Efficacy of Friction Stir Processing in Fabrication of Boron Carbide Reinforced 7075 Aluminium Alloy

Sudhakar. I[a],
[a] Department of Mechanical Engineering,
MVGRCE, Vizianagaram, India

Madhusudhan Reddy.G[b],
[b] Defence Metallurgical Research Laboratory, Hyderabad, India

Srinivasa Rao.K[c]
[c] Department of Metallurgical Engineering, Andhra University, Visakhapatnam, India

Abstract- **Aluminium alloys are widely employed in the applications demanding light weight and high strength. However all aluminium alloys exhibit poor tribological properties which restricts their applications involving as cylinder heads liners, pistons, brake rotor, sliding parts in automobile industries which need wear resistance. Thus, coating metallic substrates i.e. aluminium alloys with a ceramic or a ceramic metal matrix composite (MMC) layer is an effective solution in prolonging service life. It has inferred that fabrication of surface metal matrix composites (SMMCs) by fusion may lead to the deterioration of composite properties. During these techniques, it is very difficult to avoid the interfacial reaction and casting based defects such as shrinkages like pin hole porosity, voids. Cited defects can be addressed by adopting newly developed friction stir processing technique (TWI) based on solid state. Hence current investigation based fabrication of surface composite by incorporating boron carbide as reinforcement on AA7075 aluminium (strongest aluminium alloys in the series which can compete with steel) alloy using friction stir processing for wear resistant applications. The investigation has its significance as, it is the first time boron carbide particle successfully introduced on to AA 7075 aluminium alloy using friction stir processing.**

Key words: Substrate, Surface Metal Matrix Composite (SMMC), Friction Stir Processing (FSP), boron carbide (B_4C).

I. INTRODUCTION

Aluminium alloys are widely employed in applications demanding light weight and high strength. However, these alloys exhibit poor tribological characteristics and restrict their applications which include pistons, cylinder liners in car engines, automotive brake rotors, bearing surfaces, tank tracks, marine drums which is dictated by the surface property [1-4]. Wear resistant i.e. surface metal matrix composite can be obtained by incorporating ceramic reinforcements like boron carbide, silicon carbide, tungsten carbide, aluminium oxide etc. on to aluminium alloy surface [5-6] which found extensive applications like cylinder heads, liners, pistons, brake rotors and calibers in automobile industry. Several modification techniques, such as high energy laser beam, plasma spraying, and thermal spraying and electron beam irradiation have been developed over the last two decades to fabricate surface metal matrix composites based on liquid phase processing. Involvement of high temperature leads to formation of detrimental phases and restricted to fabricate thin coatings on the substrate [7-11]. In aforesaid fusion based techniques, it is difficult to avoid the formation of detrimental phases, defects such as pores, pin holes, shrinkage cavities, segregation, and grain coarsening [12]. Mishraet.al. [13] developed a new technique based on solid state i.e. friction stir processing was gained worldwide attention has been selected as surface modification technique in present investigation. Among aluminium alloys, AA 7075 aluminium alloy is the strongest one and can compete with steels but exhibits poor tribological properties [14-16]. Earlier investigations revealed that boron carbide can introduced successfully using friction stir processing and impart higher wear resistance compared to that of other carbides like silicon carbide and tungsten carbide [17-18]. Earlier investigation pertaining to 7075 aluminium alloys were done in the domain of superplasticity [19-21] and scanty of open literature available in establishing the efficacy of friction stir processing on the basis electro diffraction analysis (EDX) and optimizing process parameters.

II. EXPERIMENTAL DETAILS

The base material used in this study is wrought AA7075 aluminium alloy having chemical composition of magnesium 2.5%, zinc 5.8 %, copper 1.4% and aluminium (rest) based on weight percentage. Commercial available B_4C (30µm) was incorporated to form surface metal matrix composite (SMMC) using friction stir welding machine (make: ETA Technology, Bangalore, India). The base/ substrate i.e. AA7075 was subjected to friction stir processing only in the initial stage. While as two different tools i.e. flat tool (shoulder Ø 20 mm) and threaded tool (pin length 3 mm, pin Ø 6mm, shoulder Ø 20 mm) made of H-13 were used (as shown in Fig.1) to fabricate SMMC by incorporating boron carbide using friction stir processing.

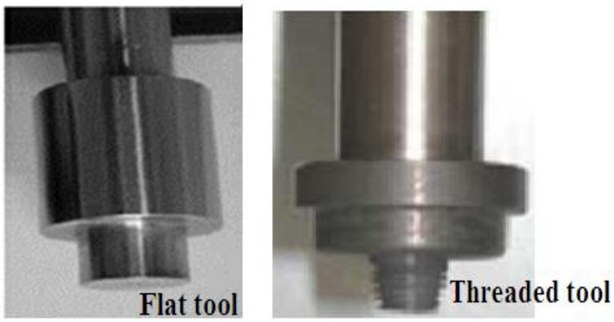

Fig.1 High Carbon (H-13) tools used during friction stir processing.

Vicker micro hardness test was done to evaluate surface hardness under 0.3 kgf of load. Metallurgical specimens were prepared from the sections of substrate, friction stir processed AA 7075, SMMC by following standard metallographic practices. Polished surfaces were etched with Kellar reagent (95% H_2O, 2.5% HNO_3, 1.5% HCl and 1% HF).

III. RESULTS AND DISCUSSION

The work pieces i.e. substrates (AA 7075 aluminium alloy) for surface modification were clamped on a backing plate during friction stir processing. Initial trial runs were made on supplied rolled AA 7075-T651 aluminium alloy for optimizing friction stir processing process parameters. Later on processed SMMC was accessed for efficacy of friction stir processing.

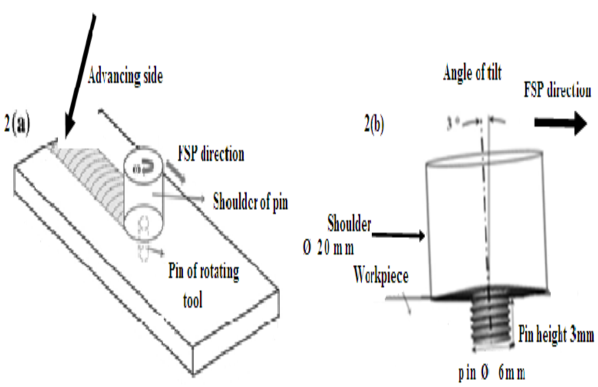

Fig. 2(a) shows the schematic representation of friction stir processing set up and Fig. 2(b) shows the schematic diagram of friction stir processing tool during FSP.

Variation of rotational speed of friction processing tool and longitudinal feed were used during initial trial runs.

Higher rotational speed (greater than 1200 rpm) of tool resulted in intense plastic deformation causing surface cracks and voids in the transverse section of processed surface composite as shown in Fig 3. Similarly, rotational speed having lesser than 750 rpm during friction stir processing led to improper mixing of B_4C particles and yield similar result as earlier.

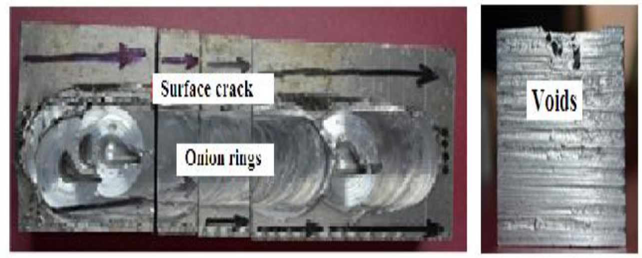

Fig.3 Surface cracks and voids along the surface and transverse section of substrate.

After number of trials for fabrication of surface composite, friction stir processing parameters such as tool rotational speed in the range of 925- 1000rpm yielded suitable plastic flow of material to form surface metal matrix composite.

Among above mentioned tool rotational speed, rotational speed in the range of 925- 1000rpm produced the best result. Hence, different tool feed rates of 20, 50 and 70 mm/ min was trialed to optimize longitudinal feed of processing with tool rotation speed of 960 rpm during preliminary stage of trial runs. Friction stir processing was used to fabricate the surface metal matrix composite (SMMC) by incorporating boron carbide particles in to AA7075 aluminium alloy. During FSP, tool movement from right to left about horizontal axis was maintained during surfacing to obtain defect free surface composite.

It is well understood that friction between work piece and tool and plastic deformation of work piece are the primary source of heat input during friction stir processing responsible boron carbide particle distribution in the surface of substrate. Higher tool feed rates causes micro and macro defects in the structure or on the surface. Increased tool feed led to deficiency in filling up and formation of surface cracks and voids. It is also witnessed that voids or holes generated around the lower part of tool's pin as shown in macrograph Fig.4.

Fig.4 shows the macrograph the friction stir processed failed SMMC during higher feed rates above 60mm/min.

These defects are attributed due to lack of penetration of heat during higher tool feed (above 60mm/ min) and causing the material not to become soft while undergoing plastic deformation and results in improper filling the material. It is also observed that increase in feed rate and higher tool rotational speed causes reinforcement particles to escape from the predrilled hole and decreases the rate of reinforcement.

While as lower tool feed rate lead to accumulation of the reinforced particles (boron carbide) on the upper portion of substrate or area closer to the surface and resulting in variation in reinforcement density from one point to other inside the base.

From the above discussion, it can be inferred that suitable tool feed rate is to be selected during friction stir processing. Tool feed of the order of 50mm/min is found to be effective in the present investigation. A tilt angle of 2.5^{o} between the tool and the vertical axis in the tool feed direction helped in plastic deformation by forging action of back shoulder portions of the tool. With the tool feed rate of 50mm/ min rotational speed 960 rpm and plunging speed of the order of 30 mm/minute with tilt angle about 2.5^{o} resulted in the elliptical and onion ring structure as shown in Fig. 5.

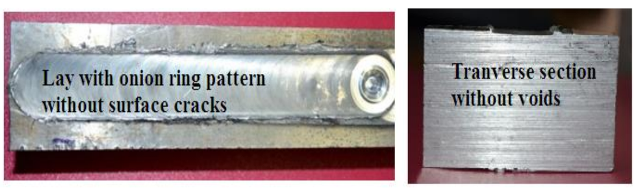

Fig.5 shows defect free SMMC using FSP.

A. Efficacy of Friction Stir Processing: It has been already explained the necessity of solid state processing for incorporating reinforcing particles (boron carbide) as it yields no dissolution of reinforcement i.e. friction stir processing maintains the real identity of boron carbide even after processing. From the EDS analysis, it is quite evident that the existence of the boron is about 81.64%, however elemental boron cannot exist in the main material so the existence of boron as boron carbide is high as shown in Fig.6.

Element	Wt%	At%
B K	81.64	88.11
C K	07.64	07.42
MgK	00.38	00.18
AlK	09.54	04.12
SiK	00.07	00.03
ZnK	00.73	00.13
Matrix	Correction	ZAF

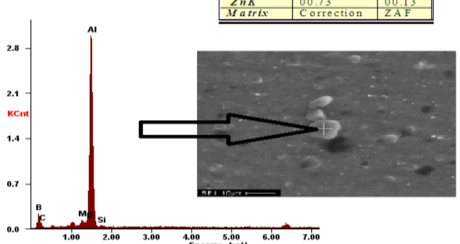

Fig.6 EDS report of surface composite fabricated by incorporating boron carbide particles using friction stir processing.

From the EDS analysis, it is understood that the friction stir processing does not result in the formation of detrimental phases which is highly beneficial for obtaining strong interfacial bonding.

B. Micrographs: The optical micrographs of samples under different condition as seen under magnification of 100x are shown in Fig.7

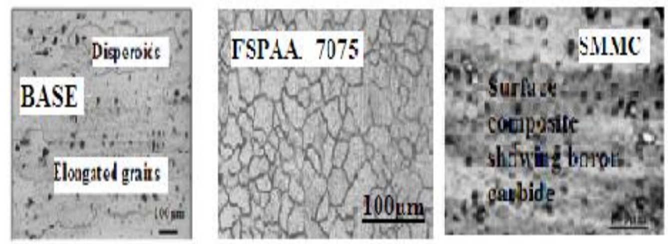

Fig.7 shows the optical micrograph of samples under different condition.

IV. CONCLUSION

A. With the tool feed rate of 50mm/ min rotational speed 960 rpm and plunging speed of the order of 30 mm/minute with tilt angle about 2.5^{o} resulted in fabrication of sound metallurgical SMMC.

B. EDX analysis supports the efficacy of friction stir processing and depicts the absence of dissolution of boron carbide and presence of boron carbide intact in SMMC.

C. The present investigation demonstrates successfully fabrication of SMMC by incorporating boron carbide particles on to the surface of AA7075 for wear resistant applications.

REFERENCE

[1]. Kiyoshi Funatami, Emerging Technology in Surface Modification of Light Metals. Surface and coating Technology. 2000; Vol.133:264-272.
[2]. Statistical data of Automotive Materials committee, Japanese Society of Automobile Industry, May 1997.
[3]. North American Passenger Car and Light Truck Aluminum Content Report1999, Ducker Research Co., Southfield.
[4]. K. Takeuchi, Y. Isobe, T. Toyama, Journal of Japanese Institute of Light metals. 1998 Issue (48) Vol.9: 446-457.
[5]. S. Suresh, A. Mortensen, A. Needleman, Fundamentals of Metal Matrix Composites, Butterworth-Heinemann, 1993.
[6]. R.L. Deuis, C. Subramanian, J.M. Yelllup, Dry sliding wear of aluminium composites—a review, Composite Science Technology. 1997; Vol.57: 415–435.
[7]. Vreeling J A, Ocelik J, Pei Y T, Van Agterveld D T and Hosson T M .Laser Melt Injection of Ceramic Particles in Metals. Acta Materialia 2000; Volume 48: 4225-4232**.**
[8]. Abboud J H and West D R F. Microstructure of Titanium injected with SiC particles by laser processing. Journal of Materials Science Letters .1991; Volume 10: 1149-1157
[9]. Pei Y T, Ocelik V and Hosson J T. Futuristic Materials, editors B.B.Jha , R.K.Galgai , Vibhuti N Misra. Allied Publishers, Indian Institute of Minerals Engineers, Bhubaneswar Chapter 2004.
[10]. Baker T N, Xin H, Hu C and Mridha S .Design of surface in situ

Metal-Ceramic composite formation via laser treatment. Journal of Materials Science and Technology 1994; Volume 10: 536-544
[11]. Weerasinghe V M, West D R F and Damborenea J. Laser surface Nitriding of Titanium and Titanium alloy. Journal of Materials Processing Technology.1996; Volume 58:79-86
[12]. Lee CS, Li H, Chandel RS. Vacuum-free diffusion bonding of aluminium metal matrix composite. Journal of Material Processing Technology.1999; Volume 89(90):326–30.
[13]. R.S. Mishra and Z.Y. Ma: Friction stir processing: A Novel technique for surfacing. Material Science Engineering. 2005; vol.50, 1–78.
[14]. Mondolfo.L.F .Aluminium alloys : Structure and properties. Butterworth London-Boston 1976. Aluminium and Aluminium alloys. Edited by R.Davis, ASM Hand Book, ASM International, 1993.
[15]. Birol Y. Pre-straining to improve the bake hardening response of a twin-roll cast Al–Mg–Si alloy. Scripta Mater 2005;52(3):169–73.
[16]. Atkinson HV, Burke K, Vaneetveld G. Recrystallisation in the semi-solid state in 7075 aluminum alloy. Material Science Engineering A 2008; Vol.49:266–276.
[17]. G. Madhusudhan Reddy, K. Srinivasa Rao and T. Mohandas Friction surfacing: Novel technique for metal matrix composite coating on aluminium silicon alloy .Surface Engineering. 2009; Issue (1), Vol. 25: 25-30.
[18]. ZY Ma, Mishra RS, Mahoney MW. Superplastic deformation behaviour of friction stir processed 7075Al alloy. Acta Material. 2002; 50: 4419-4424.
[19]. Mahoney MW, Rhodes CG, Flintoff JG, Spurling RA,Bingel WH. Metall. Properties of friction-stir-welded 7075 T651 Aluminum. Material Transactions.1998; 29A: 1955.
[20]. Rhodes CG, Mahoney MW, Bingel WH, Spurling RA, Bampton CC. Effects of friction stir welding on microstructure of 7075Aaluminum. Scripta Material. 1997; 36: 69.
[21]. Z.Y. Ma, R.S. Mishra, and M.W. Mahoney. Superplastic deformation behaviour of friction stir processed 7075Al alloy. Acta Materlia, 2002, vol. 50:4419–30.