional heat energy. FSW welding pins must be made of metal that has a melting point that is much higher than the two metals to be welded so that during the welding process there is no dirt from the deformed pin metal.



Description:
1. Downward axial force
2. Welding direction
3. Rotating indenter
4. Pin

Figure 2. Illustration of the Friction Stir Welding Process

The design of the pin in FSW can influence the welding outcomes. Joy stated that various pin shapes can lead to distinct mechanical properties and microstructures. The quality of the joint in FSW is influenced by the rotational speed of the pin. Increased rotational speed of the FSW pin generates more heat and enhances tensile strength. The maximum elastic modulus of 68.1 GPa was recorded at 3600 rpm. On the other hand, raising the welding speed led to a reduction in tensile strength. Yahya indicated that the extent of pin pressing in FSW may influence the tensile strength of the welding outcomes. Furthermore, it was discovered that the minimum tensile stress happened at the least immersion depth.

In FSW welding, defects may arise in the weld, such as porosity, which is an air pocket trapped within the weld joint and can diminish the mechanical strength of the weld joint. Tunnel defects arise from the creation of tunnels or cavities in the weld joint resulting from inadequate material flow. Insufficient penetration defects arise from the FSW pin's inadequate penetration into the material, and this flaw will weaken the joint's strength. Kissing bond defects arise from insufficient adhesion strength at the junction of the two welded surfaces. Flash formation defects arise from the accumulation of surplus material around the weld joint, caused by excessive material flow resulting from high temperatures. For pump shaft joints made with low-cost Aluminum and high-cost Copper materials, the FSW method is not ideal since the temperature rise is limited to the surface of the workpiece in contact with the pin. This condition leads to an inconsistent temperature distribution over the whole surface of the joint and is believed to weaken the joint's strength.

2.0 FRICITION WELDING ON ALUMINUM AND COPPER JOINTS

2.1 ALUMINUM AND COPPER JOINTS

Aluminum and Copper, two metals, are challenging to join via fusion welding due to notable disparities in their chemical makeup and physical characteristics. The issue occurs due to the significant difference in melting points between the two metals. Pure copper melts at approximately 1,080°c, whereas pure aluminum melts at about 670°c. Consequently, FW serves as an option for linking Aluminum and Copper, such as in the shaft joint of Aluminum and Copper materials. Both metals offer comparable benefits, such as excellent heat and electrical conductivity, and are fairly resistant to corrosion, which makes them apt for use as pump shafts subjected to corrosion stresses. Aluminum boasts excellent mechanical and physical characteristics, with a density of approximately 2,700 kg/cm3, effective electrical and thermal conductivity, comparatively high corrosion resistance, and ease of recycling. However, the melting temperature gap of about 400°c between Aluminum and Copper will greatly impact the FW process, as it needs to occur under solid or semi-solid conditions. A thorough investigation into the variations in the characteristics of these two metals is necessary to achieve successful welding outcomes. For instance, studies need to be carried out to find the ideal pressing duration, the level of pressing force, and the rotation speed. Numerous studies have been carried out to identify the optimal parameters for achieving high-quality joints in FW welding processes for Copper and Aluminum materials.

FSW of Aluminum and Copper materials achieved 203.4 MPa, representing 71.3% of the strength of the Copper base alloy. It was additionally noted that the FSW joints of Aluminum and Copper broke at the HAZ of the Aluminum side, and the fracture surface exhibited ductile fracture features. Neupane stated that when the hardness was assessed in 20 µ intervals on the Aluminum and Copper sides, the average hardness showed an increase. The hardness of the joint on the Aluminum side attained approximately 111-114 HV, while pure Aluminum measured around 94 HV, indicating an increase of roughly 20% relative to the hardness of pure Aluminum. Similarly, the joint hardness on the Copper side attained 135-140 HV, while pure Copper measures around 126 HV, reflecting a 10% rise from the hardness of pure Copper. The hardness at the welded joint significantly increased in both scenarios, with and without interlayer, because of the creation of the AlXCuY intermetallic phase. The highest hardness at the joint without interlayer reached approximately 180 HV, while the peak hardness at the joint with interlayer was around 159 HV. The hardness findings in this study were somewhat higher than those reported by Joy. They indicated that the hardness adjacent to the joint was 130 HV on the Copper side.

Indicated that the CDFW welding technique can be employed to join Aluminum and Copper, with the tensile strength of the Aluminum and Copper welds reaching a peak of 35 MPa. This state is reached at a friction pressure of 12 MPa and a friction time of 12 seconds. The use of an Aluminum interlayer is crucial for achieving a strong connection between Aluminum and Copper. In the research, the ideal thickness of the Aluminum interlayer measured approximately 0.47 mm. Joy et al noted that the hardness in the joint area of Aluminum is approximately 5-10% greater than that in the pure Aluminum region. In the Copper side joint region, the hardness is approximately 10-20% greater than that found in the pure Copper region. At the same time, the electrical conductivity of the Aluminum and Copper joint falls between the electrical conductivities of Aluminum and Copper.

Yahya stated that the rotational speed and duration significantly influence the microstructure of the welded joint. Simultaneously, Setiawan et al. noted that the tensile strength achieved by the Aluminum and Copper weld joint generally diminishes as the rotational speed increases. Moreover, Ikhsan et al. found that the design of the pin additionally influences the tensile strength of the Aluminum and Copper welding. Chapke et al. indicated that the tensile strength of the FW welding outcomes for AA6063 Aluminum with Copper can achieve 222.88 MPa by applying a friction pressure of 48 kg/mm2 along with an axial pressure of 97 kg/mm2 for a friction time of 1 second and a compression time of 3 seconds. To achieve these outcomes, the pin is constructed from stainless steel and operates at a rotation speed of 1800 rpm.

In the meantime, Joy stated that the greatest joint efficiency for welding Aluminum and Copper through the FSW technique was 79%, reached at a rotational speed of 600 rpm and a feed rate of 300 rpm (Table 2). It was additionally stated that the break at the peak UTS value took place in the thermo-mechanically affected zone (TMAZ) on the Aluminum side. The AlCu intermetallic phase was present at feed rates of 50 and 150 mm/min. Conversely, the Al2Cu intermetallic phase emerged at a feed rate of 300 mm/min since elevated feed rates decrease the heat absorption in the joint region. Kah et al. indicated that the creation of brittle intermetallic phases and their impact on weld characteristics were primarily affected by welding speed, heat input, thermal properties of the base metal and joint, along with the fluidity of both the base metal and joint metal. Kumar stated that the intermetallic phase was detected in the weld region during the welding of Aluminum and Copper. In the meantime, Shirlay et al found that the hardness of the welded joint was greater with triangular pins, while the temperature rise was elevated with cylindrical pins.

Hivaldo and colleagues carried out a study on the FSW welding technique for AA1050 Aluminum and pure Copper. The maximum UTS tensile strength recorded was 160 MPa, achieved using a cone-shaped pin at a feed rate of 12 mm/min and a rotational speed of 1200 rpm. In their study, Joy and Hivaldo employed a vertical drilling machine to join Aluminum AA6061 and pure Copper utilizing the FSW technique. They achieved the maximum UTS tensile strength of 76.8 MPa at a rotational speed of 1120 rpm with a feeding rate of 15-30 mm/min (Table 3).

Table 2. Effect of feed rate on UTS tensile strength value in friction stir welding between pure aluminum and

copper

Pin rotation speed [rpm]	*Feed rate* [mm/min]	UTS rerata [MPa]	Connection efficiency [%]	Fracture location
	50	134	55	TMAZ sisi Cu
600	150	177	73	TMAZ sisi Cu
	300	192	79	TMAZ sisi Al

Table 3. Effect of rotation speed on UTS tensile strength value and joint hardness in friction stir welding between AA6061 Aluminum and pure Copper

Pin rotation [rpm]	UTS [MPa]	Hardness[HV]
710	37.7	372
900	55.9	400
1120	76.8	460

3.0 REFERENCE

The manufacturing industry is presently expanding swiftly. In the production industry, one of these is the welding procedure. Friction welding (FW) is a welding technique that occurs in a solid or semi-solid state. FW makes use of the heat produced by friction that occurs when two metal surfaces come into contact. FW offers numerous benefits compared to the liquid phase welding method. FW is more affordable in terms of cost and offers strong welding capabilities for the same or various metals. Moreover, FW does not need filler materials. During FW welding, relatively minor shrinkage and deformation may happen, allowing for the creation of favorable mechanical properties. The inclusion of FW allows for the connection of various metal types, making FW highly applicable in manufacturing or maintenance processes to enhance the reliability of industrial machinery.

Welding various metal types, such as Aluminum and Copper for pump shafts, represents one of the benefits of FW. Aluminum and Copper possess distinct physical characteristics, yet both share similar benefits, such as being efficient conductors of heat and electricity, having a degree of corrosion resistance, and being easily manufactured via a casting method. The significant corrosion resistance is a key factor in selecting Aluminum and Copper for pump shaft materials. The case study examined this time involves a pump shaft with a circular cross-section. In comparison to Copper, Aluminum is significantly less expensive and has a considerably lower melting point than Copper.

Furthermore, aluminum is frequently produced from recycled materials, allowing for cost-effective production within the manufacturing sector. Given these circumstances, an optimal welding approach is necessary to achieve the best joining outcomes when fusion welding between Aluminum and Copper. An effective welding strategy can enhance welding outcomes, thereby improving the quality of the weld joint. The strength of this excellent weld joint is anticipated to meet industrial requirements both in the product manufacturing phase and in the upkeep process of industrial equipment. A technique to enhance welding quality is the Taguchi method. In the manufacturing industry, the Taguchi method is commonly used to enhance product quality, reduce expenses, and increase product resilience against disruptions during production.

4.0 CONCLUSION

The discusses the impact of FW joints on various metals, such as Aluminum and Copper. The quality of joints formed by friction welding is affected by factors such as rotational speed, duration of pressing, pin design, pressing force, feed rate, and the properties of the material involved. Consequently, the FW welding technique must establish the appropriate speed, friction time, and pressure force. The friction welding technique can be utilized in industry for both production and maintenance activities, as it yields more accurate welds at a lower cost, with reduced time requirements. In the situation of joining two Aluminum and Copper metals designated for pump shafts, the CDFW method is regarded as the most appropriate option, as it promotes an even temperature distribution throughout the entire surface. This will create uniform mechanical properties throughout the complete surface of the joint.

The FW welding technique in solid or semi-solid states offers numerous benefits, although it also comes with some drawbacks. Regarding operational expenses, friction welding is certainly less costly, but the cost of the FW machine is higher. Before testing various metals, comparable tests can be conducted to assess the strength comparison between similar and dissimilar metals. To assess mechanical properties, mechanical property testing of FW welding can be compared between Aluminum and Copper for instances of FW welding performed on Aluminum and Aluminum welds, or for FW welding conducted between Copper and Copper. Studies must also be conducted on metals with low melting points and on non-metal materials like polymers. For instance, pure tin melts at approximately 217°c. significantly lower than pure aluminum, which melts at about 670°c.

The technique of combining polymers and metals for industrial uses, such as in conveyor belts, is still predominantly performed through polymerization methods, adhesive bonding, or mechanical fasteners, making it essential to investigate the joining of polymers and metals utilizing the FW approach. Galvanic corrosion is likely to happen when welding different metals together. Therefore, it is essential to study an effective anti-corrosion system, such as the application of sacrificial anodes. Moreover, the Aluminum utilized in the Aluminum and Copper system should also possess high corrosion resistance, such as by incorporating Nickel elements into the Aluminum alloy. Therefore, it is essential to investigate the impact of elevated Nickel levels in Aluminum on the integrity of welded joints.

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