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Investigations on Mechanical Behaviour and Characterization of LM 13/SiC/Gr Hybrid Composite Produced Using Compocasting Method

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Abstract: Aluminium hybrid metal matrix composites replaces single reinforced composites in many applications due to its mechanical and tribological properties. Many investigations have been carried out on mechanical behaviour of hybrid composites but so far no investigations have been carried out with piston alloy. This investigation focuses on to find the influence of Graphite (Gr) particulates as secondary reinforcement on the mechanical behaviour of LM 13/Silicon Carbide (SiC) composites. The hybrid composites are produced by compocasting method in stir casting process. The reinforcement silicon carbide was varied from 0-12 wt.% in a step of 3 and the graphite is kept constant at 4 wt.%. The mechanical behaviour of the composite was investigated. The particles distribution and elemental mapping was carried out with field emission scanning electron microscopy and energy dispersive spectroscopy. The results indicate that increase in silicon carbide and graphite improves the mechanical behaviour of the composites.

Key words: Hybrid-composites, compocasting, mechanical properties, SiC, Gr, graphite

INTRODUCTION

A continuous exploration for new materials has paved way for the evolution of metal matrix composites. These new materials due to its superior mechanical, tribological and non-corrosive properties find an increased application in aerospace, marine and automotive applications (Wang *et al*., 1995). Aluminium metal matrixes are termed to be high performance materials due to its known versatile properties such as light weight, manufacturability, electrical conductivity and also because of its non-corrosiveness (Lakshmi *et al*., 1998; Natarajan *et al*., 2009). Generally liquid and powder metallurgy methods are adopted to produce aluminium MMCs (Suresh and Moorthi, 2013; Deaquino-Larav *et al*., 2014; Baradeswaran and Perumal, 2014). Stir casting method is generally preferred to produce particulate or discontinuous reinforced MMCs than other manufacturing methods due to its simplicity, flexibility, applicability and rapid production rate in large quantities. It is also attractive because of the low production time and cost (Kumar *et al*., 2012). Stir casting is a liquid state process in which aluminium alloy is melted in a furnace followed by the ceramic particles are added to the melt which is then stirred continuously to obtain a homogeneous mixture and poured into the mould which finally results in composites upon solidification (Hashim *et al*., 2002; Hashim, 2001; Kumar and Gupta, 1998). Al alloy containing 12% silicon are widely used in internal combustion engines parts such as pistons, cylinder blocks, cylinder heads since, it has high resistance to wear, corrosion and thermal conductivities (Jayaprakash *et al*., 2014). Various ceramics such as carbides, borides nitrides, oxides and aluminides are reinforced with different aluminium alloys to produce composite and study the behaviour of it various applications (Tjong and Tam, 2006; Ramesh *et al*., 2010; Mallikarjuna *et al*., 2011; Rajan *et al*., 2013; Balci *et al*., 2014). SiC is known to have better chemical compatibility with aluminium because it doesn't forms any inter-metallic phases during its interaction with the Al matrix, so, it is a very common type of reinforcement used in Al-MMCs (Sahin and Acilar, 2003). SiC is widely used as reinforcements in composites due to its good mechanical and wear resistance properties. The addition of SiC with the aluminium alloy makes the composite harder which makes the machining difficult. Thus, it is needed to retain the benefits of SiC by simultaneously addressing the problems in machining of composites by adding other reinforcements. Graphite is a solid lubricant which eases

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the machining process as well as increases the wear resistance properties of Al-SiC composites. Composites with graphite reinforcement produced by different techniques plays a vital role in engineering applications. Due to its lubricating property it is being used in a wide range of applications. It is used in components such as valves, bushes, bearing, pistons, piston rings, cylinder liners which requires resistance to tensile and wear loads (Krishnan *et al*., 1983; Barekar *et al*., 2009; Ramesh *et al*., 2009; Ravindran *et al*., 2012). Graphite acts as a solid lubricant wherever, the liquid lubricant cannot play a role which prevents metal to metal interaction by forming a thin Gr layer. Al-Gr composites have better wear resistance properties than conventional aluminium alloy (Vettivel *et al*., 2014). However, investigations are very limited on parametric study of aluminium hybrid composites for automotive applications. Thus, a study is carried out to find the effect of graphite particulates on the mechanical behaviour of Al-SiC composites.

Aim of research: Improvement in the fuel economy and emission is a major challenge to the present automotive industry. The vehicle weight and frictional loss are the two major factors which affects the fuel economy. The IC engine itself contributes a major portion in the vehicle weight and the friction encountered within the engine contributes about 40% of power loss from the produced power. Even, a small improvement in engine would reflect in the efficiency, fuel economy, emission levels which can have a major effect on the worldwide fuel economy and the environment in the long-term. One such attempt is carried out here is to find an alternative material for the piston by using eutectic aluminium alloy (LM 13) as metal matrix reinforced with silicon carbide and graphite.

MATERIALS AND METHODS

Metal matrix: LM13 is a eutectic aluminium alloy which is high resistance to wear, high load bearing capacity and a low coefficient of thermal expansion aluminium alloy due to the Si content, above 12% in the alloy. This alloy is being widely used in automotive applications such as pistons, piston heads, brake drum, cylinder liners, cylinder blocks, drive shaft, bearings and gears makes it feasible for high wear resistance applications. LM 13 aluminium alloy having density of 2.70 g/cm^3 was selected as the base matrix. The chemical composition is given in Table 1.

Reinforcements: Silicon Carbide (SiC) is made up of carbon and silicon. It is produced by a high temperature electro-chemical reaction of sand and carbon. It is manufactured with very good mechanical and thermal properties. It is widely used in applications such as abrasives, refractory, ceramics and numerous high

Table 1: Chemical composition of LM 13 aluminium alloy

Elements	Contents (%)
Al	83.4200
Si	13.0200
Fe	0.3100
Cu	1.0470
Mn	0.2520
Mg	0.8650
Ni	0.9380
Ga	0.0140
Zn	0.0068
Ti	0.0680
Pb	<0.0050
Sn	<0.0490

Table 2: Details of reinforcements

Reinforcements	Hardness (GPa)	Grain size (μm)	Density (g/cm^3)
SiC	24.50-29	25	3.22
Gr	0.25	37	2.09-2.33

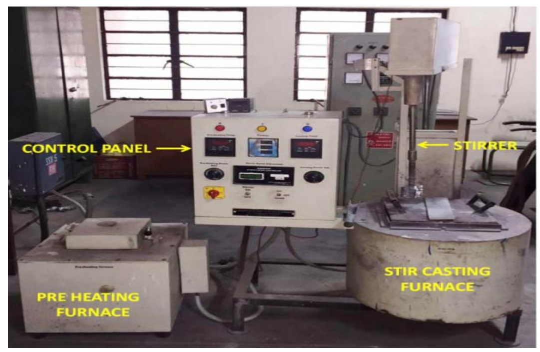


Fig. 1: MMC-Stir casting setup

performance applications. Due to its hard and strong nature it exhibits high resistant to thermal shock. Silicon carbide (25 μm) was selected as the primary reinforcement.

Graphite is a mineral composed exclusively of the element carbon. It is a soft and low specific gravity ceramic. In contrast, it is extremely resistant to heat and nearly inert in contact with almost any other material. Thus, it is compatible with various aluminium alloys which is used in automotive applications. Graphite particulate (37 μm) were used as used as secondary reinforcement. The details of reinforcements are given in Table 2.

Development of composite by compocasting process: Al-SiC and Al-SiC-Gr are fabricated using compo casting process (Selvam *et al*., 2013; Khosravi *et al*., 2014). LM13 aluminium alloy is used as metal matrix and its chemical composition after spectro-labtest is given in Table 1. The details of reinforcements SiC and Gr particulates are given in Table 2. In the first step, 1 kg of aluminium alloy was measured and melted at 800°C in a graphite crucible using a stir casting furnace shown in Fig. 1. According to the wt.% a measured quantity of SiC and Gr particles were preheated at a temperature of 400°C for about 30 min in the preheating furnace shown in Fig. 1. The preheating was done to remove surface impurities and to reduce oxide formation by the absorption of gases. Once the metal is melt it was stirred continuously at 600-800 rpm to create a vortex with the mechanical stirrer for 10 min during which a hexochloroethane tablet (C_2Cl_6) was added to the melt to degas and liberate any unwanted gases generated during the melting of the aluminium. The preheated SiC and Gr particles were added slowly and continuously into the vortex of the molten metal. In order to improve the wettability of particulates with the alloy 1 wt.% of Mg metal powder was added to the molten metal (Liu *et al*., 2010). The stirrer was frequently moved vertically up and down within the mixture to ensure uniform distribution of the added particles. After all, the SiC and Gr particulates were added into the molten metal the temperature of the furnace was set to 550°C and the composite mixture was allowed to attain the solidus state in the crucible. In the second step, the slurry mixture was reheated and melted again at 750°C. The molten metal was again stirred at 300 rpm for about 2 min. Finally, it was cast into a 100×100×10 mm preheated M.S mould. The composite was solidified in the atmospheric air and it was then removed from the mould after solidification. The metal matrix and hybrid metal matrix composites with different wt.% were produced by the same procedure.

Micro hardness measurement: The micro hardness (HV) of the composites was measured according to ASTM A-370 standard using Vickers hardness tester (Mitutoyo-HM-114). The test was conducted on the polished specimens with the applied load of 500 g for duration of 15 sec at 5 different locations on all the specimens.

Macro hardness measurement: The macro hardness (HRC) of the composites was measured using Rockwell hardness tester (Model RAB-250). The test was conducted according to ASTME-18 standard with the applied load of 100 kg for duration of 15 sec at 5 different locations.

Tensile test: Tensile test specimens were made as per ASTM E8M-04 standard from each combination of composites. The Ultimate Tensile Strength (UTS) was found using a computerized universal testing machine (UTM) (HITECH TUE-C-1000).

Metallurgical characterization: Characterization was carried out to analyse the surface fractures, information about the microstructures, examine surface contaminations, reveal spatial variations in chemical compositions, provide elemental distribution and identify crystalline structures. Specimens with dimensions 10×10×10 mm are prepared from each of the cast composites. The specimens were prepared by standard metallographic procedure and etched using Keller's reagent followed by Weck's reagent. The etching process ensures clear SEM images and elemental distribution of the composites. The Scanning Electron Microscope (SEM) image and Energy Dispersive Spectrum (EDS) pattern of the various composites are revealed using ZEISS Field Emission Scanning Electron Microscope (FE-SEM).

RESULTS AND DISCUSSION

Effect of reinforcements on micro and macro hardness: The results of the micro-hardness (HV) and macro hardness (BHN) tests conducted on the specimens with different wt.% of SiC and Gr composites is shown in Fig. 2 and 3. The hardness varies as the reinforcement contents vary in the aluminium alloy. It is very evident as the wt.% of SiC increases, the micro and macro hardness increases. From Fig. 2 and 3, it has been observed the

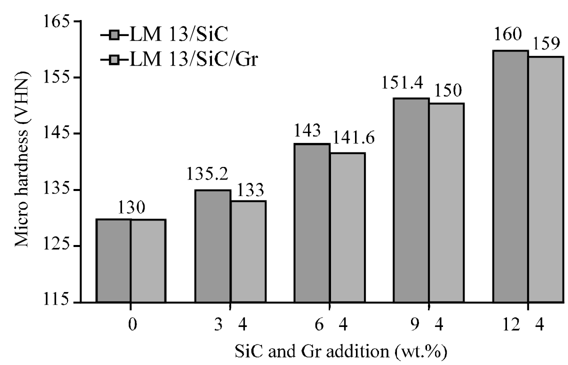


Fig. 2: Effect of reinforcement (SiC and Gr) addition on micro hardness

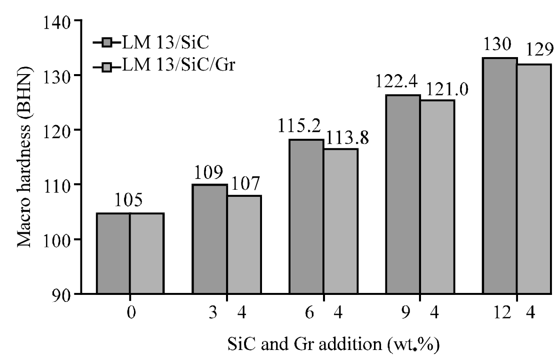


Fig. 3: Effect of reinforcement (SiC and Gr) addition on micro hardness

hardness increases linearly with the addition of SiC particulates. By various studies, it has been found that, increase in reinforcement % results in increase in hardness of the composite (Ramesh *et al*., 2011). The hardness of the hybrid composite decreased minimally due to the addition of graphite particles in the aluminium alloy. This is due to the low density of graphite which resulted in floating led to weak bonding with the metal matrix and agglomeration of Gr particles in the composites. These results are in line with the previous investigations (Hassan*et al*., 2007; Akhlaghi and Zare-Bidaki, 2009).

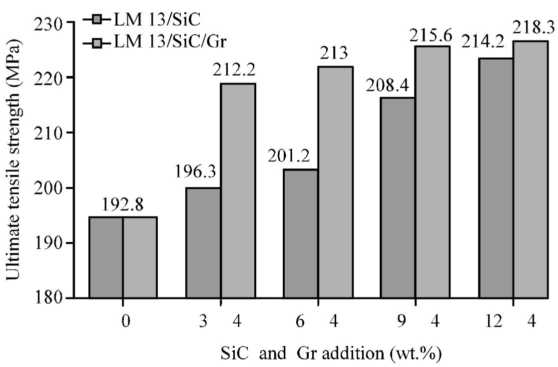
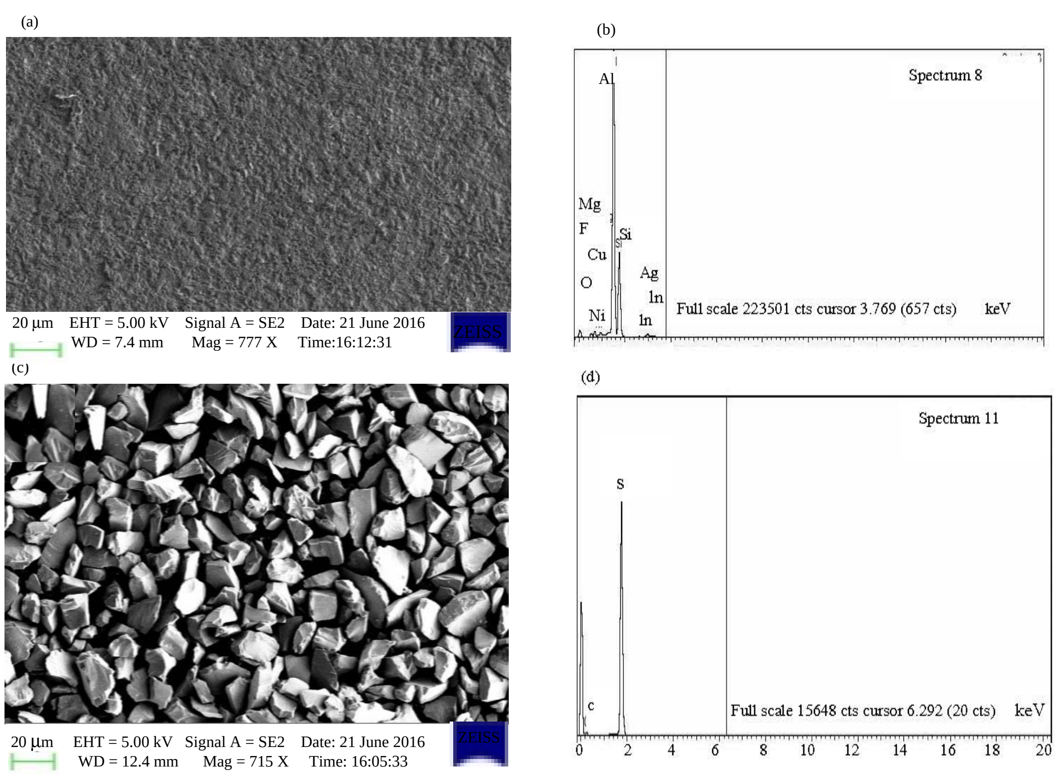


Fig. 4: Effect of reinforcement (SiC and Gr) addition on ultimate tensile strength

Effect of reinforcements on Ultimate Tensile Strength (UTS): The effect of wt % of SiC and Gr particles on UTS is shown in Fig. 4. It is very evident that, addition of hard SiC particulates has resulted in increase in UTS than the matrix alloy. The addition of soft graphite particulates has also resulted in higher UTS than the single reinforcement composite. This increase in strength is due to the addition of SiC and Gr particulates which imparts strength to the matrix alloy, resulting in enhanced resistance to tensile stresses. As the particulate content is increased there is a random distribution of it in the matrix which reduces the inter spatial distance between the particulates increases the dislocation pile-up leads to restriction of plastic flow, thereby enhancing the strength of the composites. It is found that decrease in the grain size and creation of high dislocation density in the matrix results in variation of thermal expansion between metal matrix and reinforcement leads to enhancement of ultimate tensile strength (Vogelsang *et al*., 1986).

SEM-EDS analysis: The Scanning Electron Microscope (SEM) image and Energy Dispersive Spectrum (EDS) pattern of aluminium alloy, reinforcements and composites are given in Fig. 5a-v. The SEM and EDS image of LM13 aluminium alloy is shown in Fig. 5a and b. The EDS image



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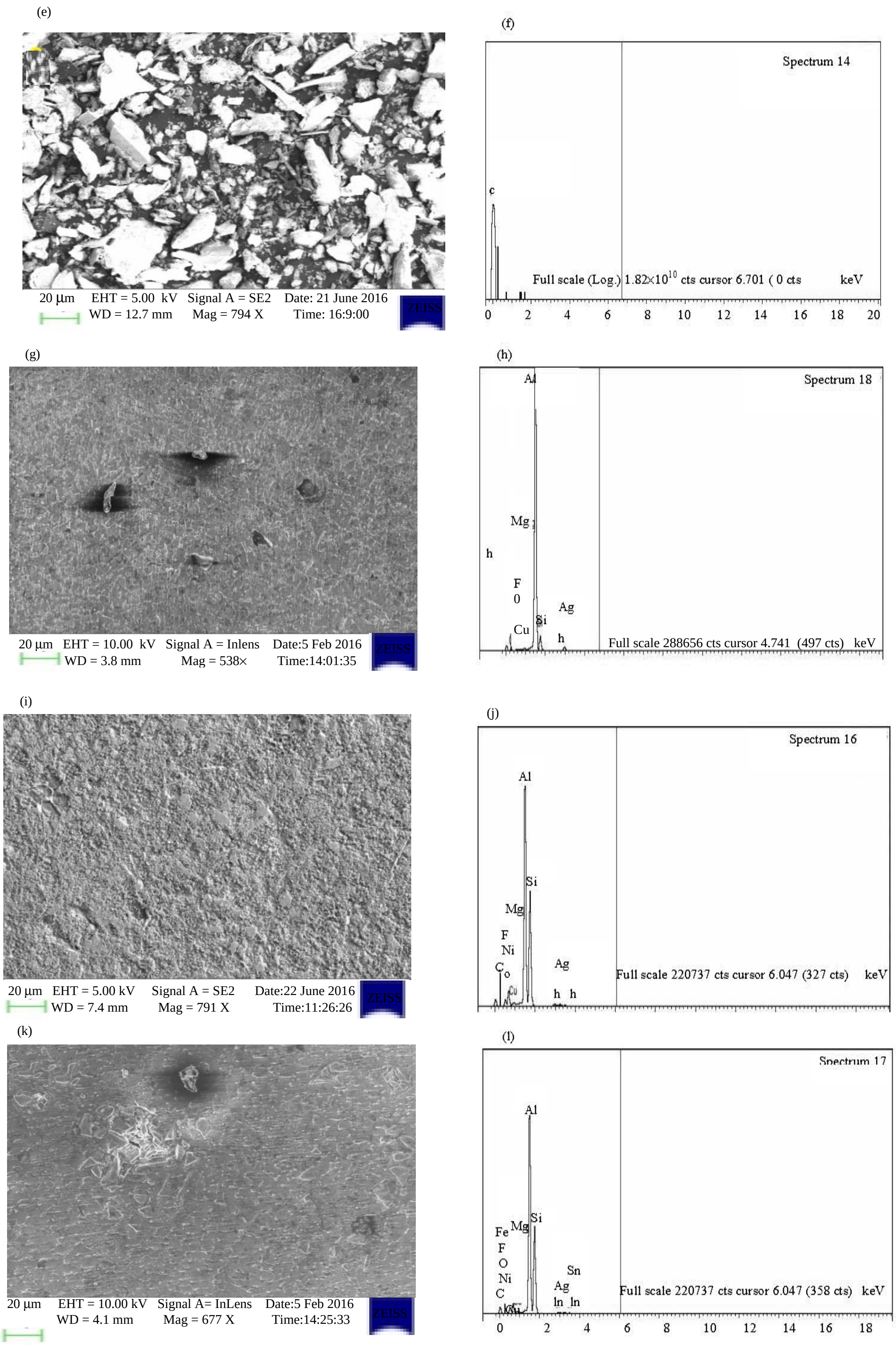

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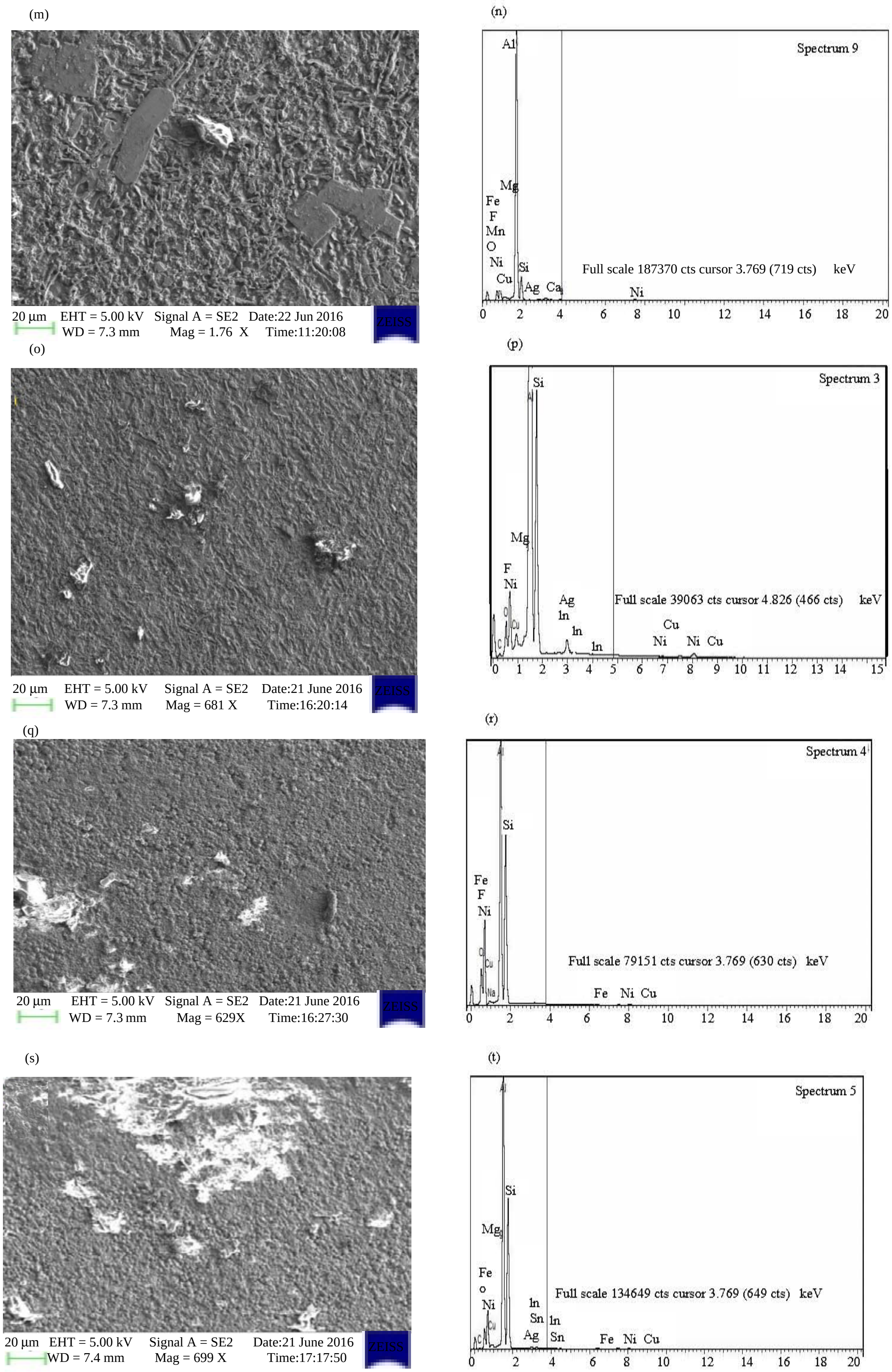

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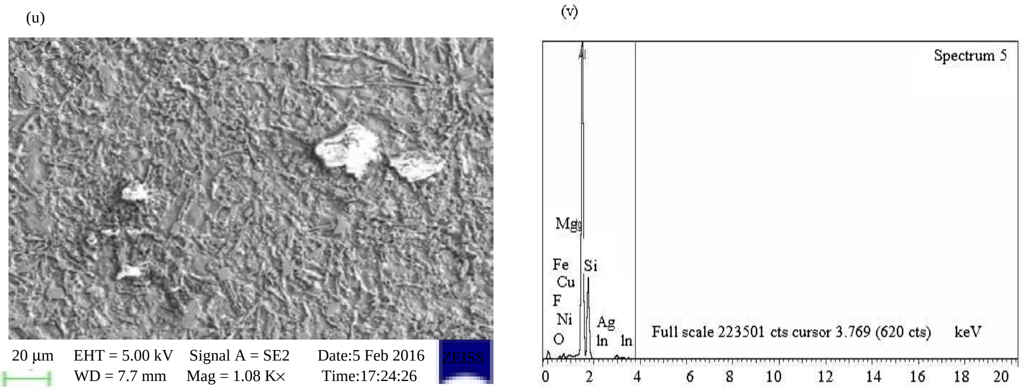

Fig. 5: SEM image and EDS pattern of metal matrix, reinforcements and composites: a, b) SEM image and EDS pattern of LM13 aluminium alloy; c, d) SEM image and EDS pattern of silicon carbide powder; e, f) SEM image and EDS pattern of graphite powder; g, h) SEM image and EDS pattern of LM13-3 wt.% SiC; i, j) SEM image and EDS pattern of LM13-6 wt.% SiC; k, l) SEM image and EDS pattern of LM13-9 wt.% SiC; m, n) SEM image and EDS pattern of LM13-12 wt.% SiC; o, p) SEM image and EDS pattern of LM13-3 wt.% SiC,4 wt.% Gr; q, r) SEM image and EDS pattern of LM13-6 wt.% SiC, 4 wt.% Gr; s, t) SEM image and EDS pattern of LM13-9 wt.% SiC, 4 wt.% Gr and u, v) SEM image and EDS pattern of LM13-12 wt.% SiC, 4 wt.% Gr

of aluminium alloy shows the high intensity peaks are formed due to the presence of aluminium, silicon, magnesium, ferrous and copper and the low intensity peaks are formed by elements such as nickel, silver, indium, carbon and oxygen, respectively. Figure 5c and d shows, the SEM and EDS image of SiC powder (25 µm). The SEM image shows, the particulates of SiC are flat, irregular shape which is in the form of chips and the peaks are formed only due to the presence of silicon and carbon elements. Figure 5e and f show the SEM and EDS image of Gr powder (37 µm). The SEM image shows, the Gr particles are agglomerated, exhibits irregular shapes that take the form of flakes of different sizes. From the EDS image, it is evident that, the Gr powder is mostly formed by the carbon element. Figure 5g-n show the SEM and EDS image of LM 13-SiC composites. Suspension of particles for more time in the matrix is highly essential to obtain homogenous distribution of particles. Compocasting is a semi solid state casting process which prevents the floating of particles during stirring at the same time it reduces the movement of the particles due to the reduction in viscosity of the slurry. This process has enhanced the distribution of particles well within the aluminium matrix. The SEM images give clear evidence that the SiC particles are homogeneously distributed within the aluminium matrix. The EDS images shows, the peaks are formed due to compounds like aluminium, magnesium, silicon, iron, nickel and copper.

Figure 5o-v show the SEM and EDS image of LM13-SiC-Gr hybrid composites. The SEM images (q and s) reveals there is a non-uniform distribution and clustering of Gr particles at some locations. The low density of Gr than the aluminium matrix causes the particles to float in the melt resulting in non-uniform distribution of particles in the composites. As the melt solidifies, the Gr particles are prevented in the direction of refined α-Al grains which resulted in the further refinement of α-Al. This has caused the agglomeration of Gr particles on which the α-Al grain is solidified. The EDS images shows, the peak are formed due to the following elements in the composite, i.e., aluminium, silicon, magnesium, nickel, copper and ferrous. The EDS results also confirm the manufactured composites are reinforced with SiC and Gr.

CONCLUSION

The following conclusions are drawn from the present investigations: the LM 13/SiC and LM 13/SiC/Gr composites were produced by compocasting process The incorporation of compocasting process has resulted in better wettability between metal matrix and reinforcements which is evident from XRD and EDS studies. Due to the addition of SiC particulates the micro hardness of composites has increased from 130-160 VHN and macro-hardness from 105-130 BHN. The micro and macro hardness decreased minimally when Gr particles is added to the composites. The ultimate tensile strength is improved by 11% due to addition of SiC and 13% due to addition of SiC and Gr in the 12.4 wt.% composite with that of the unreinforced aluminium alloy. The SiC particles are distributed homogeneously and Gr particles are agglomerated at some locations in the metal matrix via. the compocasting process. EDS analysis confirms the presence of Al, SiC and Gr in the composites.

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