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# A Summarized Review on Friction Stir Welding for Aluminum Alloys

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## Abstract

This paper explains the precept and methodology of FSW. It covers some of the technical sides which influence the process and quality of FSW joint. Large advance has been accomplished in friction stir welding (FSW) of aluminum in every side of tool manufacture, microstructure properties estimate in the last decennia. With the development of reliable welding tools and precise control systems, FSW of aluminum has reached a new level of technical maturity. influence on butt joint arrangement is studied. Effect on welding quality of main parameters:  rotation speed, travel speed, tool tilt angle, axial force and weld time has been studied. Finally, FSW is identified as an additional area for research can be carried out in the welding science.



***Keywords***

*Friction Stir Welding, Spindle speed, Welding speed, Axial force, material thickness*

## 1. Introduction

Friction stir welding (FSW) is a solid-state joining process invented at The Welding Institute welding (Thomas W. N., 1991). It was initially designed for use with aluminium alloys, but has since been extended to be used on magnesium alloys, mild steel, stainless steel, and titanium alloys (TWI)( The Welding Institute) (Thomas C. D., 1995) (A.P. Gerlicha, 2009). Some examples of how FSW has been applied can be seen in NASA's space shuttle external tanks, super liners such as the Ogasawara, Shinkansen bullet trains, and Ford's magnesium prototype spare wheel. Friction stir welding is classified as solid-state because the base plate material does not exceed its melting point throughout the process. Friction stir welding uses a nonconsumable tool composed of a pin and shoulder. The tool's purpose is to generate sufficient heat such that the base material will soften. Heat is generated through means of friction, pressure, and localized plastic deformation of the substrate. As the tool travels through the softened base plate it will also serve to mix the material near the pin and shoulder to create a joint. A common configuration of FSW is a butt weld where the FSW tool is inserted in between the edges of two sheets and traverses along the joint . The major factors affecting the FSW  process are given below (Ying Li, 1999) (T. DebRoy and H. K. D. H. Bhadeshia, 2010) (L.V. Kamble, 2012)

- Spindle speed (rpm)
- Welding speed (mm/s)
- Axial force (N)
- Material thickness (mm)

## 1.1. Spindle Speed

Spindle speed is one of the main parameters in FSW process. Optimum spindle speed is required for acquisition perfect welded joints (C.M. Chen, 2004 ) (V.Balusamy, 2008). The rotation speed produces fricative heat as well as mixing the material around the tool pin. Optimum mixing and enough heat generation is wanted to produce sound joints with fine recrystallized grains. This exhibits higher wear resistance. Increase in fricative heat obstetrics is observed with increase in tool rotational speed. Less heat input condition prevails at decrease tool rotational speeds and lack of mixing. The net outcome is poor consolidation of material and leads to poor wear resistance at less tool rotational speeds. High tool rotational speeds lead to high heat generation than required and release excessive mixed materials. The generated fricative heat through welding influence the grain size. Roughening of grains takes place at high tool rotational speeds which leads to poor wear resistance. furthermore, the temperature distribution is affected with tool rotational speed which may contribute to this trend (R. Rai, 2011).

## 1.2. Welding Speed

Welding speed is last main parameter that influence the properties of welding region. The tensile strength of the welded region is increased up to 4 mm/min and then decreases the tensile strength property of the joints for further increases in welding speed (Y. N. Zhang, 2012).The microstructure generated while welding is varies according to the increase and decrease of welding speed. The microstructure generated while welding is varied according to the increase and decrease of welding speed. The better microstructure was obtained at a welding speed of 4-10 mm/min and the grain size of microstructure increases on furthermore, increase of welding speed (El-Kassas, 2019).

## 1.3. Axial Force

The quality of friction stir processed (FSP) zone is streaked by the welding parameters of rotational speed, welding speed, material thickness and axial force. The optimization of all these welding parameters is very major to obtain perfect in joints. The formation of FSP of defect free joints zone is affected with both welding speed and pin profile (R. Palanivel, 2011). The formation of defect free joints zone and cut-out are controlled with the parameters such as rotation speed, travel speed, material thickness and axial force. These defects and discontinuities clearly effect the tensile properties of the FSW joints. The wear rate decreases as axial force increases. Furthermore higher in axial force leads to higher wear rate. The wear resistance follows an inverse trend of wear rate as predestined. Bonding happens in FSW when a pair of surfaces is brought in the area of inter atomic forces. Sufficient axial force override the flow stress of material is required to make defect free joint zone. Axial force is also accountable for the penetration depth of the pin.

## 1.4. Material Thickness

The quality of friction stirs processed (FSP) zone is streaked by the welding parameters such as material thickness. The optimization of welding material thickness is very major to obtain without defect in joints. The formation of defect without FSP zone is affected with both material thickness and pin profile (R. Palanivel, 2011) . Until now, the material thickness weld made by FSW reported in open literature has been 70-mm thick. utilizing advanced tungsten-based materials, Edison Welding Institute (EWI) conducted a series of feasibility trials to push the depths of FSW to 25-mm thick in a single pass. A series of development welds were made on 25-mm material thickness of aluminum plate with a yield strength of 70-ksi. A fully consolidated weld joint was finally achieved using welding parameters of 1800 RPM and 4 mm/min. Farthest notably, the post-weld distortion was unlimited and the cross-weld mechanical properties at 30-mm thick were similar to those tested at thinner sections (A.M. El-Kassas, 2015) (Deepati Anil Kumar, 2013) (Yeni C, 2008).

## 2. Similar Metals Welding

The major reason for joining similar metals is to higher tensile strength and hardness. By homogenous welded zone and high efficiency in welding joints (Shailesh Kumar Pandey, 2017) (Rajakumar, 2012). Various welding types are utilized for joining similar metals such as ARC welding, but it might not be applicable for aluminum. Aluminum can't successfully be arc welded in an air environment, due to the affinity for oxygen. If fusion welded in normal atmosphere oxidizes action readily happens causes slag inclusion and porosity in the weld, greatly reducing its mechanical properties.

## 3. Dissimilar Metals Welding

The major reason for joining dissimilar metals is to lessen weight. By lessening the weight the energy efficiency in automobiles, aerospace vehicles and cryogenic engines were enhanced (Cavaliere, 2005) (Da Silva, 2011). Various welding types are utilized for joining dissimilar metals, but it might not be applicable for metals having wide variation in thermal properties, and those metals which have a slope to form brittle inter-metallic combination. Welding types such as laser welding and arc welding have been utilized for joining dissimilar metals and their alloys, the poor seam surface of the weld, porosity in the welded region and the high welding cost prevent the application of this technique in practical (Santosh Kumar, 2015). FS welding has been help to produce a sound weld without forming inter-metallic phases. Friction welding can as well produce such product but it can only implement operations in cylindrical parts. Nowadays FS welding has been exceedingly applied in the industries for joining dissimilar metals and alloys having higher thermal amplification like welding aluminium. The major issue backward the dissimilar metal joining is the high difference in melting points, material flow behaviour and the microstructure development FSW method has been helped to produce perfect welded region compared to conventional types (Sabry, 2016) (A Comparison between FSW, MIG and TIG based on Total Cost, 2017). The FSW process will tool up welding region having high strength contrasted to conventional types (M. Ghosh, 2010). The welded metal has only 20% less tensile strength and 10% higher hardness than the parent metals (Bhanumurthy, 2012).

## 4. Friction Stir Welding Models

Friction stir welding (FSW) has been modelled using numerical and analytical models. The main objective of both methods is to produce a simple, practical way to understand and predict phenomenon observed during friction stir welding. The key aspects to these models has been how the tool contributes to heat generation through friction and plastic deformation, heat transfer, and contact conditions between the tool and the substrate. Models analysing temperature field also try to consider whether the location of greatest heat generation occurs at the tool shoulder, the tool pin, or a combination of both The contact conditions of friction stir welding relate to heat generation and can be broken down into two conditions: sticking and sliding. The sticking condition states that material will adhere to the moving tool, due to the contact shear stress being greater than the yield shear stress of the material. For the sliding condition, the contact shear stress is less than the yield shear stress of the material, and the substrate material will only be elastically deformed as the tool moves through it (K. Mustafa, 2010). The sticking condition implies heat generation through plastic deformation, whereas a sliding condition will produce heat through frictional mechanisms (Guerra, 2003) (Dong, 2011) (Colegrove, 2004) (Sato, 2002) (Seidel, 2003). developed models only considering a sticking condition. Models attributing heat generation to plastic deformation have been developed by (Frigaard, 2001) (Nandan, 2007). Work performed by Schmidt et al. found that a sticking condition was dominant by using tracers to study material flow (Schmidt H. H., 2004). Developed models assuming a sliding condition (Chao, 2003) (Xu, 2001). A stick-slip model factoring in a combination of both conditions has been developed (Schmidt H. H., 2005) (Schneider, 2006). Utilizing Finite Element Methods (FEM) (Khandkar, 2003). derived an uncoupled thermal model where temperature was correlated with machine power input (Zhu, 2004). Zhu and Chao used FEM to develop an uncouple model where transient temperature is used for thermomechanical simulation (Zhu, 2004) (Chen, 2003), also used FEM to develop a 3D model incorporating mechanical reaction of the tool, and the thermomechanical process of the substrate. Uncoupled thermal and thermomechanical models have also been worked on (Astarita, 2014) (Assidi, 2010) (Amini, 2015) (Mehta, 2015) .

## 5. Conclusion

At the modern of research and development in Friction Stir Welding is the successful joining of higher melting temperature materials such as aluminium. Recent studies have reported significant costs savings when using friction stir welding to join thicker section aluminium. however, Friction Stir Welding typically travels less than conventional arc welding processes, it can join material thickness sections in a single pass. The review on the FSW similar and dissimilar aluminium alloys, including many modern papers, provides a complete picture of both the joining types and tensile testing procedure for butt-joints. Although FS welded similar and dissimilar metal butt-joint has found many merchant applications. In summary, an important development has been made in friction stir welding utilized similar and dissimilar metal butt-joint formation, friction stir welding has been a cost and reliable welding types for aluminium alloys.

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