2.1 Introduction

This chapter divided into four parts. In part one the effect of welding parameters on mechanical properties has been presented. While part two studies the temperature distribution and residual stress. Part three studies the effect of welding parameter on fatigue strength and part four used Taguchi method to optimization welding parameters.

2.2 Friction Stir Welding (FSW) of Aluminium Alloys

Sato et al. (**2002**) [37] investigated the effect the FSW parameters on the hardness and microstructure for aluminium alloys 6063-T5 and T4 for 4 mm thickness welded by FSW. They used 6 mm/s, and (800-3600) rpm welding and rotation speeds, respectively. The results showed that the maximum temperature generated at high rotation speed. When the temperature increased the recrystallized grain size of the weld increased exponentially. At same welded condition the 6063-T4 showed homogeneous hardness profiles whereas 6063-T5 was softened around the weld center. Different rotational speed values had no important differences in the hardness profile in these welds. In most parts, the post weld led to increasing hardened while the over-aged regimes and the stir zone of the 800 rpm weld explained the lower increase in hardness. Microstructural analyses suggested that the small increase in the hardness in the SZ of the 800 rpm weld was strongly related to the increase in volume fraction of the Precipitation-Free Zone (PFZ) caused by the smaller grain size.

Deqing et al. (2004) [38] studied the effect of the FSW parameters on half-cold hardening aluminium with 3mm thickness. They used (850 –1860) rpm, (30 - 160) mm/min rotation and welding speeds respectively, as well as a cylindrical tool, have diameter of a pin, 2.5 mm. The results showed that the HAZ was very small, and the microstructure of the FSW zone involves very fine and equiaxed grains instead of the band-like structure of the half cold-hardening aluminium plate, As well as, the tensile strength of the welds was about 20% lower than that of the hardening aluminium plate, but about 10% higher micro-hardness was demonstrated by the welds in comparison with that of the aluminium plate in annealing condition. Both the tensile strength and micro-hardness of the FSW welds were affected by the welding speed of the head pin. Good welds could be result when used pin and shoulder diameters in the proportion of 1:3, and the better optical quality welds with a tensile strength above 100 MPa were achieved by utilizing the head with 3 mm pin and 9 mm shoulder rotating speed at 1560 – 1860 rpm.

Kumbhar and Bhanumurthy (2008) [39] investigation the effect of the FSW parameters on Al 6061-O Alloy with 5 mm and compared with AA 6061-T6. They used rotation speeds of (710, 1120 and 1400) rpm and welding speeds of (100, 80 and 63) mm/min, as well, as 2^{o} tool tilt angle. The results showed that using the base material in the O condition was suitable at a higher welding speed and lower tool rotation speeds, therefore tuned to enhance productivity. As well as, the FSW leads to enhance the weld joint strength when compared with the AA 6061–T6. The ductility in the base material was equal to or lowers than in the welding material in T6 condition.

Liu and Ma (**2008**) [40] tested the effect of the FSW parameters on mechanical and microstructure properties for the 6061-T651 aluminium alloy with 4 mm thickness. They used (900, 1200, 1400) rpm, (200,400,600) mm/min, rotation and welding speeds respectively. The tools have shoulder diameter of (16, 20, and 24) mm and pin diameter (6, 8) mm. The results showed defect-free under a wide range of FSW parameters. The grain size and shape did not significantly change from the BM to the HAZ. The tensile strength increased with increasing the welding speeds and was independent of the dimension of the tool (pin and shoulder) as well as the rotation rate. The most failure in tensile test occurred in lower hardening zone (heat effective zone). The best value of the tensile test was at rotation speed 1400 rpm and welding speed 600 mm/min and pin diameter 8 mm and shoulder diameter 24 mm.

Chen (**2009**) [41] examined the quality of weld dissimilar metals joints; SS400 low carbon steel and AA6061 aluminium alloy have 6 mm thickness. The welding speeds used were (0.9, 1.2, and 1.5) mm/s and rotation speeds were (550,800) rpm. The results showed that the high rotation speed and lower welding speed result in a higher tensile and impact value. The rotation speed of 550 rpm and the welding speed of 0.9 mm/s give an acceptable quality of tensile strength and best quality of impact values.

Rodrigues et al. (2009) [42] studied the effect of the FSW parameters on the microstructural and mechanical properties of AA 6016-T4 with 1 mm thickness. They used a conical shoulder with 2.5^o tool tilt angle and 1800 rpm, 180 mm/min rotation and welding speed, respectively and used scrolled Shoulder tools with 0^o tool tilt angle and 320 mm/min, 1120 rpm welding and rotation speed, respectively. The results showed that the differences in welding parameters led to changes in microstructure and the material flow path during the welding. The microstructure that resulted from using conical shoulder in stir zone was large grain size with few coarsened precipitates and a reduction in elongation of 30% while when used scrolled shoulder, the grain size in stir zone was smaller and contained many coarsened precipitates and reduction in elongation of 70%. The decrease in hardness by about 15% in the CW welds contrarily to the HW welds. Hot welding improves mechanical properties when compared with cold welding (low rotational speed).

Tolephih et al. (**2011**) [43] studied the effect of both FSW and conventional metal inert gas (MIG) of aluminium alloy AA7020-T6 (Al-Mg-Zn). The Plates were 5, 100, 200 mm thickness, width, and length respectively. The rotation speeds were (400, 560, 710 and 900) rpm and welding speeds (16, 25, and 40) mm/min, as well as, the tool tilt angle was 2^o. The results showed that welding efficiency was 85 % when using FSW while 58 % at using MIG welding. The minimum micro-hardness value for MIG was 70 HV 0.05 while for FSW was 133 HV0.05 at the welding metal. The localized grain size for base material was 32 µm while for MIG and FSW in the SZ was 37 µm and 12 µm respectively.

Patil and Soman (**2013**) [44] studied the effect of the welding parameters on the metallurgical and mechanical properties of dissimilar joints of AA6061 – AA6082 with the 5 mm thickness welded by the FSW. Welding speeds (50, 62) mm/min and constant rotation speed 1600 rpm were used in their study, as well as, change the alloy position on advance side. The tensile strength in the base metal was higher than of the dissimilar joint and the best conditions for ductility and strength was when used 50 mm/min welding speed and AA 6082 on the advance side. Using AA6082 on the advance side shows lower welding speed which gives higher welding efficiency while gives lower welding efficiency when used AA 6061 on the advance side. The lower micro hardness reached when used AA 6061 on the advance side at 60 mm/min welding speed and higher micro hardness when used AA 6082 on the advance side at 50 mm/min welding speed. Mechanical properties in AA6082 alloy were better of the AA6061.

Kumar et al. (**2013**) [45] investigated the quality of welding for commercial grade aluminium alloy plates with 12 mm thick joint by FSW. They used two different FSW tool geometries (Trapezoidal probe and Tapered cylindrical probe) as well as, (2000) rpm, (28, 40, 56, 80 and 112) mm/min rotation and welding speeds respectively. The results showed that FSW is effective for aluminium plates with 12 mm thick. The low welding speed and higher tool rpm led to finer grain structure and this produce higher strength and higher ductility of welded joints. Lower feed rate (welding speed) resulted in higher ductility displayed through higher elongation. The lower range of welding speed was appropriate for attaining superior mechanical properties and an increase in weld speed led to increase hardness in NZ and TMAZ explained a decreasing trend.

Alshemary (2015) [17] investigated the influence of rotational speed on the mechanical properties of dissimilar commercially pure copper and aluminium sheets with 4 mm thickness. The rotational speeds of (2200, 1700 and 1200) rpm were applied and the cylindrical tool was used. The axial force of 5 kN and transverse speed 50 mm/min. Tensile strength, X-ray diffraction (XRD) and Vickers micro-hardness tests were studied at these various rotational speeds. The results showed that welded at 1700 rpm was better when compared with other rotational speed. The hardness results were better in SZ from TMAZ and HAZ.

2.3 Temperature Distribution and Residual Stresses in FSW

Chen and Kovacevic (2003) [46] utilized three-dimensional model depends on FEA to study the thermo-mechanical and thermal history procedure in FSW of aluminium alloy 6061- T6. The heat source incorporated in the model includes the friction between the shoulder probe and the material. The relationship between the calculated process parameters and residual stresses of the weld and such as tool welding speed was presented. It is anticipated that the model can be extended to optimize the FSW operation so minimize the residual stress of the weld. The results showed that the higher temperature gradients in lateral and longitudinal orientations were placed only beyond the shoulder edge, as well as that the lateral residual stress was lower than longitudinal residual stress at the upper surface of the weld. The maximum stress was placed at the mid-thickness of the weld zone. A maximum welding speed induces a larger high longitudinal stress region and a narrower lateral stress region in the weld.

Malik et al. (2014) [47] numerical studied the influence of different tool pin shapes on power consumed temperature and SZ for welding. The welding tool pin shape has an important role in attaining desirable weld. A three-dimensional (3-D) model was developed in finite element (FE) commercial code ABAQUS/Explicit. The results show that the square profile tool pin consumes less power among studied six profiles without affecting temperature generation. Square in frustum type further aids in reducing the consumption of welding power. Defect reduces for frustum kind pins when compared to straight pins.

Experimental and numerical study for the influences of FSW parameters on tensile strength and temperature distribution of AA6061-T6 was studied by **Majid (2015)** [48]. He used welding speeds (14, 40,112) mm/min and rotational speeds (500, 1000, and 1400) rpm as well as, tool pin made of tool steel alloy. To calculate experimental temperature distribution three thermocouples in the row are placed at a certain depth in the plate which were 4.5, 3, and 1.5. The location of thermocouples was at 13.5 mm from the weld's centerline. The results showed that using 500 rpm and 14mm/min welding speed gives the best strength. Higher rotation speed gives higher temperature due to higher friction heating and product in further powerful mingling and stirring of material. Good agreement between the numerical and the experimental results.

Buglioni et al. (**2015**) [49] studied the effect of welding speeds on longitudinal residual stress for 7075-T651 aluminum alloys with 4 mm thickness. Welding parameters that used were 514 rpm rotation speed and 51 to 206 mm/min welding speeds, while 2^o tool tilt angle. Welding tool made of tool steel (H13) with smoother tapered pin and concave shoulder was used. Experimental residual stress was obtained from residual strains at different position of strain gage. Strain gage placed in the top surface (z= 4 mm) and middle of plates (x=75 mm) and different transverse positions. The results showed that the stress variation from the weld centerline to the plate edge is approximately uniform and the residual stresses are increased with increased welding speeds at low range of welding speeds, while these do not significantly vary at high speeds (206 mm / min, 146mm / min). Numerical analysis (ANSYS program) also used and gives good agreement with experimental results.

Resan et al (2016) [50] studied the effect of friction stir welding (FSW) and friction stir processing (FSP) on mechanical properties of AA 6061 – T6 with 3mm thickness. The welding parameters were rotation speeds (1100, 1300 and 1500) rpm, welding speed (60) mm/min, and cylindrical welding tool. The best result was at 1300 rpm and 60 mm/min to achieve 84.61% and 89.05% weld efficiency in FSW and FSP respectively. They are developed a finite element simulation to studied temperature distribution in of friction stir processing (FSP) of 6061-T6 Aluminum alloy. The results of the simulation are in excellent comparison with the experimental results. The Vickers hardness was increase when used FSP because of occurs refining of microstructure and enhancement of mechanical properties.

2.4 Fatigue in friction stir welding

Svensson et al. (**2000**) [51] studied the effect of FSW parameters on hardness, microstructure, and fatigue strength for 5083 aluminium alloy with 6 mm thickness. Fatigue tests were performed by 0.1 stress ratio and 140 Hz at room temperature. The results showed that the most fracture start in the center of the weld zone or in base material and samples have good fatigue behaviour. They concluded that lower welding speeds give higher fatigue resistance and the weld 5083 alloy has better fatigue behaviour when compared with 6082 alloys. The hardness was at minimum value in the thermo mechanical effective zone (TMAZ) in 6082 alloys while it was varied a little across the weld zones in 5083 Al-alloy.

Borrego et al. (2004) [52] investigated the microstructure dependent fatigue crack propagation in aged hardened AlMgSi1-T6 aluminium alloy for 3 mm. They used the compliance technique using a pin micro gauge to monitor the crack closure. Their results showed that strong material dependence and moderate stress ratio influences on the fatigue crack propagation. In the alloys with a lower content of Cr and Mn, plasticity-induced closure is dominant crack closure, while in the alloys with higher contents of Cr and Mn elements, the roughness-induced closure dominates on crack closure. In addition, the roughness-induced closure is the prime pre-overload closure mechanism, the retardation influence reductions when compared with plasticity-induced closure, which is dominant.

Booth, and Sinclair (2002) [53] investigated the effect of the FSW on fatigue performance for AA 2024-T352 alloys with 13 mm thickness while stress ratio was 0.1. They observed that failure happened either from the weld zone or from base material which surrounding by weld zone. They found that the material that failure in the weld zone had fatigue life lower than the material that failure outside the weld zone and the fatigue crack growth was perpendicular with applied load. The results for fatigue life were compared with the base material and with another thinner plate. Failure over the weld zone was identified with discontinuities in the macro-scopic flow pattern of the weld flow arm. They also observed a pronounced macro-scopic crack deflection around the "onion ring" structure of the weld nugget. In local hardness levels, they identified bands making up the onion rings during variations in local hardness levels.

Ericsson and Sandstrom. (2003) [30] investigated the effect of welding speeds on fatigue strength for AA6082 alloys with a 4mm thickness in the T4 and T6 temper conditions and comparison with another conventional welding process (MIG and TIG). They used a cylindrical tool with 6mm pin diameter and 14 mm shoulder diameter. The welding speeds were 700, 1400 mm/min and 2500, 2200 rotational speeds. The results showed that welding speed does not have a major effect on the fatigue strength and mechanical properties for welding material but, used an extra low welding speed possibly enhancement fatigue strength because of increase in the quantity of heat per unit length which is supplied to the weld joint. Using the FSW welds lead to improving the fatigue strength better than the MIG pulse and TIG welds, but TIG joint has better fatigue strength from MIG joint. The fracture in the tensile test occurs in the weld/HAZ borderline or in the weld zone.

Lomolino et al. (**2005**) [54] studied the FSW method over competing for fusion welding method for the difference of aluminium alloys at different stress ratios. The main advantage for FSW compared to conventional fusion welding methods was the enhancement of fatigue life, implying that the structural reliability of FSW components could be substantially increased. The location of Fatigue failure occurs in the weld zone and used stress ratio (R) = -1 gives fatigue strength better than (R) = 0.1. They suggested that to improve the fatigue strength used for weld surface mechanical machining.

Uematsu et al. (2006) [55] used AA6061 aluminium alloy plates joined by friction stir welding. The rotation speed was 1200 and 1800 rpm and the welding speed were 100 and 200 mm/ min, as well as the stress ratio (R), was -1 to investigate the fatigue life. The results showed that the microstructure of the TMAZ was recognized as the microstructural transition zone between SZ and HAZ, while in SZ was fine equiaxed a grain resulting from dynamic recrystallization. Vickers hardness measurement revealed softening inside the weld zone, which was attributed to the dissolution of precipitates due to temperature rise during the FSW process. They found that the location of fatigue fracture depends on the level of stress and fatigue strength for base material was higher than fatigue strength for FSW joined. In the lower stress region, the fracture happened at HAZ, while in the high-stress region, it happened at the TMAZ. Depending on the experimental result they found that the fatigue fracture at the HAZ has attributed together the dynamic ageing at the TMAZ and SZ and the grain refinement at the SZ by cyclic loading.

Kulekci and Sik (**2006)** [56] used 1050-H8 aluminium alloy plates joined with different welding parameter of FSW to investigate the fatigue behaviour.

They found that the temperature in FSW over a required level negatively affect the fatigue endurance limit of the studied joint. When comparing the obtained results with variation transverse speeds and tool rotational showed that optimization is required to achieve a reasonable fatigue endurance limit.

Kulekci et al. (**2008**) [57] investigated the influence of the FSW parameters on fatigue properties of 5754 aluminium alloy with 3mm thickness lap joint. They used three tools which have shoulder diameter of 15 mm and height of pin was 5mm. The diameters of three pins were 3, 4 and 5 mm for three tools. The following index (I) was used to assess and evaluate the influence of tool rotation speed and pin diameter on the fatigue behaviour.

$$I = \frac{w}{V} * \frac{d}{h} \,........ (2.1)$$

Where V: the welding speed, w is the tool rotation (rpm), h: pins height (mm), and d: pin diameter (mm).

They found that decreasing rotation speed at the same pin diameter leads to increase the fatigue strength and decrease the tool pin diameter at the same rotation speed increase the fatigue strength. An optimization between tool rotation speed, welding speed and tool pin diameter, are necessary to achieve better fatigue properties in the lap joint. The best fatigue properties were achieved with an index (I) of 6.

Kim et al. (2008) [58] investigated the effect of FSW parameter on fatigue crack propagation (FCP) for dissimilar jointed of 5083-H32 and 6061-T651 with 4 mm thickness. The best welding speed and rotation speeds were 200 mm/min and 1200 rpm for 6061 – T651 while was 250 mm/min 1600 rpm for 5083-H32 respectively. Samples were tested with the FCP either 45° with Dynamically

Recrystallized Zone (DRZ) at various constant ΔK value or perpendicular to (DRZ) at variable *ΔK* values and a stress ratio (*R*) of 0.8 and 0.1, respectively. The FCP rates of FSW 6061-T651 and 5083-H32 specimens in the DRZ tended to be very lower than those in the base material at both stress ratios, especially in intermediate and low ΔK regimes. The fatigue tests either 45^o or perpendicular the weld region at a stress ratio of 0.1 explain the existence zone of FSW in front of propagating crack retards the FCP rates of 6061-T651 and 5083-H32 samples significantly in intermediate and low ΔK regimes which it because of the effect of the residual stress on the FSW region.

Cavaliere and Panella (**2008**) [59] investigated the effect of the FSW parameters on fatigue behaviour for dissimilar 2024-7075 aluminium alloys. The difference of total fatigue life, crack toughness, and tensile strength, have been measured as the function of the rotating tool distance from the weld line, by shifting it on the AA2024 tool advancing side as shown in figure (2.1). They used eight specimens and level of stress and they considered that fatigue limit 10^6 cycles as well as, stress ratio (R = 0.1). The results showed that the mechanical properties of the welding materials largely increase with rising the distance from the weld line up to 1mm, after that it's dropped. This influence is especially evident in a situation of fatigue load when excellent fatigue limits can be achieved with respect to base metals when the optimized process parameters are used. The strong effect on fatigue crack growth was attributed to the positive residual stress (Kr) value measured on the cross-section of the different welds. The fatigue limit is a function of the distance of the tool from the weld line for all the studied joints.

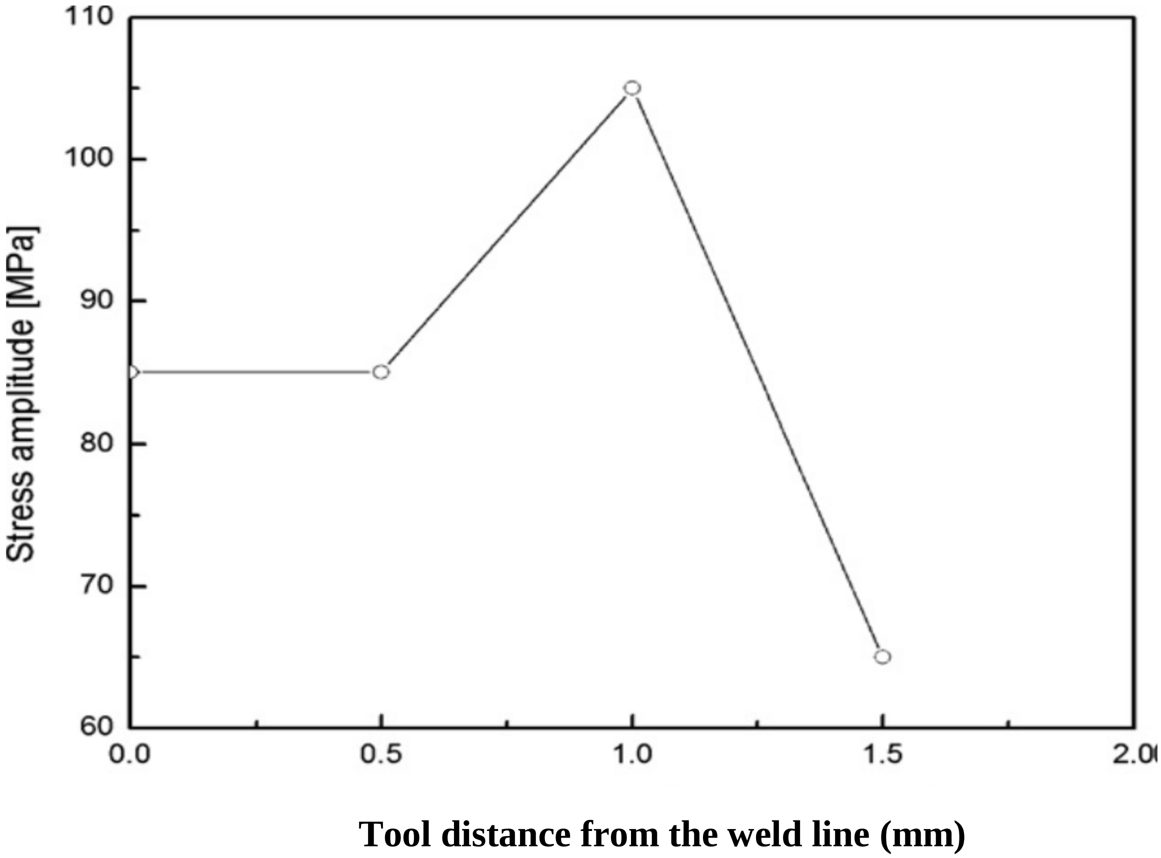

Figure (2.1) Relation between tool distances – ultimate strength [56].

Moreira et al. (**2008**) [60] studied the effect of the FSW parameters on fatigue crack growth behaviour for 6082 –T6 aluminium alloy with 3mm thickness. The threaded pin with 6mm diameter and 15 mm shoulder diameter were used while stress ratio (R) was 0.1 and 0.5. The welding parameters that used were rotational speed 1500 rpm, welding speed 800 mm/min as well as tool tilt angle 2º. The results showed that the crack growth rates in the transverse direction were lower than in the rolling direction. The failure in the tensile test occurs near the weld edge line. The weld zones have better crack propagation resistance compared with the base material and HAZ.

Lombard et al. (**2008**) [61] applied a systematic method to optimizing FSW process factors (welding speed and rotational speed) during consideration of frictional power input. Frictional power governs the fatigue life and the tensile strength in the aluminium alloy 5083-H321 during its influence on plastic flow processes in the TMAZ of the weld. They used 6, 100, 750 mm thickness, width, and length respectively. They used cylindrical tool with 2.5^o tool tilt angle. Although a close relationship, therefore, exists between fatigue performance and tensile strength, this appears from their joint dependence on the occurrence of certain defect types that are apparently specific to certain strain-hardened aluminium alloys that are FS welded. The defects are effects on paths of crack and associated with plastic flow processes in FSW for these alloy. The residual stress was measured experimental by using X-ray diffraction strain scanning. The relationship between fatigue performance and peak values of residual stresses is unknown. The work indicates that rotational speed is the key factor governing temperature, frictional power, tool torque, and hence fatigue performance and tensile strength.

Hamoody et al. (2011) [36] studied the FSW and FSP for sheets of aluminium AA 2024-T3, with 5 mm thickness. The tool was made of steel AISI H13 thread pin of 18 and 6 mm diameters for shoulder and pin respectively. It was observed that during the tensile test, the most failure occurred in advance side in friction stir welding. The results showed that 72% of the ultimate tensile strength of parent material was achieved. In addition, when using a double pass process (FSP) with opposite rotation direction and same feeding orientation, gives higher improve in fatigue strength from single-pass. The reduction in endurance limit in the double pass was 15 % and in single pass was 36 % when compared with parent material. The effect of FSW for sheet AA2024–T3 reduce the fatigue life to less than $6x10^6$ cycles and the FSP had no influence on ultimate tensile stress in significant manner (not more than 3 %) this is because FSP had no significant effect on the grain refinement but it applies additional compressive load on the metal during the second pass process. The most crack propagation which occurred in the nugget zone was due to some defects like a wormhole. While in the sample exposed to FSP, the propagated of cracks was in BM and HAZ where NZ is defect free.

Aydin et al. (**2012**) [62] investigated the effect of welding parameters on fatigue strength and tensile properties of friction stir welded 2014-T6 aluminium with 3 mm thickness. They used welding speed of (40, 80 and 112) mm/min with the pin tilt angle was 2.5^o degree, and rotation speed was (1070, 1520, 2140) rpm and stress ratio R= -1. The results showed that the decreasing in the welding speed led to decrease hardness in the softened welding regime and reached 20% from the base material. The welding speed of 80 mm/min with a rotating speed of 1520 rpm gave the best fatigue and tensile properties in the welded joints.

Vigh and Okura (2013) [63] have conducted an experimental investigation on the fatigue behaviour for the aluminium bridge deck segment welded by FSW. They used A6005C-T5 and rotation speed of 1200 rpm and welding speed (350) mm/min as well as a cylindrical tool with pin and shoulder diameter (16 and 25) mm respectively and stress ratio (R) 0.1. The influence of FSW on the behaviour of the static material is insignificant in all elastic stages of the cross-section. The results showed lower endurance limit for weldment in comparison to the base material and the critical region was located between TMAZ-HAZ borders. The crack initiates at geometrical surface defects and they suggested that removing the surface defect led to improve the fatigue life because of crack initiates is a faction of defect surface.

Ma et al. (**2013**) [64] studied the effect of rotation speed/welding speed parameter on fatigue life, tensile strength, and microstructure for aluminium alloys AA2198–T8. Crack propagation and three different stress ratios (R) were compared. The fracture mechanism analysis performed using SEM fractographic. The results showed that the tensile strength and micro-hardness decreased with increasing w/v and increase the w/v led to increase the area of the weld stir zone for aluminium-lithium 2198 alloy joints. Finer equiaxial grains form occurs due to dynamic recrystallization and w/v has a remark able influence on the shape of TMAZ. The best weld efficiency was 79% from the base material. The fracture pattern has a tendency to change from the brittle fracture to the ductile fracture. For all welding parameters and fatigue load ratios, the fatigue crack propagation rate appears similar in the nuggets weld zone.

Mohammed (2013) [22] investigated the effect of friction stir welding (FSW) parameters on micro-hardness, tensile strength and fatigue strength and comparison with the base material for 6061 – T651 aluminium alloy with 6.5 mm thickness. The cylindrical welding tool was made of high-speed steel (HSS). He used three welding speeds and six rotational speeds as well as two tilt angle (0^o and 2.5^o) with vertical axis while stress ratio was (R) = -1. The results showed that the best welding parameters were 50 mm/min and 710 rpm as well as 2.5^o, the welding efficiency under best condition was 64.7 %. The lowest reduction in micro hardness was 57.14% compared with the base material. Fatigue limit for base material was 120 MPa while for FSW and FSP was 80

MPa with a reduction of about 33% for both single and double pass (FSW and FSP). The FSP was very little improved in mechanical properties for this alloy.

Jawad et al, (2014) [23] investigated the effect of surface roughness, heat treatments and welding position on the fatigue behaviour for dissimilar aluminium alloys 6061–T6 and 2024-T3 with 3mm thickness joined by FSW. They used cylindrical welding tool and welding speed 16 m/s while rotational speed was 900 rpm. The results showed that the maximum welding efficiency achieved was 62.8 % for the similar 2024-T3 joint, and this value was improved by using post welding heat treatments and reach 67.9%. They found that the Fatigue strength strongly depends on welding line position and the fatigue strength change with change welding line position whereby the reduction in fatigue strength for welding line distance 0.35L from the side applied load was 45% for similar joint (2024-T3) and 58% for dissimilar joint (6061-T6 with 2024 –T3) while for weld distance at 0.7L the reduction in fatigue strength were 67% and 56% for dissimilar and similar material respectively. The higher reduction in fatigue strength occurs when the location of the welding line at the fixed point was 70% for both similar and dissimilar joint. The heat treatment improved the fatigue life about 31 % more than non-heat treatment for 2024-T3 joined at 0.7L and the non-finishing samples showed a reduction in fatigue strength reaching 10% more than the finishing samples of the similar 2024-T3 joint at 0.7L. Numerical study for fatigue life for a different position for welding line performed and good agreement between experimental and numerical study.

2.5 Optimization of Welding Parameters

Rajamanickam et al. (**2008**) [65] studied the effect of friction stir welding parameters on mechanical properties of AA 2014 with 5.4 mm thickness. The welding parameters that used were welding speeds (8, 12, and 20) mm and rotational speeds were (600, 900, and 1200) rpm. ANOVA was utilized to study the effect of welding parameters on mechanical properties of the welded joint. The results showed that the tensile strength increases with decrease rotation speed and increase welding speed. The ANOVA results showed that the welding speed is the mean parameter that has a higher effect on tensile strength**.**

Kumar et al. (2015) [66] optimized the welding parameters that used to join 2024-T351 aluminium alloy by friction stir welding. The dimensions of plates were 100, 100 and 6.35 mm length, width and thickness respectively. The welding parameters were welding speed of (50, 62 and 74 mm/min), the axial force of (2, 2.5 and 3 kN), and the rotation speed of (1200, 1600 and 2000 rpm). Taguchi method using L9 orthogonal array were used to find the optimum parameters were the effect on hardens and ultimate tensile stress. The percentage of contribution for each factor was found by using ANOVA analysis. The result showed that the best parameters that give the highest impact strength were 62 mm/min welding speed, 1200 rpm rotation speed, and 2.0 kN force of axial. From ANOVA results the welding speed has higher effect on tensile strength with 35.81% percentage, while the rotation speeds of 7.49% and axial force of 22.23%.

Singh et al. (2018) [67] investigated the effect of the friction stir welding parameters on tensile stress for AA7075 with 10wt% SiC plates with 6 mm thickness. The welding parameters were rotation speeds, welding speeds, and tool geometry. Taguchi results showed that the optimum case was rotation speed 1200rpm, square tool geometry, and welding speed 13 mm/min. ANOVA results showed that the welding speed had effect on ultimate strength by 15%, and rotational speed had 83%, while tool geometry had very less 2%.

Raweni et al, (**2018**) [68] used Taguchi approach to find optimum friction stir welding parameters in term of crack initiates energy, crack propagation energy that used to welded aluminium 5083 plates with 5.5 mm thickness. The parameters that were used rotation speeds, welding speed and tool title angle. They used orthogonal array L16 with values of the factors. ANOVA analyses used to find the percentage contribution of each factor. The results showed that the welding speed has a high influence on fracture toughness energy and rotation speeds had lowest effect while tool tilt angle middle between them. The optimum case was welding speed 125 mm/min, rotation speed 600 rpm and tool title angle 3^o for the energy of crack initiation and total energy.

2.6 Summary of Literature Review

2.6.1 Summary of Friction Stir Welding (FSW)

Material	t	Tool geometry	R.S	W.S	R	Eff. %	El	Ref.
	mm		rpm	mm/min				
AA 6016-T4	1	Scrolled shoulder	1120	320	———	90.64	30%	[42]
		Conical shoulder	1800	180	———	86	70%	
AA6061- T6	6.5	Screw shoulder and cylindrical pin	500	14	———	-	23.5 mm	[48]
AA7020-T6	5	concaved shoulder	900	25	———	85	30.47 mm	[43]
AA2014 -T6	3	flat shoulder ,threaded cylindrical pin	1520	80	-1	95.13	7.8 mm	[63]
AA 2198-T8	2	Cylindrical tool	800	400	0.1, 0.3, 0.6	79	5 mm	[65]
AA (6061-T6) – (2024-T3)	3	Cylindrical tool	900	16	-1	58.17	1.66 mm	[23]
Commercial pure copper)-(AA)	3	Cylindrical tool	1700	50	———	87.5	8.3 mm	[17]
AA 2024-7075	4	Cylindrical tool	1600	120	0.1	74.38	67.8	[60]
AA 6082-T6	3	Thread pin	1500	800	0.1 , 0.5	———	———	[61]

2.6.2 Summary of Friction Stir Processing

Material	t	Tool geometry	R.S	W.S	R	FSW			FSP			Ref.
	mm		rpm	mm/min		Eff. %	El (mm)	Reduction in Su %	Eff. %	El (mm)	Reduction in Su %	
AA 6061-T6	3	Cylindrical tool	1300	60	—	84.6	———	————	89.05	———	————	[50]
AA2024-T3	5	concaved shoulder	370	24	-1	72	3.43	36	69	4.48	15	[36]
AA 6061-T651	6.5	Cylindrical tool	710	50	-1	64.7	———	33	~ 64.7	———	~ 33	[22]

In currently study

- Study the effect of different orientation welding line on tensile strength, Proof strength, and elongation.
- Study the effect of FSW and FSP on fatigue life, Vickers hardness, and residual stresses.