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Short and Brief Review on Friction Stir Welding

Amit S Kudale[1], Kanwal Jit Singh[2]

[1]Guru Kashi University, Talwandi Sabo, Punjab, India
[2]Maharaja Ranjit Singh Punjab Technical University, Bathinda

Abstract

Friction stir welding (FSW) has become the most popular welding technique for nonferrous alloys among researchers of the concerned field in the recent decade. It is a solid-state welding process and most suitable for nonferrous alloys, especially aluminium and magnesium alloys. Aluminium and magnesium alloys are the hot material for structural applications in transport vehicles, aerospace, and marine due to their lower densities and superior mechanical properties. Furthermore, FSW is associated with low temperature, which is responsible for eliminating defects of fusion welding such as porosity, liquation cracking, solidification, and cracking. This review article briefly introduces FSW and explains the different methods employed for FSW. Furthermore, process parameters, microstructural, mechanical properties, metallurgical investigations, advantages, disadvantages, applications, contemporary challenges and drawbacks, and future hotspots of FSW are identified.

Keywords: Friction Stir Welding, Weld Properties, Metallurgical Structure,

I. Introduction

In FSW, the job parts are joined without the base metals being melted. This process' development was a important shift from standard rotary motion and linear reciprocating procedures of friction welding [1]. The FSW's primary characteristic is to join materials without achieving the temperature of fusion [2]. Special tool with proper parameters is used for friction welding process to creating the heating zone between two mating plates. Various types of alloys which are not welded by any process are best suited with this process. In friction stir welding, there is use of non-consumable electrode which gives the defect free joining of aluminum alloys. From the study of various researchers, there is lots of optimization techniques are used to control the various parameters to enhance the quality of this process.

In automated sectors, friction stir welding is commonly used to substitute the aluminum sheet resistance spot welding method for better and better quality production. FSW's main advantages are a solid-state technique, low distortion area unit, lack of melt-related defects, and high joint strength, even in those alloys the unit of thought-about un-welded region ready by typical methods.

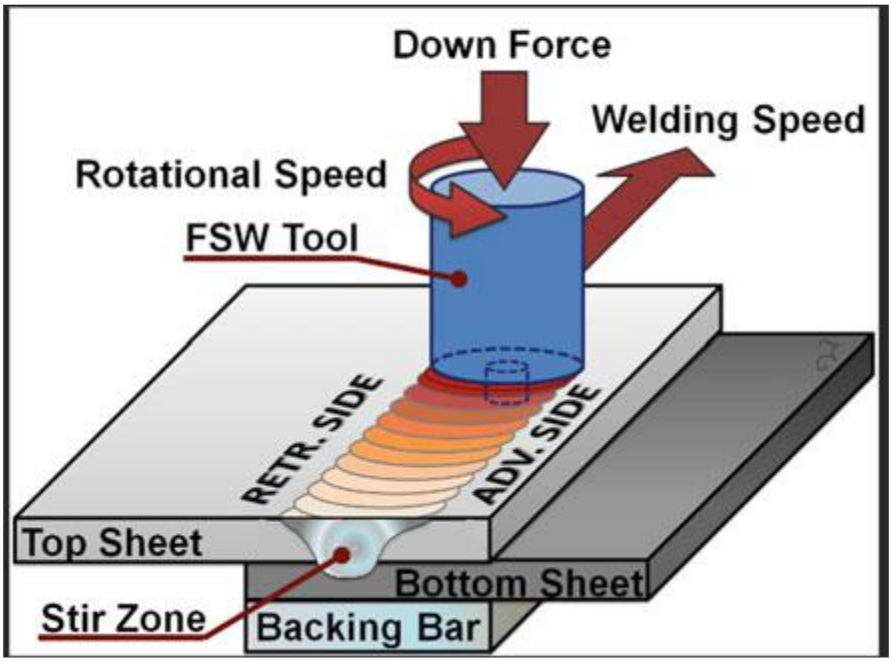

Fig. 1 Schematic diagram of FSW [3]

1.1 Working of FSW

This welding technique can be used to join butt and lap joints and having a flexible range of dimensioning for the parts to be joined. This is now widely accepted process of welding, which is used in some typical engineering application like aeronautical parts, etc. The aluminum and magnesium alloys are widely accepted by the structure, power, and automobile sector due to its lightweight. The reduction the weight of the component enhances the efficiency of the system. Moreover, these materials can b fabricated by using this welding technique. The process uses non consumable tool for welding the parts. The tool is bring into with the contact in the work piece, where heat is generated by means of friction and volumetric heating takes place, as the tool progressed over the length of the weld. The tool is made of two parts, where top part is known as probe [4, 5]. The second part of the tool is known as shoulder and it has a large diameter as compare to the probe. The tool rotates over the workpiece and produces friction at the interface. The schematic arrangement of the welded joint processed through FSW is shown in Fig. 1. The figure shows the rotating tool over the substrate. The downward force is the intensity of force required to weld the parts.

1.2 Process Parameters of FSW

Friction stir welding means that the parameters can be regulated and the energy input to the scheme can be controlled. The two main process parameters are the TRS and theWS. The geometry of the instrument (size and profile) and the process parameters influence the generation of heat, the material flow, the evolution of the microstructure, and the joint properties. In this method, the tool life is a very significant variable depending on the process parameter and obtaining a parameter that is more appropriate for the characteristics of the friction stir welding process as well as knowing the effects of the impact of these parameters on the welding microstructural conduct to be performed.

It has been explored the impact of some of the significant parameters such as axial stress force, rotation velocity, tool tilt angle, shoulder and pin diameter, welding velocity affecting welding characteristics. Therefore, an attempt was produced in this inquiry to know the impact of tool parameters and process parameters on the formation of FSP area and associated friction tensile strength characteristics. Important parameters were explored on welding characteristics such as axial tool stress (F), rotational velocity (N), and traverse velocity (S). However, few investigations [6] on formulating and optimizing the impacts of FSW parameters on mechanical and metallurgical characteristics have been carried out.

The Taguchi technique is a very significant technique used to optimize metallurgical conduct in the past to define friction stir welding by the highest possible process parameter of approx. 1150–1200 rpm rotational speed, 7 KN axial pressure, 75 mm min welding velocity, 225 MPa yield strength, and 247 MPa tensile strength. Approximately 35% more than other welding joints and the microstructure contains very good grain and equiaxial grain. Highly fine narrower grain was acquired that looked like elliptical onion ring in the middle of the weld and also increased the microhardness profile and began to descend in every 2 mm until the hardness was reached the same as the base material [7–9]. Fine and equiaxial grain was discovered around the nugget. It has been evaluated to increase the repeated fatigue life of failure.

2 Review of Literature

Colegrove and Shercliff (2005) studied the flow of material during friction stir welding process using the model based on CFD. This model was used to obtain the flow of material to all around of Trivex as well as MX-Trivex tool. The result obtained was compared to the analysis result of Triflute tools. By using Trivex tool, the analysis was indicated that the downward force as well as transverse was decreased. To know the behavior of material flow, the stream lined around the tool was used. The force along the downward direction was found to be increased using Triflute tool.

Da Silva et al. (2011) studied flow of material, microstructural behavior, mechanical properties like tensile strength and hardness based on the variation of process parameter and their effect on weld was done by friction stir welding joints of two dissimilar alloys between AA2024-T3 and AA7075-T6. Boundary of the base metal around the stir zone was clearly observed; no onion ring formation was observed.

Fratini et al. (2006), in friction stir welding method of aluminum alloy 7075, also researched how material flow occurs. He followed the numerical simulation method as well as the experiment by taking the tool rotation velocity variation, welding traverse velocity, and altering the profiled pin shape. The bonding of the material to the forward side of the friction stir welding joints is to be established. When geometry of the instrument profile was conical, the material flow was discovered tobe uniform because it enabled the vertical material motion in order to prevent the defect formation. It is well known that the effect on the weld characteristics of some needed parameters, such as moving speed and fastening velocity, is that for scientists the main subjects.

Sadeesh et al. (2008) The study of the fastening of dissimilar AA2024 and AA6061 5-mm-thick aluminum plates was also carried out using the method of friction stir welding (FSW). Optimum method parameters have been acquired for math approach applied to the victimization of joints. Sevvel P and Jai Ganesh V also outlined and examined the recent scenario of Tool Geometry’s role in FSW along with its tooling components, kinds, forms, sizes, and harm mechanisms in association with various metals along with steels, aluminum, titanium, and their alloys.

Karimi et al. (1998) studied in their research the effect of tool material and tool offset on tool erosion and metallurgical and mechanical properties of dissimilar friction stir fastening of Al alloy to steel area unit investigated. Different tool materials and offset were used in Al alloy friction stir welding to carbon steel with a steady tool velocity and feed rate of 710 rpm and 28 mm/min.

Cantin et. al. (2005) reported the friction stir welding (FSW) process as a relatively viable process for joining various forms of aluminum alloys for the reason that the oxide layer present on the aluminum surface doesn't provide any hindrance to the process. Based on their study, it was concluded that by using the FSW process, the lightweight material employed in various aerospace, transportation, marine, automotive, and railways are easily fabricated using this process.

Elangovan K., Balasubramanian (2007) have employed AA7075 aluminum plates of 7 mm thickness to investigate and analyze the FSP effect on metallurgical and techno mechanical behaviour of welds at ambient conditions in both parallel and perpendicular directions. The results indicate that the sheets are well processed using FSP while moving transversely in the direction perpendicular to the rolling direction.

Chena et al., (2006) have employed to study the effect of BM condition on FSW properties during FSW of AA2219-O and AA2219-T6. They reported that during experimentation the base material conditions have a significant effect on the weld appearance, defects formation, and weld joint efficiency. They observe 100% joint efficiency for AA2219-O compared to AA2219-T6 which is only 82%.

Rooy, E. L. (1990) they have used FSP to weld AA2014 and processed it in the parallel direction to that of extrusion to study the microstructure behavior, while at room temperature the tensile properties of the welded joints are evaluated in the longitudinal direction. A resonant electromechanical test machine was employed to evaluate the fatigue endurance (S–N) curve for welded joints by applying the constant load up to 250Hz.

Esparza et al (2002) reported the analysis of FSP zone formation and mechanical tensile strength of the weld joints using five different tool geometries namely straight cylindrical, tapered cylindrical, threaded cylindrical, triangular, and square and correlated the results by employing three different tool rotational speeds. They observed significant improvement while using a square tool pin that gives defect-free metallurgically and mechanically sounds weld than other tool pins.

Hasan et al., (2003) have reported the development of interrelationship between the SZ microstructure and mechanical behavior of the FSW welds during FSW of AA5083. The results reveal that the SZ is composed of fine equiaxed grains at different process conditions and they stated that the microstructural and mechanical behavior of the welds is significantly improved due to a decrease in heat input flow that leads to a decrease in the grain size and resulted in grain refinement.

Heinz et al (2000) reported the FSW of AA6056-T6plates to investigate the microstructural joints. It is indicated that TMAZ reveals different grain structure morphology in proximity to the NZ. The grains are more elongated and bent along the advancing side, while on the retreating side the grains are narrow and elongated. Lower tensile properties namely, tensile strength, yield strength was observed in the weld zone as compared to BM, while the ductility in the weld zone is reduced.

Hirata et al (2008) reported the effect of axial load and interface position with respect to tool axis on tensile properties of the produced FSW welds during FSW of AA7020-T6. The results indicate that the axial load is significantly varied with the change or increase in the distance of the interface between the tool shoulder and BM surface. The joint efficiency of 84% was achieved with the optimal combination of axial load that leads to defect-free welds.

Chen et al. (2006) have investigated and highlighted the effect of thermal and mechanical loadings on metallurgical behavior through experimentation and the numerical simulations during the FSW of AA7075-T6. More emphasis on the effect of residual stress occurred during the FSP of the base material.

Idown et al., (2009) have varied the welding speed from 50 – 175 mm during FSW to investigate their effect on metallurgical and mechanical behavioral properties of weldments. The UTS of BM is 84MPa, while at a lower WS of 50 mm/min the decrease in UTS of 80MPa was observed, while 71 MPa was observed at a higher welding speed of 175mm/min. This indicates that the UTS of the welded joints decrease with the increase in welding speed due to the generation of inadequate amount of heat generation. Also, at lower welding speed the generation of heat is high enough that leads to the generation of large grain size and ductility restoration by the mechanism of recrystallization. The fine equiaxed grains are observed during the microstructural examination especially when the welding speed is lower in comparison to higher WS.

Aval et al., (2011) have reported the fabrication of cast 2285 grade using 10mm.min-1,12 mm.min-1, and 15mm.min-1feed rates at 1400 rpm and 1800rpm of tool rotational speeds to illustrate the effect of FSP and to eliminate the defects occurred during casting that locally refined microstructure that helps to increases the strength (mechanical)of joints. Outcomes indicate the improvement in tensile, yield, and ductility properties during the processing of the base alloy.

Karthikeyan et al., (2009) have observed the occurrence of intermetallic phases namely Al3Mg2 and Al12Mg17, andAl2Mg3 in NZ during dissimilar submerged FSW (SFSW). They have employed water and air as a medium during SFSW and demonstrate as alternative and improved methods to improve the fine grain size of the welds with the formation of intermetallic phases. They have employed 300 rpm and 50 mm/min of constant tool rotational speed and welding speed and noted that the large fraction of intermetallic compounds, higher peak temperature, and higher hardness in the SZ were observed in the samples welded using air as a medium. While the submerged welded sample produced using water as a medium led to the generation of lower peak temperature as a result of lower generation of heat input that causes a decrease in the percentage of intermetallic compounds.

Kemp et al (2006) has used a different range of solutionized temperatures as 520, 540, and 560ºC during aging at 175ºC or 200ºC for FSW employing Post weld heat treatment (PWHT). They indicated the formation of coarse grain NZ region after the application of PWHT, while the hardness showsa uniform profile along the weld zone even after the PWHT.

Koteswara **et al (2008)** have studied the effect of different heat treatments processes namely, PWHT, solution treatment, and artificial again treatment, and their combination on tensile behavior of welded joints during FSW of AA6061. Further, the yield strength, tensile strength, elongation, and joint efficiency of different welds produced using heat treatment were also evaluated and concluded that treatment via artificial aging resulted in very useful compared to different processes.

Lakshminarayanan and Balasubramanian (2009) have conducted a comparative study to fabricate AA2219 square butt welds by employing, FSW, gas tungsten arc welding (GTAW) without filler, and electron beam welding (EBW). They have investigated the influence of three TS and post-weld aging (PWA) on fatigue and behavior tensile properties of welds those post-welds aged at 175 ºC for 12 h. Results indicated that superior fatigue is observed for post-weld aged FSW welds as compared to EBW and GTAW welds which are attributed to fine DRX grain structure formation and their distribution homogenously in NZ.

Lee et al., (2003) have conducted an FSW of AA7039 to report the effect of PWHT-T6 on microstructure and mechanical properties of welds. Experimentation was conducted at optimized process parameters of 635 rpm and 8, 12 mm/min of tool rotational speed and welding speed. Results indicate that TMAZ depicts the coarse grain structure of NZ with92.1% joint efficiency, while the yield strength, ultimate tensile strength are significantly reducing with PWHT, but percentage elongation is improved.

Kumar and Kailas (2008) have done a comparative investigation between different welding processes namely tungsten inert gas (TIG) and FSW. They noted that measurement of microhardness allows a clear indication about the decay in the mechanical behavior of TIG welds that occurred due to exposure of base alloy to high temperature. While, the FSW welds due to experience the lower temperature and severe plastic deformation occurred by tool leads to create the complex behavior and resulted in a decrease in mechanical strength in NZ, flow arm, and TMAZ. While HAZ acquire the improvement in the properties due to initial heat treatment of the alloy. The flow arm and NZ deal with a slight improvement in the hardness than TMAZ due to the phenomenon of recrystallization that gives fine grains.

Li et al., (1999) reported the investigation related to fatigue behavior of AA5052 welds produced using FSW and TIG technique in respect to fatigue testing. The results indicated that FSW welds possess good fatigue behavioral properties in comparison to TIG welds.

Lombard et al (2008) had done a comparison between the FSW and TIG welds produced using Al–4.5Mg–0.26Scalloy to analyze their effect on mechanical behavior and microstructure characteristics. For the evaluation of the mechanical strength of the welds, the tensile strength and microhardness profiles were done and used to further analyze the effect of PWHT on these properties. The results indicated that the formation of hardening precipitates is more influenced when using TIG welding in comparison to FSW. But the significant reduction in the mechanical properties for the TIG welds are occurs that later partially recovered using PWHT.

Madhusudhan et al (2009) have done a comparison analysis between FSW and TIG processes to weld Al-Mg-Mn-Sc-Zr alloy and to investigate their mechanical and metallurgical properties. The results reveal that FSW welds exhibits higher tensile strength as compared to TIG welds but lower than BM. This is attributed to a decrease in strengthening (precipitation) of Al3 (Sc,Zr), while the absence of strain as well precipitation hardening effect of Al3(Sc, Zr) particles leads to softening occurring in the weld zone. While the fine grain morphology in NZ is obtained in FSW welds as compared to TIG molten zone.

Maggiolino and Schmid (2008) used different fusion welding processes namely GTAW without filler, EBW, and FSW to weld AA2219 in square butt configuration. This was done to investigate the effect of these processes on the fatigue and crack growth behavior, for which the traverse tensile properties were evaluated for each respective weld. Results reveal that the FSW process can give extreme outstanding fatigue as well crack growth resistance when compared with other welding processes as EBM and GTAW welds, this phenomenon was occurred due to the formation of fine grain size in the weld zone of FSW welds.

Maheshwari and Pandey (1997) have employed the Taguchi method to explore the selection of the effective factor influenced and leading to higher tensile properties of the friction stir welded AARDE-40. They have obtained the optimal combination of tool rotational speed and welding speed using the Taguchi approach and indicated that axial load, tool rotational speed, and welding speed play a significant role in deciding the weld's tensile properties.

Mahoney et al (1998) have conducted a study to evaluate the influence of TRS, TS, and TG on strength of friction stir welded AA 1050/AA 5083, for this, they have employed full factorial experimental design. For this study, the UTS and the hardness of the welds are determined, and using this analysis of variance (ANOVA) were used to plot the main effect for determining the influence of process parametric conditions and accordingly choose the optimal level for each range of process parameters. The line regression equation is also derived and written to estimate and predict the output characteristics of each process parameter.

Malaryizhi and Balasubramanian (2011) have used the FSW process to establish the relationship between the metallurgical properties of the TMAZ region and the amount of heat input during FSW of AA5086. They have carried out a study in two phases, as the first phase deals with the numerical simulation of the prediction of heat input using finite element analysis (FEA), the second phase deals with the experimentation on the sample processed in two conditions as annealed and work-hardened to investigate their effect on the microstructure and the mechanical characteristics of friction stir welded welds. The results indicated that there is an asymmetrical distribution of temperature along the weld line during FSW, while the amount of the peak temperature on both sides of the weld joint, i.e., AS and RS is higher along with AS than RS as estimated through experimental data and predicted data. Also, they noted that heat input put a significant effect on the microstructure, as the TMAZ grain size is decreased with the decrease in heat input along the weld line length during FSW.

Wadeson (2006) has conducted numerical simulation and experimentation for friction stir spot welding (FSSW) of polypropylene sheets. They observed that the estimation of welding parameters and their effect on weld quality is very important to enhance the weld strength. For this experimentation, they have used L9 Taguchi orthogonal method and the experimentations were conducted according to the combination of process parameters of tool rotational speed, welding speed, plunge depth, and dwell time. The results indicated better coherence with the numerical and the experimental outcomes in a variety of weld strength conditions. To predict the influence of welding process parameters on the weld joint strength, the signal-to-noise ratio and ANOVA are employed. They observed a 47.7% enhancement in strength of a weld by employing the raw process parameters to achieve design optimization-based process specifications.

Mironov et al. (2015) examined the influence of feed rate and rotating speed on heat input in FSW as well as found that it significantly affected weld penetration. This research employed aluminum alloy 5083 as the base material. At the microscopic level, samples with increased heat input yielded bigger grains. A little lower tensile strength was obtained with the samples that welded at higher and lower heat input. Conversely, in comparison to base material samples, high tensile strength is produced by samples which welded at medium heat input. Whereas welding at high heat input results in the low hardness, a low heat input weld produced the maximum hardness

Khayyamin et al. (2013) has conducted experiments on pure copper as work piece and with three different tool pin profiles (plain cylindrical, square and taper). To maintain the low heat input, tool traverse and rotational speed were kept constant. The specimen were than investigate for micro hardness and tensile strength in order to draw the conclusion about improvement in mechanical properties.

Klobcar et al. (2012) Proposed Underwater FSW (Friction stir welding) in view to enhance the weld properties. Underwater FSW is a FSW process alternative wherein heat dissipation and conduction has been controlled along the weld line to produce high strength weld. AA 5052 H32 aluminum alloy underwater FSW has been done to draw the of tool rotation and welding speed effect on the tensile strength of the weld produced compared to the weld produced b normal FSW. There is enhancement of 2% in the ultimate tensile strength produced by underwater FSW.

2.1 Research Gap

After reviewing the literature survey, it was perceived that:

- Axial force, welding speed, pin profile and pin diameter, tool rotational speed, are the primary parameters that affects the weld's metallurgical and strength properties resulted through the FSW process.
- Many authors have worked on the MIG welded A2014 aluminium alloy by varying the parameters, but there are limited studies on the FSW of A2014 aluminium alloys by varying the parameters such as transverse speed, rotational speed and pin profile etc.

- It was learned from the literature that the welded joints' quality generally expresses such a strong tensile strength, impacting hardness and strength in terms of their major mechanical characteristics as well as metallurgical properties including HAZ and the corrosion of the weldments by sea water.

Based on such mechanical and metallurgical parameters, the welded joints' quality created at pin diameter, pin profile, axial force, welding speed, and tool rotational speed had to be determined.

3. Function of Tool in FSW

When the button comes into touch with theworkpiece, it produces heat that is deforming and frictional, softening the fabric of the workpiece. So, the material used for making tools for friction stir welding must have the following properties (Fig. 2)

- Good resistance
- Resistance to fracture
- Resistance to wear
- High temperature stability
- High temperature resistance
- Total reactivity
- Thermal expansion co-efficient.

Fig. 2 Friction stir welding tool

3.1 FSW in Industries

TWI originally patented FSW method in many industrialized countries. For many industrial applications, FSW and its numerous versions such as friction stir spot welding and friction stir welding are used.

- Used in the manufacturing industry
- Used in chemical sectors for connecting pipelines, thermal exchangers, etc.
- Used for welding wings, fuel tanks. and airplane structures in aviation sectors.

3.2 Advantages and Disadvantages of FSW

- In welded area, distortion is significantly small as well as residual stress.
- Higher mechanical characteristics.

Disadvantages

- The work piece should be very closely clamped to ensure that the weld is performed properly.

- Surface thickness is decreased marginally as no filler material is used during the method.

3.3 Typical Engineering Applications of FSW

- FSW is mainly used for welding wings, fuel tanks, airplane structure, and also for structural job in marine sectors.
- Used for the construction of railway tankers in marine sectors for structural job and railway sectors.
- Recently, began to use in automotive motor chassis and body frame.
- In the electronic sectors, friction stir welding is also used to connect bus bars, aluminum, copper, other electronic machinery and connectors.
- It is also used for welding the spacecraft fuel tank because of the strong state joining method [15–19] (Fig. 3).

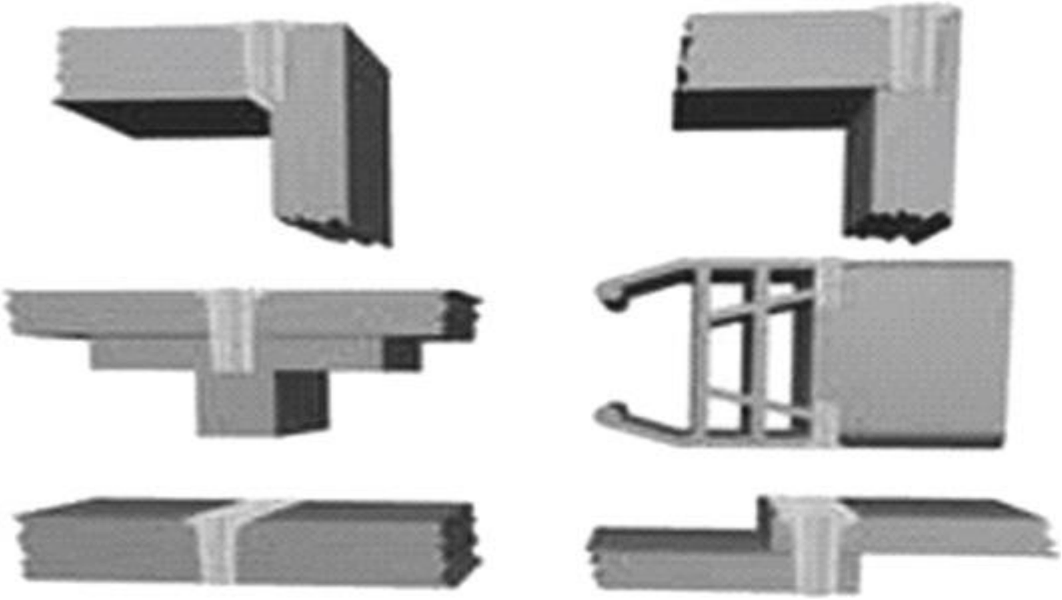

Fig. 3 Various joints by friction stir welding process

3.4 Experimental Review

AISI 1045 carbon steel and 3-mm-thick aluminum alloy A1100-H16 welded plates were welded [20, 21]. For welding purposes, AISI 4140 tool material steel with a cylindrical pin was used.

4 Friction StirWelding of Similar and Dissimilar Materials

Recently, the focus has been on creating rapid, cost-effective procedures that make the area unit-friendly. The focus was turned on friction stir attachment as a link technology capable of delivering welds with no defects frequently associated with procedures of fusion attachment.

5 Conclusion

The present reviewhas just given an introduction to FSW on aluminum alloys and how it works. The tool for FSW process must be designed taking into account numerous considerations such as material, surface quality, geometry of tools, tool and its design are the key parameters to meet the growing demands on the weld materials. A review of some previous works is done and what parameters are taken into account while analyzing the results when FSW technique used for aluminum alloys.

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