Strengthening of the Surface Properties of Al-4.5%Cu/BLA Composites by Laser Applications

Gadudasu Babu Rao, K Balasubramanian, Mona Sahu, Praveen Kumar Bannaravuri, Anil Kuamr Birru

Abstract: Aluminium composites were used widely due to merits like high strength to weight ratio, electrical and thermal conductivity. In this paper, the influence of the Laser Surface Melting on exterior surface of Al-4.5% Cu alloy metal matrix composite reinforced with 2 and 4 wt.% of Bamboo Leaf Ash particles produced by stir casting. The composite's surface was melted using a laser machine. The microstructure and the hardness of as-cast and laser melted surface of composites were studied. The results of the composites have been compared before and after laser treatment. The grain size on surface of composites was reduced after laser treatment and also observed that porosity was minimized. The hardness of surface composites was enhanced desirably after laser treatment. Thus, re-melting the surface by laser can be suitably useful to strengthen the surface properties of the Aluminium composites.

Keywords: Aluminium composites, Bamboo Leaf Ash (BLA), Stir casting, Laser Surface Melting (LSM), Hardness.

I. INTRODUCTION

Aluminium composites were prominently used in industries like automobile and aerospace industries due to their easy availability, low density, high strength-to-weight ratio, and easy processing [1]. The properties of aluminium metal matrix composites (AMMCs) improvement can be lead to increase theitr use in many industrial applications. The characteristic of AMMCs, give many adventages such as high specific strength with reduction in weight, and thermal stability [2-4]. Earlier research claims that with the addition of reinforcements in to the aluminium matrix can be change the properties remarkably [5]. Praveen and Anil [6] was fabricated Al-4.5Cu/bamboo leaf ash composite by stir casting method and observed mechanical properties were improved. Some porosity and particles agglomeration were observed in their work, to avoid these surface defects some secondary process needed.

To enhance the surface properties, a variety of surface modification technologies have been proposed and investigated. Laser surface treatment is one of these technologies that have attracted vast research interest recently. Depending on the interactions features between laser and materials surfaces, several laser modification processes have been developed such as laser surface alloying (LSA) and laser surface melting (LSM). Laser-melted surface layers produce a fine microstructure that reduced the size of particles of galvanic couples and sites in place of pits nucleation [7]. Laser surface treatment of aluminium alloys has been widely investigated since last decade [8, 9]. LSM was applied to aluminium composites also but the available literature is sparse. Pinto et al. [10] studied the variations of hardness and microstructures samples of an aluminium–copper alloy submitted to a laser surface melting treatment. Vickers hardness tester is used to carryout along the laser treated the cross-sections, and it was found that values of hardness can be increased greatly compared with the original substrate, confirming the effectiveness of the laser treatment.

Wong and Liang [11] reported that after LSM of Al-Si alloys (0–13wt.% Si) using continuous wave (CW) CO2, the solubility of Si enhanced beyond its equilibrium saturation limit. The corrosion rates of the Al-Si alloys in 10% H2SO4 and 10% HNO3 solutions were less, but, the corrosion rates in chloride solution containing 10% HCl and 5% NaCl did not reduce after LSM. The microstructure refinement on surface of Al-9% Si aluminium alloy by LSM performed with 1 kW CW CO2 laser was accomplished with reduction in the dendritic arm spacing to one fifth that of the as-cast alloy [12]. In this work LSM of aluminum Al-4.5Cu alloy and its composites with BLA particles was carried out. One composite contained 2 wt.% of BLA and, the other composite contained 4 wt. % of BLA. The experiments were carried out by varying laser specific energy (LSE). After LSM, the surface integrity was studied and compared with the as-cast material. A definite improvement was observed due to LSM.

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II. EXPERIMENTAL DETAILS

Al-4.5wt. % Cu alloy was consedered as matrix alloy and chemical composition is presented in Table 1. Bamboo leaf ash (BLA) with average particles size of 75 μm and density of 1.78 g/cm3 were selected as reinforcements for the fabriacte the composite.

Table-1: Chemical Composition of Al-4.5wt. % Cu alloy

Element	Cu	Mg	Si	Fe	Mn
Wt. %	4.52	0.066	0.538	0.663	0.131
Element	Ni	Pb	Sn	Ti	Zn
Wt. %	0.075	0.029	0.021	0.013	0.118
Element	Al				
Wt. %	Balance				

A. Fabrication of composite material by stir casting method

The Al-4.5Cu/BLA composites are fabricated using stir casting method. Magnesium in the form of ingot has been used to enhance the wettability among the matrix alloy and the reinforcements in the production of the composites[13]. Figure 1 illustrates a flowchart of method for aluminium composites fabrication using stir casting method. The microstructure and hardness were carried out with help of required tools and equipments.

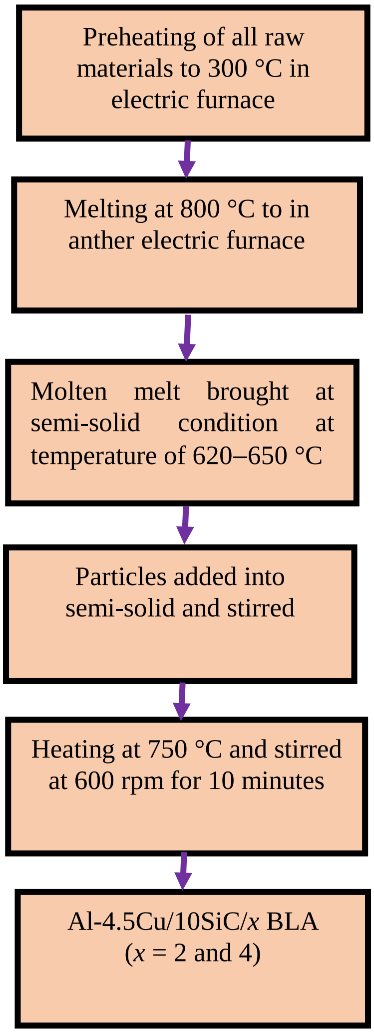

Fig. 1. A flowchart of fabrication of aluminium composites by stir casting method

B. Laser surface melting by 2.5 kW CO2 laser

The surface of the cast samples was melted by using CO_2 laser machine, a schematic digram as shown in Figure 2, at a wavelength of 10.6 μm. The laser parameters are taken for present research work presented in Table 2. All laser perameters are optimized as laser specific energy (LSE), and it can be compute as [1]

$$E = \frac{P}{vd} -------- (1),$$

where P dentoes the laser power, v denotes the scan speed taken as constant is 400 mm/s, and d denotes the laser beam diameter.

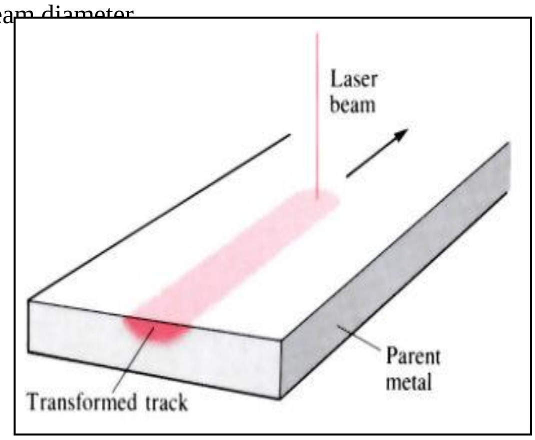

Fig. 2. Schematic diagram of LSM

Table-2: Laser parameters used for surface re-melting of composites

Sr. No.	Material	Laser Parameters		
		P (kW)	D (mm)	E (J/mm^2)
1	Al-4.5Cu matrix	1.9	6.61	43
2	Al-4.5Cu matrix	1.9	7.56	39
3	Al-4.5Cu matrix	1.9	8.5	34
4	Al-4.5Cu/2BLA	1.9	6.61	43
5	Al-4.5Cu/2BLA	1.9	7.56	39
6	Al-4.5Cu/2BLA	1.9	8.5	34
7	Al-4.5Cu/4BLA	1.9	6.61	43
8	Al-4.5Cu/4BLA	1.9	7.56	39
9	Al-4.5Cu/4BLA	1.9	8.5	34

C. Morphological analysis

The metallographic examination of the composites was carried out using an optical microscope (OM). The samples of fabricated composites were cut in the desired shapes and the surface was polished. Etched was used that Keller's reagent (95 ml of H_2O, 2.5 ml of HNO_3, 1.5 ml of HCl, 1.0 ml of HF) for microstructure examination [15]. Mocrostructure analysis was done by Opticle microscope and leaner intersect method used for measure the grain size of the composites by Image software [16]. The average grain size was determined at various places on all samples.

D. Surface of hardness measurement

From the fabricated composites, the samples were prepared for the hardness measurement and microstructure study.

The samples were prepared for the microstructure and hardness test with dimension of 10 mm × 5 mm × 10 mm. All the samples were polished to get an fine and flat surface. The hardness test was carried out by taking the average of 3 readings on every sample by Micro Vickers hardness machine as per ASTM E384-11, the load used is 100 gm. Microstructure analysis and hardness test was carried out before and after LSM.

III. RESULTS AND DISCUSSION

In the following sections microstructures analysis and hardness of the casted and LSM composites are discussed.

A. Analysis of microstructure

The opticle micrographs of the matrix alloy, Al-4.5 Cu / 2 BLA and Al-4.5Cu / 4 BLA, was shown in Figure 3 befor LSM. It was observed α-Al and Cu etectic phase and grain size was seen bigger in the matrix micrograph as shown in Figure 3a. Micrographs of composite materials reveals that BLA particles are nearly distributed uniformly in the matrix alloy as shown in Figure 3b and 3c. In all micrograph many blow holes are ditected, these becasuse of air bubbles are suctioned into the melt during stirring process due to vertex generated. Porosity also observed in the matrix and composites micrograph, reseon for porosity is entropped gases while stirring. From Figures 3b and 3c, it was seen that at some places, particles were agglomerated. The agglomerated area can break with rapid melting and also uniform distribution may achive with rapid solidification [17].

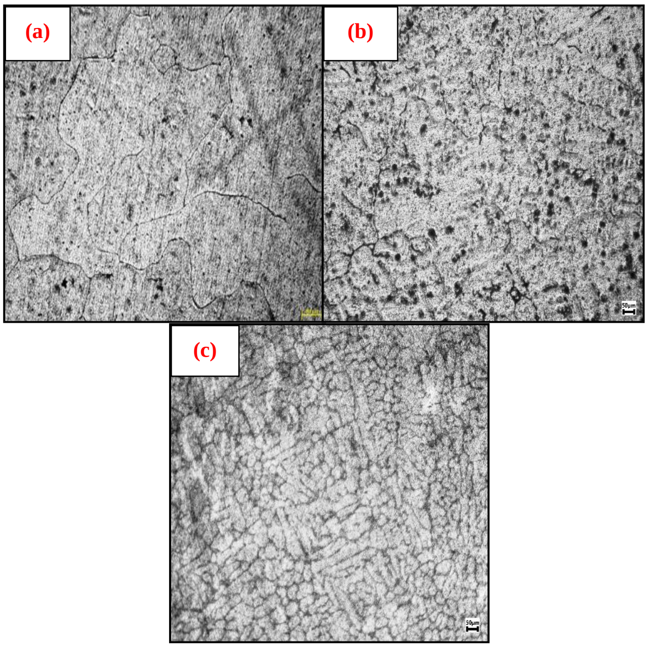

Fig. 3. Microstructure (X100) of as-cast (a) Al-4.5Cu alloy, (b) Al-4.5Cu/2BLA and (c) Al-4.5Cu/4BLA

The opticles micrograph of matrix alloy was shown in shown in Figure 4a at LSEs of 34 J/mm^2, Figure 4b at 38 J/mm^2 and Figure 4c at 43 J/mm^2. Figure 4a revels that grain refinement, at LSE of 34 J/mm^2 and some porosity was identified. It was observed that fine grain refinement at LSE of 38 J/mm^2, of the matrix alloy with diminishing the surface defects such porosity and agglomeration as shown in Figure 4b. Defect free surface was noticed at LSE of 38 J/mm^2 due to suitable melting and high solidification rate. From 4c, it was noticed that more micro-pores and craks on the surface of composites at LSE of 43 J/mm^2, these results may be because of overheating. After surface re-melting by laser, it was observed that fine grain refinement when compared with before laser melting in matrix alloy.

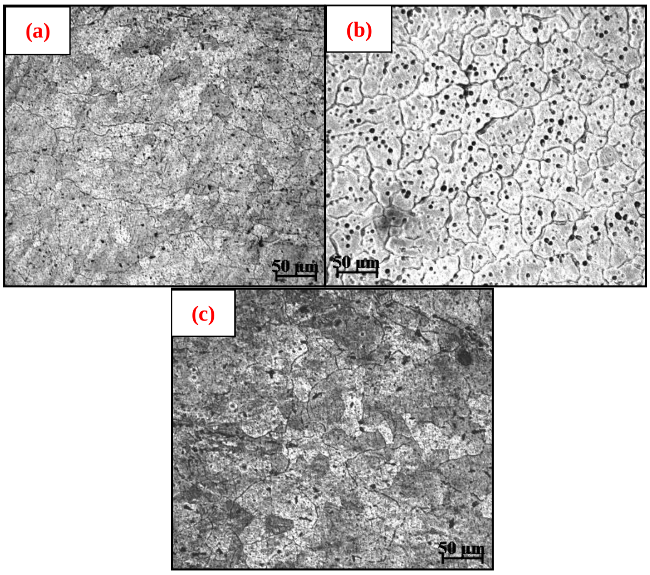

Fig. 4. Microstructure (X100) of LSM Al-4.5Cu matrix alloy at LSE of (a) 34 J/mm2, (b) 38 J/mm2 and (c) 43 J/mm2

The opticale micrograph of composites are shown in Figure 5 after laser melting at LSE of 38 J/mm^2. The clear interface between the matrix and the BLA particles observed in the Figure 5a and 5b of Al-4.5Cu/BLA composites and it can be confirms that the particles distribution is uniform. The remarkably grain refinement was noticed in the Al-4.5Cu/2BLA and Al-4.5Cu/4BLA composites. Smallest grain size was observed in the 4 wt.% of BLA reinforced composites and microcraks were not observed as shown in Figure 5b.

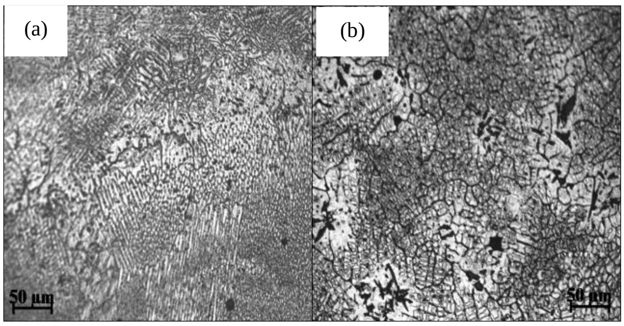

Fig. 5. Microstructure (X100) of LSM (a) Al-4.5Cu/2BLA and (b) Al-4.5Cu/4BLA composite at LSE of 38 J/mm^2

The average grain size was calculated by using linear intercept method. From Figure 7 shows it was observed that, the average graine size of the matrix and composites before and after laser melt (at LSE of 38 J/mm^2). The desire decrement in grain size of composite after laser melt when compared with cast composites this due to rapid solidification after laser remelt. The results are line with Pariona et al. [18], It was noticed that properties of the surface of Al–1.5 wt.% Fe alloy improved after re-melting the surface by using a high-power Yb-fiber laser.

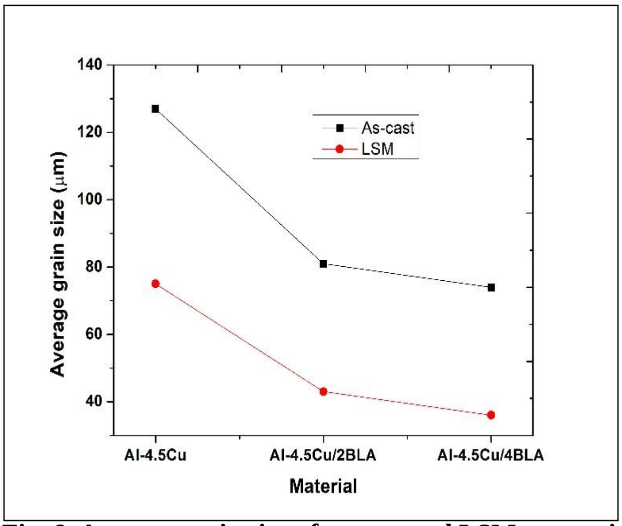

Fig. 6. Average grain size of as-cast and LSM composite material at LSE of 38 J/mm2

B. Micro-hardness

The micro-hardness and density values are presented in Figure 7 of the casted matrix and composites. The density of the matrix was bring to low when addition the BLA particles because of the lower density particles. The micro-hardness was increased with addition of BLA when compared with amtrix material. The results are line with Daniel et al. [19] was also manufactured Aluminium 5059/SiC/MoS2 composite by stir casting method.

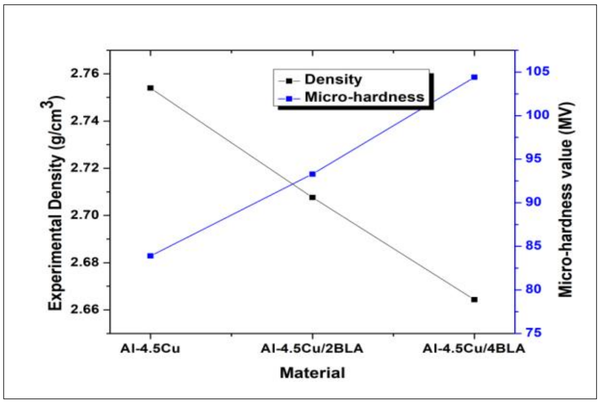

Fig.7 Density and Micro-hardness of fabricated aluminium composites

After re-melted the surface of matrix and composites, the hardness values are presented at different LSE (34, 38 and 43 J/mm^2) in the Figure 8 and Table 3. It was noticed that after laser melt hardness was improved. LSM enhanced the micro-hardness outstandingly in all the cases and highest micro-hardness was found in the Al-4.5Cu/4BLA at LSE of 38 J/mm^2 as shown in Figure 8 and Table 3. Yilbas et al. [20] have studied that micro-hardness of Al/SiC composite before and after laser melt of the surface and it is recoreded amplified the hardness more than 50% higher when compared with base material after laser melting.

Table 3 Micro-hardness vales of matrix and composites after laser melt

LSE (J/mm^2)	Al-4.5Cu alloy	Al-4.5Cu/2BLA	Al-4.5Cu/4BLA
34	98.9	105	111
38	101.519	109	119
43	85.67	93	96

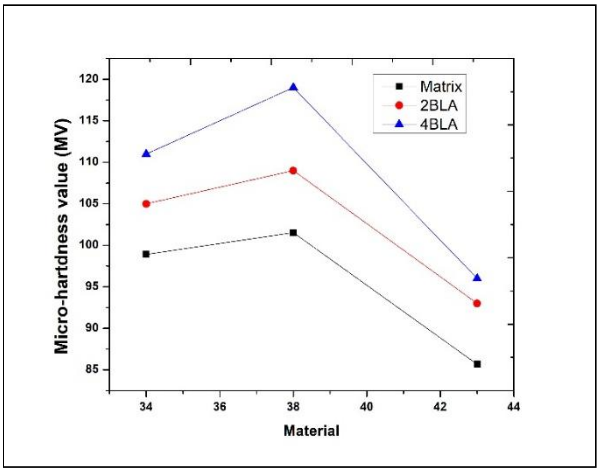

Fig.8 Effect of laser specific energy on Micro-hardness of LSM material

IV. CONCLUSIONS

Alumnium alloyed with 4.5 wt.% Cu and alloying material reinforced with 2 and 4 wt.% of BLA were prepared by stir casting method. To improve the surface of the fabrticated composites laser was applied. The BLA particles were distributed in the matrix alloy nearly homogenious when fabricated with stir casting method but some particles agglomeration and poroes were observed. The density of the matrix was reduced when addition BLA particles due to low density particles and porosity of the composites increased as increased reinforcement percentage. After re-melting the surface by laser, grain refinement was observed on the surface of the matrix and composite with minimizing the porosity. The hardness of the laser melted surface higher than the casted material.

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