A Review on the Friction Stir Welding Processes used for joining the various dissimilar materials from the year 2017 to the year 2023.

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ABSTRACT: The Friction stir welding process is a important type of Solid State welding process. Now a days, this process is used for both high and low melting materials but there is a requirement of the technology improvements and developments. In this paper, A theoretical review has been made for dissimilar materials and also studied the various tool geometries related issues and other Process Parameters of FSW. A Future work on FSW has been suggested by stating the current scenario of this process.

KEYWORDS: FSW, Alloys, Thermo-Mechanical, Materials, Tools

INTRODUCTION

Friction Stir Welding (FSW) was invented by Wayne Thomas at The Welding Institute and its Initial patent applications were in the United Kingdom in the year of 1991[15]. It may be defined as an innovative process of welding and it may also called as a solid state welding process. Friction stir welding is suitable for those alloys which have high strength and used in nuclear, navel, and aircraft industry. Friction stir processing (FSP)/FSW is a method of changing the properties of a metal through intense localized plastic deformation[1].Copper Chromium Zirconium (Cu,Cr,Zr) alloy is a precipitation hardened copper based alloy with good electrical and thermal conductivity, moderate strength and excellent resistance to softening at elevated temperature[2].

NEED OF FSW

- Joining of the dissimilar materials.
- Joining of the difficult materials like al and super alloys.
- To get improved mechanical properties.
- Fewer process parameters.

Principle of Operation

- In friction stir welding (FSW) a cylindrical, shouldered tool with a profiled probe is rotated and slowly plunged into the joint line between two pieces butted together.
- The parts have to be clamped onto a backing bar in a manner that prevents the abutting joint faces from being forced apart.
- Frictional heat is generated between the wear resistant welding tool and the material of the work pieces.
- This heat causes the material to soften without reaching the melting point and allows traversing of the tool along the weld line.

- The maximum temperature reached is of the order of 0.8 of the melting temperature of the material.
- It leaves a solid phase bond between the two pieces.
- The process can be regarded as a solid phase keyhole welding technique since a hole to accommodate the probe is generated, then filled during the welding sequence.

Figure: FSW on Milling Machine

FSW Variants

1. FSW- Friction Stir Welding
2. SSFSW – Stationary Shoulder FSW
3. RFW- Radial Friction Welding
4. FHPP- Friction Hydro –Pillar Processing
5. FTSW- Friction Taper Stich Welding

Advantages

1. Low distortion and shrinkage, even in long welds
2. Excellent mechanical properties in fatigue and tensile tests
3. No arc or fumes
4. No porosity
5. Can operate in all positions (horizontal, vertical, etc.), as there is no weld pool.
6. Energy efficient
7. One tool can typically be used for up to 1000 m of weld length in 6XXX series aluminium alloys
8. No filler wire required
9. No gas shielding is also required for welding

Disadvantages

1. Exit hole left when tool is withdrawn.
2. Less flexible than manual and arc processes
3. Work pieces must be rigidly clamped
4. Often slower traverse rate than some fusion welding techniques.
5. Cannot make joints which required metal deposition (e.g. fillet welds)

Applications

1. Shipbuilding and Marine Construction
2. Aerospace Industry
3. Land Transportation
4. Railway Industry

LITERATURE REVIEW

Husain Mehdi and R.S. Mishrasolid (2017),[1] stated the joining process that uses a non-consumable tool to join two different materials without melting the workpiece material. Heat is generated by friction between the rotating tool and the workpiece material.This joining process is energy efficient, environment friendly and versatile.They explained the Friction stir welding (FSW) for microstructural modification of metallic material. They also provide an overview of effect of FSW/FSP mechanism responsible for the formation of weld, microstructure refinement, wear of FSW tool and mechanical properties.

Pankaj Sahlot et al.(2017),[2] given the quantitative wear analysis of H13 steel tool during FSW of Cu-Cr-Zr alloy. Higher amount of total tool wear is observed for faster tool rotational speeds, and slower traverse speeds. Progressive wear rate shows similar relationship with these process parameters during initial traverse stage. With further tool traverse the wear rate decreases significantly and is not much affected by the process parameters. The quantitative wear study provides insights about tool wear during FSW process and are useful to better estimate and improve tool life. This are helpful to optimize the process parameters and tool shape to reduce tool wear during FSW of high strength materials.

Tarasov S.Yu. et al.(2017),[3] used Al-Cu-Li-Mg aluminum alloy V-1469 (AA2195) for Friction Stir Welding to find the effect of ultrasonic energy on the microstructural evolution of the welded metal. They found that ultrasonic – assisted FSW (UAFSW) reduces the recrystallized grain size in the stirring zone (SZ), facilitates strain induced dissolution of both soluble and insoluble intermetallic precipitates, enhanced solid solution grain recrystallization and precipitation of coherent metastable phases.

Y. Tao et al.(2017),[4] made FSW joints of a 2198-T8 Al-Li alloy fractured in the stirred zone (SZ) instead of the LHZ with the welding parameters of 800 rpm,200 mm/min and 1600 rpm,200 mm/min under the condition that no welding defects existed in the SZ. They suggested that SZ was not the dominant factor resulting in the unusual fracture. The SZ consisted of three subzones, i.e., the shoulder-affected zone, the pin-affected zone, and the transition zone between them. While the former two zones were characterized by fine and equiaxed recrystallized grains, incompletely dynamically recrystallized microstructure containing coarse elongated non-recrystallized grains was observed in the transition zone.

Sameer MD and Anil Kumar Birru(2019),[5] used AZ91 magnesium alloy and AA6082-T6 aluminium alloy to join by friction stir welding process. They studied the comparison of microstructure and mechanical properties between different joints by varying the different materials on advance and retreating sides.they made four different welds to find the material mixing between the similar and dissimilar joints. The investigated the joint interfaces of the welds by employing an optical microscope and scanning electron microscope. When Mg was placed on advancing side (AS), more aluminium content was soluble in nugget zone than the case where Mg was placed on the retreating side (RS). Thin intermetallic layer in the joint interface of Mg/Al and thick intermetallic layer with poor adhesion of the aluminium and magnesium have been observed in the dissimilar joints varying the sides. They found highest UTS of 172.3 MPa for Mg-Al when Mg was placed on AS and lower UTS of 156.25 MPa was obtained when Mg was placed on RS. Hardness of 86 Hv and 89 Hv were observed in the Stir zone for the dissimilar AZ91 Mg alloy and AA6082-T6 Al alloy when AZ91Mg alloy was placed on the AS and on the RS respectively.

Mingshen Li et al.(2019),[6] studied Al-Cu dissimilar materials. They reviewed the research progress and current status of Al-Cu FSSW with respect to tool features, macroscopic characteristics of welded joints, microstructures, defects in welds and mechanical properties of joints. They suggested that the further study are put forward in order to promote the development and progress of Al-Cu FSSW studies in several respects: material flow, thermal history, addition of intermediate layer, auxiliary methods and functionalization of Al-Cu FSSW joint.

Mohamed Abu-Okail et al.(2019),[7] studied the effect of different process parameters of FSW such as the tool rotational speed (R), travel velocity (t) and inclination angle (H) with different values of interlayer strip widths (W) of compensation material on microstructural characterization and mechanical properties. Optical microscope, scanning electron microscope, energy-dispersive x-ray spectroscopy and x-ray diffraction techniques are used to characterize the micro structural changes after FSW process. Micro hardness and tensile tests are also used to characterize the mechanical properties of the produced joints. The results of mechanical properties of FSW process parameters with different values of interlayer strip width showed that when the tool rotational speed is increased till 2000 rpm, the tensile strength has been increased till 321 MPa, while the reduction in tool traverse speed till 20 mm/min led to an increase in the tensile strength till 239 MPa.

Jannik Entringer et al.(2019),[8] used semi-stationary bobbin tool friction stir welding to weld Two modern aluminum lithium alloys.They investigated the influence of the Cu/Li ratio on precipitation phenomena under process heat impact by comparing the response of low Cu/Li alloy 2196-T8 and highCu/Li alloy 2060-T8. Identical process parameters with a weld pitch of one rotation per mm were used to conduct flawless weldments. The thermal history and microstructural features are studied and correlated to the resulting mechanical properties of the welds. Analysis of microstructure using differential scanning calorimetry and high energy X-ray diffractiontechnique show the significant differences in the precipitation sequence of the base metal andin the welded samples of the two alloys of interest. The low Cu/Li alloy 2196 developed a higherprocess temperatures and exhibited a more evolved precipitation sequence.

Gaohui Li et al.(2019),[9] explained the 1060 aluminum–T2 copper dissimilar lap joints produced by friction stir spot welding(FSSW) with various dwell time. All the joints possess a Cu hook extruded upward from the lower Cu plate into the upper Al plate with intermetallic compounds (IMCs) developed on its interface. Increasing the dwell time produced an increase in the heat input during welding and promoted IMC growth. At short dwell time, the interface was characterized by the interruptedly distributed $CuAl_2$ layer partially mingled with Cu-Al phase. A continuous $CuAl_2$–CuAl–Al_4Cu_9 laminated layer developed at the interface at longer dwell time. Microhardness was quite different in different zones. Hardness values in the stirzone (SZ) were much higher due to the dispersively distributed IMC particles and the refined grains. Joints with better tensile properties have a higher penetration depth of the hook into the upper Al plate as well as a continuous IMC layer at the hook interface. Results of fracture path analysis indicated that all the fracture initiated at the $CuAl_2$–CuAl or $CuAl_2$–Al interface and then extended along the IMC layer at the hook interface.

Namrata Gangil et al.(2019),[10] explained the microstructural and mechanical investigation on friction stir welding of composites fabricated through friction stir processing on a high strength Al–Zn–Mg–Cu alloy by utilizing hybrid reinforcement. Surface composites (SCs) are fabricated via FSP, sliced to the processed thickness and cut-apart through the longitudinal axis of the SCs. They are friction stir butt welded by employing varied tool rpm (560–900 rpm). The mechanical properties, microstructural analysis and micro-hardness profile was obtained for the welds.Their final Results, in comparison to SC samples the rein-forcement particle distribution of the welded samples became more homogeneous due to the weld pass. The microstructural examination indicated that minute tunneling defect was introduced in samples welded at 560 and 900 rpm whereas incomplete root penetration (IRP) defect was observed in all welded samples. The ultimate tensile strength (UTS) of welded samples were found lower than base metal which was attributed to the presence of tunnel and IRP.

Abhishek SHARMA et al.(2019),[11] studied on the surface properties of Al−SiC−multi walled carbon nanotubes (CNT) and Al−SiC−graphene nanoplatelets (GNP) hybrid composites fabricated via friction stir processing (FSP). They stated that Microstructural characterization is more homogeneous dispersion of GNPs in the Al matrix as compared to CNTs. They observed dislocation blockade by SiC and GNP particles along with the defect-free interface between the matrix and reinforcements. Nanoindentation study reveals a remarkable ~207% and ~27% increment in surface nano-hardness of Al−SiC−GNP and Al−SiC−CNT hybrid composite compared to as-received Al6061 alloy, respectively. The microhardness values of Al−SiC−GNP and Al−SiC−CNT are increased by ~36% and ~17% relative to as-received Al6061 alloy, respectively. Tribological assessment reveals ~56% decrease in the specific wear rate of Al−SiC−GNP hybrid composite, whereas it is increased by ~122% in Al−SiC−CNT composite. The higher strength of Al−SiC−GNP composite is attributed to the mechanical exfoliation of GNPs to few layered graphene (FLG) in the presence of SiC.

Karen Johanna Quintana et al.(2020),[12] explained the torque and forces in friction stir welding (FSW) which are important parameters for the process behavior, weld quality, and mechanical properties of the weld. Torque and forces are mainly influenced by rotational and welding speeds and tool geometry, including the tool pin profile. their experimental study describe the influence of the pin profile on torque and forces. They considered the influence of the threaded pin on torque and forces in the FSW process of 5052-H34 aluminum alloy. The axial, welding, and transverse forces and the torque are experimentally measured at several combinations of rotational (600rpm, 900rpm, 1200rpm and 1500 rpm) and welding speeds (100mm/min, 200mm/min, and 300 mm/min) for two pin profiles: smooth and threaded. At last residual stresses are measured by X-ray diffraction technique for some experimental conditions in the stir zone of the weld. The results show that the influence of the pin shape on the torque, forces, and residual stresses depends on the rotational and welding speeds, mainly on the rotational speeds.

Gui ju Zhang et al.(2020),[13] worked on the friction stir spot welding of AA2024-T3/AA7075-T6 Al alloys in the ambient and underwater environments by clarifying the nugget features, microstructure, fracture and mechanical properties of the joints. Their results show the water-cooling medium exhibits a significant heat absorption capacity in the AA2024-T3/AA7075-T6 welded joint. Nugget features such as stir zone width,circular imprints, average grain sizes, and angular inter-material hooking are reduced by the watercooling effect in the joints. Narrower whitish (intercalated structures) bands are formed in the underwater joints while Mg2Si and Al2CuMg precipitates are formed in the ambient and the underwater welded joints respectively. An increase in tool rotational speed (600e1400 rpm) and plunge depth (0.1mm -0.5 mm) increases the tensile-shear force of the welded AA2024-T3/AA7075-T6 joints in both the ambient and underwater environments. The maximum tensile-shear forces of 5900 N and 6700 N were obtained in the ambient and the underwater welds respectively.

Ivan S. Zuiko et al.(2020),[14] suggested a new approach to avoid the undesirable effects associated with the coagulation or dissolution of secondary phase. They proposed that these alloys in the particle-free material condition. It was also suggested that the subsequent ageing of the produced welds could provide a uniform distribution of the strengthening nano-scale precipitates. The results are in a nearly-100 pct. joint efficiency. They studied the reliability of this approach.

D Sathish et al.(2020),[15] explained the Friction stir welding is a solid state welding technique for the welding of metallic compounds. The Aluminium alloy 6063 and commercially available copper of 6 mm thickness are welded in circular butt joint geometry by friction stir welding (FSW) process, using vertical milling machine. The Friction stir welding was carried out at each rotational speed of 800 rpm and 1000 rpm for different travel speed 20 and 40 mm/min at constant probe depth of 2.9 mm, towards the trailing edge and a dwell time of 3 sec. One of the critical elements for the achievement of this method is the friction stir welding tool. It comprises of a distinct geometry cylindrical shoulder and a pin. The said instrument was intended for friction stir welding of the dissimilar metal plates in the experimental job with cylindrical pin profile. The results have been correlated with the micro structural characteristics at the bond interface using scanning electron microscopy. The results show the characteristics of different types of intermetallic compound formed at the interface derived from energy input.

S. Ranganathan et al.(2020),[16] examined that the strengthened core and surface properties of AA8011 has been enhanced by adding nanoparticles such as Nitinol shape memory alloy (NiTi-SMAs) and silicon nitrate (Si3N4) through FSP followed by two different way of post-processing techniques like case hardening, case harden with shot peening. During FSP the use of NiTi-SMAs and Si3N4 as reinforcement interlocked the grains in hybrid nano composites of the processed zone. Also besides, post-processing promises a performance enhancement of core and surface hardness, ultimate tensile strength, impact strength and homogeneous distribution which was observed through scanning electron microscopic observations. The strengthening phase was uniformly distributed in grain or grain boundary and also the hardened layer was evaluated using surface integrity with metallography study. At last ,they concluded that the coupled effect of reinforcement addition and case-harden with shot peening technique was the best choice in augmenting demanded industries for this FSP'ed hybrid composites.

Junping Li et al.(2020), [17] used friction stir welding (FSW) for 2-mm-thick Ti–6Al–4V alloy plates and a newly designed friction tool. The effect of rotation speed and welding speed on microstructure and mechanical properties of the joints are investigated. A simulation model for FSW temperature field calculation was developed, and the effect of rotation speed and welding speed on the temperature field is observed by experimental and numeric methods. The results show that the rotation speed has a dominant effect on peak temperature, while welding speed determines the dwell time of the weld exposed to high temperatures. The influence of process parameters on the microstructure of the joints was investigated using optical and scanning electron microscopy. The results revealed that there was a phase transformation in the stir zone during welding. Both rotation speed and welding speed affect the grain size of the weld. Lower peak temperature with decreasing spindle speed and shorter dwell time with increasing feed rate could produce finer grains in the stir zone of the joints, thereby could lead to higher microhardness value and the tensile strength of the joints.

Vysotskiy et al.(2020),[18] evaluated the effect of second-phase particles on microstructure evolution during friction-stir welding (FSW). To this end, Al-6.0Mg-0.35Mn-0.2Sc-0.1Zr alloy containing insoluble nanoscale Al3(Sc,Zr) dispersoids was used as a program material. A particular emphasis was given to an establishment of a microstructure-strength relationship in the welded material. It was found that pinning effect of the Al3(Sc,Zr) precipitates efficiently suppressed grain-boundary migration and promoted a concentration of slip activity in heavily-stressed near-grain-boundary regions. This gave rise to a preferential development of deformation-induced boundaries in the latter areas. Due to a complex character of slip at the grain boundaries, the newly evolved grains had nearly random crystallographic orientations. As a result, the final microstructure evolved in stir zone was characterized by relatively-fine grain size, poorlydeveloped texture and large fraction of high-angle boundaries. The retention of the coherent dispersoids as well as considerable grain refinement occurring during FSW resulted in substantial material hardening in the stir zone.

Houria Benkherbachea et al.(2020),[19] studied the rigidity of rotational friction welding of cylindrical specimens made on a parallel lathe. they performed welding of three combinations of parts: steel / steel, aluminium / aluminium and steel / aluminium according to three numbers of rotations of the spindle (900 rpm, 1250 rpm and 1800 rpm). To control the rigidity and quality of these assemblies, tensile tests are used followed by ultrasonic testing to ensure that the tips are welded and that there are no internal defects. Hardness profile of the welded zone according to the welding parameters was obtained. Metallographic observations have detected the profile of the various zones welded and affected thermally. The results of the mechanical tests showed that a rotation speed of 1250 rpm can produce a very good weld, with other parameters kept constant.

Maksymchuk IM et al.(2020),[20] explained the specific features of the crystallization kinetics of the ternary Al-Ni-Fe system due to the order of the introduction of the alloying elements are explained in terms of the cluster structure of the melts of binary metal systems Al-Ni and Al-Fe. It was established that the order of introduction of the alloying elements into the aluminum melt determines the formation of a different cluster structure, which is responsible for the mechanism of formation of crystallization nuclei and the formation of the phase composition of alloys. It is assumed that a substantial supersaturation of the solid solution with nickel atoms is associated with the introduction of Al3Ni-type clusters into the aluminum matrix of the Al-3Ni-3Fe alloy. This concept is confirmed by the presence of two exothermic peaks on the DSC curves in the region before the crystallization of the alloy and explains the abnormally high value of Young's modulus and the high yield stress of the alloy.

F. Khorashadizade et al.(2021),[21] explained the Magnesium (Mg) and its alloys are potential metals for biodegradable implants because of several benefits, including a reduction of stress shielding effect in the implant for orthopedic application and the elimination of the step of a second surgery to remove the implant. unexpected degradation can cause the Mg to collapse, and the implant fails; thus,many studies have been done to control the rate of degradation of Mg alloys. Heterogeneous corrosion of these implants leads to rapid mechanical properties loss, limiting the clinical applications. Adding ceramic reinforcements to the Mg matrix as so-called Mg nanocomposites is one method to enhance the ductility and also mechanical properties of the Mg alloys without a noticeable weight cost. Good corrosion resistance and noticeable mechanical properties of the Mg-based nanocomposites have developed their applications. However, it is difficult to uniformly disperse the ceramicbased nanoparticles as reinforcements in the Mg matrix and attain desired characteristics. As a result, selecting Mg-ceramic composite production methods and reinforcing types to overcome Mg restriction and increase the favorable material features based on their applications is critical. As a result, this review study focus on the different fabrication techniques and reinforcement material types and their influence on Mg-ceramic composites' mechanical characteristics, in vitro corrosion performance and biocompatibility. The potential applications, and future research ideas of Mg matrix nanocomposite are investigated.

Boopathi Sampath and V. Haribalaji (2021), [22] introduced the influences of joining factors on tensile strength, micro-hardness, and microstructures of FSW of Al-Mg alloy materials. In this study, they explained the effects of joining factors for example axial force, tool revolving speed, tool incline, speed, and offset on welding characterizes have been discussed to make defect-free FSW of aluminum and magnesium alloys. The microstructural behaviors of intermetallic formation and material drift in FSW zones of Al-Mg were also studied to find the scope to improve the welding quality.

Ivan S. Zuiko et al.(2021),[23] explained the effect of welding temperature on thermal stability of friction-stir welded (FSWed) 2519 aluminum alloy. A lowering of the welding temperature below the particle dissolution threshold was shown to be a very effective way for suppression of abnormal grain growth during post-weld solution treatment. They attributed this effect to a prevention of the welded material from precipitation of fine dispersoids during subsequent annealing which resulted in relatively low Zener pressure and thus provided an activation of the apparently-normal grain-growth mechanism. This phenomenon was demon- strated for the first time and could be used as a processing strategy to improve thermal stability of FSWed heat-treatable alloys.

W M Syafiq et al.(2021),[24] determined the influence of welding parameters such as tool plunge depth, tool travel speed and tool tilt angle on welding temperature during friction stir welding of AA6061-T6 and S275JR mild steel. Thermocouple placed in the aluminum alloy plate prior to welding was used to measure the temperature during the welding of joints under different set of parameter values. Joint appearance as well as defects occurring on the surface or within the joint was observed. Microhardness profiles were also taken by measuring microhardness values across the cross section of joints. Excessive flash, tunnel defects and insufficient welding were the type of weld defects observed on different joints with different parameters. Defects were attributed to the varied parameter values affecting the heat generation as well as the flow of the plasticized material. Highest temperature was recorded by the joint fabricated using the largest tool plunge depth, owing to the increased downwards pressure. Microhardness profiles were seen to be similar for all the welded joints. They observed a "plateau" of low microhardness value for all joints associated with the thermomechanically affected zone (TMAZ) and heat affected zone (HAZ). A wider plateau was observed for joints welded with higher tool plunge depth due to higher temperature.

Yang Xu et al.(2021),[25] suggested that brittle intermetallic compounds are prone to form in dissimilar joints, which significantly affected the reliability of the joints. They fined that to control the production of brittle intermetallic compounds, an inclined butt joint of 5A06 Al and AZ31B Mg alloys with 20 mm thickness using friction stir welding was designed. Microstructures and chemical composition of the joint were investigated by optical microscopy, scanning electron microscopy, micro X-ray diffraction, transmission electron microscopy. The intermetallic compounds in the weld nugget zone presented different precipitation behavior along the thickness direction. In the upper of the weld nugget zone, intermetallic compounds Al3Mg2, Al12Mg17, and non-equilibrium phase AlMg precipitated during solidification due to excessively high temperature of the upper of the weld nugget zone. The Al3Mg2 phase merely precipitated and grown along the grain boundaries in the middle and lower of the weld nugget zone. The maximum Vickers hardness value was approximately 289 HV, which was obtained at the upper of the Mg side interface, existing a thick eutectic zone consisted of Mg and Al12Mg17. The nanohardness of the Al12Mg17 layer and the Al3Mg2 layer were 5.39 GPa and 4.18 GPa, respectively. The precipitation of the Al12Mg17 and the Al3Mg2 phases plays a precipitation strengthening effect.

Liangwen Xie et al.(2021),[26] clarified the microstructural evolution and the mechanical property of dissimilar friction stir-welded joints of ZK60 and Mg-4.6Al-1.2Sn-0.7Zn magnesium alloys, they used the two types of arrangement with ZK60 at advancing side (AS) or retreating side (RS). The macrostructure and the microstructure of the dissimilar welded joints were discussed, and the microhardness and the transverse tensile properties of the joints were measured. There are three stirring sub-zones with different compositions and two clear interfaces within the joints. Due to the effect of both the original grain size of base materials and the growth of recrystallized grains, in the stir zone (SZ), the grain size of ZK60 increased slightly, while the grain size of Mg-4.6Al-1.2Sn-0.7Zn decreased significantly. The dissolution of precipitates was gradually significant from RS to AS within the SZ due to the gradual increase in strain and heat. The grain refinement led to an increase in hardness, while the dissolution of precipitates resulted in a decrease in hardness. The performance of the joints obtained with ZK60 placed on the RS is slightly better than that of that on the AS. The tensile fracture of both joints occurred at the interface between SZ and the thermos-mechanical affected zone at the AS, and showed a quasi-dissociative fracture.

Kolluru Yugandhar et al.(2022),[27] reviewed that the materials with similar and dissimilar qualities are joined effectively in their solid-state by Friction Stir Welding(FSW). FSW eliminates the conventional problems and produces crack-free and completely solidified joints. FSW process is suitable for joining the different materials having different mechanical and chemical properties and for different material structures. the aerospace applications require hybrid metal joins to offer high strength – high ductile properties by joining varied metal alloys. FSW is the feasible way to join such metals to get high properties.

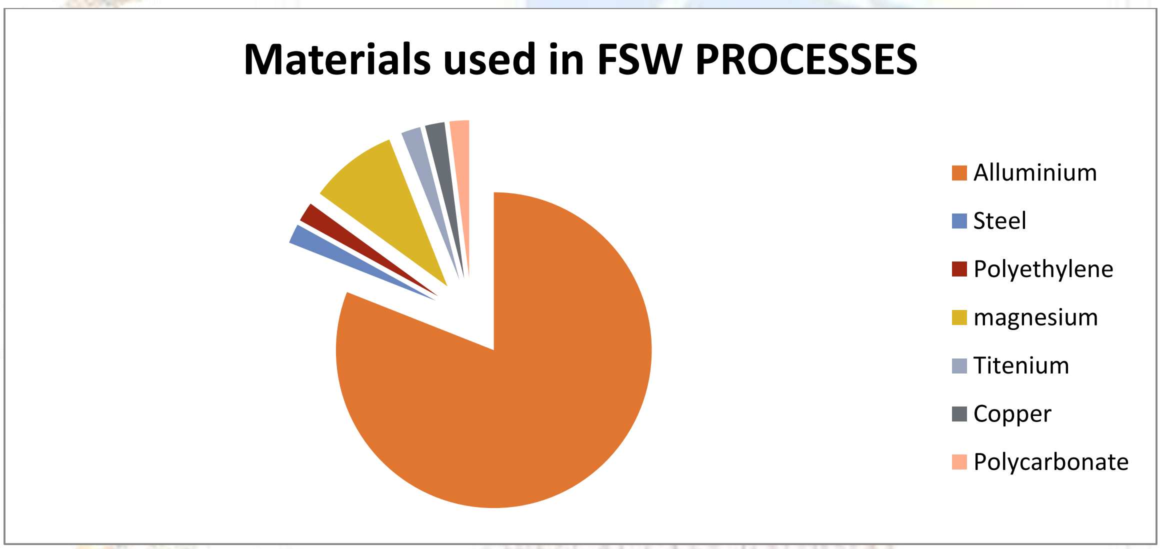
Ramandeep Singh Sidhu et al.(2022),[28] made a dissimilar joint among the AA6061 (A), AZ31B (B), and AZ91D (C) combinations based on the varying advancing side (AS) and retreating side (RS). The dissimilar joints prepared by the FSW process and characterized by tensile testing, impact testing, corrosion testing, fracture, and statistical and cost analysis. The results revealed a maximum tensile strength of 192.39 MPa in AZ91 and AZ31B, maximum yield strength of 134.38 MPa in a combination of AA6061 and AZ91, maximum hardness of 114 Hv in AA6061 and AZ31B, and lowest corrosion rate of 7.03 mV/A in AA6061 and AZ31B. The results of the properties were supported by photomicrographic fracture analysis by scanning electron microscopy (SEM) observations.

Mohammad Pervez Mughal et al.(2022),[29] used Al-6062 and Magnesium AZ31B and joined through friction stir welding (FSW) using the high-speed steel (HSS) tool. The impact of two important process parameters, including spindle speed and welding speed, has been evaluated on ultimate tensile strength (UTS). Analysis of variance has been performed based on full factorial design. For maximum UTS, the they suggested that spindle speed and welding speed of 100 rpm and 50mm/min respectively with magnesium on the advancing side. The weld strength is 110% higher than that of magnesium-magnesium weld joint.

S. Manickam et al.(2022),[30] given the focuss on friction stir spot welding process variables on shear fracture stress, including rotation speed, plunge rate, dwell period, and shoulder to pin diameter ratio. At a rotational speed of 1000 rpm, a plunge rate of 16 mm/min, a dwell time of 5 min, and a tool shoulder to pin diameter ratio of 2.5, the FSSW joint encounters a greater shear fracture strain. According to the hook height, width, and initiation point, an appropriate fracture load was discovered, which improved the mechanical and metallurgical qualities of the joints.

CONCLUSIONS

The Friction Stir Welding process for hard materials like steel and other vital engineering alloys efficiently Used. It decreases the defects and enhances uniformity of weld properties. The use dissimilar materials expands the applicability of friction stir welding in modern engineering applications. These analyses explained the influence of processing parameters on welding stages, plunging, and transition. Future work also includes analyses of non-heat treatable aluminum series and heat treatable aluminum. It is a demand of aircraft industries to substitute conventional joining applied sciences with frictional stir welding which is affordable and highly efficient.
It is find that nearly 4400 patents have been registered over last 10 years, increase of almost 75% between 2005 to 2022 patents associated with FSW { AL – 81%, STEEL- 2%, Polyethylene- 2%, magnesium -9%, Titenium-2%, copper- 2%, Polycarbonate-2% }



Below the tables summarize the Tool Geometry and materials and FSW Parameters for dissimilar alloys/metals

References	Materials	Thickness (mm)	Rotation Rate(RPM)	Traverse Speed(mm/min)	Findings
1.	Al-Cu-Li-Mg (Al alloy V-1469)	2.0	600	300	Microhardness Residual stress Grain structure The evolution of precipitation Force- 6000N-7000N
2.	Ti–6Al–4V alloy	3	800 - 900	25.37 (1 IPM) 50.74 (2 IPM) 101.48 (4 IPM)	Microstructure Tensile Strength Effect of Welding parameter (WS,TA,RS, DF etc.)
3.	Cu-Cr-Zr	6	1000	50	Tool (H13 steel) wear Analysis
4.	2198-T8 Al-Li alloy	3.2	800 -1600	200	Origin of intergranular fracture in transition zone. Origin of preferential crack initiation in transition zone Reason for formation of inhomogeneous SZ
5.	AZ91 magnesium alloy and AA6082-T6 aluminium alloy	6	1400	36	Mechanical properties of the weld Hardness distribution
6.	Al- Cu	1.5- 3.0	800- 1200	50	Microstructure Thermal History Mechanical properties
7.	AA2024 - AA7075	6	2000	20 - 80	Mechanical Properties of Welded Joints Crystal Structural Study and Phase Analysis

8.	Low Cu/Li alloy 2196-T8- high Cu/Li alloy 2060-T8	3	150	150	Macrostructural features Mechanical properties.
9.	1060 Al and T2 Cu	2	2250	100	Weld formation Microstructure evolution
10.	AA7050 and T7451	6	560-900	100	Macro and microstructure analysis
11.	Al−SiC−multi walled carbon nanotubes (CNT) and Al−SiC−graphene nanoplatelets (GNP)	5	2200	25	Microstructural evolution Mechanical and Tribological Properties
12.	5052-H34 Aluminum alloy	5	600-1500	100-300	Analysis of Torque, Axial and transverse forces during the FSW
13.	AA2024-T3/AA7075-T6	1.6	600- 1400	150	The maximum tensile-shear forces of 5900 N and 6700 N
14.	Al–Cu–Mg alloy (AA2519)	6	500-1100	---	Weld strength Ageing behaviour of the stir zone material
15.	AA 6063 Al-alloy and copper plates	6	800-1000	20 -40	scanning electron microscope (SEM) study used for weld joint
16.	AA8011(NiTi-SMA and Si 3 N 4)	4	1120	31.5	scanning electron microscope (SEM) study used for weld joint
17.	Ti–6Al–4V alloy	2	700-1300	10	Weld morphology
18.	Al-6.0Mg-0.35Mn-0.2Sc-0.1Zr	10	500	30	Mechanical properties analysed like tensil,hardness

	alloy				etc
19.	Steel(A60) – Aluminium (AA6063)	15	900-1800	---	Ultrasonic testing Ultrasonic Tensile test, The microstructure
20.	Al-3Fe-3Ni Alloy	……	…..	15 min for 170	Crystallization kinetics of these objects under conditions of rapid cooling
21.	Magnesium (Mg) and its alloys	--	--	--	Corrosion performance and biocompatibility
22.	Al-Mg alloy (Al 6061-T6)	6	600-1400	20-100	IMCs layer and material flow of FSW
23.	Aluminum alloy 2519	5	500-1100	30-760	Weld strength, Ageing behaviour of the stir zone material It
24.	AA6061-T6 and S275JR mild steel	5	500-1000	110	Microhardness profiles tool travel speed, plunge depth and tilt angle on joint
25.	5A06 Al and AZ31B Mg alloys	20	----	---	Microstructure evolution
26.	ZK60 magnesium alloy	3	500-1600	50-150	The effects ofdifferent rotation speeds and processing speeds on the microstructure and mechanical properties were compared
27.	SS400(MS) and A5083(Fe)	2	100-1200	25	The effects of pin rotation speed and pin offset toward the steel faying surface on the tensile strength of a joint were reviewed and

28.	Al- Mg alloys AA6061 (A), AZ31B (B), and AZ91D (C)	5	500-2200	25-150	hardness, impact energy, corrosion, and tensile test observed
29.	Al-6062 and Magnesium AZ31B	5	100	50	weld zone's microstructure Analysed
30.	AA6061/AZ31B	2	600-1400	8-24	Al-Mg-based intermetallic compounds (IMCs) determined

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