INFLUENCE OF TOOL DESIGN ON THE MECHANICAL PROPERTIES AND MICROSTRUCTURE IN FRICTION STIR WELDING OF AA6351 ALUMINIUM ALLOY

M.Karthikeyan.,
Assistant professor,
Department of Mechanical Engineering.
Karpagam University.
Coimbatore-641021

Dr.A.K.Shaik Dawood
Professor,
Department of Mechanical Engineering,
Karpagam University.
Coimbatore-641021

Abstract **- Aluminum alloy has gained wide acceptance in the fabrication of light weight structure requiring a high strength to weight ratio and good corrosion resistance compared to the fusion welding process, that are commonly used for joining structural aluminum alloys, Friction stir welding (FSW) process is an emerging solid state joining process in which the material, that is being welded do not weld and recast. This process uses a non consumable tool to generate frictional heat in the abutting surfaces. The welding parameter such as tool rotational speed, welding speed, axial force and tool profile plays a major role in deciding the joint strength.**

In this investigation an attempt was made to study the effect of tool pin profiles on weld. The weld structure is evaluated using tensile properties and Vickers micro hardness test of AA6351 aluminum alloy. We proposed three different tool pin profiles (square, circle, threaded) to weld the material. The structure of the weldment is evaluated with possible various tests.

Keywords:**, Friction stir welding (FSW), AA6351 Aluminum Alloy, Welding parameter, Vickers Hardness Test, Tensile Strength.**

1. Introduction

Friction Stir Welding (FSW) is a solid state welding process in which the relative motion between the tool and the work piece produces heat which makes the material of two edges being joined by plastic atomic diffusion. This method relies on the direct conversion of mechanical energy to thermal energy to form the weld without the application of heat from conventional source. The big difference between FSW and fusion welding (other than the lack of melting) is the ability to manipulate peak temperatures by choice of different welding parameters.

Welding parameters, tool geometry, and joint design make use of considerable effect on the material flow pattern and temperature distribution, thereby influencing the micro structural evolution of material. [1] Also Tensile strength is higher with lower weld speed. This indicates that lower range of weld speed is suitable for achieving maximum tensile strength. [1] Friction stir welding of Al 6061- O condition, increases the strength of the weld joint as compared to that of the parent material in O-condition. Mechanical properties substantially improve during Post Weld Heat Treatment. [2]

FSW offers a quality advantage that leads the welds strength and ductility either identical or better than that of the base metal alloy [3]. Tensile strength of FSW welds is directly proportional to the travel / welding speed [4]. The tensile strength of the FS welded is affected by the tool pin profile. The grain structure within the FSP is fine and equiaxed compared to TMAZ [5].

Tool design and material plays a vital role in addition to the important parameters like tool rotational speed, welding speed and axial force. Optimization of FSW parameters in different conditions of base material and the microstructures of the as-welded condition are compared with the post weld heat treated microstructures welded in annealed and T6 condition. [9]

This paper summarizes the results of an experimental campaign in which the aluminum alloy AA6351 was Friction stir Welded, using various combinations of process parameters (rotational and tool pin profile). Mechanical properties of the test welds were assessed by means of static tensile test, Vickers hardness measurement. Microstructure of the welds was examined by means of optical observations.

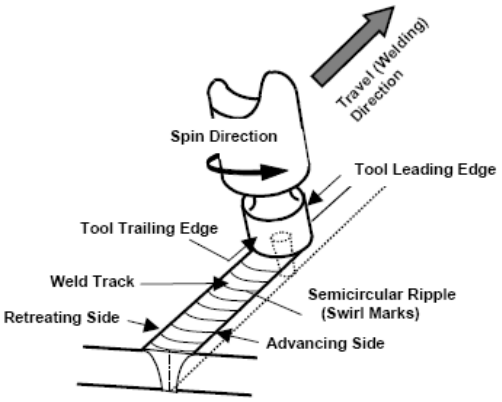


Fig 1. Terminologies of Friction stir welding

2. SCOPE AND OBJECTIVES

Aluminum occupies an important position in the family of metals with a very wide range of industrial and consumer applications. Its combination of lightweight, high strength and

corrosion resistance are utilized extensively by modern designers to conserve energy and materials. In any structural application of this alloy, consideration of its weldability is of utmost important, as welding is largely used for joining of structural components. Friction stir welding (FSW) process is a new technique and finds wide application.

From the literature review, it is understood that lot of research work has been carried out to understand the effect of tool profiles on mechanical properties in friction stir welding process. The following are the objectives of this study.

1. Studying the effect of Tool profiles on tensile strength of Aluminum alloys AA6351
2. Establishing relationship between base metal properties and FSW process parameters

3. SELECTION OF MATERIAL

Aluminum Alloy AA6351: Aluminum alloy AA6351 is a medium Strength alloy with excellent corrosion Resistance. It has the highest strength of the 64430 series alloys. Alloy AA6351 is known as a structural alloy.

Table 1 Chemical Composition of Aluminium alloy AA6351

Si	Fe	Cu	Mn	Mg	Ti
0.8	0.12	0.051	0.52	0.75	0.017
Pb	**Ca**	**Zr**	**Sn**	**Sb**	**Al**
0.012	0.011	0.003	0.004	0.015	97.51

In plate form, AA6351 is the alloy most commonly used for machining. . The addition of a large amount of manganese controls the Grain structure which in turn results in a stronger alloy.

Table 2 Mechanical properties of Aluminium alloy AA6351

Base Material	AA 6351
Density (X1000kg/m3)	2.6-2.8
Elastic Modulus (GPa)	70-80
Tensile Strength (MPa)	250
Yield Strength (MPa)	150
Hardness (HB500)	95

4. TOOL DESIGN

Tool design influences heat generation, plastic flow, the power required, and the uniformity of the welded joint. The shoulder generates most of the heat and prevents the plasticized material from escaping from the work–piece, while both the shoulder and the tool–pin affect the material flow. In recent years several new features have been introduced in the design of tools.

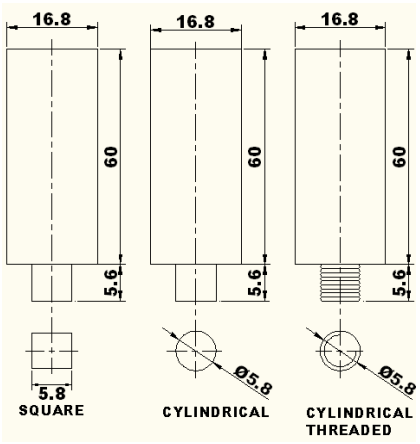


Fig 2. Schematic diagram of Different tool pin profile

5. TOOL MANUFACTURING

Three various FSW tools are designed by varying the tool pin profile. The configurations of the designed FSW tools are:

1. Tool pin profiles of Circle, Threaded, & Square.
2. Tools having D/d ratios of 3.

Out of various tool materials like Tool steel, High Speed Steel (HSS), High Carbon High Chromium steel, carbide and carbon boron nitride, among which HSS steel is chosen as tool material because of its high strength, high hot hardness, easy to process, easily available and low cost. The FSW tools are manufactured using CNC Turning center and wire cut EDM (WEDM) machine. The tools are oil hardened to obtain a hardness of 60–62 HRC.

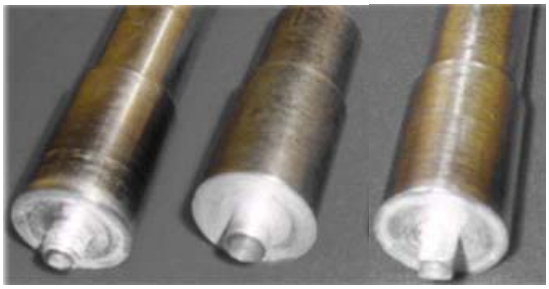


Fig 3. Different tool pin profile

6. WELDING PROCEDURE

The rolled plates of 6 mm thickness, AA 6351 Aluminum alloy, were cut into required size (100 mm x 50mm) by power hacksaw cutting and milling. Square butt joint configuration (100 mm x 100 mm) was prepared to fabricate FSW joints.

The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction single pass welding procedure was followed to fabricate the joints. Non-consumable tool, made of high carbon high chromium steel were used to fabricate the joints. Three different tool pin profiles were prepared from high carbon high chromium steel material and they were used to fabricate the joints but 18 mm shoulder was maintained for all the pin profiles. The most predominant factors which are having greater influence on tensile strength of

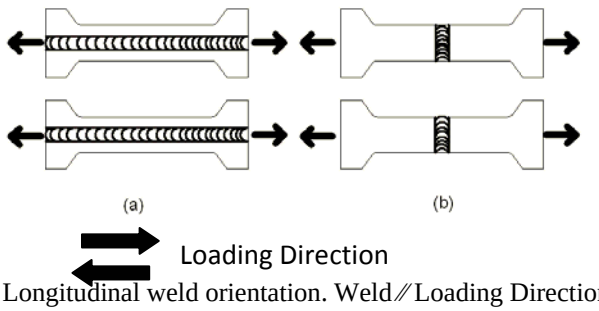
friction stir welded Aluminum alloys are the tool pin profile, tool rotational speed, welding (traverse) speed and axial (downward) force. Trial experiments were conducted to determine the working range of the above factors.

Table 3. Input parameters for welding

Process parameters	VALUES	
	Set 1	Set 2
Rotational speed (rpm)	900	1350
Welding speed (mm/min)	7.5	7.5
Axial force (kN)	10	10
D/d ratio of tool	3	3
Pin length, L (mm)	5.6	5.6
Tool shoulder diameter, D (mm)	16.8	16.8
Pin diameter , d (mm)	5.8	5.8

Tensile Testing

The welded joints were sliced using a power hacksaw and then machined to the required dimensions as shown in fig. Two tensile specimens were fabricated as per the American society for testing of material (ASTM E8M-04) standards to evaluate the tensile strength of the joints.



(a) Longitudinal weld orientation. Weld∥Loading Direction.

(b) Transverse weld orientation. Weld ⊥ Loading Direction

Fig 4. Schematic tensile specimens for testing

6. RESULTS AND DISCUSSIONS

Welding was carried out for different rotational speeds of 900 rpm and 1350 rpm but with weld speed of 75 mm/min. And three different tools of cylindrical, square and cylindrical threaded tools. Thus, Aluminum AA6351 alloy joints were welded successfully by friction welding process using two different rotational speeds. Some interesting developments of mechanical properties have been found to occur in the weldments. The tensile testing of the weld is influenced by the rotational speed and feed of the tool. The effects of tool rotation speeds and feed towards the tensile testing of the joints were investigated. The results of the tests are shown in graphs below for the specimen prepared using friction welded joints obtained at the two rotational speeds mentioned below.

Tensile strength Test

In both the above cases, Increase in rotational speed has resulted in increase of tensile strength. Primary reason is that higher the speed, higher will be the deformation and heat generation in the weld. This will result in finer grain structures, because of which tensile strength is increases. The results of tensile test which were observed during the experiment were tabulated which are shown in below

Vickers Hardness Test

The results obtained are plotted against the rotational speed of the spindle (FSW Tool) of 900rpm, 1350rpm and weld speed of 75 mm/min. It is observed that the Hardness is minimum at the weld centre shown in graph below.

Table 9.2 Properties of Weldments

Tool profile	Feed (mm/ min)	Rotational Speed(rpm)	Elongation %	Tensile strength (mpa)	Vickers hardness
cylindrical	75	1350 CYL	2.5	98	**48**
cylindrical	75	900 CYL	2.5	113	**62**
Threaded	75	1350 THD	2.5	109	**82**
Threaded	75	900 THD	2.5	82	**47**
Square	75	1350 SQ	1.25	44	**71**
Square	75	900 SQ	1.25	112	**110**

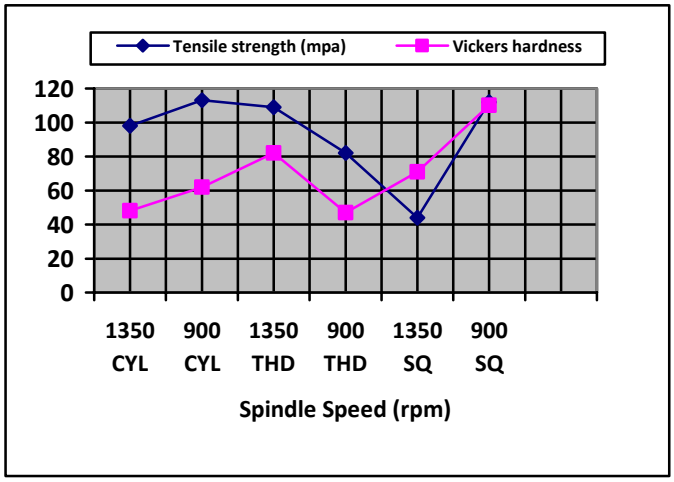
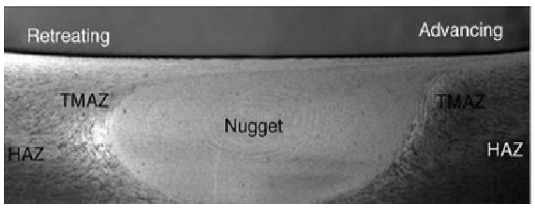


Fig 5. Spindle speed Vs Tensile strength & Vickers hardness

Microstructure Analysis

The solid-state nature of the FSW process, combined with its unusual tool and asymmetric nature, results in a highly characteristic microstructure. The microstructure can be broken up into the following zones.



TMAZ – Thermo Mechanically Affected Zone
HAZ – Heat Affected Zone

Fig 6. *A typical macrograph picture showing various micro structural zones.*

The following are the various microstructures taken for different pin profiles

Fig. 7. Microstructure of base alloy AA6351

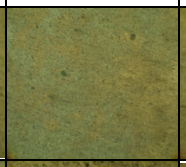
Welding Speed	Cylindrical Pin	Square Pin	Cylindrical Threaded Pin
900 rpm			
1350 rpm			

Fig. 8. Micrographs of the microstructure of the FSW joints at the centre of welded zone produced at several tool rotational speeds and tool pin profile.

By comparing all microstructures with the parent metal, the formation of very fine grain microstructure, uniformly distributed fine precipitates and higher stir zone hardness are obtained in square tool at 900rpm.

7. CONCLUSION

In this investigation an attempt was made to study the effect of tool pin profile on the weldments by using tensile properties and micro structure of aluminum alloys. From this investigation, the following important conclusions are derived:

1. The similar AA6351 aluminum alloy can be welded by FSW without any defect.
2. The tensile strength of the FS welded is affected by the tool pin profile.
3. Among the three different tool pin profile straight square tool at (900rpm) give more tensile strength & Vickers hardness when compared to other tools.
4. The formation of very fine grain microstructure, uniformly distributed fine precipitates and higher stir zone hardness are obtained in square tool at (900rpm)
5. For AA6351aluminium alloy High speed welding will affect the welding strength

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M.Karthikeyan is a post graduate in manufacturing engineering from Government College of Technology, affiliated to Anna University, Coimbatore. presently working as an assistant professor in mechanical engineering, Karpagam university. Coimbatore. He has 3 years of experience in teaching. His research interest includes friction stir welding, and metallurgy.

Dr.A.K.Shaik Dawood is doctorate in Mechanical Engineering from PSG College of Technology, Coimbatore which is affiliated to Anna University Chennai. Presently working as Professor in Mechanical Engg, Karpagam University, Coimbatore.

He has got 13 years of teaching experience. He has published 3 papers in international journals and 1 paper in national journal and also has published 14 papers in international & national conference. His research interests include Robotics, CFD, Industrial Engg, Metallurgy and Production. He is a Registered PhD supervisor of Anna University, Coimbatore and Karpagam University. He is currently guiding 6 PhD research scholars.