Microstructure and Hardness Studies on AMC's Welded by FSW

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Abstract- *Metal matrix composites (MMC) have been the subject of scientific investigation and applied research for about two decades but only in the past few years these advanced materials became realistic candidates for critical structural applications in industrial sectors. Particulate reinforced aluminum matrix composites have recently become a major focus of attention in the automotive industry, defense, aerospace and many other engineering fields. Al alloy Al6061 is widely used in numerous engineering applications including transport and construction where superior mechanical properties are essentially required. Ceramic materials generally used to reinforce aluminum alloys include the carbides (e.g. Sic, Tic), borides (TiB2, ZrB2), nitrides (AlN, Si3N4) and oxides (Al2O3, SiO2). Among these reinforcing particulates, titanium diboride (TiB2) is particularly attractive because it exhibits high elastic modulus and hardness, high melting point, and good thermal stability. However, friction stir welding (FSW), the above considerations formed the background of the present investigation in which Al6061 based TiB2 MMC was fabricated and then friction stir welded. Stir casting based in-situ reaction method was employed for manufacturing the Al MMCs. The composites with varying percentages (viz., 6%, 8% and 10%) of the particulate TiB2 were, then, subjected to mechanical and metallurgical characterization. FSW process parameters were carried out in order to maximize UTS and % ductility of the welded joints. Metallurgical characterization including elaborate microhardness surveys were carried out on the AlTiB2 weldments fabricated at different heat input conditions. The microhardness profiles of the FS welded specimens, however, indicated that there was not any appreciable difference between the hardness values at the root, middle and top levels of the weld cross section. Extensive micro structural analysis of the FS welded specimens revealed the nature of various phases present in the three distinct regions of the weld viz., weld nugget, thermo mechanically affected zone and the heat affected zone. The micrographs clearly showed that FS welding carried out at high tool rotational speeds combined with greater axial loads produced a weld nugget with finely broken and evenly distributed reinforcing particulates contributing to the mechanical strength. This investigation concludes that an Al6061based MMC with a particulate presence of up to 10% could be manufactured through the in-situ reactive processing route employing manual stir casting method and that 'sound' joints of AlTiB2 MMCs could be produced through the friction stir welding technique by appropriately controlling the process parameters.*

Keywords- FSW, MMCs, Al alloy, XRD, etc.

I. INTRODUCTION

Friction stir welding (FSW) is a solid state joining process using frictional and adiabatic heat generated by a rotating and traversing cylindrical tool with a profiled pin along a square butt weld joint. The tool rotation promotes mechanical (solid-state) mixing of the material on the advancing and retreating sides of the weld. The welding of the material is facilitated by severe plastic deformation in the solid state, involving dynamic recrystalization of the base material (Somasekaran and Murr 2004). The FSW process can produce a high quality joint compared to the conventional processes, and also make joining of dissimilar metals possible. FSW being a solid-state welding process in which the metal to be welded is not melted during welding, defects like crack and porosity often associated with fusion welding process are eliminated. In this chapter, a brief history of friction stir welding is discussed. The significance of aluminum metal matrix composites (MMCs) in the present day industrial applications is highlighted. The need and objective of undertaking the present research work are described. The plan adopted and the sequences followed in the research work are provided in the form of flowcharts. The chapter-wise organization of the dissertation is also presented.

II. NEED FOR RESEARCH

The FSW process is at present entering into the initial stages of commercialization and the research has mainly been concentrated on the area of process development including tool design and process control. Despite extensive research on their microstructure and material characterization, at present the metal matrix composites have not reached widespread industria applications. One of the major reasons behind this is the problem associated with their secondary processing such as cutting, machining, forming, and joining. As regards the joining process, though it appears that all the conventional welding techniques used for joining aluminum alloys can also be employed for Al-MMCs, a number of difficulties have been identified, mainly in the case of fusion welding techniques. Some of these problems can be linked to (i) high viscosity of the MMCs melt above the melting point while compared with the unreinforced alloy, (ii) segregation of the reinforcement during resolidification, (iii) reinforcement-matrix interactions etc., (Nakata et al 2003). However, a great potential exists for the use of metal matrix composites in aerospace, automotive and marine system joining applications.

Research has showed that some joining processes such as fusion welding (Urena et al 2000, Huang et al 2001 and Wang et al 2000), brazing (Zhang et al 1999) and diffusion bonding (Zhang et al 1999, Urena et al 2000 and Askew et al 1998) resulted to different degrees in the degradation of mechanical properties. Friction stir welding is being considered as the prospective joining process to solve this problem. As a solid-state joining process, FSW can eliminate the welding defects associated with fusion welding processes. The effectiveness of joint developed by friction stir welding, to a large extent, depends on the various process parameters such as tool rotational speed, welding speed, axial load, etc. While developing the welding procedure for any specific application, these parameters have to be characterized and fully specified. This is possible by empirical, analytical or numerical methods. Present day computing facilities enable the easy modeling of any process or physical phenomenon. Therefore, it is decided to develop mathematical models for the prediction of mechanical properties in the friction stir welding process for the joining of Al-MMC namely Al-TiB2. It is to be noted here that so far there has not been any publication either in the FSW process as applied to Al-TiB2 MMC or its modeling. Hence, this maiden attempt, it is believed, will pave way for broader research in the said area which has potentially significant applications in the industry.

III. LITERATURE SURVEY

Aluminum based composites reinforced with hard ceramic particles have created considerable interest because they can offer relative ease of processing and nearly isotropic properties in comparison to fiber reinforced composites. In addition, these composites exhibit high strength and stiffness, creep resistance and superior wear resistance apart from providing good electrical and thermal conductivity.

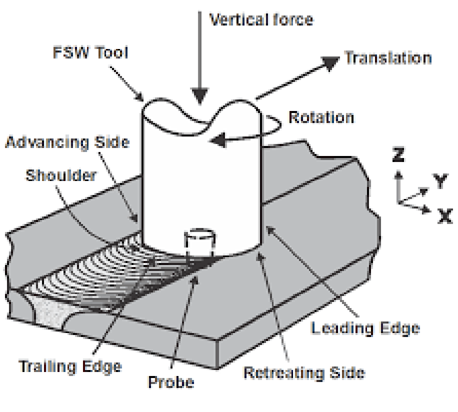
The friction stir welding process, a novel solid state joining technique is being successfully employed in the joining of Aluminum alloys and Aluminum based metal matrix composites. Research efforts in developing commercially viable FSW techniques are gathering momentum. Investigations in FSW include (1) understanding of the FSW process and its parameters (2) prediction of required results and inference (3) theoretical and numerical studies that are based on mathematical equations governing the fundamental physical phenomenon such as adiabatic heat generation due to stir, material flow due to plastic deformation, heat transfer etc., and (4) experimental studies for validation of results of theoretical and numerical studies.

This chapter presents details of literature survey carried out on the fabrication of Al – MMCs which include the methods of manufacture of the MMC employed by different researchers, the parameters selected and their influence on the formation of different phases of the composite. Mention is made of the various works carried out in the FSW process development with a focus on its application for Al – MMCs. Studies on the selection of FSW parameters and their influence on the mechanical and metallurgical properties of the welds are presented. Past research on the effect of FSW tool in the production of quality welds is also summarized. Literature on the technique of Design of Experiments (DOE) and its application to the friction stir welding process is also included.

IV. FUNDAMENTALS OF FRICTION STIR WELDING

In FSW, two discrete metal work pieces are butted together, along with the tool (with a probe), as shown schematically in Schematic Diagram of the FSW Process (Somasekaran and Murr 2004)

During the friction stir welding process, the cylindrical-shouldered tool, with a specially profiled probe (nib or pin) is rotated at a constant speed and fed at a constant traverse rate into the joint line between two pieces to be welded as seen in Figure.



The parts have to be clamped rigidly onto a backing bar in a manner that prevents the abutting joint faces from being forced apart. The length of the probe is slightly less than the weld depth required and the tool shoulder should be in intimate contact with the work surface. The nib is then moved against the work, or vice versa. Frictional heat is generated between the wear-resistant welding tool shoulder and nib, and the material of the work pieces. This heat, along with the heat generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without reaching the melting point, allowing the traversing of the tool along the weld line. As the FSW tool is moved in the direction of welding, the leading face of the tool forces plasticized material to the back of the tool while applying a substantial forging force to consolidate the weld metal. The joining of the material is facilitated by severe plastic deformation in the solid state, involving dynamic recrystallization of the base material. The solid-state nature of the FSW process usually results in the different zones in the weld/adjoining areas as shown in Figure.

V. METALLURGICAL STUDIES

Microhardness Test

Three numbers of samples in each case (in respect of the base alloy and the composites) were prepared for the test. Standard metallurgical procedures were used to prepare the samples for microhardness studies.

Berahascolour etchant (200 g CrO_3, 20 g Na_2SO_4, and 7 ml HCl in 1000 ml H20) was used for the Al MMC specimens. The specimens were immersed in the etchant for 15 s, rinsed and dried in hot air later. Pre-etching was carried out in an etchant containing 10 % aqueous solution of NaOH and 50 % HNO_3. For the base alloy, 5 ml HF (48 %) in 95 ml distilled water was used as the etchant. Microhardness test was carried out on a Mitutoyo Microhardness Tester using 100 gm load.

Microstructure Analysis

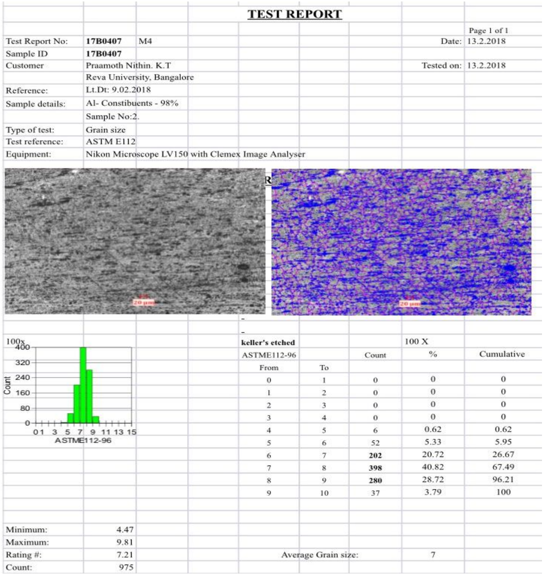
Experimental Procedure the specimens cut from the $AlTiB_2$ metal matrix composite plates manufactured through the in-situ process were carefully prepared as per standard metallurgical procedure for the micro structural observation. They were polished with different grades of emery sheets, from course to fine. Final polishing was done with diamond paste of 2 ȝ size.

a. Microstructural Examination

Olympus Optical Microscope was used to examine the Aluminum 6061 alloy and Al MMCs at different magnifications. Photomicrographs were taken on the top surface of the specimens. A few of the micrographs are included in this thesis.

b. Grain Structure Analysis

It is covered by the specification of ASTM E112 covers the measurement grain size in all single phase metals. Most metals are crystalline in nature and contain internal boundaries, commonly known as “grain boundaries”. Such grain boundaries are detected using electron microscopy. The test results are shown below



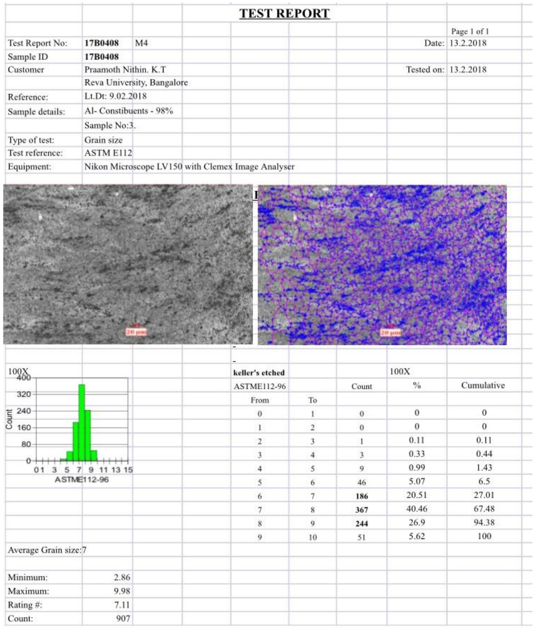
TEST REPORT

Page 1 of 1

Test Report No: **17B0407** M4 Date: 13.2.2018
Sample ID **17B0407**
Customer Praamoth Nithin. K.T Tested on: 13.2.2018
Reva University, Bangalore
Reference: Lt.Dt: 9.02.2018
Sample details: Al- Constibuents - 98%
Sample No:2.
Type of test: Grain size
Test reference: ASTM E112
Equipment: Nikon Microscope LV150 with Clemex Image Analyser

keller's etched			100 X	
ASTME112-96		Count	%	Cumulative
From	To			
0	1	0	0	0
1	2	0	0	0
2	3	0	0	0
3	4	0	0	0
4	5	6	0.62	0.62
5	6	52	5.33	5.95
6	7	**202**	20.72	26.67
7	8	**398**	40.82	67.49
8	9	**280**	28.72	96.21
9	10	37	3.79	100

Minimum: 4.47
Maximum: 9.81
Rating #: 7.21 Average Grain size: 7
Count: 975



TEST REPORT

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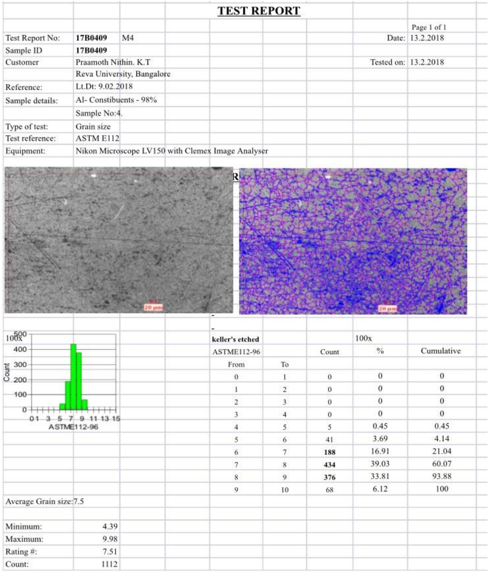
Test Report No: **17B0408** M4 Date: 13.2.2018
Sample ID **17B0408**
Customer Praamoth Nithin. K.T Tested on: 13.2.2018
Reva University, Bangalore
Reference: Lt.Dt: 9.02.2018
Sample details: Al- Constibuents - 98%
Sample No:3.
Type of test: Grain size
Test reference: ASTM E112
Equipment: Nikon Microscope LV150 with Clemex Image Analyser

keller's etched			100X	
ASTME112-96		Count	%	Cumulative
From	To			
0	1	0	0	0
1	2	0	0	0
2	3	1	0.11	0.11
3	4	3	0.33	0.44
4	5	9	0.99	1.43
5	6	46	5.07	6.5
6	7	**186**	20.51	27.01
7	8	**367**	40.46	67.48
8	9	**244**	26.9	94.38
9	10	51	5.62	100

Average Grain size:7

Minimum: 2.86
Maximum: 9.98
Rating #: 7.11
Count: 907



TEST REPORT

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Test Report No: **17B0409** M4 Date: 13.2.2018
Sample ID **17B0409**
Customer Praamoth Nithin. K.T Tested on: 13.2.2018
Reva University, Bangalore
Reference: Lt.Dt: 9.02.2018
Sample details: Al- Constibuents - 98%
Sample No:4.
Type of test: Grain size
Test reference: ASTM E112
Equipment: Nikon Microscope LV150 with Clemex Image Analyser

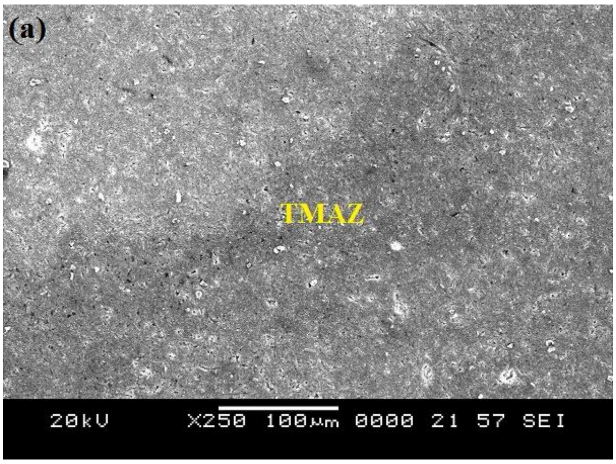
keller's etched			100x	
ASTME112-96		Count	%	Cumulative
From	To			
0	1	0	0	0
1	2	0	0	0
2	3	0	0	0
3	4	0	0	0
4	5	5	0.45	0.45
5	6	41	3.69	4.14
6	7	**188**	16.91	21.04
7	8	**434**	39.03	60.07
8	9	**376**	33.81	93.88
9	10	68	6.12	100

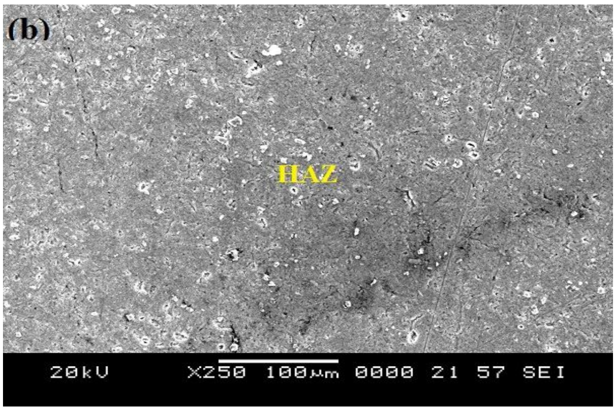
Average Grain size:7.5

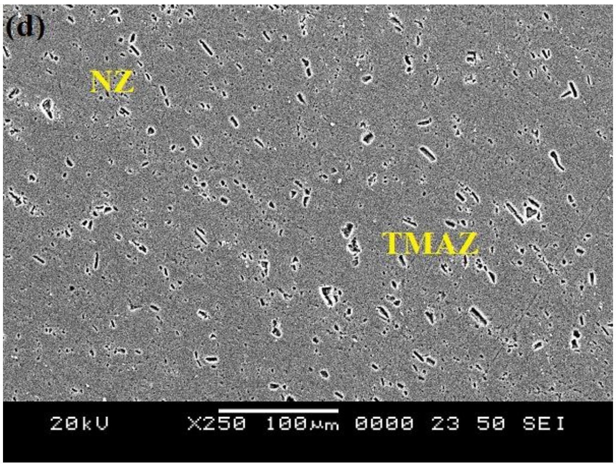
Minimum: 4.39
Maximum: 9.98
Rating #: 7.51
Count: 1112

c. Scanning Electron Micrograph

The microstructures of the fabricated Al-TiB2 composite as well as the fracture surfaces of the tensile test specimens were observed by scanning electron microscope (Joel JSM 6360) using Cu-KĮ radiation. A few of the scanning electron micrographs are included in this thesis.







VI. CONCLUSION

An approach of the microstructure, mechanical properties of FSW AA6061-AA6061 aluminum alloys had been made. The order of average grain size in different weld zones was as follows: BM> HAZ> TMAZ> NZ. The minimum hardness of 80.2 HV was obtained in the HAZ region, and the max value of 106.32 HV was present in the BM. The tensile and yield strengths of the weld zones were less than that of the BM tensile specimens. In to the properties of the BM, the ductility increased in the longitudinal tensile test specimens (that consist of the NZ).Fracture occurred in the HAZ region, which had the lowest hardness of all of the weld zones. The EDAX analysis depicted in Table 1 revealed that high contents of oxygen and aluminum are present.

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