Friction Stir Welding and Friction Stir Processing of Dissimilar Alloys: A Review

K Palani¹ and C Elanchezhian²

¹ Department of Mechanical Engineering, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya (Deemed to be University), Kanchipuram, 631561, Tamilnadu, India
² Department of Mechanical Engineering, Sri Sairam Engineering College, West Tambaram, Kanchipuram, 600044, Tamilnadu, India

E-mail: palani.k@kanchiuniv.ac.in

Abstract. The present work is focused on friction stir welding and friction stir processing of dissimilar alloys due to its emerging technique applied in the wide area of applications viz., aviation, ship building, defence industries etc. In recent years, the novel solid-state joining techniques viz., friction stir welding and friction stir processing are applied in joining of dissimilar alloys even though there is the difference in mechanical properties and chemical composition of the alloys. Due its eco-friendly, versatile and energy-efficient process, these are implemented to reduce the harmful effects and formation of defects in joining of dissimilar alloys compared to the fusion welding techniques. The specially designed non-consumable rotating tools are used in joining process by generating frictional heat between the tool surface and alloys to produce the sound welds. This work discusses the status, opportunities and challenges of above processes in joining of dissimilar alloys, viz., aluminium, steels, titanium etc.,

Keywords: Friction stir welding; Friction stir processing; Mechanical properties; Optimization techniques; Material characterization.

1. Introduction

The quality of the welded joints was studied in joining of the various similar and dissimilar alloy materials in the aerospace, fabrication and aviation industries. Initially, the fusion welding process was tried to fabricate the dissimilar material viz., steel and its alloys. Besides, it can be extended into the FSW process due to avoid the unnecessary defects produced by the fusion welding processes. The FSW process was applied to produce the similar and dissimilar joints with considerable amount of frictional heat between the tool circumferential surface and base materials. The various designed non-consumable tools were used to fabricate the dissimilar joint efficiently compared to the fusion welding processes. The researchers have focused on the material characterization, material flow, heat transfer, grain boundary formation, temperature distribution in the dissimilar joints. The various optimization techniques viz., response surface methodology, Taguchi method, grey relational analysis, fuzzy approach and artificial intelligence techniques were applied to study the significant parameters which decide the quality of the joints.

2. Mechanical and Metallurgical Characterization on dissimilar FSW Joints

The various welding process parameters, such as different combinations of materials, tool materials, geometry of the FSW tools, different grades of electrodes were carried out in the similar and dissimilar welded joints of friction stir welding process. These above independent factors are mainly applied based on the mechanical and metallurgical characterization of the joints.
2.1 Mechanical Properties

The defect-free joints were achieved by the suitable welding parameters in assisting to enhance the mechanical properties of the fabricated welded joints. The investigation was made on the dissimilar friction stir butt welding of pure titanium and AA5083-H321 aluminium alloy by Amini et al. [1] and they examined that there was no region for the thermo-mechanically affected zone (TMAZ) due to the higher melting temperature of the pure titanium compared to the aluminium alloy. Also, they reported that the highest hardness was predicted due to the dynamic recrystallization and material flow in the nugget zone (NZ) whereas the interface has the brittle intermetallic compounds (IMCs) for the welded joints. Aonuma et al. [2] found that the titanium with AA7075 aluminium alloy has the lower tensile strength relate to the titanium alloy with AA2024 aluminium alloy. The lower tensile strength of the welded joints was observed for pure titanium with aluminium alloy welded joints by increasing the travel speed whereas the titanium alloy and aluminium alloy combinations has the lower tensile strength of the welded joints.

The dissimilar butt joining between AA 2024-T3 and AA 7050-T7651 aluminium alloys of 2 mm thickness was successfully done by friction stir welding (FSW) and stationary shoulder friction stir welding (SSFSW) processes by Barbini et al. [3]. They found that the welded samples along the thickness, the frictional heat was not properly generated due to the non-uniform material flow and plastic deformation and presented in Figure 1. The half of the stir zone width was examined at the bottom of the weld relate to the crown of the weld due to the variation in microstructure with non-uniform heat distribution in FSW joints.

![Figure 1](image)

**Figure 1.** Comparison of the SZ area in SSFSW and conventional FSW for different Heat Input

Azizi et al. [4] used the square pin tool to investigate the microstructures and mechanical properties with 10 mm thick pure copper plates of four different welding speeds of 50, 100, 150, and 200 mm/min and constant rotational speed of 700 rpm of the butt joints. The defects with finer grains were examined due to the less heat input and high peak temperature at the higher welding speeds of the tool. The more ductile fracture surfaces were observed at the lower welding speeds, whereas the lower tensile elongation was found at the higher welding speeds of the tool. Charit et.al [5] improved the tensile properties of the as-cast alloy using the friction stir processing in addition with Zn, Mg and Sc particles. They reported that the different grain sizes 1.8 μm, 5.5 μm and 0.68 μm were found for the artificial aged, solution heat treated and no post heat treadered cast alloy by variations in plunge depth conditions.
Dehghani et al. [6] reported that the formation of fine equiaxed grains at the stir zone was found whereas the coarse grains with precipitates occurred at the heat affected zone of the friction stir welding of AA7075-O aluminium alloys. The maximum strength and hardness was found at the stir zone of the FSW butt joints which were more than the strength and hardness of the base materials and also it indicates the there is no formation of defects at the welded joints. Delijaicov S et al. [7] reported that the irregular mixing of materials was found at the low penetration depth due to the more tilt angle of the tool with its vertical position. The transverse speed and tool tilt angle are the most influencing parameters on the joint strength of the fabricated FSW joints. Zhang et al. [8] made an investigation on the microstructure and mechanical properties of the dissimilar ultrasonic spot welded AA2139 aluminium alloy to Ti-6Al-4V titanium alloy with 1 mm thick sheets. Due to the less fracture at the interface of the lap joints, the maximum shear strength was found owing to other dissimilar combinations of the Lap joints.

Cao et al. [9] investigated that the effects of the FSW process parameters, viz., rotational speed and the pin length on the microstructure and mechanical properties of the lap welded 2 mm thick AZ31B-H24 magnesium alloy sheets. The variation in probe length of the tool increased the tensile shear load, while these load initially increased by increasing the rotational speed and further increment of the tool rotational speed induced the decrement of the load for magnesium alloy joints and presented in Figure 2. Also, they have studied that the grain sizes, heat distribution rate were increased by increasing the tool rotational speed due to the development of the grain growth after recrystallization.

![Figure 2](image_url)  
**Figure 2** Effects of tool rotational speed on grain size and hardness in the stir zone of the top sheet at the mid-Thickness obtained at a welding speed of 20 mm/s and a pin length of 2.75 mm

Dorbane et al. [10] investigated effects of the welding parameters on the microstructural, mechanical, and fracture properties of dissimilar friction stir welded AZ31B magnesium alloy and AA6061-T6 aluminium alloy joints using the various combinations of the rotational speeds and welding speeds of the tool and found the superior properties at optimal FSW process conditions. They observed that the grain refinement of the both Mg-rich and Al-rich alloys were occurred at the stir zone (SZ) with the grain sizes of 2.43±0.87 µm and 0.94±0.24 µm respectively. From the Figure 3, they examined the formation of the thin layer of intermetallic compounds (IMC) at the interface near the SZ which deteriorates the weld properties. The discontinuity of microhardness was found at the weld interface due to the presence of IMCs in the joints.
Figure 3 (a) Microhardness values obtained at 2 mm from top of weld for the various parameters, (1) 1600 rpm and 250 mm/min, (Mg on AS) (2) 1600 rpm and 500 mm/min, (Al on AS) (3) 1400 rpm and 500 mm/min, (Al on AS) (4) 1200 rpm and 500 mm/min, (Al on AS) and (b) Microhardness obtained on welded joints using 1400 rpm, 500 mm/min parameters at three different distances from top of the weld.

3. Various Optimisation techniques used in FSW and FSP Processes

The various welding process parameters, such as different combinations of materials, tool materials, geometry of the FSW tools and the optimisation of the process parameters were important to achieve the objectives for the good quality of the welded joints. The different optimization techniques were applied on the similar and dissimilar aluminium alloy materials to achieve the quality of the joints [11 -13].

3.1 Similar and Dissimilar FSW process

Farzadi et al. [14] used the effective statistical technique, namely response surface methodology for the optimization of the parameters of the FSW of AA7075 aluminium alloy butt joints by proper selection of parameters, viz., rotational speed, transverse speed, shoulder diameter, and pin diameter of the tool on the tensile strength of the welded joints. They found the maximum tensile strength and joint efficiency with the optimum process parameters settings 510 rpm of rotation speed, 95 mm/min of welding speed, and 16 mm of shoulder diameter with 5 mm of pin diameter of the tool.

Sundaram et al. [15] successfully welded the hot worked AA2024 aluminium alloy with the cold worked AA5083 aluminium alloy with five different tool pin profiles using the FSW process. They developed the mathematical models which give the good correlation between the process parameters and the responses of the friction stir butt welded joints. They examined that the highest tensile elongation and tensile strength of the joints was found for tapered hexagon pin profile due to its higher pulsating effect and smooth material flow, whereas the straight cylinder pin profile gave the lower strength and elongation of the joints.
Palani et al. [16] successfully optimized the friction stir welding parameters of the dissimilar AA8011-H24 aluminium alloys and Ti3Al2.5V titanium alloys using the Taguchi based grey relational analysis with principal component analysis. They reported that the drastic reduction of the strength of the dissimilar welded joints with the optimum process settings of 1700 r/min tool rotational speed, 60mm/min welding speed, 6 kN axial load using the square pin profiled tool. Winiczenko et al. [17] optimized the process parameters on the tensile strength and microstructural properties of the dissimilar AISI 1020-ASTM A536 joints using the hybrid RSM based Genetic Algorithm. They developed the mathematical model was used to predict the tensile strength of the joints and also, they studied the effects of the welding parameters on the fabricated joints. Okuyucu et. al. [18] applied the artificial neural network algorithm on the friction stir welded aluminium plates and the better correlation results have been observed by comparing the measured and predicted results of tensile strength, hardness of weld metal and hardness of HAZ compared to elongation and yield strength of the FSW weld specimens.

Sahu et al. [19] made a feasibility study of the optimization of the FSW parameters of AM20 magnesium alloy using Taguchi grey relational analysis. They reported that the analysis by response surface methodology showed the better results compared to the taguchi method at the optimal process parameters of the welded joints. Palani et al. [20] applied hybrid fuzzy approach to optimize the process parameters, such as rotational speed of 2050 rpm, tilt angle of 90o and transverse speed of 40 mm/min with the responses, Vickers microhardness of 57.7 HV, and Impact strength of 12.4 J for the AA8011-H24 aluminium alloy FSW joints. They showed that the tool tilt angle is the most significant parameter for the Vickers microhardness followed by the welding speed, whereas welding speed is the most significant parameter for Impact strength of the joints followed by the tool tilt angle.

Shojaeefard et al. [21] made the friction stir welding process successfully on dissimilar AA 5083 aluminum alloys and brass plates and optimized the process parameters of the welded joints using Taguchi method. They reported that the sound welded joints were occurred based on the variation in rotational speed of the tool with the formation of fine and equiaxed grains at the stir zone, while the elongated grains were examined at the thermo mechanically affected zone. Also, they examined that the tensile shear force initially increases by increasing the rotational speed and further increment of rotational speed reduced the tensile shear force due to the variations of heat input between the tool and workpiece contact surfaces.

### 3.2 Similar and Dissimilar FSP process

Dadashpour et al. [22] investigated the friction stir processing of cast AZ91C magnesium alloy with and without SiO2 Nano particles and also studied the effect of SiO2 Nano particle addition and the fracture mechanism on the mechanical properties of the fabricated joints. Also, they reported that the enhanced mechanical properties are found in the fabricated joints with nanoparticles addition related to the base cast alloys and joints without nanoparticles due to the evenly dispersion of the alloying elements in the weldment. Due to the evenly dispersion of the alloys, it deteriorates the fracture behaviour of the fabricated joints.
Khodabakhshi et al. [23] studied the deformation behavior of a hybrid aluminium matrix nanocomposite reinforced with TiO2, MgO and Al3Ti nanoparticles using FSP with threaded tool pin. They reported that the enhanced tensile properties are observed at the atmospheric temperature for the reinforcement of Al3Ti and MgO nanoparticles due to the dynamic strain ageing with a negative strain rate compared to the TiO2 nano particles reinforcement in the fabricated joints. Cioffi F et al. [24] investigated that the lateral off-set was the dominant parameter for the fracture location and resistance of the dissimilar friction stir welded AA2024 alloy and 17%SiC/2124Al composites which improves the bonding quality of the welded joints. They reported that the boundary of the alloy-composite mostly affects the strength of the welded joints through the variation in hardness.

Bodaghi et al. [25] aimed to make the joints of AA5052-O aluminium sheets with the addition of SiC Nano powder and investigated the effect of SiC nanoparticles on the mechanical properties and microstructural behaviour of the welded joints. The grain size of the welded joints at stir zone was reduced due to addition of SiC Nano powder during FSW process whereas the tensile strength was decreased. The microhardness was considerably increased compared to the welded specimen without Nano powder and higher loss of weight and poor wear resistance was observed due to improper distribution of Nano powder in stir zone.

4. Effect of Process Parameters on the Mechanical properties of the joints

4.1 Tool Pin Profile

The effect of the microstructure and mechanical properties of the of the friction stir welded AA6061-T6 aluminium alloy joints using various tool tilt angles and two different profiled pin tools were discussed by Banik et al. [26]. They found that the tapered threaded pin tool produced the stacked onion ring pattern, whereas there was no onion ring formation in the welded region. Also, they observed that the more stable flow of material using the tapered threaded tool with higher tilt angle and it enhances the tensile properties of the welded joints. Ramachandran et al. [27] studied the effect of geometry of the tool pin profile on the dissimilar friction stir welded AA5052 aluminium alloy and HSLA Steel joints using the various profile angles of the tapered tools. The tapered tool produced the significant penetration in steel side by the formation of the intermetallic compound which enhances the strength properties.

Palani et al. [28] discussed that the variations of welding speed affected the strength of the joints due to the lack of diffusion of the parent materials. Also, they examined that the tensile strength was improved by keeping constant rotational speed of the tool (1250 rpm) and welding speed (50 mm/min) with variations of plunge depth range of 2.25 to 2.5 mm. Further, they suggested that the hexagonal tool pin produced the higher tensile strength and higher hardness of the joints compared to other profiles. Amini et al. [29] FSW joints of AA 5083-O aluminium alloys successfully with different tool pin shapes. They examined that the concentric tool pin produced the more temperature relate to the offset pin due to the friction between the tool and work piece surfaces, whereas the temperature of the half pin and arched pin tools significantly increased with increase in rotational speed owing to the other tools. From the Figure 4, the maximum tensile strength was observed at the welding speed of 100 mm/min and rotational speed of 1120 rpm for the offset pin tool compared to other tools.
The offset cone pin (Tool O) exhibited superior tensile strength due to the sufficient material flow which produces the fine equiaxed grains in the welded joints compared with other profiled tools, viz., half cone with concentric pin (Tool H), and arched concentric pin (Tool A), whereas concentric cone pin (Tool C) produced the lower tensile strength due to the transferring flow of material was impossible in the direction from front side to the back side of the tool. Dehabadi et al. [30] made an investigation on the microhardness of friction stir welded AA 6061 aluminium alloys using the two different pin profiles, such as triangular pin and tapered cylindrical pin profiles and employed the effect of the pin profiles on the welded joints in the stir zone. They reported that both the tools increased the tensile strength and yield strength of the welded joints due to the generation of higher heat input between the contact surfaces and also found that the quality of the welded joints on the strength was achieved by using conical tool.

Dressler et al. [31] investigated the feasibility study on the weld properties of the dissimilar friction stir welding of TiAl6V4 titanium alloy and AA2024-T3 aluminium alloy with 2 mm sheets. Due to the variations in properties of these alloys, the profiled tool pin was positioned to an offset distance from the weld centre towards the Al alloy side. They observed that the maximum tensile strength was found at the weld interface which was 73 % more than the strength of the Al alloy, whereas minimum harness and maximum local elongation was presented in Al alloy side. Due to the swirl-like structure formation at the nearer to the weld interface, the fracture was occurred at the interface between the alloys. Wang et al. [32] investigated the effect of tool rotational speed on the microstructure and mechanical properties of bobbin tool friction stir welding of Al–Li alloy joints. The asymmetric material flow occurred around the tool in the weld SZ due to the different frictional heat of the rotational speed of the tool which leads heterogeneous plastic deformation in the SZ. The increasing rotational speeds produce the low tensile elongation in SZ.
4.2 Welding Speed

Guo et al. [33] reported that the effects of materials position and welding speed of the tool on the flow behavior, microstructure and microhardness of the dissimilar aluminium AA6061 and AA7075 alloy joints. They reported that the AA6061 aluminium alloy side is more effective for proper material mixing than the AA7075 aluminium alloy side at the nugget zone of the welded joints. Also they observed the onion rings formation and decrease in hardness due to increase in welding speed of the friction stir welding tool. Lee et al. [34] studied the microstructure and mechanical properties of the friction stir welded AA6061 aluminium alloys and observed that the fine equiaxed grains, elongated grains and coarse grains were examined in the stir zone (SZ), Thermo-mechanically affected zone (TMAZ) and Heat affected zone (HAZ) respectively in the weld zone of the joints. They reported that the decrease in width of the strain and maximum strain was found nearer to the retreating side due to increment of welding speed. They realized that the increment of the welding speed decreases the ultimate tensile strength significantly.

Sabari et al. [35] made an investigation of the effect of tool pin profiles on the tensile properties in the stir zone of underwater friction stir welding of AA2519-T87 aluminium alloy joints. They used the four different tool pin profiles, such as straight cylindrical pin (SC), straight threaded cylindrical pin (STC), taper cylindrical pin (TC) and taper threaded cylindrical (TTC) for the welded joints. The defect-free welded joints were found for the straight threaded cylindrical and taper threaded cylindrical pin profiles compared to other pin profiles. The dissimilar lap welding between TC1 Titanium alloy and LF6 Aluminium alloy using FSW process by Yu-hua et al. [36]. The titanium alloy particles are stirred with aluminium alloys in stir zone by the FSW process conditions, such as increment of welding speed and/or decrement of rotational speed with minimum axial force of the tool.

4.3 Rotational Speed

Suri [37] reported that the increase in hardness was found by increasing the rotational speed of the tool on dissimilar friction stir welded aluminium alloy joints. The generation of more heat was found due to the fine grains at the stir zone which increases the hardness. Ghorbanzade et al. [38] investigated the effect of tool rotating speed on the microstructural evolution and mechanical properties of friction stir welded AA 2024-T3 aluminium alloys. They reported that 10 % increase in tensile strength and yield strength at the rotational speed range of 400 rpm to 800 rpm due to precipitates distributed evenly at the stir zone and the lower hardness was found at the speed range 400 rpm to 630 rpm at the stir zone compared to the hardness of the base material.

Ilangovan et al. [39] investigated the effects of tool pin profile on microstructure and tensile properties of dissimilar hot worked AA 6061 aluminium alloy with cold worked AA 5086 aluminium alloy materials. They reported that the threaded cylindrical tool gave the superior performance of the joints over the tapered cylindrical tool followed with straight cylindrical tool due to the formation of finer and uniformly distributed precipitates, circular onion rings and fine equiaxed grains at the Stir Zone.
Saravanan et al. [40] investigated the effects of the shoulder diameter to pin diameter ratio on tensile strength, microhardness and microstructure of the dissimilar FSWed aluminium alloys of AA2024-T6 and AA7075-T6 joints. They examined that the maximum hardness was occurred in weld nugget zone due to the formation of fine grains whereas the minimum hardness was observed in HAZ region on advancing side. Also they found that the superior tensile strength and microhardness were confirmed in NZ due the presence of fine recrystallized structures. Taveres et al. [41] investigated successfully the friction stir welding of AA2198 aluminium alloy plates and studied the microhardness distribution and tensile behavior of the joints. The Figure 5 showed that the hardness values in the SZ was more than the TMAZ and lower than the base metal. Also, they reported that the 90% of the tensile strength and yield strength was achieved in the stir zone whereas only 40% elongation was found at the zone for all the welded joints.

![Microhardness measurements along cross section of the weld](image)

**Figure 5** Microhardness measurements along cross section of the weld

**4.4 Axial Force**

Liu et al. [42] observed that the effect of solid solution strengthening was weaker than the effect of precipitation strengthening in TMAZ and SZ region due to the formation of β” and β’ grains at the peak temperature. The appearance of these grains near the centre of the weld reduced the hardness gradually at the stir zone. From the Figure 6, the β” precipitates were increased by increasing the axial force which initially decrease the microhardness and then increased due to the formation of the solid solution strengthening in the SZ and TMAZ and “W” shaped microhardness profiles were observed from the retreating side.

![Effect of axial force on the microhardness distributions of the HSFSW joints](image)

**Figure 6** Effect of axial force on the microhardness distributions of the HSFSW joints
Song et al. [43] made an investigation of the effects of probe offset distance on the microstructure and mechanical properties at the interface of the dissimilar 2 mm thickness titanium alloy Ti-6Al-4V and aluminium alloy AA6061-T6 joints. They reported that the sound defect free joints occurred at the 750 rpm and 1000 rpm rotational speeds and 120 mm/min welding speed with proper probe edge offset distance. Also they found that the higher joining performance and formation of intermetallic compounds at the interface between the two dissimilar alloys were due to the proper selection of probe offset distance. Li et al. [44] investigated the dissimilar butt joints of Ti-6Al-4V and Al-6Mg alloys using FSW process. The reduced shoulder attrition of the FSW tool with no back flow of materials was benefited with the use of modified joint configuration and pin plunge setup of the joints. They examined the continuous intermetallic layers at the interface of the dissimilar joints which improve the properties of the joints and also the joint strength was 92% more than the strength of the aluminium base alloys.

5. Effect of Process Parameters on the Microstructure of the joints

The microstructure of the welded joints plays a major role in deciding the good quality of both fabricated welded joints. From this analysis, the presence of defects, nature of the defects and corresponding justification has obtained on the responses of the joints. Xue et al. [45] discussed the effect of interfacial microstructure evolution on mechanical properties and fracture properties of FSW 1060 aluminium alloy and pure copper plates of 5 mm thickness. They examined that the presence of intermetallic compounds (IMCs) enhances the mechanical properties in the welded joints. Due to the cooling time of the welded joints, the increasing size of the IMC layer in the welded SZ was inferior the strength properties.

![Figure 7](image_url)

**Figure 7** Microstructures of the nugget zone: (A) advancing side and (B) retreating side
The microstructural study was made in different zones, namely thermo-mechanically affected zone (TMAZ) and Stir zone (SZ) of the friction stir welded AA2024-T3 aluminium alloy joints by Franchim et al. [46]. The fine small grains sizes were observed in weld stir zone due to the proper material mixing by the frictional heat. From the Figure 2.5, the grains were arranged parallel to the weld interface in the advancing side of the weld transition zone which was contrasted grains appearance in base Al alloys, while the formation of highly deformed grains were presented in the weld interface. Barenji [47] was made the investigation on the mechanical properties and microstructure of the welded joints based on the process parameters of the friction stir welding process and also he investigated that the effects of the welding speed on the microstructure of the AA 7020 aluminium alloy welded butt joints. Also, they discussed the relationship between the heat input and the welding speed with rotational speed of the tool.

The stationary shoulder friction stir welded Ti-6Al-4V titanium alloy with the 7 mm thickness was successfully carried out by varying welding speeds and tool rotation speeds by Jiang et al. [48]. The formation inherited α-phase texture and reconstructed β-phase texture at the weldment were found by the variant selection analysis. They reported that the decrement in heat input and smooth surface appearance were found at the welded joints due to increase in welding speed and decrease in tool rotational speed. Komerla et al. [49] focused on the dissimilar welding of AA6016 aluminium alloy with DC04 deep drawing mild steel using friction stir weldng process and investigated the microstructure, microhardness, surface texture and Grain size of the welded joints. The fine Fe grains were observed in the weld nugget zone (WNZ) whereas grain growth was examined in the thermo-mechanically affected zone (TMAZ) owing to the interaction between the alloy material and tool surface. Mao et al. [50] investigation was made on the microstructure and mechanical properties of the nugget zone on the friction stir welded AA7075-T6 aluminium alloy plates. The smallest grains at the top side and coarse grains at the root of the welded joints were observed by EBSD analysis. They examined that the maximum values of 415 MPa tensile strength, 255 MPa yield strength and 8.1% elongation were found for the AA7075-T6 aluminium alloy plates.

Palani et al. [51] studied the effects of the process parameters on the microstructure and microhardness of the dissimilar friction stir welded/processed AA5083-H321 with AA8011-H24 aluminium alloys. They showed that the defect-free sound welded joints were found compared to other joints from the macrostructural in addition to Al2O3 and SiC nanoparticles. Also, they reported that the maximum hardness was observed at the weld SZ in addition to Al2O3 nanoparticles in dissimilar AA8011-H24 and AA5083-H321 welded joints due to sufficient material flow occurred at the welded region at the SZ whereas, the variations of hardness occurred at the TMAZ which produces the lower hardness at the stir zone. The influence of FSP parameters on the tensile properties and microstructure of dissimilar AA8011-H24 and AA6061-T6 aluminium alloy joints in SZ were discussed by Palani et al. [52]. They reported that the better microstructure was occurred at SZ in addition of SiC nanoparticles than the other zones. Also they examined that the tensile strength of 98.58 % and 90.08 % were established at the weld nugget zone of the similar AA6061 aluminium alloys in addition to SiC nanoparticles and dissimilar friction stir welding of AA 8011 with AA 6061 aluminium alloys without nano additions respectively.
6. Conclusions

The friction stir welding and friction stir processing play a critical role in joining of the various combinations of dissimilar alloys due to their difference in mechanical properties and chemical composition in fabrication industries to decide the quality of the joints. The effects of process parameters on the weld properties and material characterization of the welded joints are effectively studied and also the performance of the welded joints is improved by applying the various optimization techniques. From the review, it can be realized that, the various studies are discussed in joining of the dissimilar alloys with the application of the different optimization techniques using friction stir welding and friction stir processing techniques. Also, this study is highly helpful to solve the complex problems which may occur in joining of dissimilar alloys with energy efficient and cost effective process.

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