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Experimental Investigation of Friction Stir Welded Aluminium Alloy AA6010 Joint

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Abstract

The features like low weight, low cost with moderate strength of aluminium (Al) alloys fascinate various modern industries to replace steels in different applications. The newly invented FSW (Friction Stir Welding) is well suited for Al alloys compared to other conventional welding processes. The solid-state type of this process overcomes melt-related defects when compared to fusion welding processes. It also overcomes many other defects like voids, cracks, and distortion and forms sound weld joint. FSW joints show a fine clear grain structure in the weld nugget area compared to the parent material. In this investigation, tensile properties and microhardness properties of Al AA6010-T6 alloy are studied.

Keywords: FSW, Al AA6010-T6 alloy, Tensile strength, Microhardness.

1.0 Introduction

In 1991, The Welding Institute (TWI, UK) developed a novel welding process, Friction Stir Welding (FSW) as shown in **Fig. 1.** This is a solid phase welding technique i.e. complete process completes below the melting point of the material to be welded. Since, its inception, very popular in the joining of ferrous and as well as non-ferrous materials [1-3]. This process is environment-friendly and does not produce any fumes or radiation [3-5]. This process can be carried out in both conventional milling machines [5] and CNC milling machines [6].

The FSW tool consists of profiled pin or probe with an attached shoulder. The tool is designed in such a way that the shoulder diameter is larger than the pin diameter. The tools are stronger than the materials used for welding and made with wear-resistant material to withstand both the static and dynamic properties at elevated temperatures [9]. The smaller diameter of the pin first makes contact with the workpiece and then it is plunged into the welding joint region. The weldments are rigidly fixed with clamps, bolts, and nuts to prevent joint faces from being forced apart when the probe passes through along the welding seam [7-11]. For welding thick plates, a smaller size diameter pilot hole than the pin must be made for assistance before plunging the FSW tool. The weld is formed due to the frictional heat generated between the rotating tool and weld material [12]. The heat-affected zone (HAZ) size is much wider on the top side of the weldment and reduces its size in taper form when it comes down to the bottom side [13].

The microstructure cross-section of the welded zone is classified into four different zones as shown in **Fig. 2**. They are unaffected base material (represented as 'A' in the figure), heat affected zone (HAZ) (represented as 'B' in the figure), thermo-mechanically affected zone (TMAZ) (represented as 'C' in the figure) and weld nugget (represented as 'D' in the figure).

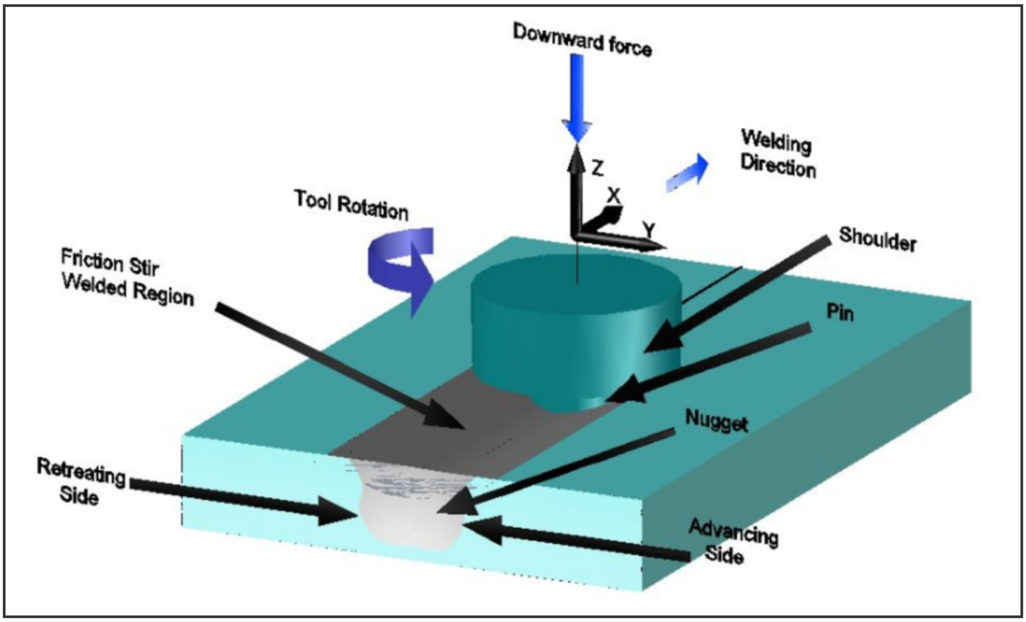

Fig.1 : FSW Process.

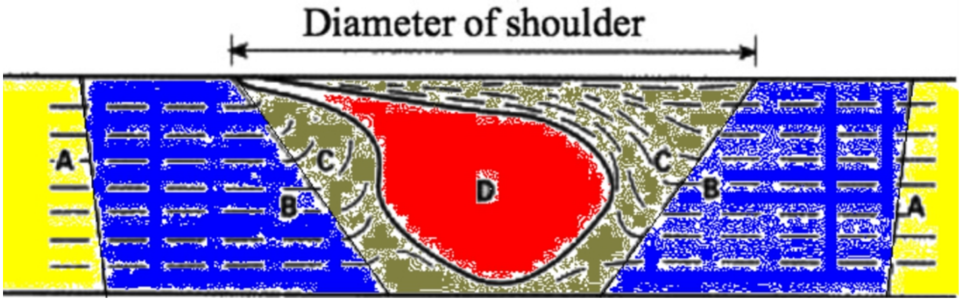

Fig. 2 : Schematic cross-section of the FSW weldment shows four different zones.

A. **Unaffected base material:** This region as shown in **Fig. 2** is far away from the center of the weldment. It has no effects from heat generation. In this region, no changes in microstructure and mechanical properties.

B. **Heat affected zone (HAZ):** This region experiences microstructure and mechanical properties due to changes in a thermal cycle but have no plastic deformation.

C. **Thermo mechanical affected zone (TMAZ):** In this region, the grain size of the weldment is small compared to the parent base metal. This region experiences modification of microstructure and/or mechanical properties due to plastic deformation.

D. **Nugget or weld nugget or stirred zone:** This region is part of TMAZ and experiences the recrystallization process. In the region, ten times smaller grains are formed compared to the parent material. This results in a positive effect on metallurgical and mechanical properties [14]. The shape of the nugget varies depending on the base material used for welding and used process parameters. The nugget diameter is slightly more than that of the FSW tool diameter but considerably smaller than the tool shoulder diameter [15].

2.0 Experimental Procedure

The base material used in this study is Aluminium AA6010-T6 alloy. The chemical composition of this material is mentioned in **Table 1** and mechanical properties are mentioned in **Table 2**. A high-speed steel (HSS) tool with a shoulder of 20 mm diameter and conical shaped pin of length 4.5 mm, 4 mm diameter on the shank side, and 2 mm on the welding side is used for processing. FSW process is carried out in a CNC milling machine with a constant welding speed of 0.2 m/min. A total of six rotational speeds of the tool are considered for this process.

Table 1 : Chemical composition of AA6010-T6.

Eminent	Mg	Si	Fe	Cu	Cr	Mn	Ti	Al
% Composition	0.9	0.64	0.38	0.256	0.211	0.033	0.018	Balance

Table 2 : Mechanical properties of AA6010-T6

Property	Vickers Number (VHN)	Yield Strength (MPa)	Tensile Strength (MPa)	Percentage Elongation
AA6010-T6	107	291	317	17

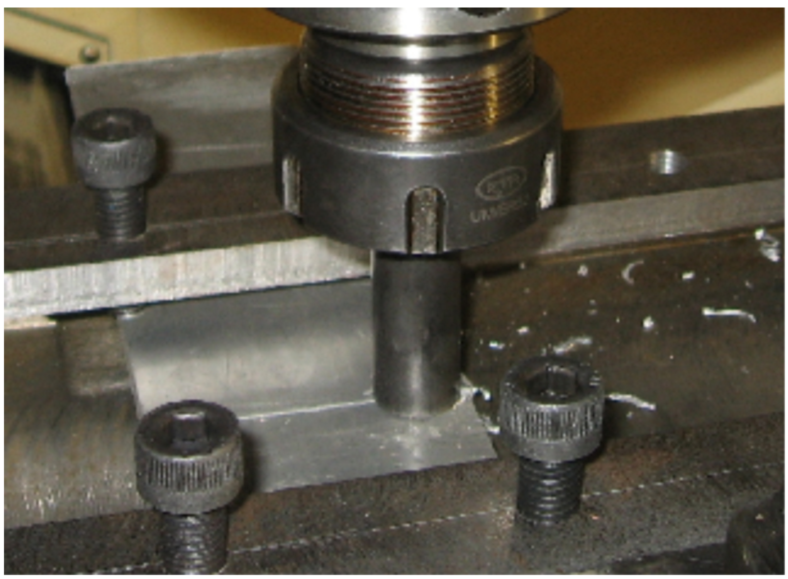

Fig.3 : FSW Process during welding

They are 1100, 1400, 1600, 2000, and 2500 rpm. The plates to be welded are clamped firmly on a steel backing plate in the butt joint position. The FSW tool is firmly fixed to the spindle of the CNC milling machine with a 0° tool tilt angle. The procedure of the FSW process is as follows. Initially, the rotating tool is to be contacted the base material and stopped for one minute to rub the surface of the material. Then tool moves at a specified speed and feeds along the joint line and completes the welding process. This process during the welding is shown in **Fig. 3**.

3.0 Results and Discussion

3.1 Tensile Properties

From **Fig. 4** and **Fig. 5**, it is apparent that yield and tensile strength values increase initially and come down at a particular rotational speed of the tool. These values again increase after crossing that particular speed. In the FSW process, the strength of any weldment is primarily determined by microhardness and defect formation in that area. Lower microhardness and formation of small defects lead to lower strength values [16,17]. The rotational and traverse speed of the tool is determined by the strength of the weldment. If the speed is too low, incomplete fusion occurs then a zig-zag pattern [18] and pinholes [19] are formed. This leads to lower strength of the weld. If the speed is too high, weldment melting occurs then large size wormholes [19] are formed. This also again leads to lower strength of the weld. So, an appropriate welding speed is required for the formation of a better weld.

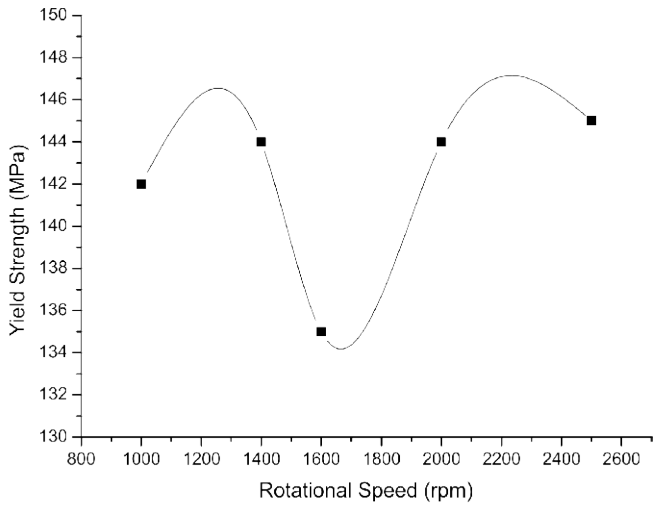

Fig. 4 : The effect of speed in yield strength

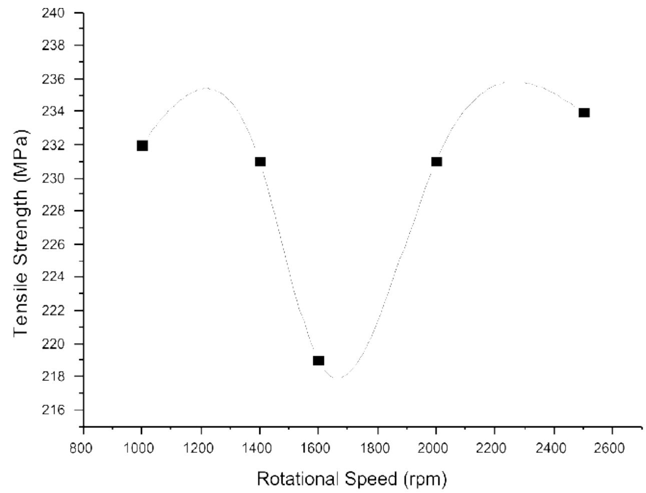

Fig. 5 : The effect of speed on tensile strength

3.2 Hardness

Microhardness profiles indicate the changes in characteristics that occur in different zones of the microstructure. It reflects the strengthening precipitate variations in different zones within the material. It also indicates changes in grain size as alloy composition is fixed [20]. The important variations of microhardness values are shown in **Fig. 6** and **Fig. 7**. It is apparent from the figure that the microhardness values are lower between TMAZ and HAZ at both advancing and retreating sides of the weldment compared to the center of the weld. Lower microhardness values are seen in this region because of rupture and necking formations due to increasing stress concentration. These values reach the higher side when measuring away from the HAZ location. These variations were also represented by other investigators [21, 22].

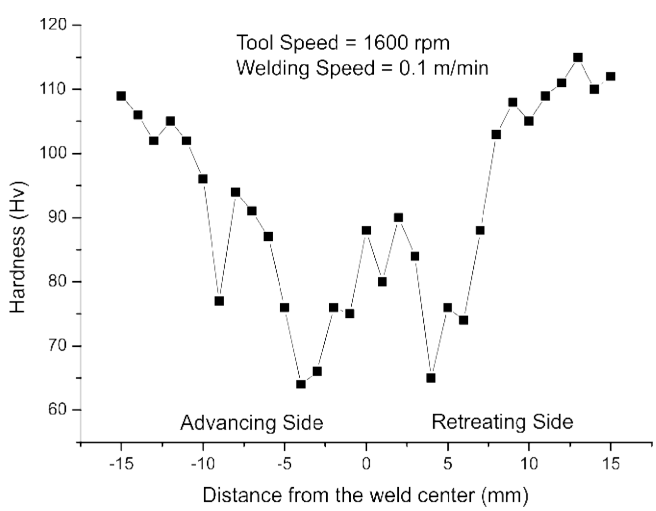

Fig. 6 : Microhardness profile across weld center at a speed of 1600 rpm

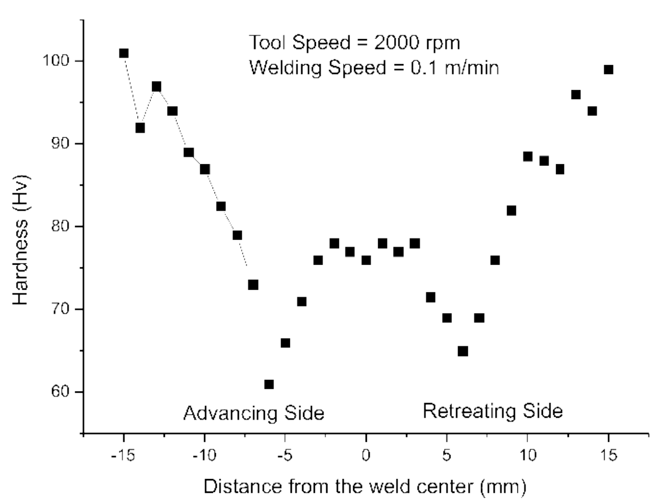

Fig 7 : Microhardness profile across weld center at a speed of 2000 rpm.

4.0 Conclusions

The conclusions arrived from this research work are as follows.

1. The tensile properties increase with a decrease in speed. After attaining a lower value at a particular speed, the strength of the weldment increases correspondingly with an increase in speed. Insufficient heat affects the formation of defects and leads to lower strength of the weldment at that value.
2. Least microhardness values were noticed between TMAZ and HAZ due to changes in grain size. Higher microhardness is observed when it is measured away from HAZ.

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