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A Critical Review on Influence of different performance characteristics by using different cooling media for Magnesium alloys by FSP

Parkhe Ravindra A[1, a*], Kale Kishor B[2, b], Kabudake Padmakar D[1,c]

[1]Pravara Rural Engineering College Loni, M.S, India

[2]DVVP COE, Ahmednagar, M.S., India

[a] parkhe.ravindra@gmail.com , [b] kishorkale.iisc@gmail.com, , [c] kabudkepadmakar@gmail.com

Abstract: In the current scenario, the demand for operating properties of manufactured components has increased, and on the other hand, the need for weight reduction of components or structures has initiated the finding of alternative material for the improvement of its strength for the fulfillment of required operating properties. The weight reduction of structures has been introduced by using magnesium alloys in several industries, such as aerospace, automotive, etc. Different material alloys have their dynamics by which weld quality gets impacted. Thus it is recommended to introduce techniques to improve the weld quality. Different techniques or conditions for Friction stir processing are observed as one of the approaches to improve the material's mechanical and microstructural properties.

In the current paper, the Research progression of various conditions and applications of welding techniques for magnesium alloy welds are reviewed with various perspectives. Different process parameters and effects for the same are discussed with metallurgical and microstructural studies. Hardness, fatigue, tensile and shear strength; mechanical Properties are reviewed. The main aim of the paper is to get an overview of current advances in Mg alloys weld to get a platform for follow-up research. This paper discusses the current state and progress of the FSP technique. It also examines the variations in the use of FSP welded joints to determine the knowledge shortfall.

Keywords: Friction Stir Process, Friction Stir Weld, Mg alloys, Microstructural analysis, Fatigue analysis, and Wear analysis

1. Introduction

Magnesium and its alloys with a 40 percent less weight than aluminum alloy and 78 percent that of steel, is a lightweight alternative to conventional metal alloys. As a result, alloys of magnesium are extensively used in automotive and light vehicle components. Because of the latent heat, approximately two-thirds of that of aluminum and with low melt solubility for iron and higher fluidity, magnesium alloys offer certain major benefits over aluminum alloys. This gives magnesium alloys a lower cycle time and the alternative for reactive steels in the die-casting.

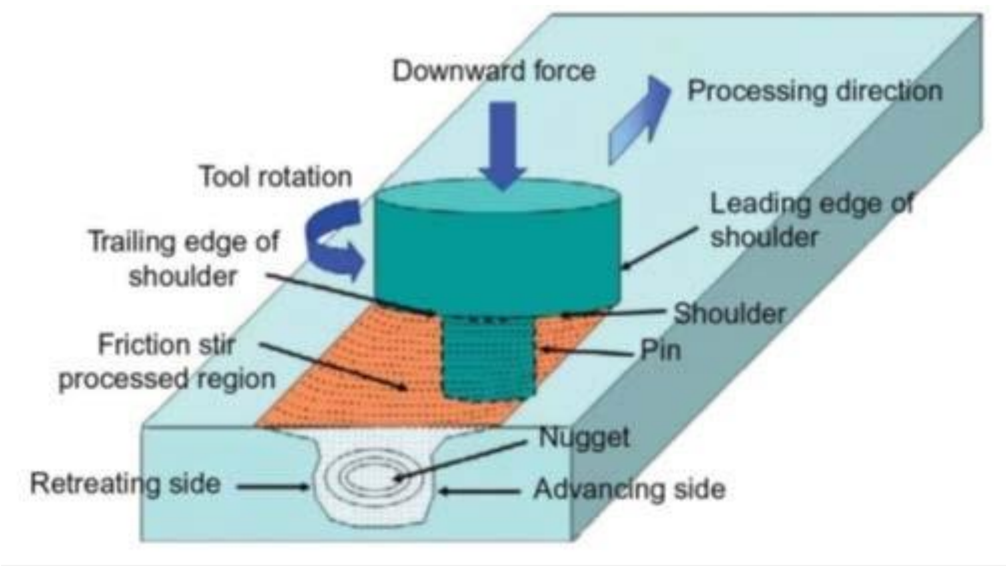
Excellent specific strength, useful castability, outstanding workmanship, excellent formability, and recyclability are well known for magnesium alloys. It is also regarded as an advanced material in environmental pollution and energy conservation problems. Multiple automotive components such as engine blocks, wheels, steering columns, and seats, etc. have been manufactured by magnesium alloys[1]. The refinement and homogenization of the microstructure allow for improved mechanical characteristics. Smaller grain sizes and a more even grain structure can contribute to improved mechanical characteristics such as the Strength-to-weight ratio, wear behavior, corrosion resistance, material resistance, and superplastic formability of lightweight alloys. Conventional procedures for grain improvement such as thermal rolling are expensive and time-consuming with a high energy consumption. Therefore, other processing for grain alternation needs to be looked for.

There are numerous methods of processing that improve the grain structure adequately. These include Equal-Channel Angular Processing (ECAP)[2], High-Pressure Torsion (HPT)[3], and Accumulative Roll Bonding (ARB)[4], and Severe Plastic Deformation (SPD). However, they have

certain fundamental disadvantages such as low size, high load, and long processing times that limit the vast industrial applications of such approaches[5]. In the current scenario, among all the processing methods to modify the base material microstructure by grain alternation friction stir processing (FSP) is mostly used Method.

1.1 Friction Stir Processing (FSP)

Friction stir process (FSP)[6] is a method to modify the material surface by grain refinement on the friction stir Welding (FSW) principle which was established as a solid-state joining technology at TWI, UK in 1991. Several applications, including super-plasticity[7], composite-faced surface [8], metal matrix composites (MMC), and microstructural refining of various alloys controlled by microstructure alteration applications in metallic materials[9]. A non-consumable tool with a designed shoulder with pin profile was penetrated in base material during the Friction Stir Process (FSP). The grain refinement lead to in improvement of the microstructures and mechanical properties of various alloys by performing the FSW/FSP with a non-consumable pin. The Stir Zone (SZ) involves major changes in microstructure, where recrystallization creates a finely grained equipped microstructure. The path to the region as depicted in Figure 1.1 has been followed [10]. The processing tool serves two main actions: (a) workpiece heating, and (b) material movement to create property changes. The heating of the workpiece is achieved through friction force betweenthe workpiece and the tool and plastic workpiece deformation.



(Source: Mishra & Ma 2005)[6] Figure 1.1 Schematic illustration of FSP

As a consequence of being locally heated, the material beside the pin is softened due to the collective effect of tool rotational speed and transverse motion assists the circulation of material around the pin.

The material is shown to cause serious plastic deformation and thermal exposure to the local microstructure, resulting in a notable development. Fig. 1.1 indicates a potential of symmetrical behavior on the one hand of the processing region and the other, due to the rotating tool tangent speed vectors in the same direction. If the tangent vector of the tool rotating and the direction of travel are identical, the Advancing side (AS) is named, and if not, it is called the Retreating side (RS). In general, FSP material fits into four different areas of the visual microstructure based ontheir impact. These zones are shown in Figure 1.2. The zones are:

Stir Zone (SZ): This is the metal structure that is created when the stir zone is cooled by which a solid bonding is created among the two metals in the weld. The recrystallized structures of fine grains are observed with onion rings.

Heat Affected Zone (HAZ): This area undergoes a heat cycle without plastic deformation. A similar grain microstructure as base material is retained.

Thermo-Mechanically Affected Zone (TMAZ): It's a distorted area. The base material included elongated grains that were upwardly distorted around the stir zone. In this zone, recrystallization is observed due to an insufficient strain of deformation despite TMAZ undergoing plastic deformation.

Unaffected Base alloy: the non-impacted area that does not affect several welding parameters.

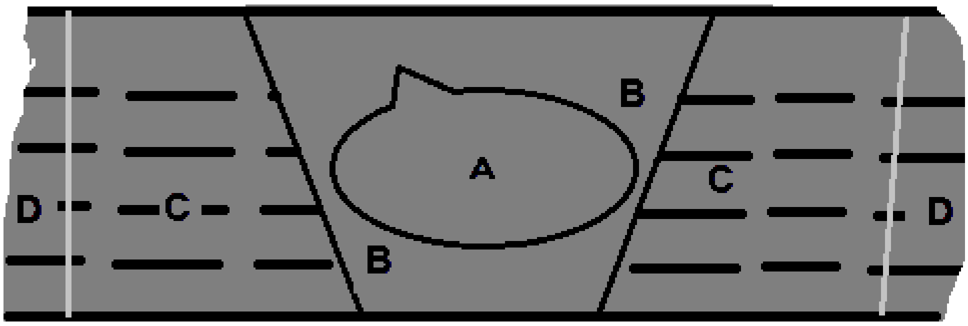


Figure 1.2 Images of FSP zones

(A- Stir Zone, B- Thermomechanically Affected Zone, C- Heat Affected Zone, D- Unaffected Zone)

During FSP processes, intensive plastic deformation with frictional heat are produced in recrystallized structures with fine grain. Diffused baseline alloy is observed between the base material and stir zone. The retrieval side of the tool is smooth but that advancing side is sharp. This leads to a significant role for FSP tool parameters in improved mechanical properties. For controlling the material flow, FSP parameters, including pin geometry, tool rotation, and tool speed are needed. Among these various factors, the pin profile has a crucial role in improving the strength and flexibility of the material in several alloys[11].

1.2 Applications of Magnesium Alloy

Tao et al. (2001), Magnesium has a substantial potential for reduction in weight replacing steel and aluminum with suitable design consideration applied. Most magnesium components are manufactured by the casting process. No significant reduction in weight was observed for the use of magnesium was extended for other applications other than sheet metal forming. The lower ductility of the alloy at ambient temperature was revealing its considerable use of magnesium alloy AZ31 which is in the market in sheet form. However, the alloy has limited ductile property and at room temperature is noticed for its brittle-like behavior. Recent research indicates that AZ31 sheets can be formed at elevated temperatures by certain assumed conditions and superplastic behavior[12].

According to Park et al. (2003), in structural applications magnesium (Mg) alloys are widely used. Magnesium alloys are an appropriate advanced material to replace aluminum alloys in automotive and aerospace industry applications such as various automotive components and aircraft components due to their uniqueness. Low density, a high strength-to-weight ratio, and exceptional castability are unique characteristics of magnesium alloys. It has been considered as an advancing material in energy conservation and pollution regulations, which has a crucial role in their uses and applications[13].

Blawert et al. (2004), Magnesium alloy has been used in a variety of applications like structural components in automobile and aircraft components. Magnesium components are used in automobiles as Ford light truck vehicles, Benz, Renault 18 Turbo, and Chrysler Jeep. The extensive utilization of magnesium alloy has resulted in lower fuel consumption[14].

According to Mathis et al. (2005), magnesium alloys are soft and demanding replacing structural materials due to their 40 percent and 78percent lighter than aluminum and steel respectively. Magnesium alloys have wide application in the aircraft, vehicle, and chip manufacturing industries due to their good dampening properties, castability, excellent machinability, superb formability,

important electromagnetic interference shielding, and recyclability. Magnesium alloys had been applied for manufacturing a variety of automotive parts, including the wheels, engine blocks, seats, dashboard, and steering columns. The relative sliding motion in various components causes material loss in wear and friction analysis[15].

Kulekci et al. (2008), had noted that there is a need to reduce fuel consumption and running costs related to the aerospace and automotive sector by replacing components with light alloys. As compared to aluminum, Magnesium alloys are 35 percent lighter and have good machinability and castability. Magnesium alloys also have high elastic modulus, outstanding specific strength, and good damping/vibration properties[16].

Azushima et al. (2008), have referred to magnesium alloys as a replacing metallic material employed for lightweight which can be conveniently used in energy-saving structures, and medical equipment. But the practical use of it is challenging at room temperature due to the low formability process. Ductility can be improved by using thermomechanical processes for magnesium alloys[17].

2. LITERATURE SURVEY

The results of previous research results with different performance characteristics in the Friction Stir Processing (FSP) by using different cooling media (air, water, and cryogenic) with various parameters used by this research are identified in a literary survey. On various conditions. The multi-optimization investigations are discussed in the FSP using different approaches. The earlier research studies of researchers for the past two decades in the area of FSP are discussed. The technique/methodology executed by the researchers for modifying the material properties which were low in strength showed better improvement in their mechanical properties with ultra-fine grain size. Such improvements/developments along with the lightweight properties of these materials make them capable of use in various industrial applications.

Several strategies for surface improvement have been employed for the improvement of strength and grain refining of different alloys. Refinement in the size of grain is an effective method that can improve magnesium alloys strength and formability. Some of the procedures involving extreme plastic deformation have been implemented for magnesium alloys, including Roll Compact Process (RCP) and the Equal Channel Angular Pressing (ECAP). In the current scenario, Friction Stir Processing (FSP) is one of the best processes for improvement in the microstructure of the processed alloy[2].

2.1.1 Influence of Tool Process Parameters, Geometry, and Pin Profiles on Microstructural Analysis, Mechanical Properties and Temperature Distribution

Padmanaban et al. (2009), In this study five different cylindrical, simple, threaded, triangular, square, and tapered cylindrical shoulders with diameters 15 mm, 18 mm, 21 mm were used. As a result, the 18 mm shoulder diameter with threaded pin geometry tool found tensile strength greater than other tool pin profiles. The stepping tool generates greater tensile strength at minimum tool rotation speed and maximum rate of feed. With Minimum tool rotation speed and maximum rate of feed produces insufficient frictional heat, and also time to deform the grains not enough. This induced ground grain development. However, very fine grains are manufactured by increasing feed rates at a higher tool rotation speed. This phenomenon is caused by the heat provided by the maximum tool rotation speed and the quick reinforcement of kernels at a high tool feed rate[18].

Gupta et al. (2015), focused on the FSP of AZ31 alloy with parameters such as tool rotation speed, pin profile, and rate of feed. Samples were joined with a fixed tool rotation of 2000 rpm and two different traverse speeds of 50 mm/min and 40 mm/min. To study the development of the tunnel defects, two different tool geometry were used, cylindrical and truncated conical probes. The result detected a smaller defect in the welded specimen using the truncated conical probe at tool rotation speed 2000 rpm and feed rates of 40 mm as compared to the geometry of the cylindrical

tool pin. Grain size plays an important role in the improvement of the tensile strength of the welded AZ31B alloy by using step shoulders[19].

Khodaverdizadeh et al. (2013), in this study the pin and the shoulder in FSW were referred to as the important parameters. The Implementation of the tool friction in the processing is for workpiece heating, agitate deformed material, move the plasticized material beneath the shoulder of the tool and make the welded junction. Based on the microstructural or mechanical properties of copper alloy FSW welds, the effects of the square and cylindrical shape pin with thread tool pin profiles have been examined and the test results have shown the presence of thinner recrystallizing grains in the squared pin tool and improved mechanical features over the threaded cylindrical shape pin[20].

Ganesh Balamurugan et al. (2013), FSP tools parameters for the achievement of excellent mechanical characteristics had been described. For control action of the flow of the material FSP parameters such as pin geometry, tool rotation speed, and rate of the traverse are necessary. The pin profile is an important parameter that affects grain formation and increases material strength or flexibility in the specific region of microstructure for Mg alloys. Some studies have recently indicated the importance and the use of various pin profile designs, which could significantly improve the grain formation with microstructure, microhardness, tensile strength improvement[21]. Elangovan et al. (2007), different tool pin geometries were employed for FSW. Compared with a cylindrical pin, the triangular pin showed increased material flow. The axial force as well as the material flow are affected by threads to the pin surface. Due to a wider area between interfaces improved heat generation rate with effect on material flow and the effect of axial and transverse force due to the threads and flutes on the pin. The square head geometry of the pin results in more homogenous distribution than other tools, whereas the circular head tools suffer significantly less wear as compared to flat tools[22].

Babu et al. (2012), In comparison with diameter of shoulder 18 mm, defection-free processed zone with FSP for diameter of shoulder 24 mm was obtained for Mg alloy AZ31B. Ductility improvements resulted in the work material with ultra-fine grain in the treated zone with diameter of shoulder 24 mm, a tool rotation speed of 1000 rpm, and a rate of traverse 75 mm/min. The rate of elongation of the basic alloy is increased by 1.82 times[23].

García-Bernal et al. (2016), Studied the influence of tool pin geometry on superplastic behavior in magnesium alloys. A tool rotation speed of 400 rpm and a rate of traverse 0.42 m/s were taken into account using four distinct tools used for welding and were compared. The data showed that the various tool pins (T1, T2, T3, and T4) produce an ultrafine grain microstructure from 0.92 μm to 2.15 μm. Tool T1 and T3 showed the best results with finer microstructures. As the tool (T2) had a wider shoulder than the other tool, enough temperature resulted and it generated a homogenous microstructure. The mechanical properties for the material welded by T1 and T2 were achieved at room temperature. For the T1 tool, the 210 MPa tensile strength with 30 percent elongation is achieved, and that for tool T2 290 MPa tensile strength and 25percent elongation. T2 acquired superior strength due to its high density and fine grain sizes while having a thinner grain with T1[24].

Bahrami et al. (2011), analyzed the microstructural effects and mechanical Properties of Al7075 alloy on the tool pin profile. The tapered pin has gained its highest hardness with five different pin profiles while the triangular tool pin has the best tensile strength with other process parameters[25].

Asadi et al. (2010), employed a 3.54 mm square pin with 2.5 mm long. The diameter of both shoulders was 15 mm. Speed Variation in tool rotation was observed between 710 and 1400 rpm and 125 to 63 mm/min in traverse speeds. As a result, an increase in the speed of rotation has led to larger size of grain and decreased microhardness of the stir zone. The size of grain decreases with an increase in traverse speed and increase of the microhardness of the stir zone[26].

Rodrigues et al. (2009), reported FSW welds using two different tool profiles for weld of AA 6016-T4 alloy sheet 1 mm thick. The analysis with a comparison for the mechanical properties with microstructural was conducted. The welds produced with the scrolling shoulder result in a very fine size of the grain, as compared with the conical shoulder. These microstructure variances led to a 15 percent decrease in hardness in scrolling shoulder, whereas 70percent and 30percent reduction in elongation respectively for the scrolling shoulder and conical shoulder[27].

Cartigueyen et al. (2015), the effects of FSP with six tool pins on copper alloy plates have been studied. The results indicated how the hexagonal and threaded pin profiles show effective FSP surface development in the copper alloy. The effect of heat input and subsequent kinematic mixture in the stir zone was determined for copper-treated plates. High tensile strength and superior kinetic mixing resulted from threading and square pin-shaped tools[28].

Raja et al. (2017), an experimental study of Mg alloy AZ91by FSP with a 150mm/min traverse speed and 750 rpm spindle speed was conducted. The study demonstrated that the FSP sample had greater tensile and fracture strength due to ultrafine grain refining and reduced defects. As a result, broken down precipitates and grain refinement was the cause for improvement of the tensile and fractural properties of Mg alloy AZ91 by FSP[29].

Nia et al. (2013), evaluated the effect on Mg alloy AZ31 weld by rate of cooling, traversal speed, and pin profile of tools. The conclusion was that the pitch had a certain effect on microhardness, tensile strength which resulted in a homogeneous grain formation on the treatment zone. However, it has a low impact on ductility. The cooling reduced the size of grain and increased the hardness, ductility, and tensile strength. As a result, the 58 mm/min traverse rate was the optimal speed for improvement in microstructural and mechanical characteristics[30].

Galvao et al. (2013), studied the effect of scroll shoulder on grain formation. As a result,scroll shoulders improved the microstructural and mechanical properties in comparison to conical, concave, or flat tools. The scrolling shoulder tool obtained significant material flow whereas the flat shoulder generated the weld with defects[31].

Mansoor et al. (2012), studied FSP with the rotation speed 3000 rpm and rate of feed 127 mm/min with tool tilt angle 30. The outcome of aging was precipitation of the fine and evenly distributed particles with an equiaxed and recrystallized microstructure gaining 0.8 µm size of grain in the stir zone[32].

Heidarzadeh et al. (2015), studied and found the tool with a scrolling shoulder improved weld strength compared with conical shoulder. However, the importance of optimal rotation speed was observed to get defect free welds in both geometries. The scroll geometry showed ultra-fine grain refinement and increased micro-hardness and tensile strength in the SZ[33].

Pan et al. (2016), The weld manufactured by FSW with 1000 rpm constant tool rotation speed and varying traverse speed from 120 mm/min to 180 mm/min. The influence of FSW on microhardness, microstructure, and tensile properties of Mg-5Al-3Sn alloy was reported . As a result, max tensile strength of 259 MPa at 180 mm/min was obtained. As compared to basematerial 87percent improvement was observed[34].

Zhang et al. (2012), has done the review for FSP tools with different types of tool, geometries, material and wear analysis. It was found that the tool wear and design are major influencing parameters due to which manufacturing applications of FSP gets limited for alloys with maximum strength and maximum melting temperature. It was summarized that major development in weld cost, life with process tools has been carried out for low strength material like Mg and AL alloys. Although, major development has been done but still unable to reduce cost for abrasive and high strength material. So major efforts can be taken for designing and developing special tools withnew materials[35].

Darras et al. (2007), conducted a study on Mg alloy AZ31 impact on issues of different processing parameters, the resulting thermal structure, and mechanical strength, applied to thermal histories. Variation in tool speeds ranging from 1200-2000 rpm, and transverse speeds ranging from 20-30 in/min were used to process the samples. As a result, 72 HV and 68 HV microhardness achieved for weld and base material respectively. The basic alloy and weld specimen average sizeof grain 6 µm and 3 µm, respectively[36].

Patel et al. (2016), The FSP technique for improving the microstructure was investigated. There has been an increase in grain size with increased tool speed, and decreases with increasing traversal velocity. But the grain size from the tilt angle was not significantly affected. In microstructure with a greater tool angle, distorted grains were found. The average microhardness value achieved in the SZ with low heat input was the highest, which was equivalent to higher tool rotation and traverse speeds. The size of the grain becomes finer with increased rotation speed due to high input heat, resulting in the grain growth of the FSP samples at a high tool rotation speed. Grain size varied and increased as the transverse speed was raised from 50 to 78 mm/min. It was concluded that grain size was not affected by tool tilt, as there is variation in heat generation during the operation. However, the size of the grain dropped by a narrow margin, as the tool tilt increased. The distorted grain structure in 40 and 60 tilts was detected[37].

Patel et al. (2017), used three distinct types of polygon pin geometry to investigate the effect of processing parameters such as transverse speed, tilt angle, and tool rotation speed. During the friction stir procedure, the square, pentagon, and hexagon pin tools reached maximum temperatures of 379oC, 368oC, and 346oC, respectively. Due to the higher shoulder surface in the tool pin profiles, the square pin produced the highest temperature in the SZ. The macrostructure and microstructure of the SZ were defect-free in all regions, owing to its four faces, which might have supplied the best action, followed by superior material churning and mixing. In the case of the hexagon and pentagon pins, little cavitation was formed in the stir zone. Furthermore, the microhardness results were nearly identical across all samples[38].

Mansoor et al. (2009), the experiments were carried out by the final finding of a faster translation speed resulted in a lower SZ temperature, which in order resulted in less grain formation. In the case of varied tool translational speeds, however, the finding was that increasing the tool rotation speed in order resulted in increased grain size, which was attributable to the formation of a maximum temperature. Even though increasing rotational speed causes higher strain rates, which leads to finer grain sizes, the comparable increase in temperature was resulted to have a more distinct influence on microstructure growth than increased strain rate[39].

Albakri et al. (2013), During FSP, Mg alloy AZ31 with varying spindle and traverse speeds was employed. The model parameters and the experiment parameters were selected, and temperature peaks were compared. As a result, the friction heat into the workpiece was reduced as the traverse speed was increased from 3 mm/sec to 15 mm/sec with decreased temperature. The weld specimen at 1000 rpm and 3 mm/sec attained the maximum temperature of 7430K. Temperature decreases up to 7000K and 6880K, when traversing speed increases 9mm/sec and 15mm/sec, respectively. The lowest traverse speed produced the highest peak temperature, which reduced as travel speed increased. The samples with the slowest rotational speed had the minimum temperatures. In contrast, the sample at 2000 rpm recorded the maximum temperature because of itsplastic dissipation and higher strain rate in the SZ results[40].

2.1.2 Effect of Process Parameters on Fatigue and Frictional Properties

Arora et al. (2013), estimated the result for wear test by different process parameters. Weld developed by three different traversal speeds of 3 m/s, 1 m/s, and 0.3 m/s, with varied weights of 5 N, 10 N, and 10 N, 2500 m sliding distance. As the sliding velocity was increased, the wear rate increased for both the base alloy and the FSP samples. When the sliding velocity raised from1 to 3 m/s, the decline in wear rate was larger than when it was changed from 0.33 to 1 m/s. The maximum wear rate at the maximum load, which reduces practically linearly as the normal load values decrease[41].

Cavaliere et al. (2007), used a fixed tool rotation of 1500 rpm and a rate of feed 56 mm/min to perform FSP on AZ91 alloy. The weld quality with FSP was found to have good ductility and tensile strength values, as an outcome of fine grain structure. The absence of casting defects results in an increase in ductility and material strength in comparison to the base alloy. It was observed that the fatigue life was increased due to grain alteration and the removal of porosities and defects[42].

Darras et al. (2007), performed FSP by using the air media and recorded temperature readings during processing. The FSP specimen was produced with the finest microstructure with a normal size of grain 6 µm. As a result maximum temperature, rate of cooling, and rate of heating are essential for process control and optimization[36].

Alidokhta et al. (2012), the study on the microstructure as well as sliding wear behavior of aluminum alloy A356 by FSP at various rotational speeds was done. As a result, weld carried out by FSP observed considerable microstructural change in the A356 aluminum alloy with improved wear behavior. Wear resistance was improved as a result of considerable changes in grain size, morphology, Si particle dispersion, and microhardness. Increased tool rotating speeds shows more effective results for microstructure refinement, increasing the wear-resistant[43].

Sharma et al. (2004), used FSP to explore the fatigue life of Mg alloy A356. FSP samples welds with varying tool spindle speeds and tool feed rates were manufactured. As a result, a visible breakup and uniform spreading of Si particles in the MMC, as well as porosity and defect reduction was observed. In the SZ of weld samples, fatigue life increased more than 80 percent[9].

Tajiri et al. (2015), evaluated the influence of tool spindle speed on fatigue life and texture research of FSW on A356-T6 alloy in two distinct processing settings. The process parameters, fixed rate of feed 150 mm/min and the tool spindle speed ranging from 500 rpm to 1000 rpm was considered. The FSP samples increased fatigue life was attributed to a higher fracture initiation rate than the base alloy due to the elimination of porosities and defects. As a result, lower tool speed improves the fatigue strength of weld[44].

2.2 Cryogenic (LN2) Friction Stir Processing (CFSP)

This research study was reviewed by FSP under the cryogenic media. The paper focuses, in particular, on controls over thermal boundaries and FSP's influence under cryogenic (LN2) media, based on an exhaustive assessment of relevant literature. These categories are discussed briefly below. The effect of FSP under Cryogenic Media on Microstructure and mechanical properties is discussed below.

Chang et al. (2007), had described the effect of cooling in the improvement of surface finishing during any manufacturing process.As a result, combined effect of FSP with cooling control produces ultra-fine grain refinement and improves mechanical characteristics. It was concluded that by controlling the process temperature ultrafine grains with uniform structure can be obtained. Obtaining ultra fine sized grain the microhardness can be improved. Ultra fine grain structure can be achieved with a high rate of strain and using a rapid heat source in low process temperature for FSP[45].

Zhemchuzhnikova et al. (2015), studied the influence on microstructural and cryogenic characteristics for Al Mg Sc Zr alloy by FSW. For both material conditions, microstructure developed a smaller size of grain in the stir zone. The microstructure was dominated by fully recrystallized 1 μm tiny grains. As a result, due to material temperature circumstances the remoting zone showed superior toughened fractures, this impacted with refined and distracting grain of the coarse Al6Mn particle[46].

Khodabakhshi et al. (2015), conducted experimental studies with process parameters ranging 800 rpm - 1400 rpm and 50 mm/min - 200 mm/min with the varying machine speed and traverse speed accordingly. It was observed, uniformly distribution of reinforced particles was achieved at 1400 rpm tool rotation speed and 50 mm/min after four passes. The rate of cooling during FSP was increased and the sizes of HAZ, TMAZ, and SZ were refined. The refinement of grain in SZ was more perceptible when nanoparticles were introduced. For Al-Mg alloy containing pre-inserted TiO2 particles that were submitted to the processing under the LN2 medium, the finest size of grain structure with an average size of 1 μm was obtained. A significant improvement of grain structure, particulate matter was achieved by an increase in cooling rate during FSP[47].

Li et al. (2018), investigated the effect on weld properties by FSW of steel with cryogenic coolant (LN2). As a result, almost 95 percent improvement in weld properties than base alloy were reported for the tensile strength and elongation of the annealed weld joint[48].

Surya et al. (2015), conducted an experimental study of Mg alloy AZ31B by FSP with cryogenic media (liquid nitrogen), and compared the findings with FSP in air-media samples.as a result, variation in mechanical properties observed with different cryogenic process. It is also observed a drop in mechanical properties like the tensile, impact strength with cryogenic cooling temperatures[49].

Devaraju et al. (2016), Provides a brief discussion on weld manufacturing by FSP using cryogenic refrigeration and air msdia. During the cryogenic refrigeration media, the result was finer and higher grain size than the FSP under air sample for the AZ31B alloy FSP. Recently, several researchers are using cryogenics (LN2), which has been regarded as the optimal approach for use in aerospace and automotive applications at low temperature[50].

2.3 Submerged Friction Stir Processing/ Welding

As previously researchers mentioned, water has the maximum heat capacity as compared to air, with the increase in the rate of cooling and declaying the highest temperature as compared with FSP with underwater and air media. There has been a limit of the heat input in the treated area and an increase of the cooling rate, placed on grain growth in the processed area, which allows higher mechanical characteristics and alteration of microstructure. Influence of SFSP with water cooling as media on Mechanical properties, wear behavior with thermal histories are discussed below

Upadhyay et al. (2010), the influence of thermal boundaries for friction stir welding with underwater and air media was examined. Friction stir welding was performed on samples immersed in water and air to investigate the effect of the quenching rate on the joint characteristics and certain weld reaction parameters. The maximum temperature during the welding process was found to be practically identical for air-swept samples and water-treated ones; however, in submerged samples, the cooling rate was higher than that for air-swept samples. Furthermore, the grain size was smaller in submerged friction stir welded samples than in air welded samples. This also suggests that welds in water have a higher tensile strength than those welded in air, which has been demonstrated experimentally. However, it was discovered that submerging the sample in water lowers the welding temperature, causing more torque requirement to stir the material, requiring a higher rotationalspeed and hence increased power consumption[51].

Hofmann et al. (2005), SFSP was utilized to achieve a faster rate of cooling of the sample and a shorter time of exposure to a maximum temperature. The size of the grain was reduced from about 2 μm to 200 nm after increasing the axial rate of feed from 0.42 mm/sec to 1.27 mm/sec. The higher feed rate of 1.69 mm/sec resulted in a reduction in heat input, allowing for rapid quenching of the sample, subsequently in ultra-fine grain structure (100 to 200 nm)[52].

Su et al. (2005), used a mixture of methanol, dry ice, and water, to cool the plate quickly in their studies on FSP. In the modern era, SFSP has emerged as a novel version of FSP, with the added complexity of completing the complete plate processing underwater. Water can absorb a lot of frictional heat and cool quickly because of its high specific heat capacity. When compared to alternative cooling systems, SFSP is more convenient, cost-effective, and eco-friendly[53].

Fratini et al. (2009), in three different (air, forced air, and water) situations, had created FSW. Use of externally cooling in Fsw improved the mechanical properties.The mechanical strength of the weld was significantly improved underwater compared with others. The fracture was observed at the weld line in the stir zone due to variation in mechanical properties obtained by the water flux[54].

Zhang et al. (2011), SFSW on 2219 aluminum alloy were carried out at a fixed weld speed and different tool rotation speeds to investigate the effect of rotation on the underwater joint performance. The tensile strength improved by tool rotation increased from 600 to 800 rpm. Following this, the tensile strength was significantly reduced as a consequence of the creation of the vacuum defect. The weld tended to be broken in the stir zone with a lower rotation speed[55].

Liu et al. (2013), used a friction stir technique in a water medium to refine the grain size of the 2219-T6 aluminum alloy. Performed FSP using water with traverse rates ranging from 200 to 400 mm/min and a constant tool rotation speed of 1000 rpm. As a result, a significant reduction in grain size from 1.7 μm to 1.3 μm is achieved. Microstructure and mechanical properties were affected by post-processing heat treatment. In comparison to the base alloy, which has a microhardness of 138

HV, the SZ has a microhardness of 95 HV. The microhardness in the Stir Zone decreased by 90-100 HV after 18 hours of aging at 165^0C[56].

Fang Chai et al. (2013), estimated studies of FSP of AZ91 alloy in water and air media. As a result, SFSP obtained remarkable grain restructuring , and SFSP and FSp obtained an average size of grain 1.1 μm and 7.8 μm respectively. Grain Boundary Sliding observed the main superplastic deformation mechanism in FSP and SFSP. In superplastic deformation a major failure cause was observed cavities and growth of grain in FSP and SFSP[57].

Rui-dong et al (2011), FSP for 7050 aluminum alloys was conducted by under air, the cold, and hot water medium. The tensile strength, fracture analysis, and fracture zone microstructures were investigated. As a result, in comparison with other samples, improvements in tensile characteristics were found for joints welded in hot water[58].

Xu et al. (2012) conducted an optimized investigation with AA2219 aluminum alloy to explore the microstructures, tensile characteristics, and stress-hardening conduct of the FSW air-to-water medial. The outcome was stronger strength and ductility than the air media in the water medium FSP[59].

Cao et al. (2015), FSP was performed underwater on an Mg-Y-Nd alloy at a constant traverse speed of 60 mm/min and a tool rotation speed of 600 rpm. A tool with a 15mm shoulder diameter, a 4 mm threaded conical pin, and a 2.5o tool tilt angle was used. Due to the fast cooling action that happens during the water medium, the average size of grain for the SFSP sample 1.3 µm was found to be finer than the base alloy 54 µm[60].

Feng et al. (2013) researched FSP in a 2219-T6 aluminum alloy water media. The processing was done at a fixed traverse speed of 200 mm/min and a tool rotation speed of 600 to 800 rpm. When compared to the base alloy, which has a microhardness of 138 HV, the average microhardness in the SZ was found to be 100 HV, 95 HV, and 90 HV, corresponding to tool rotating speeds of 600 rpm, 800 rpm, and 1000 rpm, respectively. The decrease in rotational speed causes an increase in microhardness. TEM scans revealed that the average grain size was 1 m at a rotating speed of 1000 rpm[61].

Genghua et al. (2015), examined the microstructure formation of magnesium alloy under FSP and SFSP, as well as its impact on mechanical characteristics. A tool with a 15 mm diameter shoulder was utilized with a continuous spindle speed of 800 rpm and a rate of feed of 40 mm/min. According to the findings, the base alloy has the lowest tensile strength, a percentage elongation of 178 MPa, and a microstructure modification of 3.4 percent. The tensile strength and elongation observed to 291 MPa, 7.5 percent, and 297 MPa, 1.8 percent, respectively, under FSP and SFSP. As a result, when compared to others, the SFSP samples had the highest tensile strength and elongation[62].

Zhao et al. (2015), used a water medium of Al alloy 6013 and Mg alloy AZ31 to perform FSW to reduce heat and control the development of brittle intermetallic compounds. SEM investigations were used to examine the mechanical characteristics, microstructures, and fracture mode of the welded connections. The welded joint's tensile strength and elongation reached 152.3 MPa, which equaled 63.5 percent Mg alloy AZ31 strength. At a tool rotation speed of 1200 rpm and a weld speed of 80 mm/min, the welded sample had a maximum hardness of 143 HV[63].

Fang Chai et al. (2015), As part of their examination of the microstructural and mechanical properties of the processed samples, conducted experiments on FSP and SFSP of AZ91 alloy at a fixed tool rotation speed of 600 rpm and a rate of feed 60 mm/min. Tensile strength, microhardness, and elongation of SFSP Mg alloy AZ91 with ultra-fine grain structure were found to be much greater than base alloy and FSP samples. The FSP and SFSP specimens have average grain sizes of 8.4 and 2.8 m, respectively[64].

Arora et al. (2013), AE 42 magnesium alloy was chosen as the material for investigation and the wear effect on samples of the SFSP was evaluated by variations in load speed and sliding speed. With a universal tribometer, the wear test was performed for different loads (5-20 N) and a sliding speed of (0.33 – 3 m/s). A considerable decrease in wear rate was seen in the FPS specimens, which was assumed to lead to an increased microhardness and ductility of the treated specimens, aside from a higher work hardening capacity, for the microstructural changes. The wear mechanism was changed from oxidation and abrasive wear with low loads and sliding speed. Oxidation and abrasion showed the low speed on the work surface for intermediate loads. At high speeds, the important mechanisms of wear were delamination and Plastic Deformation. At low speed and high loads, abrasion, delamination, and plastic deformation were deemed the associated mechanism, whereas the high-velocity mechanism was serious plastic deformations and delaminations. The materials obtained showed a coefficient of friction (CoF) value greater than the processed specimen at 5 N with 10 N excluding weights and complete sliding speeds. The treated material showed a CoFhigher than the basic alloy with 0.33 m/s sliding speed and a load of 20 N[41].

Wang et al. (2015) had investigated the corrosion behavior of 7055 aluminum alloy submerged friction stir welding. In comparison with conventional FSW, the joint strength of the FSW has improved by 15 percent. It was obvious from the tablet curves that the underlying articulation had a greater negative corrosion potential and a less corrosion current density than the typical FSW articulation and base metal. $MgZn_2$ formation in underwater FSW has more potential for negative development than in conventional FSW formation in $MgCu_2$. This gives the base metal a stronger resistance to corrosion[65].

Bhadouria et al. (2017) performed AZ91-D magnesium alloy FSP under air and water media. The best process parameters were a tool rotation speed of 1000 rpm, a traversal speed of 50 mm/min, and six passes. In compression, FSP under air sample was shown to reduce the grain size by 13 percent, and hardness increased by 14 percent along with the depth and width of SZ of the SFSP sample. A factor that was considered to explain these traits was the dynamic recrystallization and elimination of the surplus heat that inhibits the formation of post-grained alloy. Pin-on-disk wears testing has been performed to compare the wear performance of FSP[66].

Hofmann et al. (2007), the study pointed out that FSP underwater increases the rate of cooling and decreases the grain size of bulk samples. SFSP was considered to be a relatively new method and much of the research focused on aluminum and magnesium alloys. Studies were carried out in the field of SFSP mg alloys, in particular thermal history measurement[67].

Liu et al. (2010), performed SFSP on 2219 aluminum alloy to improve weld performance by changing welding temperatures. The results showed that the tensile strength of the welded joint of 324 MPa can be enhanced by external cooling effects of normal water to 341 MPa[68].

Mofid et al. (2012), the use of FSW as an alternative and improved way of fine welding production and therefore of reducing problems in the development of intermetallic phases were demonstrated. A rotational fixed rate of 300 rpm and 50 mm/min feed rate were employed. Due to lesser heat input the creation of intermetallic compounds, SFSW resulted in lower peak temperature[69].

Darras et al. (2013), analyzed various (air, cold, and hot) circumstances on the effect of temperature studies on FSP. Dramatic alterations were seen upon water immersion in the thermal history of the treated samples. In contrast to FSP in air samples, however, cooling rates were higher in water medium samples. Moreover, a major performance in water refining was ascribed to two primary factors: (1) the water was submerged and the maximum temperature dropped; (2) the duration of the treated material was decreased above a particular temperature. For FSP under air, warm and cold water, the average measurements achieved were 13.3 μm, 15.9 μm, and 18.9 μm. This investigation indicated that the strength of the tensile is greatly rotating. The rotary speed of more than 1400 rpm was increased and vacuum flaws in the mud zone were formed. it was observed as the speed of ration increases the grain size and, the dislocation density in the stir zone increases[70].

Zhao et al. (2014), FSW done in water and air conditions on spray formed 7055 aluminum alloy. Thermal cycle curve analysis and residual stress distribution were performed. The welded joint underwater was performing better. A comparison of the distribution of residual stress and thermal cycle curves in various materials has been used to detect the cause of this occurrence. The investigation showed that the underwater weld had more tensile strength, hardness, and plasticity than the air weld[71].

Sankar Ramaiyan et al. (2018), investigations of AZ31B magnesium alloy under SFSP with the results are summarized. Manufacturing of defect-free material, cylindrical tool pin, step-cylindrical tool pin and stepped-square tool pin profiles are significantly used. The ultrafine grain size of 1.99 μm is reached by the various pin profiles which have the smallest Scrolled Stepped Square pin profile compared to 8.48 μm and 4.99 μm respectively, by the Scrolled Cylindrical, and Scrolled Stepped Cylindrical. Consequently, for the material received before processing the grain alteration was maximally 1.99 μm per Scrolled Stepped Square pin, taking into account a grain size of 41 μm. Due to the effect of its pulsation effect which results in greater plastic deformation, greater heat induction and the impact of the shoulder geometry on size of grain dimensions in stir zone, the microstructural results achieved by Scrolled Stepped Square pin profile pin in SFSP at rotational speed of tool 1000 rpm and travel speed of 60 mm/min resulted in a stress strength, extension and microhardness of 23.46 % and 112 (HV0.5)[72].

R. Sankar et al. (2019), Three different pin profiles examined in this study were used for the SFSP hot-rolled AZ31B. Considering the responses, several performance optimizations were performed for UTS, and elongation, micro-hardness. From the experimental study a maximum value of the closeness coefficient is observed reflecting the praiseworthy performance under the optimum SFSP parameter condition with Stepped square pin profile, rotational rate of 1000 rpm and traverse rate of 30mm-min. ANOVA was used to evaluate the percentage contribution under SFSP parameters. ANOVA shows that the SFSP parameters have a significant influence to output response at the 95% confidence level considered. Utilizing the stepped square tool which caused a higher microstructural change, improving UTS and extending the percent of the SFSP of AZ31B hot rolled Mg alloy are seen. In the area of the processed material, the scrolling shoulder achieved superior grain structure, increased microhardness and mechanical characteristics[73].

2.4 Numerical and Mathematical Modeling

Numerous investigations on numerical and mathematical modeling of friction stir processing have been undertaken. To investigate, and anticipate the impacts of friction stir processing, various models were established. Numerical modeling can help you fully comprehend specific aspects of the process, such as temperature distribution and material flow. Furthermore, by validating the results for numerical methods with experimental observations, the numerical model may be used to forecast changes in outcomes owing to differences in the input parameters, saving experimental time and money.

Chen et al. (2003), for thermal behavior and thermo-mechanical process research in FSW of aluminum alloy 6061-T6, suggested a three-dimensional model based on FEA. The model included the mechanical reaction of the welded material in the tool and the thermo-mechanical process. In the model, the heat source was the friction between the material, the probe, and the shoulder. The observations show the high stress is placed in the region stretching down from the crown to the mid-thickness of the weld. Higher traverse speeds result in a bigger high longitudinal stress zone and a narrower lateral stress zone in the weld, which is consistent with prior synchrotron and neutron findings. The observations showed that the fixturing release to the welded plates will change the stress distribution of the weld[74].

Nazzal et al. (2008), in this study, the impacts of an initial grain size gradient within the sheet on SPF properties were investigated using Finite Element models for the free bulging of a dome formed of 7075 Al alloy. The results demonstrated that selective grain improvement can be used to eliminate severe dilution and enhance the integrity of the superplastic component[75].

Song et al. (2003), a 3D heat transport model for FSW has been provided. In this work, the heat created through the tool pin and shoulder was taken into account, and friction heat was assumed. The heat transmission process for friction stir welding can be modelled using this model. If the input heat ux is high enough, the local temperatures directly beneath the tool shoulder could be extremely close to the material melting temperature. During the primary welding time, the heat transmission in the portion perpendicular to the welding direction can be assumed to be quasi-steady. The heat generated by plastic deformation can be modelled as a homogeneous volumetric heat source[76].

Jayaraman et al. (2009), A similar technique has been utilized to discover the effects of three factors of the process on the friction strength of the aluminum alloy A319 stir. The authors analyzed variance(ANOVA) to find statistically meaningful parameter processes in both investigations. It has been discovered that a nonlinear regression model created to correlate TS is beneficial in predicting TS. Nonlinear terms, on the other hand, have a minor role in the regression model. As a result, the linear regression model may be successfully used to design process parameters for FSW A319 alloy[77].

Chao et al. (2003), had examined thermal generation between workpiece and tool shoulder surface and have formulated the standard boundaries problem which is resolved by a reverse approach minimizing the error in the tool shoulder-work part interface between experimentally measured temperature profiles and numerically computed friction heat generation[78].

Elangovan et al. (2009), to establish a relationship between tensile strength, and process parameters for AA6061, built a mathematical model utilizing the Responsibility Surface Method (RSM). The process parameters comprised a winding speed, axial strength, welding speed, and pin profile. Increased rotating speed and axial force increase the length by percentage but decrease constantly with increased welding speed[79].

Feulvarch et al (2013), the 3-dimensional FSW heat transmission model for aluminum alloy was considered. In their work, the heat created by the complex tool pin and shoulder was taken into account. A simple moving mesh technique is designed to prevent the problem of mesh distortion, which is commonly encountered by traditional ALE technology. For displaying the control equations, a finite difference approach was employed. The effectiveness and resilience of the moving mesh technology for a complicated 3D geometry of the instrument[80].

2.5 Optimization Techniques of Various Process Parameters

Because of the large number of process parameters in the FSP, optimizing the process parameters has resulted in significant improvements in welding performance.

Hashish et. al. (1991), optimization studies had shown the Taguchi approach to be an important tool to increase quality and production at affordable expense. Its use has been identified in the optimization of a single performance. However, more research efforts are seen as the necessity to address the multi-objective performance[81].

Lin et al. (2002), in carrying out a multi-criteria decision analysis, applied numerous decision- making methodologies. Grey relation analysis (GRA), the seamless solution-to-ideal order- performance technology (TOPSIS), and the engineering issues associated with the analytical hierarchy process (AHP). TOPSIS was suggested by Hwang and Yoon. It operates with a simple computing technique, reduced time and values near the optimal answer[82].

Palanikumar (2006), took up the use of Taguchi's method and his study on Pareto ANOVA analysis. It is intended with the PCD Tool to reduce surface ruggedness to optimize machining parameters in turning GFRP composites. The machining parameters were evaluated, i.e. the cutting speed, feed rate, and cut depth. In the examination of the effect of cutting parameters and their interactions, an orthogonal array L27, the signal-to-noise ratio, and Pareto ANOVA analysis were utilized. The test results showed a feed rate followed by a cutting speed as the most relevant processparameter. The Taguchi and Pareto ANOVA methods[83].

Puviyarasan et al. (2012), the composites of AA6061/SiCp were manufactured with the FSP under the air media. Taguchi experimental design was used to determine the combination of the most important characteristics capable of providing higher strength. The optimization was carried out. Analysis of variance (ANOVA) technology was used to obtain the testing of experimental data. The Taguchi technique has been used to determine the optimum process parameter level. The results were tested with the tests of confirmation[84].

Seveel etc. (2014), the impact of improved parameters on the taper pin geometry on the FSW of the alloy AZ31B was demonstrated. The welding joint, with the geometry of the taper pin tool, at a tool rotation speed of 1000 rpm with a tool transverse speed of 30 mm/min achieved maximum tensile strength of 183 MPa and was entirely without defects[85].

Vijayan et al. (2010), The FSW of AA-5083 Aluminum Alloy was employed, with numerous orthogonal-based answers and GRA optimization of process parameters. The results revealed that the peak tensile strength was generated and that the process settings were used the minimum energy[86].

Zhang et al. (2013), made special efforts to implement FSW in 2219-T6 aluminum alloys underwater media. Specially created mathematic was used to optimize the weld parameters for tensile strength. The results showed that the maximum voltage force reached under air media was higher than FSW. To prevent the tensile strength of a submerged FSW 2219-T6 aluminum alloy, a mathematical relation was created between tensile strength and welding parameters[87].

Kumar et al. (2014), performed a GRA and Taguchi technique for multiple process optimization parameters of the FSW of different aluminum alloys. The selected process parameters were tool speed, the geometry of the tool pin, and the angle of tilting while tensile resistance, elongation, and output were chosen. Optimum process condition for carrying out a confirmatory test to demonstrate the mechanical strength improvement and ensure the effectiveness of the GRA technique[88].

Yuvarajann et al. (2014), conducted a multi-reaction analysis on optimizing the parameters of the abrasive water jet cutting process based on the TOPSIS approach. During the abrasive water jet cutting process using the TOPSIS technique, the test results highlighted the possible reactions of the AA5083-H32. The ANOVA test was conducted to determine important elements for the cutting process in the abrasive water jet[89].

Lokesh et al. (2016), using TOPSIS and Taguchi technique, worked hard to optimize the FSW process parameters. The selected process parameters were tools rotational speed, crossing speed of the tool, tool pin profile, and tensile strength as output reaction, and elongation. The optimal procedure requirement for bringing light to mechanical strength improvement and determining the robustness of the TOPSIS technique was confirmed[90].

Tripathy et al. (2016), For the evaluation of the efficacy of optimizing several functions of H-11 die steel with the help of the copper electrode, the author applied the Taguchi approach in combination with TOPSIS and

GRA. Process variables effects including powder concentration, pulse, and maximum current in duty cycle, gap tension, and time were investigated in the investigation, on respondent parameters such as removal rate of material, wear rate of tools, the wear ratio of electrodes, and surface ruggedness. For the parameter determination at a 95percent confidence level, ANOVA and F-test was performed. Confirmatory tests showing 0.1616 and0.2592 improvements[91].

Achebo et al. (2015), are seeking strategies to improve weld quality by successfully using TOPSIS. It is based on the ideal alternative motion which requires the minimum distance from the perfect solution and the maximum distance from the solution. The inevitable conclusion was that TOPSIS was able to optimize the settings of the input process that provided the best mechanical characteristics. This study employed a step-by-step strategy to applying the TOPSIS technology[92].

Summary

As we go through the past research many researchers concluded that by controlling the process parameters we can improve the grain formation of the base material. Grain formation can be controlled by selecting the proper profile of tool pin and geometry with optimized transverse, and rotational speed. By controlling the grain formation microstructural as well as mechanical properties can be improved. Mostly weld quality is affected by tool pin profile, geometry, and tool material. The heating of the workpiece is mainly generated by the frictional force between the workpiece and the shoulder of the tool. So mostly affecting factor is tool pin profile and shoulder head. Square pin, threaded pin as well as scrolled-headed shoulder is superior to produce high-quality welds.

As a result, it is observed that tensile strength increases with shoulder head diameter. Max the deformation in friction stir process more substantial residual stress is generated. The retreating portion has residual stress of low level as compared to the advancing portion. The thermomechanical affected zone, as well as the stir zone, consumes tensile residual stress and the heat-affected zone consumes residual stress is compressive in nature on the advancing side Lower hardness was observed in the region between the thermomechanical affected zone and stir zone as well as thermomechanical affected zone and heat- affected region and in the stir zone side slightly decreased hardness is observed. The weld stir zone microstructures were observed with finer uniform grains as compared to HAZ and TMAZ. The base metal zone had coarser grains than the heat-affected zone and the thermo-mechanically affected zone.

Due to the effect of its pulsation effect which results in greater plastic deformation, greater heat induction, and the impact of the shoulder geometry on the size of grain dimensions in stir zone, the microstructural results achieved by Scrolled Stepped Square pin profile pin in SFSP. ANOVA shows that the SFSP parameters have a significant influence on output response at the 95% confidence level considered. Utilizing the stepped square tool which caused a higher microstructural change, improving UTS, and extending the percent of the SFSP of AZ31B hot rolled Mg alloy are seen. In the area of the processed material, the scrolling shoulder achieved superior grain structure, increased microhardness, and mechanical characteristics.

Concluding that with the finer size of grain in the stir zone more improved microstructural and mechanical properties of the weld. FSW is used to weld different metals and their alloys which cannot be joined using conventional methods. With its safe and eco-friendly operation, it has a wide range of uses. As a result, FSW is a new alternative method for fusion welding.

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