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Experimental Investigation of Mechanical Properties in Dissimilar Al-Cu Joints Using Friction Stir Welding

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Abstract- — Friction Stir Welding (FSW) is an advanced solid-state joining technique used for welding similar and dissimilar metals without melting the base materials. In this project, an experimental investigation has been carried out to study the mechanical properties of dissimilar joints between Aluminium Alloy AA6061 and Copper (ETP Copper) using the Friction Stir Welding process. The purpose of this study is to evaluate the effect of welding parameters on the strength and quality of the welded joints. The welding experiments were performed using a carbide conical ball nose tool under different process conditions such as rotational speed, welding speed, and plunge depth. Proper fixture arrangements and clamping systems were used to obtain defect-free joints. AA6061 aluminium and copper were selected due to their wide applications in aerospace, automobile, marine, electrical, and heat transfer industries where light weight materials with high thermal and electrical conductivity are required. After the welding process, the joints were examined through visual inspection and tested for various mechanical properties including tensile strength, hardness, and microstructural characteristics. The experimental results showed that welding parameters greatly affect heat generation, material flow, and intermetallic compound formation at the weld interface. Optimized welding conditions produced sound joints with better tensile strength and uniform hardness distribution. The investigation concludes that Friction Stir Welding is an efficient and economical process for joining dissimilar aluminium-copper materials with fewer defects and Improved mechanical properties compared to conventional fusion welding methods. The results of this project can be useful for industrial applications requiring strong, lightweight, and conductive dissimilar metal joints.

Keywords- Friction Stir Welding (FSW), AA6061 Aluminium Alloy, Copper, Dissimilar Metal Joining, Mechanical Properties, Tensile Strength, Hardness Test, Microstructure Analysis, Welding Parameters, Solid-State Welding.

I. INTRODUCTION

The rapid growth of modern industries such as aerospace, automobile, railway, marine, electrical, and manufacturing sectors has created a great demand for lightweight materials with high strength, good corrosion resistance, and excellent thermal and electrical conductivity. Aluminium and copper are two of the most widely used engineering materials because of their unique properties and industrial applications. Aluminium alloy AA6061 possesses low density, high strength-to-weight ratio, good machinability, and corrosion resistance, while copper offers excellent electrical and thermal conductivity along with high ductility. Combining these two dissimilar metals in a single component can provide both mechanical strength and superior conductivity, which is highly beneficial in industrial applications. Joining of dissimilar metals using conventional fusion welding techniques is very difficult due to differences in melting temperature, thermal conductivity, coefficient of thermal expansion, and metallurgical incompatibility between aluminium and copper. During conventional welding, excessive heat generation often leads to defects such as porosity, cracks, distortion, and formation of brittle intermetallic compounds. These defects reduce the mechanical strength and quality of the welded joint. Therefore, industries require an advanced joining technique capable of producing high-quality dissimilar joints with minimum defects.

Friction Stir Welding (FSW) is a modern solid-state welding process invented by The Welding Institute (TWI) in 1991. In this process, the materials are joined without melting the base metals. A non-consumable rotating tool having a specially designed pin and shoulder is inserted between the adjoining surfaces of the workpieces. The frictional heat generated by the rotating tool softens the material, and the plasticized material is stirred together to form a strong joint. Since the process occurs below the melting temperature of the materials, defects associated with fusion welding are significantly reduce.

In the present project, an experimental investigation is carried out on dissimilar joining of AA6061 aluminium alloy and ETP copper plates using the Friction Stir Welding process. A carbide conical ball nose tool is used for welding under controlled process parameters such as rotational speed, welding speed, and plunge depth. The welded specimens are evaluated through mechanical and metallurgical testing methods including tensile strengthtest, hardness test, and micro structure analysis. The study aims to determine the influence of welding parameters on the quality and mechanical performance of the welded joints.

The main objective of this project is to develop defect free dissimilar aluminium-copper joints with improved mechanical properties and to understand the behavior of materials during Friction Stir Welding. The findings of this investigation will help in selecting suitable welding parameters for industrial applications requiring lightweight structures with good electrical and thermal conductivity. This study also contributes to the development of advanced joining technologies for dissimilar materials in modern engineering applications.

- To fabricate defect-free dissimilar joints of AA6061 aluminium alloy and copper using the Friction Stir Welding process under different welding conditions.
- To investigate the effect of FSW parameters such as tool rotational speed, traverse speed, and plunge depth on weld quality and joint formation.
- To study the micro structural and metallurgical changes occurring in the stir zone.
- To evaluate the mechanical properties of the welded joints through tensil testing, hardness testing, and bend testing for determining optimum welding parameters.

II. PROPOSED SYSTEM AND METHODOLOGY

1. Ideation Phase
In this phase, the problem related to joining dissimilar AA6061 aluminium and Copper using conventional welding methods is identified. The need for a solid-state welding process such as Friction Stir Welding(FSW) for producing defect-free and high-strength joints is studied through literature review and reference research papers.

2. Material Selection Phase
In this phase, the problem related to joining dissimilar AA6061 aluminium and copper using conventional welding methods is identified. The need for a solid-state welding process such as Friction Stir Welding (FSW) for producing defect-free and high-strength joints is studied through literature review and reference research papers.

3. Tool And Fixture Preparation Phase
A suitable FSW tool made of tool steel/carbide material is selected for welding. Proper fixture and clamping arrangements are designed and prepared to hold the workpieces rigidly during the welding process and avoid vibration or misalignment.

4.Welding Process Phase
The Friction Stir Welding process is performed on AA6061 aluminium and copper plates using different welding parameters such as rotational speed, traverse speed, and plunge depth. Different combinations of process parameters are used to obtain sound welded joints.

5. Testing and Analysis Phase
Mechanical tests are carried out to evaluate tensile strength, hardness, bend strength, and joint efficiency of the welded specimens .Microstructural analysis is also performed using optical microscopy or SEM to study grain refinement, material flow, and formation of weld zones such as SZ ,TMAZ, and HAZ.

6. Result and Comparison Phase
The results obtained from different welding conditions are compared and analysed to Identify the effect of welding parameters on the mechanical and metallurgical properties of the welded joints. Optimum welding parameters are determined based on maximum joint strength and weld quality.

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IV. WORKING PRINCIPLE

In Test 1, friction stir spot welding of AA6061 aluminium alloy and ETP copper was carried out using a carbide conical tool on a CNC-VMC machine. The welding parameters selected for this trial were 1250 rpm rotational speed, 28 mm/min traverse feed, 5 seconds dwell time, and 0.5 mm plunge depth. During the welding operation, it was observed that the heat generated at the weld interface was comparatively low. Since aluminium and copper are dissimilar materials with different thermal properties, proper heat generation is extremely important to soften both materials and achieve sufficient plastic deformation. However, in this test, the selected dwell time was too short to produce the required amount of frictional heat. As a result, the material around the tool pin did not become sufficiently plasticized, and proper stirring action between aluminium and copper could not take place effectively. After completion of welding, visual inspection of the welded specimen revealed poor surface appearance and incomplete nugget formation. The weld spot lacked proper bonding between the two materials, and the joint failed during inspection due to weak metallurgical bonding. The failure of Test 1 clearly indicates that the welding parameters were not suitable for joining 4 mm thick aluminium and copper plates. Copper has very high thermal conductivity, which causes rapid dissipation of heat from the weld zone. Therefore, the generated frictional heat was insufficient to maintain the required welding temperature at the interface. The lower plunge depth of 0.5 mm also reduced the contact area between the tool shoulder and the material, limiting the forging pressure and material mixing. Because of inadequate heat generation and insufficient penetration, the weld zone experienced poor material flow and lack of proper consolidation. No significant flash formation was observed, which further confirmed that the material was not softened adequately. In friction stir spot welding, controlled heat generation and proper stirring action are necessary to form a defect-free nugget zone. The experimental result demonstrated that lower dwell time and insufficient penetration produce weak weld joints with poor strength and incomplete bonding. Therefore, Test 1 was considered unsuccessful due to low heat input, poor plastic deformation, and improper weld formation.

In Test 2, the welding process was performed at 1000 rpm ,rotational speed, 20 mm/min traverse feed, 15 seconds dwell time, and 1.5 mm plunge depth. Compared to Test 1, higher heat generation and greater material deformation were observed during welding. The increased dwell time allowed more frictional heat generation, improving the softening of aluminium and copper near the weld region. However, excessive plunge depth caused severe penetration of the tool into the material, resulting in excessive flash formation and surface deformation around the weld spot. The weld region showed partial bonding, but defects such as material expulsion and distortion were clearly visible. The failure of Test 2 was mainly due to excessive plunge depth and overheating of the weld zone. The depth of cut of 1.5 mm was too high for 4 mm thick plates, causing over softening of the aluminium material and weakening the joint region. The prolonged dwell time further increased heat concentration and promoted excessive material flow. As a result, the weld developed surface defects and unstable bonding conditions. This experiment demonstrated that although sufficient heat is necessary for proper welding, excessive penetration and overheating can significantly reduce weld quality and lead to weld failure.

V. RESULTS AND DISCUSSION

In this experimental investigation, friction stir spot welding (FSSW) was carried out on dissimilar materials AA6061 aluminium alloy and ETP copper using a carbide conical tool. The objective of the experiment was to study the effect of welding parameters such as tool rotational speed, dwell time, plunge depth, and traverse feed on weld quality. During the experimental trials, two different parameter combinations were tested on CNC VMC machine. After welding, the welded specimens were visually inspected and analyzed for surface appearance, bonding condition, heat generation, and weld defects. The experimental trials resulted in unsuccessful weld joints due to improper parameter combinations. However, the failed trials provided important information regarding heat input, material flow behaviour, and parameter optimization for aluminium-copper friction stir spot welding. The observations obtained from the experiments are discussed in detail in this chapter.

Scope & Future Work

The present experimental work mainly focused on studying the effect of basic welding parameters on the joining behaviour of AA6061 aluminium and ETP copper using friction stir spot welding. Although the weld trials were unsuccessful, the study provided important information regarding parameter optimization and defect formation. There is significant scope for further research and development in this area to improve weld quality, mechanical properties, and industrial applicability of the process. Future work can be carried out by optimizing the welding parameters more accurately using multiple experimental trials and design of experiments techniques such as Taguchi method or Response Surface Methodology (RSM). Parameters such as rotational speed, plunge depth, dwell time, tool tilt angle, and axial force can be varied systematically to identify the optimum condition for achieving defect free weld joints with higher strength. The use of different tool geometries such as threaded pins, tapered pins, cylindrical pins, and square pins can also be investigated to improve material mixing and nugget formation. Further studies can be performed on microstructural analysis and mechanical testing of welded joints. Tests such as tensile strength testing, hardness testing, bend testing, fatigue testing, and impact testing can be conducted to evaluate the performance of welded specimens under different loading conditions. Advanced metallurgical investigations using optical microscopy, scanning electron microscopy (SEM), and X-ray diffraction (XRD) can also be used to study grain refinement, intermetallic compound formation, and fracture behaviour of the weld region. Another important area for future research is the reduction of defects such as flash formation, keyhole defects, tunnel defects, and excessive thinning of the material. Proper backing plate design, improved clamping systems, and controlled heat input can help minimize these defects and improve weld stability. The effect of cooling techniques and hybrid welding approaches can also be explored to control heat generation and reduce formation of brittle intermetallic phases between aluminium and copper. Future research may also focus on the application of friction stir spot welding for other dissimilar material combinations such as aluminium-steel, aluminium magnesium, and copper-steel joints. Automation and real-time monitoring systems can be implemented to improve process control and industrial productivity. Numerical simulation and finite element analysis can additionally be used to predict temperature distribution, stress formation, and material flow behaviour during welding. In conclusion, friction stir spot welding has strong potential for lightweight structural applications because of its energy efficiency, low distortion, and solid state joining characteristics. With proper optimization of process parameters and tool design, the process can be further developed to produce high-quality dissimilar joints suitable for advanced manufacturing industries.

VI. CONCLUSION

The present project focused on the experimental investigation of friction stir spot welding (FSSW) of dissimilar materials AA6061 aluminium alloy and ETP copper using a carbide conical tool on a CNC-VMC machine. The main objective of the work was to study the effect of important welding parameters such as rotational speed, dwell time, plunge depth, and feed rate on the quality and performance of welded joints. Since aluminium and copper possess different thermal and mechanical properties, joining these materials using conventional fusion welding methods is difficult because of excessive heat input, distortion, porosity, and formation of brittle intermetallic compounds. Friction stir spot welding was selected as a suitable solid-state joining technique because it eliminates melting of the materials and provides improved mechanical and metallurgical properties. During the experimentation, two welding trials were conducted using different process parameter combinations. In the first trial, the welding process was performed at 1250 rpm rotational speed, 5 seconds dwell time, and 0.5 mm plunge depth. The weld joint failed mainly because of insufficient heat generation and poor material flow between the aluminium and copper plates. The shorter dwell time and smaller penetration depth were unable to produce the required plastic deformation and stirring action needed for proper bonding. As a result, incomplete nugget formation and weak joint strength were observed. In the second trial, the dwell time and plunge depth were increased in order to improve heat generation and material mixing. Although the material flow improved slightly, excessive plunge depth and prolonged dwell time caused overheating, excessive flash formation, surface deformation, and unstable weld quality. The weld again failed because of over penetration and excessive softening of the aluminium material.

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