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Friction Stir welding of Magnesium Alloy: A Review of Experimental Findings (Process Parameters, Quality Weld Generating Variables)

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Abstract - *It is a latest solid-state joint method, in this method non-consumable material is used. Main benefit is that it produces very negligible pollution. In recent study, FSW of AZ31B is used to enhance the weld quality. Magnesium alloys have number of mechanical properties such as low density, high strength. It can be clearly foreseen through data and patterns employed in joining processes that use of Mg alloys will grow exponentially in the upcoming future generation. Experiment & investigations are being carried out in order to uncover technical facts and parameters related to the wear losses & tensile strength, resistance to corrosion of the fabricated magnesium weld.*

Friction stir welding is a fastest growing welding process in manufacturing and production industries. This is a latest technique that has resulted in high joint strength and low distortion when compared to any other welding techniques. Mostly, FSW has capacity of joining almost all types of Al and Mg alloys. Very few techniques are known for the welding of Mg and its alloys due to studies have nearly limited to that few magnesium alloys.

Key Words: Friction stir welding, Magnesium alloy, Process parameters, weldability, weld properties.

1. INTRODUCTION

Welding is one of a very important process in manufacturing and production. Welding helps and ensures in producing complex parts which are very difficult to form completely in single set. It is not an alternative to manufacturing process but it acts as a secondary joining process that most of the time follows the primary process. Now a days the ordinant dictation to engender intricate components that are very arduous to manufacture as single components has grown. The field of welding has grown abruptly in recent years and is now in present era it is considered as one of the most consequential and critical manufacturing processes. To fulfil the above discussed requirement a relatively new process of joining materials has been introduced, that is Friction Stir Welding. In this welding process heat generated is frictional heat that is generated between tool shoulder and base material, it causes the material below rotating tool to go into plastic state.

Stirring and extrusion together responsible for the elongated grains to break into smaller grains, and this replaces the original base material grain structure into a very fine grain [5]. Rotating tool is used to stir the base metal plastically. Because of this severe plastic deformation occurs, the coarse elongated grains are fragmented into equiaxed and fine grains. Its great influence can be optically discerned in the welding of alloys that are arduous or infeasible to weld by conventional fusion welding techniques. The magnesium alloys AZ31B and kindred composition of alloys are one such kind of alloys which are astronomically sensitive to weld solidification, thus they are welded by friction stir welding (FSW). In integration, FSW consumes less energy than fusion welding processes and eliminates the filler wire, thereby making FSW a more environmentally cordial technique [10].

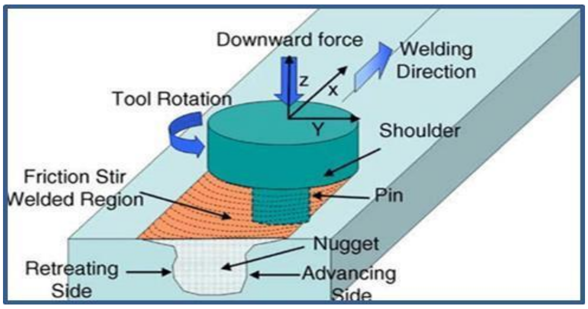


Fig -1: Schematic diagram of friction stir welding [1]

FSW process finds its commercial applications in sundry industries, such as space technology and aviation industry,[19] automotive industry, marine and shipbuilding [18,19]. Some advancement in FSW process has been recently developed by manufacturing industries to suit their requisites. Friction stir spot welding (FSSW) is one of the types of welding process that has been introduced by the automotive industries as an alternative to the resistance spot welding [20]. FSSW has withal been prosperously applied for joining of aluminum (Al) to steels plates which are not even possible by conventional spot-welding processes [17]

Two distinct sorts of the FSW apparatus geometries in particular, the stepless cylindrical shoulder tool and the stepped cylindrical shoulder tool. The two imperative parameters to be considered in friction stir welding, is the means by which quick the device pivots and how rapidly it navigates the interface. These two parameters have extensive significance and must be carefully picked to guarantee a fruitful and proficient welding cycle. Specialists have effectively endeavored hybridizing the FSW procedure by utilizing extra warmth source in type of laser or gas tungsten curve welding (GTAW) alongside FSW. In spite of the fact that hybrid FSW is investigated for welding of AZ31B another grade of magnesium alloys, endeavours to weld divergent materials including magnesium and aluminium by FSW has been attempted. The additional warmth source is utilized for preheating the work material during hybrid FSW. The utilization of gas tungsten arc welding (GTAW) helped mixture erosion mix welding to join Mg-based composites was found to build the quality and increase the strength and elongation of the welds contrasted with traditional FSW.

This paper talks about various parts of FSW of Magnesium composites, for example, the procedure parameters, tool design, mechanical and microstructural portrayal and deformities common to FSW joints. The connection between different FSW parameters and microstructure and mechanical properties of the weld joints will be explored in detail.

2. MAGNESIUM ALLOY

The weight reduction plays a major role in the application of magnesium alloys in aerospace and automotive application [17]. Magnesium is the most abundant material and given priority in terms of terms of strength next to iron and aluminum [17]. Magnesium alloys have light weight properties due to its low densities and high mechanical stiffness. The magnesium alloys improve the CO2 emissions and reduction in weight in automobiles nowadays [16]. It gives green revolution to the environment.

It has good thermal conductivity, cast ability and machinability [16]. Magnesium alloys when added with aluminum improves in corrosive resistance and if Magnesium alloys is added with zinc improves tensile properties when present at 1% [1]. Currently magnesium alloys are prepared with addition of rare earth metals for enhancement in properties. Based on the operation process magnesium alloys can be classified as cast alloys and wrought alloys. Magnesium (Mg) alloys are casted because magnesium houses a hexagonal packing structure which resists plastic deformation when casted [1].

The wrought magnesium alloys mechanical properties are determined from the actual specimen manufactured techniques like extrusions, forgings or rolled products [1].

ASTM standards decides the grade name of magnesium alloys in the form of elements starting name and its percentage of composition. For example, AZ31 Magnesium alloy represents the composition of aluminum as 3% and zinc as 1% with the help of series. Magnesium alloys have limitation due to its poor weldability. It undergoes special welding process to perform welding operation in magnesium alloys such as friction stir welding etc.

Table -1: Effect of alloying element of Magnesium [1]

Alloying Elements	Properties	Effect
Aluminum	Hardness	Increases
	Strength	
	Ductility	Decreases
Beryllium	Oxidation	Decreases
Calcium	Oxidation	Decreases
Cerium	Corrosion resistance	Increases
	Yield strength	Decreases
	Strength	Increases

	Ductility	Decreases
Nickel	Yield and Ultimate Strength	Increases
	Ductility and Corrosion resistance	Decreases
Rare Earth Metals	High temperature creep	Increases
	Corrosin resistance	
	Strength	
Silicon	Corrosion resistance	Increases
Zinc	Corrosion resistance	Increases

3. Friction stir welding (FSW)

Expanded interest for lightweight materials and parts in vehicle, marine and aviation ventures have gone about as an impetus for the exploration on lightweight metals, especially on magnesium (Mg) and its alloys. The composition of Wrought AZ31 Mg alloy sheets is (2.75% Al, 0.91% Zn, 0.001% Fe, 0.01% Mn and remaining being Mg by wt.%). Mg density (1.74 g/cm3) is much lower in contrast with the other every now and again referred to light metal, for example, aluminum (2.4 g/cm3) [17]. Mg demonstrates a high strength to-weight proportion and better damping properties. Nonetheless, poor weldability and flexibility are the confinements of Mg. While concentrating on these issues, Mg composite based materials can end up promising contender for a wide assortment of basic applications. AZ series is the generally utilized compound among all Mg combinations, it contains basically aluminum and zinc as their alloying components in different extents [16]. Welding of Mg compounds is too mind boggling in light of their exceptionally receptive nature and high inflammability. As of late, Friction stir welding (FSW) has risen as a potential device to join comparable and unique metals as a solid-state joining technique. In an alternate report, Mishra and Ma likewise contemplated the rule behind joint development in FSW was clarified impeccably [21].

Friction stir welding is the procedure in which welding is done by heating and blending the base material. It is a solid-state welding innovation which was created by The Welding Institute United Kingdom in 1991[3]. FSW does not dissolve the base material and consequently totally wipes out the issues related with solidification that generally show up in fusion welding [22]. At the time of friction stir welding temperature advancement happens because of which residual stresses are created in AZ31 Mg alloys and these are studied to show signs of improvement comprehension of the systems engaged with this procedure, heat is produced because of the rubbing between the tool shoulder and the workpiece and plastic distortion happens around the tool.

It is hard to accomplish deformity free welds utilizing old customary combination welding systems because of the nearness of imperfections, for example, thermal cracks, porosity, and oxidization [5]. Indeed, even in friction stir welding additionally, a portion of the deformities will show up because of ill-advised procedure parameters. Legitimate learning and comprehension of the temperature conveyance are exceptionally vital, it impacts the weld microstructure and its subsequent mechanical properties

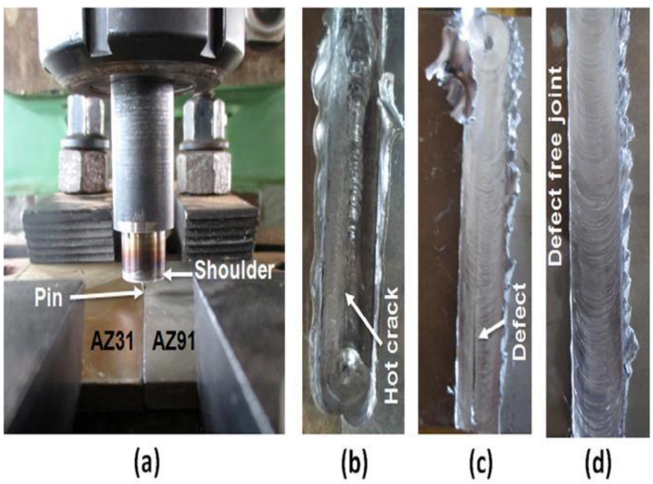


Fig -2: (a) FSW set up for joining AZ31 & AZ91 Mg alloys, (b) appearance of hot crack just after welding, (c) joint with tunneling imperfection (d) defect free joint [17].

[13]. In an alternate report, Zhang Bing, YUAN Shouqian, and WANG Xunhong studied Friction Stir Welding equipment has a rotating tool with a shoulder which will be plunged into the material and permitted to navigate in the centerline of the workpiece. Consolidated pivoting movement and blending activity of the apparatus produces heat and stirs the material expelling the mellowed plasticized workpiece material around it and forging happens in a similar spot which resulting in to form a solid-state seamless joint [14].

Joining of the material takes place in solid states that implies material will be joined without heating It over its softening point, keeping temperature low creates great quality of weld. Customary welding parameters current and voltage are missing here, it is totally mechanical procedure in which heat is induced with force. FSW material comprises of essentially four unmistakable microstructural zones which are referenced as Heat affected zone (HAZ), Nugget zone (NZ), and Base material (BM) Thermo mechanically affected zone (TMAZ) [3].

4. Process parameter

There are a lot of welding parameters to consider when using FSW as a machining process. It's important to examine these factors to determine if FSW is right for your application.

4.1 Tool speed

FSW is a relatively slower process than another sort of welding. It is a result of cylindrical tool should swing to deliver heat on the joint part, and afterward opposite to the length of the joint transmitting heat. The welding instrument is tipped with utilization of the probe, which generally rotates with the scope of 200 - 2000 revolutions for every minute (rpm) [3]. The navigate rate of the instrument along the joint line is between 10 to 500 millimeters for every minute (mm/min). The speed is for the most part inspected with the application and the metal are joined, yet it isn't fundamentally unrelated, a gradually rotating tool can't move very quick over the joint line [6]. Table 1 demonstrates that the distinctive welding speed and feed which gives diverse sorts of joint, an appropriate set of speed and different parameters offers ascend to legitimate weld (parameters 4). Fig. 3 demonstrates the presence of the material surface was welded by various parameters. For the AZ31B Mg compound with a thickness of 15 mm [14].

Table -2: Parameters of FSW [14]

Sl.no	Rotation speed / (rpm)	Welding speed
1	1500	95
2	950	95
3	750	60
4	750	37.5

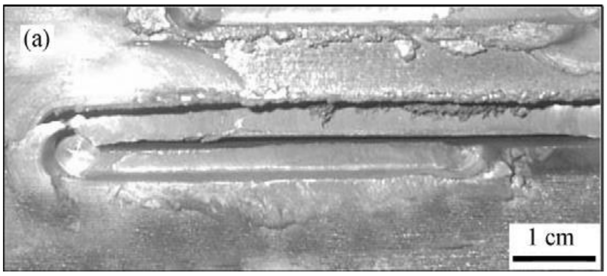
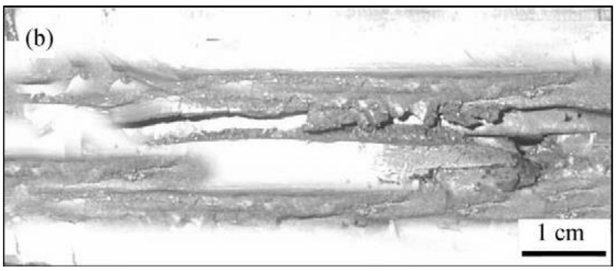
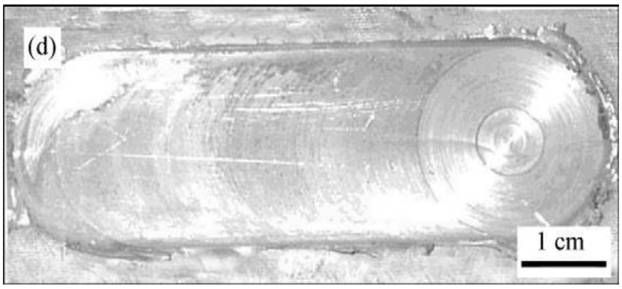


Fig. 3. (a) welded by parameters No. 1[14]



(b) welded by parameters No. 2[14]



(d) welded by parameters No. 4[14]

4.2 Tool Tilt and shape

Tool tilt and shape plays a crucial job in manufacture of legitimate weld joints. Tool tilt is an exceptionally valuable procedure parameter. Normally tool tilt is estimated as for the work surface [3]. A typical range for tool tilt is 2 to 4 degrees, along these lines the tool inclines in the joint part. While exceptionally little, the tilt can leave influence by which the tool can move effectively over the joint line since least pressure is applied toward welded line [6].

In Stephan Thangaiah I S exploratory work, a nitty-gritty examination was done to comprehend the job of the geometry of the FSW tool. Primarily two distinct kinds of FSW tool geometries stepped cylindrical shoulder tool and stepless cylindrical shoulder tool are utilized for FSW work under various combinations of FSW process parameters. In his study Stephan Thangaiah, I S found that Stepped cylindrical shoulder tool has created extremely stable quality joints with better rigidity esteems for the combinations of different low estimations of rotational speeds and higher navigating feeds of the FSW device. In his test work Stephan Thangaiah, I S found that Mg alloy joints welded utilizing a stepped cylindrical shoulder tool indicates higher rates of corrosion in contrast with that of the Mg alloy joints manufactured utilizing a stepless round shoulder tool [4].

4.3 Depth plunge

Plunge depth is explained as the depth at which the shoulder of the tool nib dove into the work piece material [3]. At the point when tool touches the work piece rubbing between them produces the warmth important to plasticize the work piece metal [8]. Plunge depth is inspected by rotation time and thickness of the material. TIER et al (2007) investigations additionally demonstrate that the impact of FSW parameters on the shear quality and microstructure of 5042 aluminum welds and found that the most noteworthy factors were Plunge depth and tool rotational speed [23]. In a test consider by Zhong-ke ZHANG on FSW of Mg composites, Measurable examinations of the test outcomes demonstrated that the pin diameter is observed to be the most powerful procedure parameter pursued by the shoulder plunged depth, it was discovered that for best nature of weld ideal procedure parameters for FSW of 3.0 mm thick AZ31B were a combination of a turn speed of 1200 r/min, a pin diameter of 5.5 mm, and shoulder plunge depth of 0.3 mm [24].

Certain mechanized frameworks made up concentrated friction for a reasonable timeframe, at that point device is embedded down to its foreordained depth. Others are robotized to pursue the Plunge depth processed in advance rely upon to what extent the tool need to work for the chose depth [11].

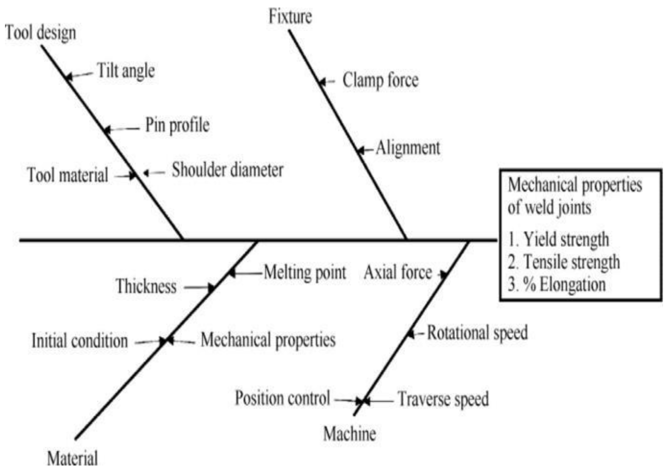


Fig. 4. (Cause and effect diagram used for selection of process parameters for optimization [25].

4.4 Force

In FSW, there are three types of force applied on the tool. Vertical force (Y- force) longitudinal force (X – Force), lateral force (Z-axis Force). The transverse is positive in the perpendicular direction and traverse force acts parallel to the tool speed direction. The joint quality can be control with the use of right quantity of torque and force.

5. Parameters influencing Weld Quality

So many quality parameters are responsible for a good welded joint and these parameters acts as a deciding factor for best weld. Welded joints should possess these quality parameters. Important weld quality parameters are classified as follows:

5.1 Microhardness:

Microhardness is normally decided at center thickened area all through Weld. Primary explanations for improved hardness of the stir zone are: (I) Grain structure refinement assumes vital job in giving material quality strength, grain size of stir zone of weld material is better than that of base metal. Hardness will doubtlessly increment as the grain size will diminishes. (ii) Little particles of intermetallic mixes are likewise mindful to hardness improvement. [10]. From the performed trials it is seen that the variety of hardness is firmly impacted by the post weld heat treatment (PWHT) forms [12].

5.2 Mechanical properties:

A portion of the normal and best mechanical properties that decide the weld quality are Malleability, Rigidity, Versatile properties, Corrosive behavior, hardness, percentage extension, Strength/weight proportion, break attributes, Shear strength, Fatigue and so on [3] Mechanical properties of the weld assume a critical job in application- based areas. The weld joint dependably has best mechanical properties at whatever point contrasted with base material properties.

5.3 Thermal Properties:

Apart from mechanical properties one of the major influential parameter for weld is temperature. The weld temperature tends to vary during Friction Stir Welding owing to change in tool pin profile, process parameters etc. Some of general thermal analysis techniques are Differential thermal analysis, Thermo gravimetric analysis, Thermo mechanical analysis etc. All of these analysis procedures are required and used for proper thermal analysis and evaluation. Welding heat causes precipitates to disappear, due to which softened region will be formed in the weld zone. During the thermal cycle of the welding such a softening was caused by dissolution of precipitates (Mg_2Si, $MgZn_2$). [11]

5.4 Microstructural Properties:

The resultant microstructure subsequent to welding will be very not quite the same as parent material. Every single procedure parameter which are chosen amid welding that has noteworthy effect on final microstructure of the weld. These microstructure changes can be seen by metallographic examination systems. Metallographic techniques that are for the most part utilized for assurance of microstructural properties are Examining Electron Microscopy (SEM), Surface geography, and Optical microscopy.

6. CONCLUSION

In this review work Friction stir welding (FSW) of Magnesium (Mg) alloy AZ31B was considered. Impact of every selected process parameters on final weld quality, mechanical properties, microstructural analysis have been considered in very detailed manner. Among various grades of Mg alloy AZ31 grade were used in abundantly. The process parameters selected were mainly Tool Welding speed, rotational speed, tool tilt angle etc. Though different tool profiles have been used the tool material for almost every works remains to be H13 Tool steel thorough literature review related to Friction stir welding of Mg alloys has been done for limited period. The works of various researchers has been highlighted throughout the paper. Remarks of various works are also highlighted.

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