Effect of TiB_2 on Mechanical Properties of Friction Stir Processed AA5083 Alloy

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I. ABSTRACT

In recent years, Aerospace and automotive industries have attention to new welding technique based on a solid state joining process, called friction stir welding (FSW). Friction stir welding shows several advantages, in particular possibility to weld dissimilar metal alloys. In present work, the effect of processing parameters on the mechanical properties (Tensile and Hardness) and micro structural features of FSW welds (AA5083) were studied and compare with those of base materials. Aluminium Alloy AA5083 were taken in H111 condition. Transverse weld tensile properties were evaluated according to ASTM E8. It was observed that FSW specimens led to very significant grain refinement and improved the tensile properties are revealed. Weld microstructures were characterized using optical and scanning electron microscopes (SEM) with energy dispersive x-ray analysis (EDAX). Fractographic studies were carried out using SEM. The analytical temperature analysis of the plates during welding were studied.

In present work, The Tensile specimens as per ASTM: E-8 standard, were cut perpendicular to the welding direction, and then were tested for tensile strength of the welded region using Universal Testing Machine. Similarly Vicker's hardness Machine used for testing hardness of Friction stir processed AA5083/TiB2. The mechanical properties and microstructure characterization were observed and are compared with the base metal's mechanical properties and microstructure. Also this paper discuss the technique used for optimization of process parameters of friction stir processing of AA5083 material.

***Keywords*—** AA5083, TiB_2, FSW, FSP, Mechanical properties

II. . INTRODUCTION

As compared to the conventional welding methods, FSW consumes considerably less energy. . The joining does not involve any use of filler metal and therefore any aluminium alloy can be joined without concern for the compatibility of composition, which is an issue in fusion welding. When desirable, dissimilar aluminium alloys and composites can be joined with equal case. The friction stir welding (FSW) technology is going to become a very important new tool in the aircraft and automotive industry solving more of the problems related to the need of high-performance joints.

Aluminium alloy is difficult to weld by traditional methods, due to high thermal conductivity, resulting in defects like porosity, cracks etc.. Hence FSW is being increasingly used. The process is especially well suited to butt and lap joints in aluminium since aluminium is difficult to weld by arc processes, but is very simple to weld by FSW.

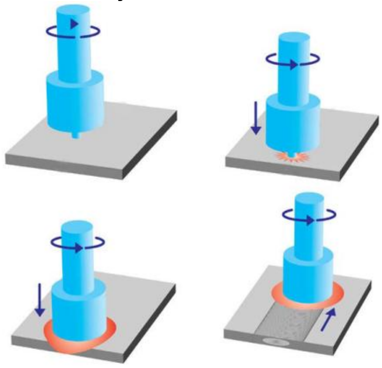

Fig-1 Friction stir processing

Many techniques had been reported for fabrication of AA5083 alloy, but FSP has been identified as one of the most promising techniques.

Prashant Prakash et.al [2], has revised that Friction stir welding (FSW) is a relatively new solid-state joining process. This joining technique is energy efficient, environment friendly, and versatile. The principal advantages are low distortion, absence of melt related defects and high joint strength. In FSW parameters play an important role like tool design and material, tool rotational speed, welding speed and axial force. The paper focuses on process parameters that in required for producing effective friction stir welding joint.

In present work, AA5083 alloy as being one of the stiffest and strongest aluminium alloy, has been used as base material. Whereas Titanium boride (TiB_2), as being one of the hardest materials found on the earth has been used as reinforcement phase. AA 5083/ TiB_2 composite has been formed by drilling holes on the base material. Investigation of microstructure, Micro hardness and Mechanical properties had been done for the AA5083/TiB_2.

Before the experimentation is taken-up, the design of experiments, which is an important aspect to decide the number of experiments. Some times the number of experiments will be conducted without any need or without any scientific way of doing things. Therefore, many of the experts have proposed various techniques to decide the number of experiments to be carried out based on the input variable and process parameters. Such variable parameters influencing the experiments are considered based on the levels and suggested the optimum number of experiments need for experimentation.

Before selecting a particular L9 Orthogonal Array (OA) to be used as a matrix for conducting the experiments, the following two points must be considered: 1) The number of parameters and interactions of interest; 2) The number of levels for the parameters of interest.

TABLE-1
Selected L9 orthogonal array

Expt. No.	PARAMETERS		
	Parameter1	Parameter2	Parameter3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

The above three parameters considered are Rotational speed, welding speed, Axial force with three different levels.

III. MATERIALS AND METHODOLOGY

AA 5083 alloy is considered as base material and it is known for exceptional performance in extreme environments. 5083 is highly resistant to attack by both seawater and industrial chemical environments. Alloy 5083 also retains exceptional strength after welding. It has the highest strength of the non-heat treatable alloys but is not recommended for use in temperatures in excess of 65°C.

Table-3 chemical composition of AA5083

Ele	**Cu**	**Mg**	**Si**	**Fe**	**Mn**
%	0.04	4.29	0.17	0.36	0.61
Ele	**Zn**	**Ti**	**Cr**	**Ni**	Al
%	0.06	0.03	0.10	0.006	94.2

The second requirement is a tool specially designed for the process. The Fig-2 depicts a simple tool used for FSW. The tool is designed to heat the material and deform it to produce a void free joint.

Fig-2 H13 Tool Steel

FSW uses a non-consumable rotating tool, that moves along the line of joint of the two plates to produce good quality butt or lap joint welds. The FSW tool is generally made up of a profiled pin, which is contained in the centre of a larger size shaft namely tool shoulder. For butt joints the length of the pin is a little less than the plate thickness. The pin is traversed through the joint line while the shoulder is in contact with the top surface of the work piece.

TABLE-2
Process Parameters with their values at corresponding levels

S.No	Range	Level 1	Level 2	Level 3
1	800-1600rpm	800	1200	1600
2	24-36 mm/min	24	30	36
3	600-1200N	600	800	1200

In present work Titanium Boride (TiB_2) Powder is selected as assumption inorder to fill in the holes which are drilled on the AA5083 plates. The micro structure of TiB_2 is shown in the Fig-3.

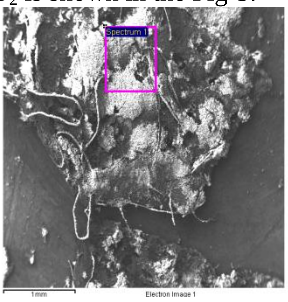

Fig-3 Micro structural analysis of TiB_2 powder

Holes are drilled on the AA5083 plate at the centre with 2mm drill bit with the help of a hand drilling machine. The holes are drilled on an average of 4.6mm depth so that the TiB_2 powder can be filled in it according to the percentage of the weight calculated. 11 holes are drilled in jig-jag manner as shown in the Fig-4.1 and Fig-4.2 6% of TiB_2 powder is filled equally in every hole. By using a weighing machine the powder is equally distributed in all the holes.

Fig-4.1 Drilling holes on AA5083 plate

Fig-4.2 Hand drilling machine

The FSW involves complex material flow and plastic deformation. Tool geometry, welding parameters, preheating of the plates, joint design and material variables can be considered as the process parameters. They exert significant effect on the material flow pattern and temperature distribution and thus influencing the grain structure and micro structural evolution of the welds.

The evaluation of mechanical properties of the FSW specimens is very important for which the following tests should be conducted.

1. Mechanical hardness
2. Tensile strength

Heat-treatable (precipitation-hardenable) alloys and non heat-treatable (solid-solution-hardened) alloys are the two classifications of aluminum alloys. The change in hardness in the friction stir welds is different for heat-treatable and non heat-treatable aluminum alloys. FSW creates a softened region around the weld center in a number of heat-treatable aluminum alloys that causes by coarsening and dissolution of strengthening precipitates during the thermal cycle. The hardness profile was strongly affected by precipitate distribution rather than weld grain size.

The tensile specimens are retrieved from the nugget zone in the direction normal (transverse) to the weld which contained microstructures of all the four zones, i.e., parent material, HAZ, TMAZ and SZ. The as-welded samples show a reduction in yield and ultimate tensile strengths and elongation in the weld nugget. In order to recover the lost tensile strength of the SZ, post weld aging treatment can be done on the FSW sample. The increase in the yield strength of post weld samples was attributed to the increase in the volume fraction of fine hardening precipitates, whereas the reduction in the ductility was accounted for by both the increase in the hardening precipitates and the development of precipitate-free zones (PFZs) at grain boundaries.

Failure occurs as shear fracture in the HAZ in both as-welded and aged condition. The ductility is an average strain over the gage length including various zones. The HAZ has the lowest strength due to significantly coarsened precipitates and the development of the PFZs. Thus, during tension, strain occurs mainly in the HAZ. The low-strength HAZ locally elongated to high levels of strain (12–14%), eventually resulting in necking and fracture, whereas the nugget zone experiences only 2–5% strain (Mishra R.S et al.,).Therefore, fracture always occurred in the HAZ, resulting in a low strength and ductility along transverse orientation of the weld. The joining efficiency for FSW is significantly higher than that for conventional fusion welding, particularly for heat-treatable aluminum alloys.

It is usually accepted that all welded structures go into service with flaws ranging from volume defects like porosity, non-metallic inclusions to different planar defects like cracks induced by hydrogen or hot tearing. There are standards for acceptability of the welds pertaining to different inspection codes. The non-acceptable flaws must be repaired before the weld is put into service. FSW is generally found to produce defect-free welds. However, no established code exists so far for FSW. Considering potential applications of FSW, there is a critical need for proper evaluation of the fracture behaviour of the friction stir welds. The most commonly used parameters are the crack tip intensity factors for linear elastic loading and the integral or the crack opening displacement for elastic–plastic loading.

IV.EXPERIMETATION

The experimental work that has been done includes, investigation of the effects of process parameter (rotational speed, weld speed and axial force) on the resulting hardness, tensile and micro structure quality of the FS processed pass of AA5083 sheet. In this chapter, the material that has been processed as well as experimental setup and procedures have been discussed. SEM analysis is discussed. The effects of rotational speed, weld speed and axial force within the processed area on hardness are presented in this chapter.

Friction Stir Process machine is shown in the Fig-5.

Fig-5 The friction stir welding machine

The specimens are prepared and fixed in a specially designed and fabricated fixture and clamped firmly so that the plates stay in place and do not fly away due to the welding forces as shown in Fig-. The cross section of the tool used for welding is a cylindrical. AA5083 plates are kept on the advancing side and retreating side of the tool respectively. The rotational motion of the spindle is started and the tool comes in contact with the surface of the plates and the probe is penetrated to a predetermined depth of 4.6 mm at the middle of the aluminium alloy where the holes are filled with TiB_2 micro powder.

Fig-6.1 Fixture used to hold the base materials

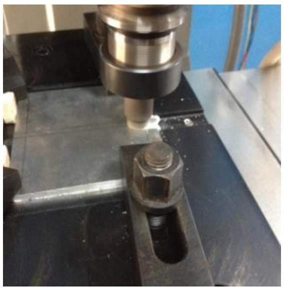

Fig-6.2 Clamping and Fixture setup performing FSW

EXPERIMENTAL PROCEDURE:

With reference to the L9 Orthogonal array parameters the best parameters are obtained where maximum tensile strength and hardness are occurred are taken into consideration so that those parameters are used for the Aluminium Alloy matrix composites of AA5083/Tib_2.

STEPS INVOLVED IN EXPERIMENTATION:

1. With the best parameters obtained Friction Stir Processing is done to the AA5083 with the addition TiB_2.
2. With constant parameters (rotational speed, axial force and weld speed) the passes are done on the AA5083/TiB_2.
3. A single pass is done on the first plate and accordingly two passes on the second plate and three passes on the last plate.
4. In the process the temperature has increased when number of passes increased.
5. After the process the plates are carried out for tensile cutting according to ASTM E-8 standards.
6. Hardness testing is done on the plates by using Vickers digital micro hardness tester.
7. The tensile specimens are carried out for testing, with the help of Universal Testing Machine (UTM).
8. Micro structural analysis is done by using Scanning Electron Microscopy (SEM).

Hardness is defined as the ability of a material to resist the indentation or surface abrasion. In order to characterize uncoated and duplex coated surface, hardness tests are performed by using Vickers digital micro hardness tester as shown in Fig-7

Fig-7 Vickers digital micro hardness tester

In present work dwell time of 15 seconds is given and load of 500N is applied. After the dwell time is complete, the material to be tested is placed on the surface provided and the microscope is adjusted so that the grain particles can be observed on the surface, then the probe is set and dwell time of 15 seconds is set and the start button is pressed after the dwell period a squared shaped intend is observed on the surface of the AA5083/TiB_2 plate. The size of the indent is determined optically by measuring the two diagonals (d1 and d2) of the square indent. The Vickers hardness number is a function of the test force divided by the surface area of the indent. The average of the two diagonals is used in calculating the Vickers hardness.

ASTM E8 describes tensile testing of metals such as steel or metal alloys. This test determines important mechanical properties such as yield strength, ultimate tensile strength, elongation, and reduction of area. E8 tensile tests determine the ductility and strength of various metals when the materials undergo uniaxial tensile stresses. Such information is important for alloy development, design, quality control, and comparison of different sets of metals. The geometry of tensile specimen is shown in the Figure below

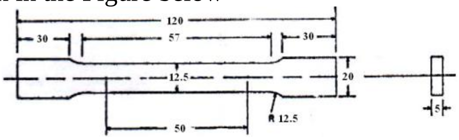

Fig-8 Geometry of the tensile specimen

After the tensile cutting the specimens are carried out for tensile test on Universal Testing Machine (UTM). The specimens are shown in the Fig-8.1 and Fig-8.2 of all the three passes.

Fig-9.1 Tensile specimen made as per ATSM-E8

Fig-9.2 Tensile specimens of all different passes

Three specimens are tested for each condition prepared from the same joint and average of the three values is reported. The specimen finally fails after necking and the load versus displacement is recorded. Tensile elongations are also measured after carefully placing the fractured pieces together. The Ultimate Tensile Strength (UTS), Yield Strength (YS) and percentage of Elongation (%E) are evaluated. The fracture surfaces of the Friction Stir Welds are studied using Scanning Electron Microscope (SEM).

Computer Controlled 10 tonne Universal Testing Machine (UTM) (model: UTO9103 AC- Mumbai, India) used for tensile testing is having a capacity of 10 metric tons. The machine is hydraulic powered, water cooled, very versatile and several different tests can be carried out by changing the die set on the hydraulic actuator. The machine with hydraulic wedge grippers has a data acquisition system attached to it which helps to record and save the data obtained during the testing process as shown in Fig-9. The data from the acquisition system can be retrieved and processed to obtain final results. The grippers have control for adjusting the gripping force on the specimen and the grippers are equipped with rough surface to hold the specimens without slipping.

Fig-10 Universal Testing Machine

Fig-10 shows the typical failure tensile test sample. The samples are broken at a particular point and at that point the maximum tensile strength are generated in the computer.

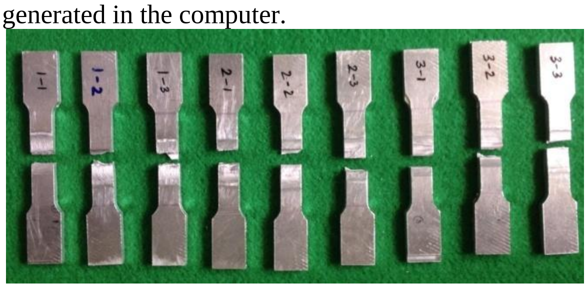

Fig-11 Failure of tensile specimens of AA5083 with the addition of TiB_2

SEM micrographs were taken with secondary electron image mode at 20kV. Fractography of friction stir processed AA5083 aluminium alloy can be studied by using Scanning Electron Microscope. The scanning Electron Microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity.

Fig-12 Scanning Electron Microscopy

In the present work the factographic and micro structural images of failed tensile specimens are obtained by using SEM. The micro structural analysis is conducted on the fractured surface where the specimen is broken apart. SEM images are produced on all the fractured surfaces of the specimens. The resultant images of SEM are discussed in results and discussions.

V.RESULTS AND DISCUSSION

a. Base Metal properties:

The base metal (AA5083) carried out for testing of hardness, tensile strength and the % of elongation. The hardness test is conducted on Vicker's micro Hardness tester. The mechanical properties obtained for the AA5083 base metal are shown in the table-4

Table-4 Mechanical Properties of base metal

Material	Hardness	Tensile strength	% of elongation
AA5083	140	306	39.98

FSP was Planned according to the Taguchi design L9 Orthogonal array and Hardness, Tensile strength and % of Elongation were evaluated and are shown in the table-5.

Table-5 L9 Orthogonal array of different parameters

S.no	Weld speed	Rotatio-nal speed	Axial force	Tensile strength	% of el	Hard ness
1	24	800	600	193	6.0	114
2	24	1200	800	215	7.8	114
3	24	1600	1000	143	8.4	107
4	30	800	600	205	8.0	106
5	30	1200	800	168	4.4	113
6	30	1600	1000	122	4.0	108
7	36	800	600	193	7.3	103
8	36	1200	800	186	7.2	106
9	36	1600	1000	120	1.3	110

Among all the parameters maximum tensile strength and hardness are occurred at 24 mm/min weld speed, 1200 rpm rotational speed, 800 N axial force. These parameters are considered for further experimentation purpose.

b. Microstructures:

Optical micrographs of base metal of AA5083 is shown in Fig.6.2.1. Investigation of metallographic specimens of the Al-Mg alloy the occurrence of precipitation of various morphologies and phase contrast. A microanalysis of the chemical composition has shown that light-etching precipitations indicate the presence of Al, Mg, Mn, Si and Fe.

Fig-13 Micro structure for AA5083 alloy

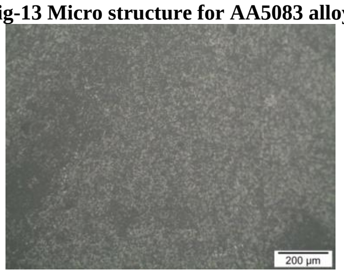

Fig-14 Microstructures of friction stir welded AA5083 stir zone

c.Influence of Mechanical Properties on Friction Stir Processed AA5083/TiB_2:

In the present section, focus is on the study of mechanical responses namely microstructures and various mechanical properties (Vicker's micro hardness(Hv), Tensile strength (TS), percentage of elongation and tensile fracture of the FSProcessed aluminium alloys at Pass-I, Pass-II and Pass-III are presented. FSProcessed Welds have been prepared with all the possible conditions and the results are presented as the outcome of this project.

Table-6 Comparison of Mechanical properties of Base metal and FSProcessed AA5083/TiB_2

Friction stir processing	Hardness	Tensile strength	% of elongation
Base metal	140	306	39.98
Pass-1	123	255	10.00
Pass-2	131	270	8.36
Pass-3	137	295	7.00

d. Scanning Electron Microscopy Analysis:

A special feature remains on the fractural cross-section of the materials, which is useful to investigate the cause and mechanism of the fracture. To obtain a better understanding of the failure micro-mechanism of the base metal and FSProcessed weld zones at three passes, a fractographic examination using SEM was performed on the fracture surface of the tensile test specimens.

Fractographs of the fractured tensile specimen of the base metal and FSProcessed weld at different passes are shown in the Fig-14(a-d)respectively. SEM fracture surface micrographs show the deep grooves on the specimen edges where the elongated grains pulled out when de-cohesion occurred in the grain boundaries.

Fig-15(a) The factographic image of AA5083 alloy

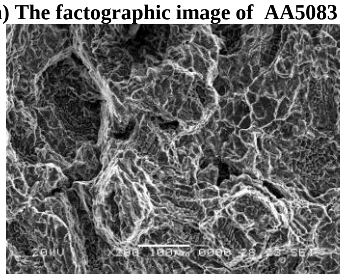

Fig-15 (b) The factographic image of AA5083/TiB_2 at Pass-I

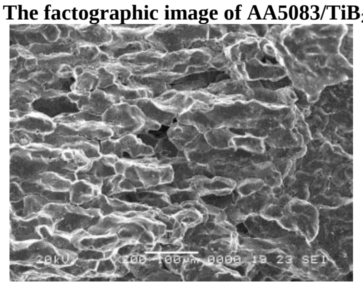

Fig-14 (c) The factographic image of AA5083/TiB_2 at Pass-II

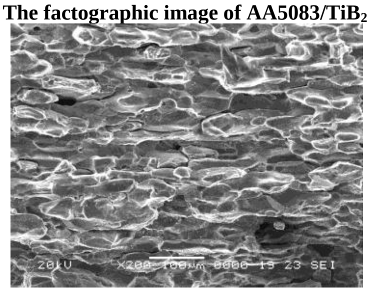

Fig-14 (d) The factographic image of AA5083/TiB_2 at Pass-III

VI.CONCLUSIONS

From this experimental investigation, the following important conclusions are derived.

i. Friction Stir Processing has successfully done to AA5083 alloy with addition of TiB_2 micro powder.

ii. The effect of process parameters on the FSProcessed AA5083 with the addition of TiB_2 at different passes results in increase of mechanical properties which provides greater strength to the alloy when compared with the base metal.
iii. Of the three passes conducted on the AA5083/TiB_2 plates the Hardness, Tensile strength and % of Elongation are increasing gradually from Pass-I to Pass-III.
iv. The rotational speed of 1200rpm used to fabricate the AA5083/TiB_2 plates, resulted in superior mechanical properties, irrespective of the weld speed and axial force.
v. Similarly the weld speed of 24mm/min used to fabricate the AA5083/TiB_2 plates, resulted in superior mechanical properties, irrespective of the rotational speed and axial force.
vi. The axial force of 800KN used to fabricate the AA5083/TiB_2 plates, resulted in superior mechanical properties, irrespective of the rotational speed and weld speed.
vii. The dominant parameter for better tensile strength is tool rotational speed followed by the weld speed. Axial force comparatively shows minimum effect on tensile strength.
viii. Finally the increase in the number of FSP passes on the AA5083/TiB_2 plates there will be an increase in the mechanical properties.
ix. Compared with the base metal the Mechanical properties of FSProcessed AA5083/TiB_2 at Pass-III is relatively greater.

VII.BIOGRAPHIES

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