International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 06 | June - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Short Review on Recent Advancement in Welding of Aluminium Based Alloys and Composites

Santanu Pandey[1], Pritam Singh[2], Soumojit Dasgupta[3]*, Sumanta Chatterjee[4]

[1-3]*Mechanical Engineering Department & JIS College of Engineering*

[4]*Computer Science Engineering Department & JIS College of Engineering*

**soumojit.dasgupta@jiscollege.ac.in*

---***---

Abstract - Aluminium (Al) is one of the most widely used elements throughout the world. Alloys and composites of aluminium find huge application in various industries owing to their high strength-to-weight ratio, light weight, high thermal and electrical conductivity, corrosion resistance property. All these properties make aluminium and its alloys and composites to be used in various applications. Owing to its light weight, it is used in aviation and automobile sectors, where joining of parts play an integral role. Thus, welding of aluminium alloys and composites is an important factor during fabrication. Different welding processes are used for joining Al. Primarily, Friction Stir Welding (FSW) and Tungsten Inert Gas (TIG) welding are used. Also, Gas Metal Arc Welding (GMAW) process is often used. This paper makes a review study of different advancements in welding of Al based alloys and composite materials. Several findings related to mechanical properties, microstructure, macrostructure, microhardness etc. were reported.

Key Words: Aluminium, Alloys, Composites, Welding, Mechanical properties

1. REVIEW STUDY

As welding of Al based alloys and composites is an important research topic and many applications have been reported, therefore an attempt is made to review some of the recent developments in this area. Some of the studies are reported as follows.

A comparative weldability study of 6061-T6 aluminium alloy under three different weld joint conditions was attempted by Ambriz et. al [1]. Plates of 6061-T6 aluminium alloy of 12.7 mm thickness were welded with gas metal arc welding process (GMAW) using three different joint designs, i.e. a single V groove butt joint, the indirect electric arc (IEA) joint and the modified indirect electric arc joint (MIEA). MIEA is a modification of the IEA joint which requires preheating of the plates prior welding to achieve full penetration with an ER-4043 filler wire. The single V groove joint was welded at atmospheric temperature with four welding passes. IEA and MIEA joints were welded with preheating at 50, 100 and 150 °C. Comparative study of macrostructural and mechanical characteristics revealed that joining this alloy is feasible with the different joint geometries. However, thermal effect on the single V groove joint was large leading to overage zone in the base metal that affected the mechanical strength of the welded joint. This effect was less for IEA and MIEA joints due to lower heat inputs.

In another investigation by Ambriz et. al [2], the effect of welding profile generated by MIEA technique on the fatigue behavior of 6061-T6 welded joints was reported. It was observed that fatigue life of welded samples using this welding technique was larger compared to data reported in literature. Also, microhardness and tension testing were performed to study the effect of fatigue damage on the mechanical properties of these welds. For undamaged samples, fatigue damage increased the microhardness in the weld metal and heat affected zone (HAZ) whereas it only produced a moderate increase in yield strength.

In a review study by Christi et. al [3], the recent trends in friction stir welding (FSW process of aluminum alloys and aluminum metal matrix composites (Al MMCs) were made. A number of FSW techniques were developed recently, such as underwater friction stir welding (UFSW), vibrational friction-stir welding (VFSW), and others, for welding of aluminum alloy joints to overcome the issues of welding using conventional FSW. It discussed the effect of welding parameters of traditional and state-of-the-art developed FSW techniques on the welding quality and strength of aluminum alloys and Al MMCs. Comparison among the techniques and advantages and limitations of each were considered. The review suggested that VFSW is an alternative option for welding aluminum joints due to its energy efficiency, economic cost and versatile modifications.

Another review was made on the parameters used during friction stir welding (FSW) of aluminium composites (AMC) to obtain good weld quality. Uday and Rajamurugan [4] found that the FSW joint efficiency of (AMC) varied between 80 and 95 percent and joint efficiency was obtained by selecting the optimal combination of tool rotation speed, welding speed, and applied axial load. The tool rotation speed varied between 600 and 1200 rpm, with a 30–110 mm/min welding speed for uniform grain size in the joint using moderate axial loads. The tool profile and process parameters had significant impact on welded joint hardness and tensile behaviour.

Properties of aluminium matrix composites are highly influenced by the appropriate selection of metal matrix, processing routes, and reinforcement. Various ceramic particles (oxides, carbides, nitrides, borides, etc.) are used as reinforcements for aluminium matrix composites. Significantly different properties may be obtained using various reinforced particles and matrix material, which makes it difficult for the traditional fusion welding techniques to meet the joining requirements of these composites and is restricted to certain grades of materials. Solid-state welding process offers greater advantages over the conventional fusion welding. As a solid-state joining process, friction stir welding has proven to be a better and promising technique for joining aluminium matrix composites. Mir et. al [5] reviewed on friction stir welding of aluminium composites. Weldability, macrostructure and microstructure of aluminium matrix composite joints, mechanical properties of joints, fractography and wear of friction stir welding tool during welding of aluminium matrix composite were studied.

2. MICROSTRUCTURE STUDY

Jayashree et. al [6] performed Tungsten Inert Gas (TIG) welding on aluminium composite with varying percentage of SiC reinforcement. For all the conditions of the specimen, the welding parameters were kept identical. The welded composites were thermally aged to peak age-hardening conditions. After aging, microstructure showed refinement in grain size and preferential orientation. Hardness and tensile strength increased at different rates with increase in SiC content indicating that hardness was a clear function of stored energy and strength had a dependence on the misorientation. The increase in tensile strength with decreased misorientation was a clear indication that the effect of annihilation of dislocations as a result of recovery was less pronounced and precipitation strengthening was dominant. The objective was to study the role of SiC addition in aluminium metal matrix composites on the welded microstructure and finally relate the microstructural changes to the observed mechanical behavior of the welded joints.

In an interesting experimental investigation by Xu et. al [7], the explosive welding of 2A14 aluminum alloy and niobium with and without a 1060 Al interlayer was investigated by experiments and a two-step numerical simulation. Microstructure observations revealed a continuous molten layer with plenty of micro-defects at the joint interface by direct welding, and for the welding situation with an interlayer, straight and curled joints devoid of imperfections were obtained at the upper and lower interfaces, respectively. The tensile-shear strength for the direct welded samples was 84.4 MPa, while a rise of 38.2% was achieved for the composite with an interlayer. The Lagrange-Eulerian simulation showed a decline in impact velocity and an increase in collision area and duration due to insertion of the interlayer, the resulting less kinetic energy loss at the joint interfaces eliminated the formation of the intermetallic compounds. The introduction of the interlayer strengthened the weldment by adjusting the way the interface accommodates the impact-induced strain.

Rajesh et. al [8] fabricated aluminum alloys and aluminum matrix composites (AMCs) using stir casting and joined them by friction stir welding (FSW). Dissimilar grades of aluminum alloy, i.e., Al 6061 and Al 1100, were used for the experimental work. Alumina and Silicon Carbide were used as reinforcement with the aluminum matrix. Mechanical and corrosion properties were experimentally measured. The FSW process was analyzed by comparing the welded alloys and welded composites. Finally, the best suitable FSW combination was selected by a Multi-Attribute Decision Making (MADM)-based numerical optimization technique called Weighted Aggregated Sum Product Assessment (WASPAS).

Friction Stir Welding was performed on aluminium 6061 metal matrix composite by Kumar et. al [9] to study the influence of welding parameters on the corrosion rate of hybrid Aluminium Metal Matrix Composite (AMMC). AMMC plates were joined through friction stir welding technique, with tool rotating speed of 650 rpm, 950 rpm, and 1150 rpm and also collated welding speed of 30 mm/min, 80 mm/min, and 120 mm/min respectively.

An attempt was made by Paul et. al [10] to study weldability of aluminium composite (AA5052-H32/B4C) by friction stir welding using titanium nitride coated tool. Boron carbide (B4C) reinforced AA5052-H32 aluminium composite was fabricated by stir casting method. Friction stir welding (FSW) was used to join two similar AA5052-H32/B4C plates using a titanium nitride (TiN)-coated square tool. The tool wear loss, microhardness, and tensile strength of FSW joints were examined using Taguchi design of experiment technique. Welding parameters were TiN coating thickness, tool rotational speed, welding speed, and axial thrust. Maximum tensile strength (140.134 MPa) was obtained by increasing the TiN coating thickness, tool's rotational speed, axial thrust, and welding speed. At the highest tool speed and axial trust, the maximum microhardness (158.3 HV) was attained. The minimum tool wear loss (9.023%) was obtained by welding at a moderate speed with maximum rotational speed, axial thrust, and TiN coating thickness. Fractography and SEM analysis was performed to analyze the microstructural behaviour of welded aluminium composite materials and worn-out tool surfaces. The Additive Ratio Assessment (ARAS) multi-criteria optimization technique was applied to predict the best welding parameters to attain the optimal welding characteristics.

Joining aluminium with fusion welding processes leads to joint deterioration. Friction stir welding (FSW) produces joints at temperatures below the melting temperature, thus avoiding flaws associated with high heat input, yet requires improvement in the resultant joint properties. Recent studies have shown that nanoparticle reinforcement in FSW joints can improve weld properties. Vimalraj and Kah [11] attempted to review similar and dissimilar friction stir welding of AA5083 and AA6082 with carbide and oxide nanoparticle reinforcement. The effect of welding parameters on reinforcement particles and the effect of nanoparticle reinforcement on weld microstructure and properties, as well as development trends using nanoparticles in FSW were analyzed. Analysis showed that friction stir welding parameters have a significant influence on the dispersion of the reinforcement nanoparticles, which contributed to determining the joint properties. Moreover, the distributed nanoparticles help in grain refinement and improve joint properties. The type, amount and size of reinforcement nanoparticles together with the welding parameters significantly influenced the joint properties and microstructures in similar and dissimilar aluminium welds.

To investigate the weldability of aluminium alloy and carbon fiber reinforced plastics lightweight materials, the hybrid joints of 5052 aluminium alloy (AA5052) and carbon fiber reinforced polyether ether ketone composites (CF-PEEK) were subjected to friction stir spot welding by Dong et. al [12]. The variance analysis revealed that the dwell time and plunge speed were the most significant factors. By optimizing the welding parameters, the ultimate tensile shear load reached 2690±64 N. The interface could be divided into pin-affected zone, shoulder-affected zone, resin adhesive zone and resin concentrated zone. Since resin concentrated zone could not provide interfacial bonding due to delamination, the shoulder-affected zone and pin-affected zone were decisive regions for mechanical properties.

A defect-free dissimilar weld joint of AA7075-T6 and AA6061-T6 reinforced with Al_2O_3 nanoparticles was fabricated by Jain and Mishra [13] using friction stir welding (FSW). The influence of tool rotational speed (700, 900 and 1100 rpm), traverse speed (40, 50 and 60 mm/min) with varying volume fractions of Al_2O_3 nanoparticles (4%, 7% and 10%) on microstructural evolution and mechanical properties were investigated. The findings revealed that the reduction in grain size in the Stirring Zone (SZ) was observed owing to the addition of Al_2O_3 nanoparticles produced the pinning effect, which prevented the growth of grain boundaries by dynamic recrystallization (DRX). The increasing volume fraction of

Al_2O_3 nanoparticles enhanced the mechanical properties such as tensile strength, % elongation and micro-hardness. Agglomeration of particles was observed in the SZ of the Friction Stir Welded joints produced at lower tool rotational speed of 700 rpm and higher traverse speed of 60 mm/min due to unusual material flow.

To enhance the performance of resistance spot welded joints between aluminium alloy (AA) and mild steel (MS), Qiu et. al [14] used a specific electrode termed embedded composite electrode during welding. The microstructure and properties of the joints obtained under different welding parameters were characterized. The observation results on the cross-section of the joints showed a nugget formed on the AA and MS sides of the joints and a reaction layer with bimodal thickness distribution was found at the welding interface. The maximum tensile shear of the joints reached 5.86 kN at the welding current of 26 kA. The study revealed that the resistance spot welding with composite electrodes is a promising approach for restraining the intermetallic compounds growth in the welding central region.

3. SCANNING ELECTRON MICROSCOPE (SEM) ANALYSIS

Weldability study of aluminium composite (AA5052-H32/B4C) by friction stir welding using titanium nitride coated tool was performed [10]. SEM analysis was performed to analyze the microstructural behaviour of welded aluminium composite materials and worn-out tool surfaces.

The results showed presence of agglomeration and scattered boron carbide (B4C) in the composite as shown in Figure 1.

Fig -1: SEM Analysis

4. CONCLUSIONS

In this review study on recent developments in welding of aluminium alloys and composites, several findings, analysis and newer techniques were reported. The following conclusions were inferred-

1. A comparative weldability study of 6061-T6 aluminium alloy under three different weld joint conditions, i.e. a single V groove butt joint, the indirect electric arc (IEA) joint and the modified indirect electric arc joint (MIEA) were performed. Comparative study of macrostructural and mechanical characteristics revealed that joining this alloy is feasible with the different joint geometries. However, thermal effect on the single V groove joint was large leading to overage zone in the base metal that affected the mechanical strength of the welded joint.
2. Friction stir welding has emerged as an important welding process for joining Al based alloys and composites. A number of FSW techniques were developed recently, such as underwater friction stir welding (UFSW), vibrational friction-stir welding (VFSW), and others, for welding of aluminum alloy joints to overcome the issues of welding using conventional FSW.
3. Tungsten Inert Gas (TIG) welding is another mostly sought process for welding Al. Varying the process parameters, good quality welds can be obtained.
4. Dissimilar welding of Al based alloys and composites using FSW were attempted with relative success.

REFERENCES

[1] Ambriz, R.R., Barrera, G., García, R., López V.H., A comparative study of the mechanical properties of 6061-T6 GMA welds obtained by the indirect electric arc (IEA) and the modified indirect electric arc (MIEA), Materials and Design, 30(7), (2009), pp.2446-2453

[2] Ambriz, R.R., Mesmacque, G., Ruiz, A., Amrouche, A., Lopez, V.H., Effect of the welding profile generated by the modified indirect electric arc technique on the fatigue behavior of 6061-T6 aluminum alloy, Materials Science and Engineering A, 527, (2010), pp.2057-2064

[3] Christy, J.V., Mourad, A.H.I., Sherif, M.M., Shivamurthy, B., Review of recent trends in friction stir welding process of aluminum alloys and aluminum metal matrix composites, Transactions of Nonferrous Metals Society of China, 31(11), (2021), pp. 3281-3309

[4] Uday, K.N., Rajamurugan, G., Influence of process parameters and its effects on friction stir welding of dissimilar aluminium alloy and its composites – a review, Journal of Adhesion Science and Technology, 37(5), (2023), pp. 767-800

[5] Mir, F.A., Khan, N.Z, Siddiquee, A.N., Parvez, S., Joining of aluminium matrix composites using friction stir welding: A review, Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 236(5), (2022)

[6] Jayashree, P.K., Gowrishankar, M.C., Sharma, S., Shetty, R., Hiremath, P., Shettar, M., The effect of SiC content in aluminum-based metal matrix composites on the microstructure and mechanical properties of welded joints, Journal of Materials Research and Technology, 12, (2021), pp. 2325-2339

[7] Xu, J.F., Ma, H.H., Shen, Z.W., Li, Y.H., Effects of interlayer on the interfacial microstructures and thermomechanical kinetics of explosive welded 2A14 aluminum alloy-niobium composite, Materials Today Communications, 33, (2022)

[8] Rajesh, P.V., Gupta, K.K Cep, R., Ramachandran, M., Kouril, K., Kalita, K., Optimizing Friction Stir Welding of Dissimilar Grades of Aluminum Alloy Using WASPAS, Materials-MDPI, 15(5), (2022)

[9] Kumar, N.M.S., Sadashiva, M., Monica, J., Kumar, S.P., Investigation on Corrosion Behaviour of Hybrid Aluminium Metal Matrix Composite Welded by Friction Stir Welding, Materials Today Proceedings, 52(4), (2022), pp. 2339-2344

[10] Paul, A., Thilagham, K.T., Christiyan, K.G., Reddy, P.V.R., Ravishankar, S., Boopathi, S., Multi-criteria optimization on friction stir welding of aluminum composite (AA5052-H32/B4C) using titanium nitride coated tool, Engineering Research Express, 6(1), (2024)

[11] Vimalraj, C., Kah, P., Experimental Review on Friction Stir Welding of Aluminium Alloys with Nanoparticles, Metals-MDPI, 11(3) (2021)

[12] Dong, H., Tang, Z., Li, P., Wu, B., Hao, X., Ma, C., Friction stir spot welding of 5052 aluminum alloy to carbon fiber reinforced polyether ether ketone composites, Materials & Design, 201 (2021)

[13] Jain, S., Mishra, R.S., Effect of Al2O3 nanoparticles on microstructure and mechanical properties of friction stir-welded dissimilar aluminum alloys AA7075-T6 and AA6061-T6, Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 236(4) (2021)

[14] Qiu, R., Li, J., Shi, H., Yu, H., Characterization of resistance spot welded joints between aluminum alloy and mild steel with composite electrodes, Journal of Materials Research and Technology, 24, (2023), pp.1190-1202