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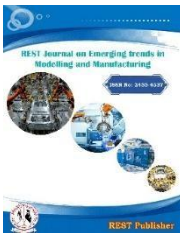

Comparative Study of Friction Stir, Stud and Seam Welding of Aluminium Alloys Using Different Grades

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Abstract. *Friction stud welding is an innovative and efficient welding process used to create strong and reliable bonds between studs or fasteners and workpieces, particularly in applications where rapid and secure fastening is critical. This welding technique involves generating friction and heat between the stud and workpiece to forge a strong joint. The process consists of several key steps, including preparation, rotation, weld formation, and cooling. Friction stud welding offers numerous advantages, such as speed, consistency, minimal distortion, and the elimination of the need for additional filler materials. It is widely employed in various industries, including construction, automotive, and aerospace, for applications ranging from structural steel connections to automotive component assembly. However, successful friction stud welding necessitates careful selection of materials, welding parameters, and skilled operators to ensure durable and dependable welded joints. This abstract provides a concise overview of the friction stud welding process and its essential features.*

Keywords: *Friction stud welding, welding parameters, welded joints, speed, consistency.*

1. INTRODUCTION

Friction stud welding is a versatile and innovative welding process designed for creating robust connections between fasteners or studs and a wide range of workpieces, predominantly composed of metals. It is a technique that finds extensive application in industries where the need for secure, rapid, and reliable fastening is paramount. This process leverages the principles of friction and heat to forge a solid and durable joint. The fundamental concept behind friction stud welding is to generate the required heat and friction by rapidly rotating the stud while it is pressed against the workpiece. As the stud and workpiece come into contact and rotate against each other, the friction between them generates heat, which softens the material at the interface. This softened material then undergoes plastic deformation, allowing the stud to forge into the workpiece, forming a secure and integral bond. Once the welding process is complete, the joint is allowed to cool and solidify, resulting in a high-strength connection. Friction welding is one of the latest and recent developing fields which were developed in early 1950's. Thermal analysis of the welding process can be carried out by means of different methods. The heat transfer, temperature distribution, heat flux can be found by means of FDM or FEM. A proportional analysis of heat generation in friction welding of steel bars is determined by using four different methods; constant coulomb friction, sliding-sticking friction, the experimentally measured power data and the inverse heat conduction approach.

A comparison amongst the calculated temperature profiles and the experimental data demonstrations that the inverse heat conduction approach forecasts the heat generation rate exactly, however the constant friction coefficient approach leads information to the most inaccurate temperature profile. The finite element analysis indicates that the heat generation rate due to the plastic deformation in the work piece away from the interface is negligible compared to the heat generation rate by friction. Continuous drive friction stud welding is a solid-state joining process very similar to friction welding. It produces coalescence by the heat developed between two surfaces by 123 Author's personal copy Arab J Sci Eng mechanically induced rubbing motion. When the appropriate rotation speed is reached, the two work pieces are brought together and an axial force is applied. The two surfaces are held under pressure. After a predetermined time, the rotation stops and the pressure is increased to facilitate forging and local upsetting of the heated metal. Filler metal, flux, or shielding gas is not required with this process. Since, friction welding does not involve melting of the parent material, it is an ideal joining process for high-strength aluminium alloys and aluminium-based metal matrix composites. Friction welding is well proven in the automotive industry, where it is used in fabrication of critical components such as drive shafts and hydraulic cylinders.

Friction stud welding, Friction Plug Welding, Diffusion bonding, Friction Welding, Friction Drilling, and Friction Riveting, are few processes employed for joining of dissimilar metals. Friction stud welding, a solid phase welding technique that uses a stud rotating at a high speed, being forced against a substrate and generating heat by friction. The metal surfaces reach the temperature of plasticity and they flow plastically under pressure, surface impurities are expelled and a forged weld is formed. The melting point of metals are much higher than the maximum temperatures attained. It is a unique type of friction welding process. Portable equipment for friction stud welding is available for the use on construction work sites, offshore, underwater and in workshops. These units are portable and are lighter and smaller than the large static friction welding machines. The weld time being short, around only 4 seconds for a 10mm diameter stud. Weld quality is consistently high, and when destructively tested, failure invariably occurs in the weaker parent material and well away from the weld.

The friction stud welding (FSW) process: uses compressive force to weld the work piece to the stud while removing material from the faying surfaces. The fundamental idea behind this approach is the conversion of mechanical energy into heat energy. Additionally, the heat affected zone is minimal and slag inclusion defects are absent as well as less consumed time process. When the metal surfaces reach a certain temperature, surface contaminants are ejected, the metal surfaces flow under pressure, and a forged weld is created. The highest temperatures that can be reached while welding are significantly smaller than the metals' melting points.

The contact region of the friction welded joints is fully welded. The heat is produced at the contact surface as a result of the friction between the pieces. When the rotation stops at the welding temperature, an upsetting force is applied to the deformed material, allowing the joint to cool and consolidate. When the melting temperatures of two metals differ significantly, this process alters conventional welding methods. Another reason is the use of anodes that produce electricity in moist environments, which conducts electricity and causes corrosion in the welding region.

Applications for the friction stud welding procedure are varied, but the most crucial ones include offshore settings, explosive conditions, and live pipelines. The promising employees of this method are the using in trusses and shear connectors of structures and bridges as well as the foundations of structures. A limited number of studies were conducted in the field of underwater FSW to investigate the relationship between the process variables and the performance of the welded joint.

Friction stud welding offers several key advantages that have made it a popular choice in various industries:

1. **Speed**: This method is renowned for its efficiency and speed. It is well-suited for high-volume production environments where rapid assembly is crucial.
2. **Consistency**: The process ensures a high degree of weld consistency, contributing to the reliability of the connections it forms.
3. **Minimal Distortion**: Friction stud welding typically results in less distortion and reduced heat-affected zones in the workpiece compared to some other welding techniques.

No Filler Material: In most cases, friction stud welding does not require the use of additional filler materials, simplifying the welding process inception and continues to be a valuable tool in modern manufacturing and fabrication processes.

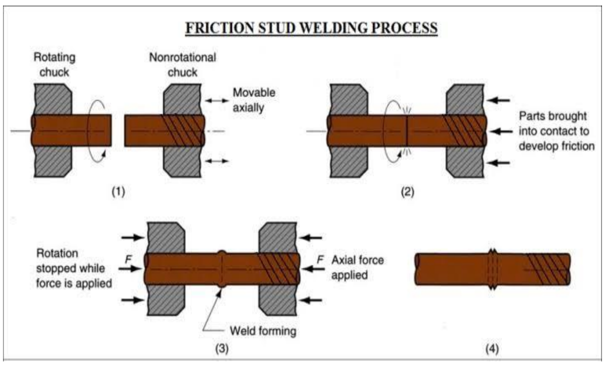

FIGURE 1.

2. LITERATURE REVIEW

Friction Stir Welding (FSW) is a solid-state welding process that was invented by The Welding Institute (TWI) in 1991. Unlike traditional fusion welding processes, FSW does not involve melting the materials being joined. Instead, it relies on frictional heat generated between a non-consumable rotating tool and the workpieces to soften the material and facilitate the welding process**.** Friction Stir Welding has proven to be a valuable technique for joining materials in applications where traditional fusion welding methods may face challenges. Ongoing research continues to explore new materials, joint configurations, and process optimizations to broaden the range of applications for FSW.

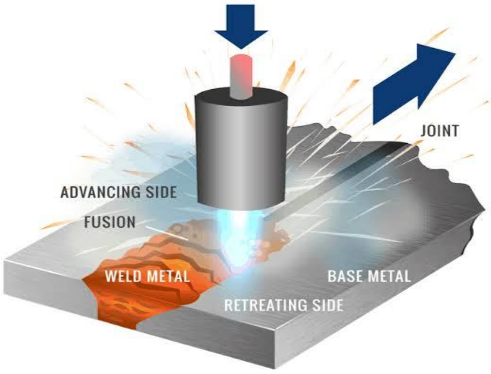

FIGURE 2. Friction Stir Welding

3. LITERATURE REVIEW

Literature reveals findings on Wire-cut Electro Discharge Machining of various materials. Most of the work is reported to study the parameters like Pulse on time, pulse off time and servo voltage, wire tension, wire speed, to find out Surface roughness, Material removal rate (MRR)and Kerf width using different types of tools and with the help of design of experiments and statistical optimization techniques

1. Paul A. Fleming , Christopher E. Hendricks , D. M. Wilkes ,George E. Cook(The International Journal of Advanced Manufacturing Technology. Vol: 45, page:490-495, Year- 2009) presented a paper on Automatic seam-tracking of friction stir welded T-joints. This research is about a method for implementing automatic seam-tracking for friction stir welding, referred to hear as Weave Track, is presented. In this extrumum-seeking control technique, the tool weaves back and forth during welding to maintain the location where axial force is greatest, which is shown to be the center of the weld. Results demonstrate the effectiveness of this technique in tracking both known and unknown weld-seams

2. D.G. Hattingh, D.L.H. Bulbring, A.Els-Botes, M.N. James(Materials & DesignVol:32,Issue: 1, Page: 3421 – 3430, Year-2011) presented a research paper on Tool Positions of Process parameter influence on performance of friction taper stud welds in AISI 4140 steel. This paper considers the effect of weld process parameters on weld defects, macrostructure and mechanical properties in AISI 4140 steel. It also presents 3D residual stress data for a typical friction taper stud weld.
3. Jorg Hildebrand, Hadi Soltanzadeh (International Journal of Steel Structures, Vol:14, Page: 412 – 438, Year-2014) proposed a paper on the topic of A review on assessment of fatigue strength in welded studs. This paper mainly concentrates on the unwanted side effects occur like thermal strains and altering of certain material properties induced by heating and melting. These effects lead to distortions and high residual stresses which should be kept to a minimum. To minimize distortion, various strategies are being developed.
4. R. M. Chandima Ratnayake, H. 0. Ytterhaug, P. Bogwald, S. T. R. Nilsen (Journal of Offshore Mechanics and Arctic Engineering. Vol:137, Issue: 1 Page: 401(1 - 6), Year- 2015) presents a paer on the topic of Underwater Friction Stud Welding Optimal Parameter Estimation: Engineering Robust Design Based Approach. This paper briefly explains about an experimental study has been initiated to investigate the optimal FRSW parameter combinations and corresponding values leading to optimal ultimate tensile load capacity (UTLC) values in the welded joint. The engineering robust design (ERD) approach has been deployed to run the experiment.
5. N.Rajesh Hynes, P.Nagaraj, R.Tharmaraj (International Journal of Applied Engineering Research. Vol: 8, Page No:6107-6110. Year-2015) proposed a paper about Prediction of Thermal Profile during Friction Stud Welding of aluminium - Mild Steel Joints. In this study numerical simulation is carried out using ANSYS software and the temperature profiles are predicted at various increments of time. `adequate to predict thermal profile of friction stud weld Aluminium – mild steel joints.
6. S. Yu.Tarasov,V. E. Rubtsov,E. A Kolubaev,, S. F. Gnyusov (Radioscopy of remnant joint line in a friction stir welded seam.Vol: 51,page: 573–579. Year-2015) presented Radioscopy of Remnant Joint Line in a Friction Stir Welded Seam. The possibilities of the radioscopic detection of defects such as remnant joint lines, which occur during friction stir welding, have been evaluated. In addition to common radioscopy, a micro focus source of Xray radiation and metallography were applied to attain high geometric magnification.

7. Rahul Jain, Surjya K.Pal, Shiv B.Singh (Journal of Manufacturing Processes.Vol:23,Page:278 – 286, Year-2016) present a paper in the topic of A Study on the variation of forces and temperature in a friction stir welding process. This paper explains about a finite element approach. A Three-dimensional coupled thermo-mechanical finite element model (FEM) is proposed to simulatea friction stir welding (FSW) process based on Lagrangian incremental technique. Since FSW is a large deformation process, workpiece is considered as a rigid visco-plastic material.
8. Hui Gao, Juntie Che,Yanhong Gu.Huijuan Ma (Journal of Materials Engineering and Performance. Vol:27, Page:666 – 676. Year-2018) proposed a paper on Microstructure, Chemical Composition and Local Corrosion Behavior of a Friction Stud welding Joints. This paper details about the scanning vibrating electrode technique (SVET) and localized electrochemical impedance spectroscopy (LEIS) were used to investigate the localized corrosion behaviors of the welded joint.
9. A. Lukaszewicz (Journal of Friction and Wear .Vol : 39,page:612–619, Year-2018) presents a paper on Nonlinear Numerical Model of Friction Heating during Rotary Friction Welding. This research is about A calculation procedure to determine the temperature field during rotary friction welding of metal is proposed. An axisymmetric nonlinear boundary value problem of heat conduction taking into account the frictional heating of two cylinders (specimens) of finite length is formulated.
10. Juan Dong, Lingbo Wei, Xiaopeng Gu (Journal of Advanced manufacturing technology- July 2019) presents about a topic on Ultrasonic C scan detection research for effective connection area of arc stud weld joints. This paper is fully about the analysis of friction stud welding through ultrasonic echo signals and C-scan detection. Ultrasonic detection has been widely used because of its convenience, reliability, safety, efficiency.

TABLE 1.

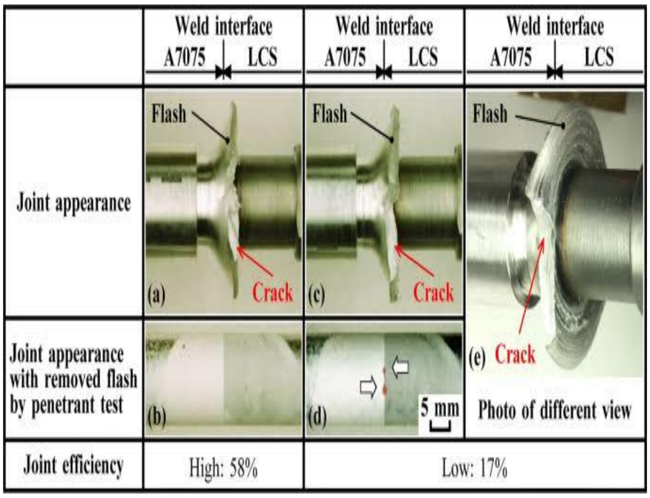

TABLE 2.

Description	Friction Stir welding	Friction Stud welding	Friction Seam Welding
Definition	FSW works by using a non-consumable tool, which is rotated and plunged into the interface of two workpieces.	friction stud welding is done by the process of rotating a round stud and pressing it against a sheet or plate. The process can be used for joining dissimilar metals.	Seam welding uses a wheel-shaped electrode to make either a series of overlapping spot welds to form a continuously welded and leak tight seam or a number of spot welds spaced apart

TABLE 3.

Description	Friction Stir Welding	Friction Stud Welding	Friction seam welding
Principles	Involves a rotating, non-consumable tool that stirs and forges materials together without melting.	Involves rotating a stud against a stationary workpiece, generating heat and pressure to create a solid-state bond.	Uses frictional heat and pressure to create a seam between two overlapping materials.
Advantages	1. A high welding speed. 2. No filler material. 3. No cooling period required.	1. Reduced heat affected zone. 2. Minimal residual stress. 3. Versatile: a) materials b) environment.	1. Automation potential 2. High strength and durability. 3. Suitable for large structures.
Applications	Commonly used in aerospace, automotive, and marine industries.	Commonly used for attaching studs to various components, especially in construction and automotive applications.	Often applied in the automotive industry for components like fuel tanks.
Tool Material used	1.High-Speed Steel (HSS) 2.Tungsten Carbide (WC) 3.Polycrystalline Boron Cubic Nitride(PBCN) 4.Tool Steel 5.Composite Tool	1.High-Speed Steel(HSS) 2.Tungsten Carbide (WC)	1.Rotating Wheel

4. SELECTION OF MATERIAL

The different types of materials used in this work are aluminium matrix composite (AMC) and AISI 304 stainless steel. Aluminium alloy (AA 6063) in ingot form is used as a base material for preparing metal matrix composite, and the reinforcements are silicon carbide (SiC), boron carbide (B4C) and graphite in powder having the size of 220 mesh. The composition of AMC is 80% AA 6063, 10% SiC, 5% B4C and 5% Gr. Nagy and Adler evaluated solid state bond microstructure using ultrasonic principle. Using ultrasonic technique, Linertetal. conducted investigation on the microstructure of Aluminium based metal matrix composites. In the present work, dissimilar metals aluminium alloy AA 6063 and AISI 1030 steel are welded by friction stud welding process and the resulting properties were investigated. The purpose of choosing ultrasonic testing is to determine various mechanical properties like longitudinal modulus, bulk modulus, shear modulus, Young's modulus, Poisson's ratio in dissimilar welded joints. From the obtained data, mechanical properties were found using standard formulae [11] and variations of the properties at different locations of the AA 6063/AISI 1030 joint could be determined. Experimentation was done in rotary friction welding machine. The in-house was made with the capacity of 15 HP. The machine consists of one rotating chuck to which the taper stud is held and a stationary chuck in which the plate is fixed. Upsetting pressure is applied by means of a hydraulic actuator. To hold the plate in chuck, a special fixture is designed and fabricated to withstand against heavy axial force and torsional force. Taper studs were made out of Ti6Al4V titanium alloy with 20 mm diameter and 70 mm length.70 9 40 9 30 mm size aluminium alloy AA2024 was chosen for welding trials. The stud had a nominal angle of 600 as shown in Figs. 1 and 2. The stud is fixed to the rotating member of the friction welding machine. The AA2024 plate was fixed to the reciprocating stationary chuck with the help of the fixture.

The material used in the present study was 6061BE-O aluminium alloy (A5083-JIS) bar and plate. The chemical composition and mechanical properties of the base metal are listed in Tables 1 and 2, respectively. Prior to welding, a round bar was cut to 77.0 mm in length and machined down to 16.0 mm in diameter. In addition, for the arc stud welding, a 20 mm length of bar on the welding end was machined down to 12.7 mm in diameter and a 135° vertical angle, with a protrusion of 2 mm in diameter and 1 mm height on the centre of the welding surface, as shown as Fig. 1. For both welding methods, a plate was machined down to 45.0 mm in diameter and 14.0 mm in thickness. The arc stud welding was conducted on a stud welding machine (Nippon Stud Welding Co., Ltd.: N800i and 40SD gun). The arc stud welding parameters were 520 A welding current, 900 ms welding time, 7 l/min Ar shielding gas, positive electrode polarity, 4.8 mm electrode extension, and 3.2 mm electrode pull-up. A ferrule was not used. Friction welding was conducted using a brake-type friction welding machine. The friction welding parameters were 9.8 MPa friction pressure, 14.7 MPa upset pressure, 3.0 mm total loss, and 1800 rpm rotation speed.

An austenitic stainless-steel stud (ASS 304) and low-carbon steel plate (LCS 1017) were used in the investigation, with chemical composition and mechanical properties shown in Tables 1 and 2. The dimensions of the stud were (16x75 mm), while the plate dimensions were (6x50x50 mm). The tools used in this study are the load cell, weight indicator, and manufacturing grip for fixing the plate. Finally, we were using Al-6061 and Al-6082combinational metal. Al-6061 is a high-strength, non-heat-treatable alloy primarily composed of aluminium (Al), magnesium (Mg), and a small amount of manganese (Mn). It is known for its excellent corrosion resistance and weldability. AL6061 is often used in marine and aerospace applications due to its high strength and resistance to seawater corrosion. When using AL6061 for friction stud welding, it's essential to ensure proper cleaning and surface preparation to remove any contaminants and oxidation. Both AL6061 and AL6082 can be used for friction stud welding. However, it's crucial to ensure that the stud material is compatible with the base material. Select a stud material that complements the aluminium alloy's properties to achieve a strong and reliable weld.

5. FABRICATION METHODS AND EXPERIMENTAL WORKS

The setup for friction stud welding process is by using Milling machine. In this setup, we will fix the Stud in the milling machine for friction welding. This will makes some frictional loss in the workpiece. Friction stud welding was used to join the dissimilar materials of low carbon steel (LCS) plate and austenitic stainless steel (ASS) stud. The load cell was mounted on the tail stock of the lathe using a fabricated grip as part of the procedure.
After working in the milling machine, we may make some tests in the weldment for checking its Tensile strength by the followings:

Tensile Test: Tensile tests were conducted in accordance with ISO 14555. The specimens were installed in fabricated grips in accordance with ASTM A370, as depicted. The WDW 200 E type tensile test apparatus was used. This test aims to determine the maximum ultimate tensile strength (UTS) and the load to failure of friction-welded joints in comparison to base metals**.**

Torque Test: According to ISO 14555, the three specimens were required to undergo a torque test. ASME BPVS IX-2019 and the acceptance criteria has been compared.

Microstructure and Macrostructure Test: Microstructure testing for aluminium alloys involves examining the internal structure of the material at a microscopic level to assess its grain size, phase distribution, and the presence of defects. These tests help determine the quality, mechanical properties, and suitability of the aluminium alloy for various applications.
The macrostructure test was conducted to determine the general attitude of the welded specimens as well as any surface defects and homogeneity. The alignments of the welded specimens were also examined by the created flash.

Rockwell Hardness Test: The Rockwell hardness test is a widely used method for assessing the hardness of materials, including aluminium alloys. There are specific Rockwell scales suitable for testing the hardness of aluminium alloys. The two primary Rockwell scales commonly used for aluminium alloys are the Rockwell B and Rockwell E scales.

6. TOOL MATERIALS

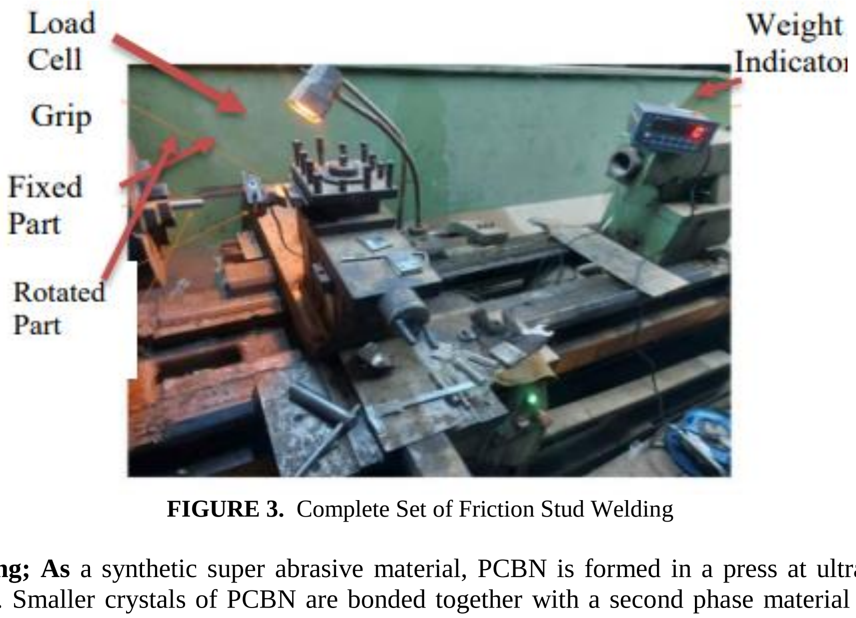

FIGURE 3. Complete Set of Friction Stud Welding

Friction Stir Welding; As a synthetic super abrasive material, PCBN is formed in a press at ultra-high pressure and elevated temperature. Smaller crystals of PCBN are bonded together with a second phase material acting as a catalyst during the sintering operation. PCBN is second in hardness only to diamond, exhibit excellent high-temperature strength and hardness, and offers greater thermal and chemical stability than diamond. Sorensen et al. [5–8] and Rai et al. [9] have provided thorough summaries of PCBN super abrasive materials, material processing, characteristics, and basic tool designs. The design of PCBN FSW tools has changed dramatically over the past decade. Early tools had no features, i.e., a smooth concave shoulder with a featureless cylindrical or truncated cone probe. In 2003, a step spiral threaded feature was added to the probe, and in 2005, scrolls were added to a convex shoulder. These features helped to improve process productivity, and eliminated adverse microstructures and defects characteristic to the older generation of tool designs. The PCBN family of FSW tool materials have been successfully used in joining a number of high softening temperature alloys, such as austenitic stainless steels, duplex stainless steel, super martensitic stainless steel, nickel alloys, tool steels, and a variety of other steels.

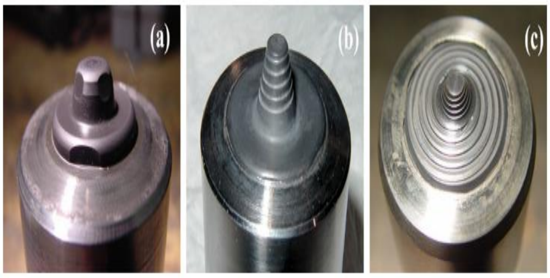

FIGURE 4.

Friction Stud Welding; An austenitic stainless-steel stud (ASS 304) and low-carbon steel plate (LCS 1017) were used in the investigation, with chemical composition and mechanical properties. The dimensions of the stud were (16x75 mm), while the plate dimensions were (6x50x50 mm). The tools used in this study are the load cell, weight indicator, and manufacturing grip for fixing the plate

Friction Seam Welding; AISI 304; AISI 1012; Ni-based alloys: IN 600, IN 625, HX; AA 6061; commercially pure CP Cu, CP Ni, and Ti6Al4V. The thickness ranges of metallic sheets were 0.5–5.0 mm. The dimensions of the sheets used were as follows: 190 mm × 200 mm × thickness. Non-consumable rods, CP Mo with 25.4 mm dia. and AISI 304 with 25.4 mm dia. and R_a 1–2 μm were used to obtain the seam welds. CP Mo rod was used for seam welding of high temperature melting metallic sheets, AISI 304, AISI 1012, In 600, IN 625 and HX sheets, CP Cu, CP Ni, and Ti6Al4V. AISI 304 rod was used for low temperature melting metallic sheets, AA 6061. It can be noted that the non-consumable rods used were pin less in contrast to the tool used with pin for the conventional friction seam welding.

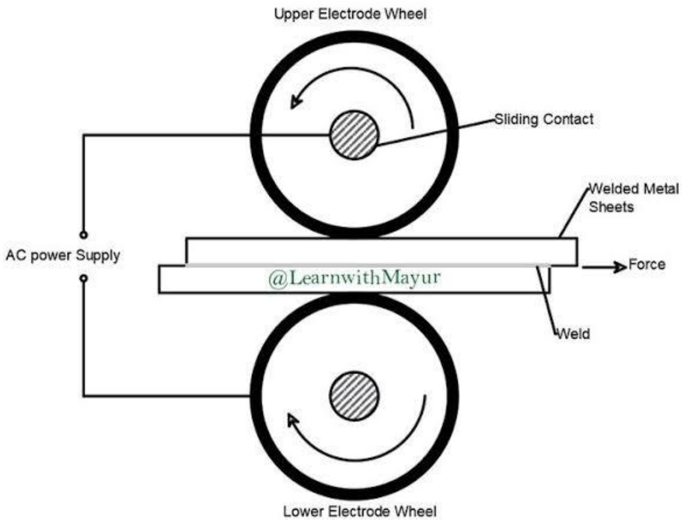

FIGURE 5. Resistance Seam Welding

7. EXPERIMENTAL RESULTS

Tensile test results: The ultimate tensile strength of the tested specimens and withstand forces of specimens were finded out. In comparison to Al 6061 material, the standard specimen of 304 austenitic stainless steel has the lowest ultimate tensile strength. The load to failure results indicate that S3 is more withstanding than S1 and S2 when comparing. As the diameter of the employed stud was increased, the specimens' bonding strength increased. The reason is that the larger diameter specimen has larger welded contact area than smaller diameter specimen.

Torque test results: The torque test results for aluminium alloys AL6061 and AL6082 can provide information about their mechanical properties, including their resistance to torsional forces. Torque testing is typically used to assess the strength and ductility of materials. The results can be obtained in the form of torque values at which various types of failure occur. These values may include the maximum torque, yield torque, and fracture torque. However, without specific torque test data, I cannot provide you with precise results for AL6061 and AL6082. Torque test results can vary depending on the alloy's temper, heat treatment, sample geometry, and the specific testing conditions.

Rockwell Hardness Test: Heat-affected zones are second in order of Rockwell hardness after the welding zone. Frictionally welded specimens typically exhibit hardness values that are similar to base metals and that are higher on the edges than in the core. Because smaller diameter specimens lose more heat than larger diameter specimens do, the S1 of smaller diameter specimens has a higher hardness value than those of bigger diameter (S2 and S3).

8. CONCLUSION

In conclusion, friction stud welding is a solid-state welding process that offers several advantages for joining a wide range of materials, including various types of metals. It is a versatile and efficient method for creating strong and reliable connections. Here are the key points to consider regarding friction stud welding:

Solid-State Welding: Friction stud welding is a solid-state welding technique, meaning it doesn't involve melting the materials. Instead, it relies on heat generated through friction to create a strong bond.

Materials: This process can be applied to various materials, including aluminum, steel, and other metals. The choice of materials depends on the specific application requirements.

Process Steps: Friction stud welding involves several key steps, including the preparation of materials, friction heating, forge pressure, upset forging, and controlled cooling. Proper control of these parameters is crucial for successful welding.

Clean Surfaces: Adequate surface preparation, including the removal of contaminants, oxides, and impurities, is essential to ensure the quality of the weld.

Quality Control: Rigorous quality control measures are necessary to assess and confirm the integrity of the welds, including microstructure tests and other non-destructive testing methods. **Compatibility:** The choice of stud and base materials should be compatible to achieve a strong and reliable connection.

Applications: Friction stud welding is used in various industries, including automotive, aerospace, construction, and shipbuilding, where strong and durable connections are required.

Operator Training: Proper training and experience are essential for operators to perform friction stud welding safely and effectively.

Overall, friction stud welding is a valuable welding process that offers advantages in terms of joint strength, efficiency, and the ability to join dissimilar materials. It plays a significant role in modern manufacturing and construction processes, providing durable and high-quality connections in a variety of applications.

REFERENCES

[1]. N. Rajesh Jesudoss Hynes, R.Kumar, and J. Angela Jennifa Sujana. (2016). " Modeling of Process Parameters of Friction Stus Welding Using Fuzzy Logic System ". International Journal of Advanced Engineering Technology, Vol. 7, no. 1, pp. 0413-417.

[2]. N. Rajesh Jesudoss Hynes. P. Nagaraj. R. Palanichamy. C. A. K. Arumugham. J. Angela Jennifa Sujana. (2014). "Numerical Simulation of Heat Flow in Friction Stud Welding of Dissimilar Metals". Arabian Journal for Science and Engineering, pp. 9.

[3]. M.J. Jweeg, Z.Kh. Hamdan, A.H. Majeed, K.K. Resan, and M. Al-Waily. (2021). "A new method for measurement the residual stresses in friction stir welding". Archives of Materials Science and Engineering, Vol. 112, no. 2, pp. 63-69.

[4]. Serkan Bati, Musa Kilic, and İhsan Kirik. (2016). " Friction Welding of Dissimilar AISI 304 And AISI 8640 Steels". European Journal of Technic, Vol. 6, pp. 79-86.

[5]. Ali A. Aslman, Ayad M. Takhakh, and Kadhim K. Resan. (2016). "Study the Mechanical Properties and Numerical Evaluation of Friction Stir Processing (FSP) for 6061-T6 Aluminum Alloys ". Al-Nahrain University, College of Engineering Journal, Vol. 19, no. 2, pp. 255-264.

[6]. N. Rajesh Jesudoss Hynes, P. Nagaraj, and R. Tharmaraj. (2015). "Prediction of Thermal Profile during Friction Stud

Welding of Aluminium - Mild Steel Joints ". International Journal of Applied Engineering Research, Vol. 10, no. 8, pp. 6107-6110.

[7]. Ihsan Kırık, Edip Çetkin, Musa Kılıç, and Zülküf Balalan. (2019). "Investigation of Microstructural Properties of 5140 Steel with 316 Stainless Steel Joined by Friction Stud Welding". 4th International Science Symposium, Kiev-Ukraine, pp. 19-24.

[8]. Hynes, N.R.J. Nagaraj, P., and Sujana, J.A.J. (2014). "Ultrasonic Evaluation of Friction Stud Welded AA 6063/AISI 1030 Steel Joints". Materials & Design, Vol. 62,pp. 118-123.

[9]. R.E. Chalmers. (2001). IOP Manufacturing Engineering, 126, pp. 64–65.

[10]. D.E. Spindler. (1994). "What Industry Needs to Know About Friction Welding". Welding Journal. pp. 37–42.

[11]. H.E. Boyer, and T.L. Gall. (1988). "Metals Handbook". Desk Edition, Ohio, pp. 30–58.

[12]. P. Jenning. (1971). "The Welding Institute, Abinghton Hall Cambridge, pp. 147–153.

[13]. R. Tharmaraj, N. Rajesh Jesudoss Hynes, and P. Shenbaga Velu. (2020). "Investigation on friction stud welded AMC/AISI 304 steel joints with ceramic intercoating". Journal of the Brazilian Society of Mechanical Sciences and Engineering, Vol. 42, no. 538, pp. 8.

[14]. Sare Çelik and Ismail Ersozlu. (2014). "Investigation of Microstructure and Mechanical Properties of Friction Welded AISI 316 and Ck 45 Steels ". High Temp. Mater. Proc., Vol. 33, no. 2, pp. 161-170.

[15]. D.S.Samuvel Prem Kumar, R.Pravin, S.Kavin Raj, Ms. B.Benita , N.Samuel Dinesh Hynes, and R.Nagarajan. (2020). "Process Capability & Fascinating applications of Friction Stud welding ". IOP Conf. Series: Materials Science and Engineering 923.

[16]. G. Kapil. (2020). "Surface Engineering of Modern Materials ". South Africa, Ch. 2.

[17]. K. Kamil, C. Yilmaz, and C. Ahmet. (2006). "Heat Transfer in Continuous-Drive Friction Welding of Different Diameters". An International Journal of Computation and Methodology, Vol. 48, no. 10, pp. 1035-1050.

[18]. H. P. David. (2016). "Welding Engineering. An Introduction". United Kingdom, Ch. 4.

[19]. N. O¨ zdemir. (2005). " Investigation of the mechanical properties of friction-welded joints between AISI 304L and AISI 4340 steel as a function rotational speed". Materials Letters, Vol. 59, pp. 2504-2509.

[20]. Amit Handa, and Vikas Chawla. (2016). " Experimental Evaluation of Mechanical Properties of Friction Welded Dissimilar Steels Under Varying Axial Pressures". Journal of Mechanical Engineering – Strojnícky časopis, Vol. 66, no. 1, pp. 27-36.

[21]. D. Ananthapadmanaban, V. Seshagiri Rao, Nikhil Abraham, and K. Prasad Rao. (2009). " A study of mechanical properties of friction welded mild steel to stainless steel joints".Materials and Design, Vol. 30, pp. 2642–2646.

[22]. ISO 14555:2006E. (2010). Welding — Arc stud welding of metallic materials. Geneva, Switzerland.

[23]. ASTM A370- 14. (2014). Standard Test Methods and Definitions for Mechanical Testing of Steel Products, U.S. Department of Defense, USA.

[24]. ASME BPVS. IX. (2009). Boiler and Pressure Vessel Code- Welding, Brazing, and Fusion Qualifications. USA.

[25]. ASTM E3-2014. (2014). Standard Guide for Preparation of Metallographic Specimens, USA.

[26]. Voort Vander GF. (2004). "ASM handbook, Metallography and Microstructures". Vol. 9, Russia.

[27]. Abu Bakar Dawood, Shahid Ikramullah Butt, Ghulam Hussain, Mansoor Ahmed Siddiqui, Adnan Maqsood and Faping Zhang, "Thermal Model of Rotary Friction Welding for Similar and Dissimilar Metals"Metals, vol. 7, no. 224, pp. 14, 2017.