Determination of Microstructure and Mechanical Properties of Aluminium Boron Carbide using Friction Stir Machining Process

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Abstract:- Aluminium Metal Matrix Composites of the 6000 series are known to have good formidability, weldability and high strength-to-weight ratio. They have constituted the highest volume of Al extruded product and been widely used for automobile and aerospace industries, architectural applications, bicycle frames, transportation equipment, bridge railings, welded structures. The major alloying elements in the heat-treatable 6000 series are silicon and magnesium. Both elements are required for precipitation strengthening. Strengthening can be enhanced further by refining the grain size to a few micrometers and lower. This can be achieved by friction stir processing (FSP).An improvement in the mechanical properties was accomplished due to the microstructural modification of aluminium alloy by friction stir processing which is a solid state microstructural modification technique using a frictional heat and stirring action.FSP is used for improvement of microstructural and mechanical properties of alloys. Samples with 100% overlap were created using FSP in order to locally modified the microstructural and mechanical properties of aluminium alloy. The microstructural properties in terms of particles distribution and also the mechanical properties in terms of hardness and tensile strength of the processed zone were addressed with respect to the number of passes and transverse speeds.In the present study, 2.5% (by weight) B4C particles were incorporated by using stir casting into the aluminum to form particulate composite material. Samples were subjected to machining by Friction stir machining process on CNC machine with constant rotational and transverse speed by using HSS tools having 16mm and 18mm as diameter and number passes are varied. Microstructural observations were carried out by employing optical microscopy modified surfaces. Mechanical properties were evaluated by hardness test on Brinell hardness tester (Rockwell) , Surface roughness test on surface roughness tester and chemical composition.

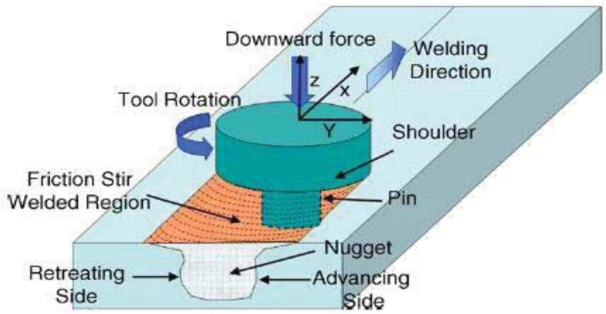
Keywords – Metal Matrix Composite, Friction Stir Machining Process, Micro Structure, Mechanical Properties

I. INTRODUCTION

Friction Stir Processing (FSP) is a recent outgrowth of the Friction Stir Welding (FSW) process and relies on solid-state deformation to modify the surface of the working surface/materials. FSP has been shown to locally eliminate casting defects and to refine the microstructure of alloys to improve their mechanical properties and enhance corrosion resistance. Such improvements have important implications for manufactured components for a variety of automotive and other industrial applications.

In Friction Stir Processing a rapidly rotating pin tool is plunged into the surface of the component and traverses across the surface and locally deforms the component. Frictional heating and extensive plastic deformation occur in the material causing considerable changes in the traversed area. Friction stir processed zones can be produced in metallic components to depths of about 50mm below the surface with a gradual transition from a heavily worked material at the surface to the underlying original material.

Figure showing FSP Process



FSP involves complex material movement and plastic deformation. Welding parameters, tool geometry, and joints design exerts significant effect on the material flow pattern and temperature distribution, thereby influencing the micro structural evolution of material. In this section, a few major factors affecting FSP process, such as Geometry, Welding Parameters, and Joint Design are addressed. The strength of Friction stir welding depends on the following three process parameters. They are

- Spindle Speed
- Feed Rate
- Depth of Penetration

Boron carbide is known as roboust material having high hardness, high cross section for absorption of neutrons (i.e., good shielding properties against neutrons), stability to ionizing radiation and most chemicals. Its Vickers hardness (38GPa), Elastic modulus (460GPa) and fracture toughness (3.5MPa-m) approach the corresponding values for diamond (115GPa and 5.3MPa-m1/2).It was first prepared by reduction of boron trioxide either with carbon or magnesium in presence of carbon in an electric arc furnace. In the case of carbon, the reaction occurs at temperatures above the melting point of B_4C and is accompanied by the liberation of large amount of carbon monoxide.

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramics or organic compound. MMC's are made by dispersing a reinforcement material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix.

The hardness test measures the resistance of a material to an indenter or cutting tool. The indenter is usually a ball, pyramid, or cone made of a material much harder than that being tested. A load is applied by slowly pressing the indenter at right angles to the surface being tested for a given period of time. An empirical hardness number may be calculated from knowledge of the load and the cross-sectional area or depth of the impression. Tests are never taken near the edge of a sample nor any closer to an existing impression than three times the diameter of that impression. The thickness of the specimen should be at least ten and one-half times the depth of the impression.

Surface roughness, often shortened to roughness, is a component of Surface texture. It is quantified by the deviations in the direction of the normal vector of a Real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Roughness is typically considered to be the high frequency and short wavelength component of a measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose.

Chemical analysis is performed to accurately determine the concentration, amount or percentage of one or more elements in a test sample. This technique, along with qualitative analysis, provides information on what type and how much of each element is present in a sample for complete elemental analysis.

II. PROPOSED ALGORITHM

CNC PART PROGRAM USED FOR FSP

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N010 G71 G92 X0 Y0 Z5
N015 G90
N020 T05 S1000 M06          (T05-FSP Tool of 16mm diameter)
N025 G00 X0 Y25 Z2 M03
N030 G01 X150 Y25 Z-4.5
N035 F20 M07
N040 G00 Z2 M05 M09
N045 G00 X0 Y0
N050 M30
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A CNC milling machine was used for friction stir processing (FSP) of Aluminium MMC. The machine was a maximum speed of 6000rpm and 10-horse power.The materials used in this work are commercial Al6351 (tempered condition) rolled plates with nominal composition as shown in table. The surface plates were cleaned with grinding paper and methanol before processing.

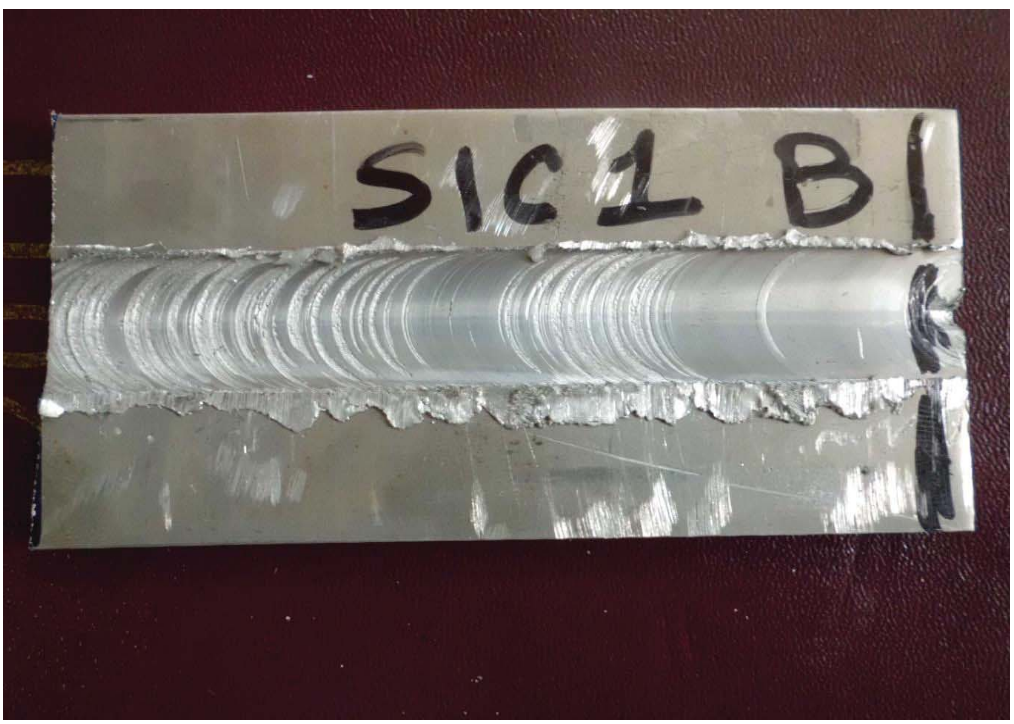
A hardened HSS tool was used that consists of a shoulder with diameter of 16mm, pin with a tapper diameter of (2 x 3) mm and length 2mm respectively. This tool is fitted into the tool holder and work piece is rigidly clamped to machine table using fixtures.

The CNC part program is written for tool movement at first the tool is fixed in arbor and after setting the process parameters the rotating tool pin is made to plunge into the work piece dwell time is maintained for some time to develop heat. Then the tool is traversed along the groove. If the tool moves from one end to other end then it is one pass. The tool get stop at the 5mm before of the end of the specimen. The same process is repeated for the remaining experiments. The FSP was conducted with constant tool rotating rate 1000rpm and travel speed of 20 mm/min. The same process is repeated for 18mm diameter HSS tool.

Table Showing Experimental Details

Experiment No.	Rotational speed(rpm)	Transverse speed(mm/min)	Tool Diameter(mm)	Material	No. of passes
1	1000	20	16		
2			18	Al+2.5%B4C	1 pass
3	1000	20	16		2 pass
4			18	Al+2.5%B4C	
5	1000	20	16		3 pass
6			18	Al+2.5%B4C	

vertical CNC machine



Friction stir processed sample specimen

Processing is done at constant process parameters like spindle speed and tool feeds by using tapper tool clamped to the CNC milling machine. A total of six work pieces is processed, two pieces for with B_4C at 1-pass with two tools having 16 and 18 mm diameter and similarly two pieces of B_4C at 2-pass and two pieces of B_4C at 3-pass.

III. EXPERIMENT AND RESULT

1. HARDNESS RESULTS

The results of the Vickers micro hardness values for all the test samples are shownin table 5.2. The hardness of Al 6351 base alloy with single pass has increased compared to Al 6351 base alloy without FSP. For the multi-pass test specimens the hardness is found to be decreased due to grain softening caused by excessive heat input and non-uniform distribution of boron. For Al
6351- B_4C composite with single pass, the hardness is found to increase compared toAl 6351 base Alloy with single pass, this is due to the inclusion of hard B_4C particles into the Al matrix. However the effect of multi-pass FSP on hardness of both Al 6351 base alloy and Al 6351- B_4C composite is found to be decreasing due to heat input and grain softening during multipass FSP.

TABLE SHOWING RESULTS 0F BRINELL HARDNESS FOR BASE METAL AL6351

BASE MATERIAL AL 6351	NO.OF PASSES	HARDNESS VALUES
AL 6351	1	135.9
	2	120.6
	3	105.5

BRINELL HARDNESS OF FRICTION STIR PROCESSED SAMPLE SPECIMENS

SAMPLE	PASS	HARDNESS(HBW)
Al+2.5% B_4C (18mm Diameter HSS Tool)	1-PASS	149.5
Al+2.5% B_4C (16mm Diameter HSS Tool)	1-PASS	146.2
Al+2.5% B_4C (18mm Diameter HSS Tool)	2-PASS	121.6

Al+2.5% B4C (16mm Diameter HSS Tool)	2-PASS	126.9
Al+2.5% B4C(18mm Diameter HSS Tool	3-PASS	102.8
Al+2.5% B4C (16mm Diameter HSS Tool)	3-PASS	106.5

2.SURFACE ROUGHNESS TEST

1. From table below, it was observed that roughness values of Al+ B4C alloy at 2-pass are found to be less than that of Al+ B4C at 1-pass when machined with 18mm HSS tool and 16mm tools.

Therefore it is resulted as when machined with 18mm and 16mm HSS, surface roughness values decreases as the passes are increasing, which might be due to the sufficient heat generated at tool work piece interface, distribution of B4C particles .

Table Showing Surface Roughness measurements

SAMPLE	PASS	ROUGHNESS(µm)
Al+2.5% B4C (18mm Dia of HSS Tool)	3-PASS	2.50
Al+2.5% B4C (18mm Dia of HSS Tool)	2-PASS	5.50
Al+2.5% B4C (18mm Dia of HSS Tool)	1-PASS	7.30

Al+2.5% B4C (16mm Dia of HSS Tool)	1-PASS	2.50
Al+2.5% B4C (16mm Dia of HS Tool)	2-PASS	4.90
Al+2.5% B4C (16mm Dia of HS Tool)	3-PASS	6.50

3.MICROSTUCTURE RESULTS

Microstructure of the Al 6351 FSPed nugget cross-section was observed by optical microscope. The micro structures of the base metal and specimens are shown in figures.

For all passes Microstucture consists of uniformly distributed fine intermetallic particles in a matrix of aluminium solid solution.grain flow pattern are seen.

In the present study all the experiments are conducted at 1000rpm rotational speed and 20mm/min traverse speed. From fig(5.1) for single pass it is observed that around 43.6% by volume boron flakes are present in α-Al matrix. As the no.of passes increased, with 100% overlap a refinement of boron flakes is observed and volume % of boron increased to 44.81%. In the third pass, the boron flakes are further refined and volume % of boron is found to be

42.8%. It is noticed that the grain size is reduced for 100% overlapping specimens compared to specimens with single pass(without overlapping).

4.CHEMICAL COMPOSITION

Below report shows the chemical composition of alluminium boron carbide which is tested using west analysis tester.

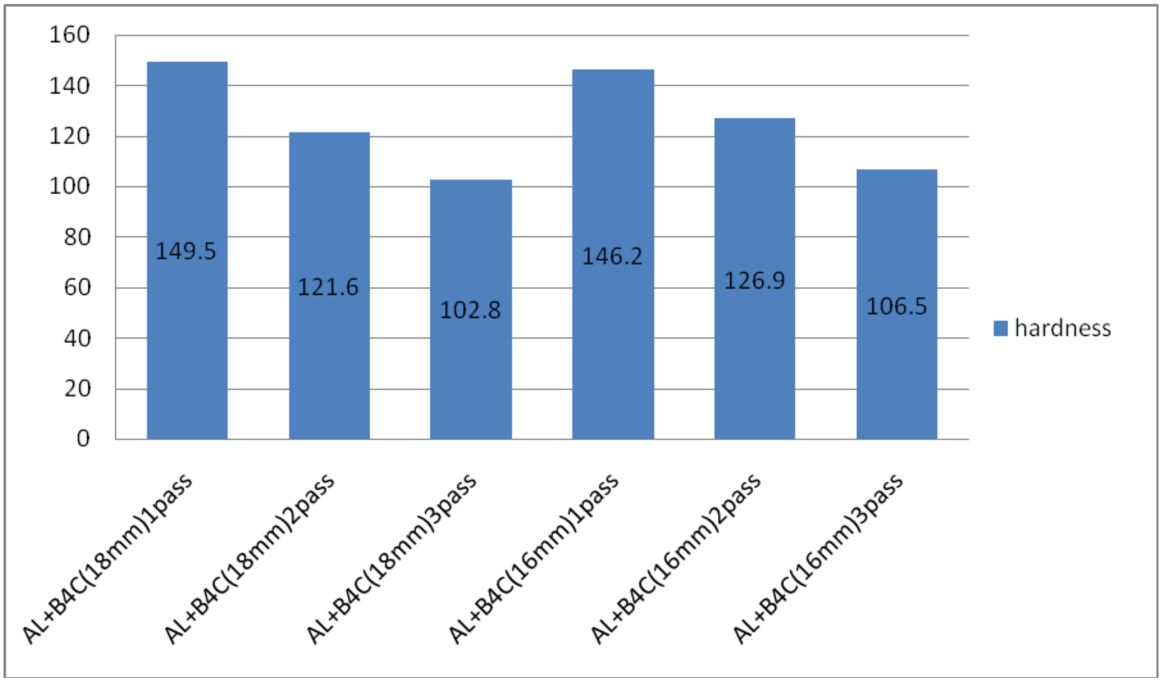
The result declares that all the elements are within the limits.

TABLE CHEMICAL COMPOSITION RESULTS

ELEMENT	AL	Br	Fe	Cu	Mn	Mg	Zn	Cr	Si
AMOUT(%)	REMD	0.4-2	0-0.5	1.2-2	0-0.3	2.1-2.9	5-6	0.2-0.3	0.2

IV. CONCLUSION

1.HARDNESS(HBW)



Therefore from above bar chart we can conclude that the effect of multi-pass FSP on hardness of Al 6351- B_4C composite is found to be decreasing due to heat input and grain softening during multipass FSP.

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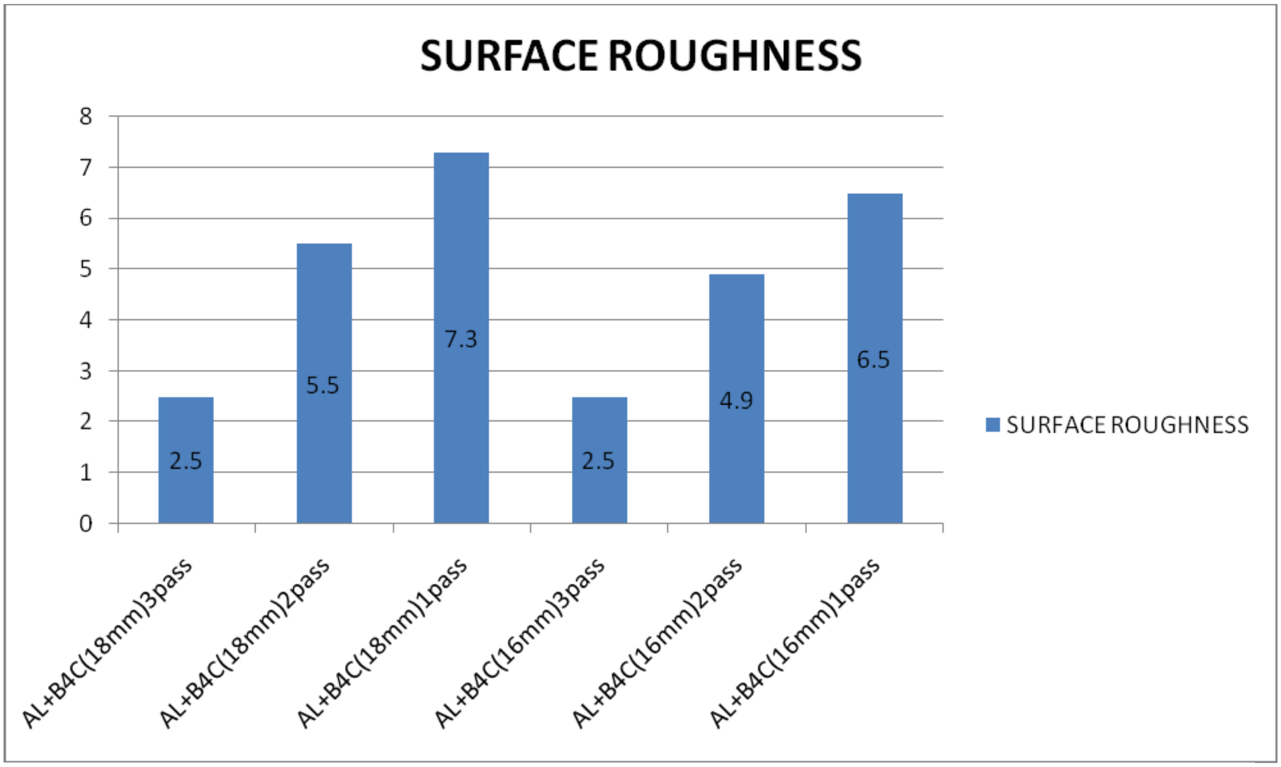

4.MICRO STUCTURE

TYPE	MICRO STUCTURE RESULT
1.AL+B4(16mm)-1pass	Grain flow pattern seen.No cracks and porosity are seen.
2. AL+B4(16mm)-2pass	Grains are slightly elongates.
3.AL+B4(16mm)-3pass	Grain flow pattern and cracks,porosity seen.
4. AL+B4(18mm)-1pass	Grain flow pattern seen.No cracks,porosity seen.
5. AL+B4(18mm)-2pass	Discontinuous grain flow pattern are seen.No cracks,porosity.
6. AL+B4(18mm)-3pass	Discontinuous grain flow pattern and cracks,porosity seen

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