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Research Article

Effect of Tool Materials on Mechanical Properties and Microstructure of Friction Stir Welded AA6061 Joints

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Abstract

In Friction Stir Welding frictional heat is generated by means of a non consumable rotating tool that forms plastic deformation at welding location. It leads to high joint strength, free from melt related defects, low distortion. Aluminum alloys are important for the fabrication of components and structures which require high strength, low weight. Here aluminum alloy 6061 is selected for the present study. Butt joints were made with friction stir welding; the tool materials used were SS 304, SS 316 and MS. Tensile strength of the produced joints were tested and microstructures of weld zone of Friction stir welds were analyzed using scanning electron microscope. The results obtained revealed that the tool material SS316 gives high hardness, impact value and tensile strength when compared to SS304 and MS.

Keywords: *Friction Stir Welding, microstructure, tensile strength, scanning electron microscope, impact test*

1. Introduction

In many industrial applications steels are readily replaced by nonferrous alloys, in most cases by aluminum alloys. With the need for fuel economy and weight saving, aluminum alloys are increasingly used in cars, and its two most important properties are density and thermal conductivity. Over the past 15 years the aluminum content of cars has increased from around 5% to 13% by both volume and weight. In engines they are used for pistons, cylinder heads and sumps**.** Even though the production of aluminum alloy is not complex, its joining may create problems. Absence of structural transformation in solid state and the thermal and electrical conductivities creates problems in fusion and resistance welding of aluminum alloys**.** It led to the development of Friction Stir Welding (FSW), solid state joining technique in which the joined material is plasticized by heat generated by friction between the surface of the plates and the contact surface of a special tool, composed of two main parts: shoulder and pin. Heat generation and formation of plasticized material in the weld region is associated with shoulder, while the materials to be welded are mixed by pin, thereby creating a joint. The main advantages of FSW when compared to conventional welding techniques, is its ability to join materials that are difficult to fusion weld, low distortion, high energy efficiency, better mechanical properties etc.

Nowadays, in most of the applications steels are replaced by aluminum alloys. The production of Aluminum alloy is not so complex but there exists problem with joining. Excellent thermal and electrical conductivity and absence of structural transformation in solid state cause problems in fusion and resistive welding of aluminum alloys (A.K. Jha et al, 2001; Rajiv.S.Mishra et al, 2007). It leads to the development of Friction Stir Welding (FSW), solid state joining process, in the year 1991 at The Welding Institute (TWI) in UK by Wayne Thomas (Powell et al, 1996). FSW can improve the local mechanical properties of Al alloys compared to the base material (Santella et al 2005). The effect of welding speed, rotational speed and tool index on mechanical structures of 6061Al-T651 alloy (S.R Ren et al, 2007) was studied. The influence of friction stir welding parameters on grain size in stir zone and the mechanical property of FS welded 5083 Aluminum alloy were investigated (Tomotake et al, 2007) and found that hardness of the stir zone is increased, and also formability improved by decreasing the friction heat flow. A study on Evaluation of Strength Degradation and Microstructure in Friction Stir Welded Aluminium 6063-T6 was conducted (Parminder Singh et al, 2012).

The present study focuses on the effect of tool material on mechanical properties and microstructures of friction stir welded AA6061 aluminum alloy. Friction stir welded joints of aluminum alloy A6061 were made using with different tools made of different materials, viz. SS 304, SS 316 and MS. The specimens of the weld joint were tested for tensile strength. Also hardness of weld nugget and HAZ were determined. Microstructures of the weld were analyzed with scanning electron microscope (SEM).

2. Experimental Procedure

In the present study, aluminum alloys 6061were friction stir welded (6mm thick plates) with three different tool materials SS304, SS316 and MS. The welding was carried out on Universal Milling Machine with tool rotation speed

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1645rpm, travel speed 100mm/min. The diameter of pin and shoulder of the tool is 5.5mm and 18mm respectively. The Fig.1, Fig.2 and Fig.3 shows fabricated tools, FSW setup and welded joints.

Fig.1 Fabricated tools of SS304, MS and SS316

Fig.2 FSW setup showing workpiece and tool

Fig.3 Welded joints

The physical properties of welded joints were analyzed using hardness, impact and tension test. Also Scanning electron micrographs were taken for analyzing the welded joints.

2.1 Hardness test

Hardness measurements of the welded joints were taken in a transverse direction to the weld.

Fig.4. Brinell Hardness Testing machine

Load applied was 250kgs and indenter was a steel ball of 2.5mm diameter. In all hardness testes, a define force is mechanically applied on the test piece for about 15 seconds. In determining the hardness of the metal by this test, a steel ball diameter 'D' is forced by a force 'F' to cause an indentation 'd', on the surface and is being measured using a Brinell microscope after the removal of the load. The instrument used for hardness testing is shown in Fig.4.

2.2 Tensile test

Tensile test was conducted on Universal Testing Machine until the rupture of specimen. The specimen was prepared according to the ASTM E8M-04 standards, i.e, each specimen having 150mm length 25mm breadth and 6mm thickness. The instrument used for tensile testing is shown in Fig.5.

Fig.5. Universal Testing machine

2.3 Impact test

Impact energy is the energy required to fracture a standard specimen when the load is applied suddenly. The Charpy impact tests were conducted for the weld joints. The capacity of impact testing machine was 300Joules. The instrument used for impact testing is shown in Fig.6.

Fig6. Impact Testing machine

3. Results

The results obtained from various tests are tabulated in the following section.

3.1 Hardness test

A reduction in hardness of 10% in weld nugget has been observed for SS 316 tool. The reduction in hardness for SS 304 and MS found to be 22% and 15% respectively in the nugget. Maximum HAZ value is found to be 15% less than parent metal for SS304 tool and 10% and 20% for SS 316 and MS respectively. Fig 7 shows the hardness profile for various tools

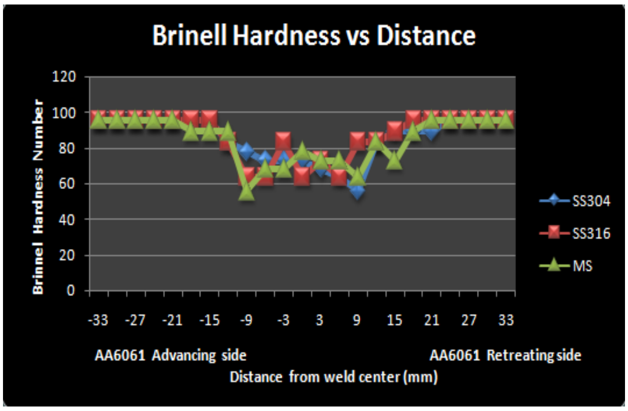


Fig.7. Hardness Profile

3.2 Tensile test

Tensile strength of the weld joint made by SS 316 tool was found to be greater. The greater tensile strength may be due to the formation of very fine grains in the weld nugget. The results obtained SS 304, SS 316 and MS are tabulated in Table 1. The specimen for tensile test is shown in fig.8.

Fig.8. Tensile test specimen

3.3 Impact test

Charpy impact test were used to measure the impact strength of AA601 (Metals Handbook, 1998). The results obtained are shown in Table 2. Fig.9 shows the specimen drawing for impact test. Impact values of the welded were found to be twice that of fusion welds (20 versus 10 Joule). Also the impact value of the joint was found to be 65 % higher than the parent metal. The higher impact strength was attributed to the fine, recrystallized microstructure in the friction stir weld compared to the cast microstructure created by the fusion welds. SS 316 has a better impact value compared to SS 304.

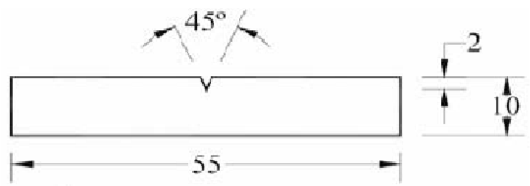


Fig.9. Specimen drawing for Impact test

Table 1 Tensile strength

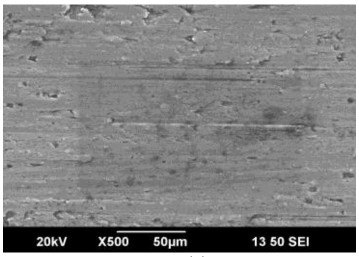
Tool Material	Tensile Strength of joints (MPa)
SS 304	100
SS 316	123
MS	110

Table 2 Impact test

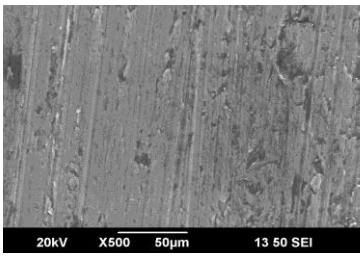
Tool Material	Energy absorbed (J)
Parent metal (AA6061)	13
SS 304	16
SS 316	20
MS	22

3.4 Scanning Electron Microscopy

To investigate the microstructure of metallic materials Scanning Electron Microscopy (SEM) is used (H.E. Exner et al, 2004) in which the resolution range is more than one order of magnitude to approximately to 10nm. Fig 10 shows a SEM image of the upper surface of the joint



(a)



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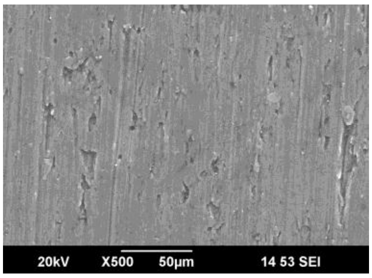

(c)

Fig.9. SEM images of a) SS 304 b) SS 316 and c) MS

Conclusions

Mechanical properties of FSW welded aluminum alloy 6061 change with various tool materials. Better properties were found while using SS316. The reduction in hardness of weld nugget was minimum in the case of SS316. Tensile strength of the joint made by SS316 found to be greater than the others. Impact values of the welded were found to be twice that of fusion welds. The impact strength of joint was found to be higher by 65% than the parent metal. It was found that SS 316 has a better impact value compared to SS 304.

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