An investigation on the tensile properties and micro-structure of hybrid metal matrix composites

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Abstract: In recent years, aluminium metal matrix composites (AMMCs) have emerged as a promising high class of materials. Metal matrix composites are emerging as very promising materials especially in the fields of aerospace, electrical, electronics and automotive for their various applications and technical demanding properties. In the present work, a brave is consummate to prepare and compare the tensile properties of LM25-Gr and LM25-graphite/boron carbide (B_4C) hybrid composites. The composites were primed to make use of stir casting process in which quantity of reinforcement is speckled from 4 wt% of Gr and 3 wt% of B_4C. The prepared composites are characterised by micro-structural studies and tensile properties were estimated as per the standards. The microphotographs of the composites revealed the reasonably homogeneous supply of the particles in composites with a group at a small number of places. The dispersed graphite and B_4C in LM25 alloy contributed in enhancing the tensile strength of the composites. The SEM of the illustration specifies the homogeneous supply of the reinforcement particles in the matrix without any annulled.

Keywords: metal matrix composites; aluminium alloy LM25; tensile strength; B_4C; Gr; scanning electron microscopy; SEM; stir casting; micro-structure.

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1 Introduction

Matrix material distinguishes the MMC from the unreinforced matrix in terms of increased strength, higher elastic modulus, higher service temperature, improved wear resistance, high electrical and thermal conductivity, low coefficient of thermal expansion and high vacuum environmental resistance. These properties can be attained with the proper choice of matrix and reinforcement. The main function of the matrix is to transfer and distribute the load to the reinforcement. This transfer of the load depends on the bonding which depends on the type of matrix and reinforcement and the fabrication technique (Suresh et al., 1993; Clyne, 1995).

The matrix material should be carefully chosen depending on its properties and behaviour with the reinforcement. As it is the primary constituent in MMC, the matrix alloy should be chosen only after giving careful consideration to its chemical compatibility with the reinforcement, to its ability to wet the reinforcement, and to its own characteristic properties and processing behaviour (Mehrabian et al., 1974).

Aluminium-based metal matrix composites (MMCs) have received increasing attention in recent decades as engineering materials. The introduction of a ceramic material into a metal matrix produces a composite material that results in an attractive combination of physical and mechanical properties which cannot be obtained with monolithic alloys (Christy et al., 2010).

LM25 is a common purpose alloy of aluminium is used where good mechanical properties are needed. It has a good resistance to corrosion and has a high strength. It responds well to heat treatment and is available in four different conditions. Its uses are increased by its availability in as-cast and partially heat-treated condition as well. Common applications of LM25 are electrical, food, chemical, marine for example plus numerous other wide-ranging uses. It is extensively used in the automotive sector where cylinder blocks, wheels, heads and other parts are regularly cast in this aluminium alloy. LM25 offers a good machinability (Shabani et al., 2012).

Reinforcement increases the strength, stiffness, and the temperature resistance capacity and lowers the density of MMC. In order to achieve these properties the selection depends on the type of reinforcement, its method of production and chemical compatibility with the matrix and the following aspects must be considered while selecting the reinforcement material. Reinforcements are characterised by their chemical composition, shape, dimensions, and properties as in gradient material and their volume fraction and spatial distribution in the matrix (Ahamed, 2009).

The various reinforcements that have been tried out to develop aluminium matrix composites (AMCs) are graphite, silicon carbide, titanium carbide, tungsten, boron, Al_2O_3, flyash, Zr, TiB_2. The addition of hard reinforcements such as silicon carbide, alumina, and titanium carbide improves hardness, strength and wear resistance of the composites (Baradeswaran, 2011; Suresh et al., 2003; Christy et al., 2010).

The sliding wear tests were carried out on different sizes and volume fractions of coated B_4C particles reinforced 2024 aluminium alloy composites fabricated by a squeeze casting method. The micro structural examination showed that the B_4C distributions were generally homogeneous in the matrix while some particle clustering was observed at relatively high particle containing composites (Mazahery and Shabani, 2012). The enhancement of wear resistance with a small amount of SiC and B_4C is achieved by the cooperating effect of reinforcement particles (Uthayakumar et al., 2013). The present study focuses on the influence of addition of graphite particulates as a second reinforcement on the tribological behaviour of aluminium matrix composites reinforced with SiC particulates (Suresha et al., 2010).

Comparison of the wear losses for the monolithic Al-Si7 matrix and its composites revealed that alumina fibers improved this property, but the addition of graphite improved seizure resistance. The composites reinforced with graphite fibers were less sensitive to the applied load than both the matrix and the composites reinforced with graphite flakes (Naplocha and Granat, 2008). The stir-casting manufacturing route followed by hot extrusion was utilised, being one of the cost-effective industrial methods (Shorowordi et al., 2003).

The focus of this experiment is to investigate the effects of different factors such as:

1 Tensile specimen strength.

2 Cast specimen micro-structure.

3 Tensile specimen SEM analysis of the composites. Mechanical properties were evaluated as per ASTM B-557M standards using the computerised universal testing machine.

2 Experimental details

2.1 Material selection

LM25 aluminium alloy having a density of 2.68 gm/cm^3 and protuberant properties like weight, toughness, heat conduction etc., be chosen as the base matrix due to its usage in automotive pistons. In the purpose of increasing the wear resistance of this piston alloy, B4C particles of 200 mesh sizes were choosing as reinforcement. This B4C has the lower density (2.52 gm/cm^3), higher hardness relative to SiC and Al_2O_3, excellent chemical and thermal stability (Jiang et al., 2006), which makes it as a suitable reinforcement to improve the wear performance of the alloy. this graphite density 2.26 g/cm^3 and the hardness of the composites decreases as the % of graphite (Gr) increases (Ravindran et al., 2012). The spectroscopy analysis was carried out for LM25 aluminium alloy and its chemical composition was given in Table 1.

Table 1 Chemical composition of LM 25 aluminium alloy

Elements	Si	Fe	Cu	Mn	Mg	Cr	Ni	Sn	Ti	Pb	Ca	Sb	Zn	Al
%	7.23	0.73	0.12	0.14	0.29	0.02	0.02	0.01	0.02	0.01	0	0	0.14	Balance

2.2 Preparation of composite

Stir casting process was used for the fabrication of the composite due to its cost-effectiveness (Mishra et al., 2012). Primarily matrix material was tended to the graphite crucible and melted in an electric resistance furnace. The melting of the alloy takes place in an inert gas atmosphere, which avoids chemical reaction and produces a sound casting. Subsequently attaining the molten metal condition, preheated reinforcements was added regularly to the molten metal and stirred continuously at 350 rpm for six minutes to ensure uniform distribution of reinforcement particles of molten metal. The molten metal was then poured at the temperature of 760ºC into preheated (300ºC) steel molds of dimensions 100 × 14 mm and allowed to solidify.

3 Testing of composites

3.1 Tensile strength

The micro tensile test was conceded out in harmony with ASTM B-557M standards by means of different specimens as a dimension of 50 mm length and gauge length of 30 mm as shown in Figure 1 for each MMC's family. The cast specimens are prepared by the machining as per the standard. The micro-tension was conceded out for the elongation, load capacity, tensile properties, with respect to the speed, for the sample, tensile readings recorded. The digital tensometer among two perfunctory seize is used to hold the tensile specimen as shown in Figure 2.

Figure 1 Tensile test specimen

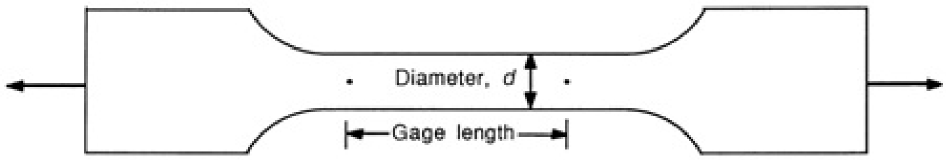


Figure 2 Digital tensometer setup (see online version for colours)

3.2 Microstructural investigation

The composite specimen remained erudite for eliminating rubbish present on the surface. Particle distribution remains estimated at the support of optical microscopes. The casting process remained inspected under the optical microscope to determine the reinforcement pattern of cast structure. A section remained cut from the castings. They remained grained using 100 grit silicon carbide paper tracked by 220, 400, 600 and 1,000 grades of emery paper before optical surveillance the samples were mechanically polished and etched by Keller's reagent to obtain a better disparity. The specimens remained pictured on diverse magnifications (100x, 200x, 400x) to display the occurrence of reinforcements and its distribution of the metal matrix diverse elements/ compounds which were present in the graphite and boron carbide are difficult to distinguish by optical micrographs.

3.3 SEM analysis

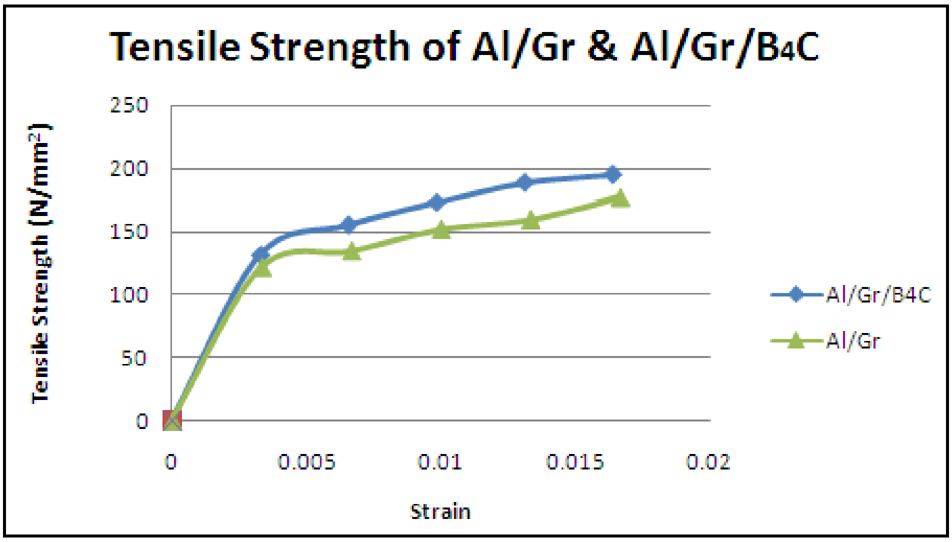
Scanning electron microscopy (SEM), also known as SEM analysis or SEM microscopy, is used very efficiently in microanalysis and failure psychotherapy of solid inorganic materials. Scanning electron microscopy is achieved at high exaggerations, engenders high-resolution imagery and accurately measures very tiny facial appearance and objects. SEM provides completed high-resolution imagery of the taster by rastering a focused electron beam across the surface and distinguishes derived or backscattered electron signal. An energy dispersive X-ray analyser is also used to endow with elemental detection and quantitative compositional information.

4 Results and discussions

4.1 Tensile test

From Figure 3, its demonstrates that the tensile strength of the composites augmented with augmenting in B_4C reinforcement, and the tensile strength is additional in hybrid composites than single reinforcement. Figure 3 shows the variation in micro tensile strength with the MMC's. While increasing the reinforcement of graphite (4%) and boron carbide (3%) load value increase gradually.

Figure 3 Tensile strength of composites (see online version for colours)

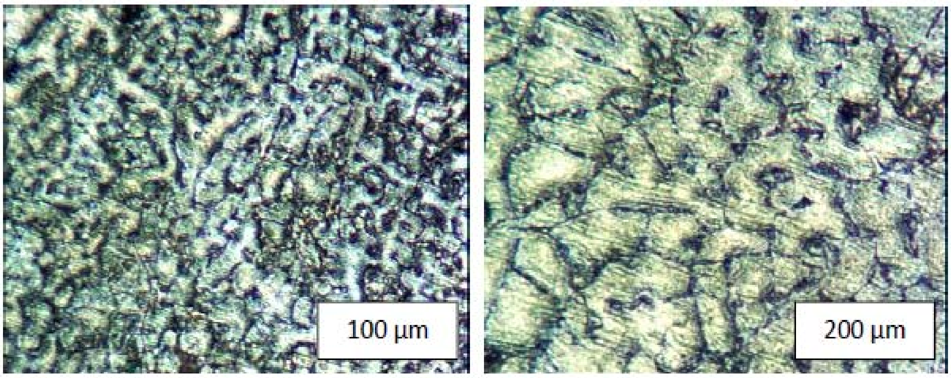


4.2 Microstructure

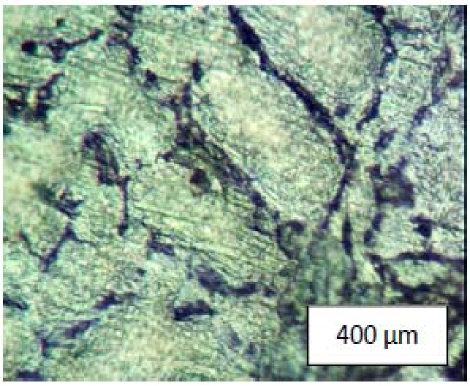
4.2.1 Microstructure of LM 25 with 4% of Gr

The optical microstructures of aluminium alloy LM 25 with a reinforcement of 4% graphite are shown in Figure 4 at different magnifications 100x, 200x and 400x. Micro structural investigation reveals that the particle distribution in the matrix was uniform. It was clear that the 4% graphite react with the aluminium and arising Al_4C_3 carbide induces corrosion and its larger volume in relation to the substrates can cause squeezing it out from the matrix to the reinforcement. This lead to breaking and degradation of the reinforcement, and finally lead to deterioration of the strength properties.

Figure 4 Optical microstructure of the aluminium alloy LM25 with 4 % Gr, (a) 100x (b) 200x and (c) 400x (see online version for colours)



(a) (b)

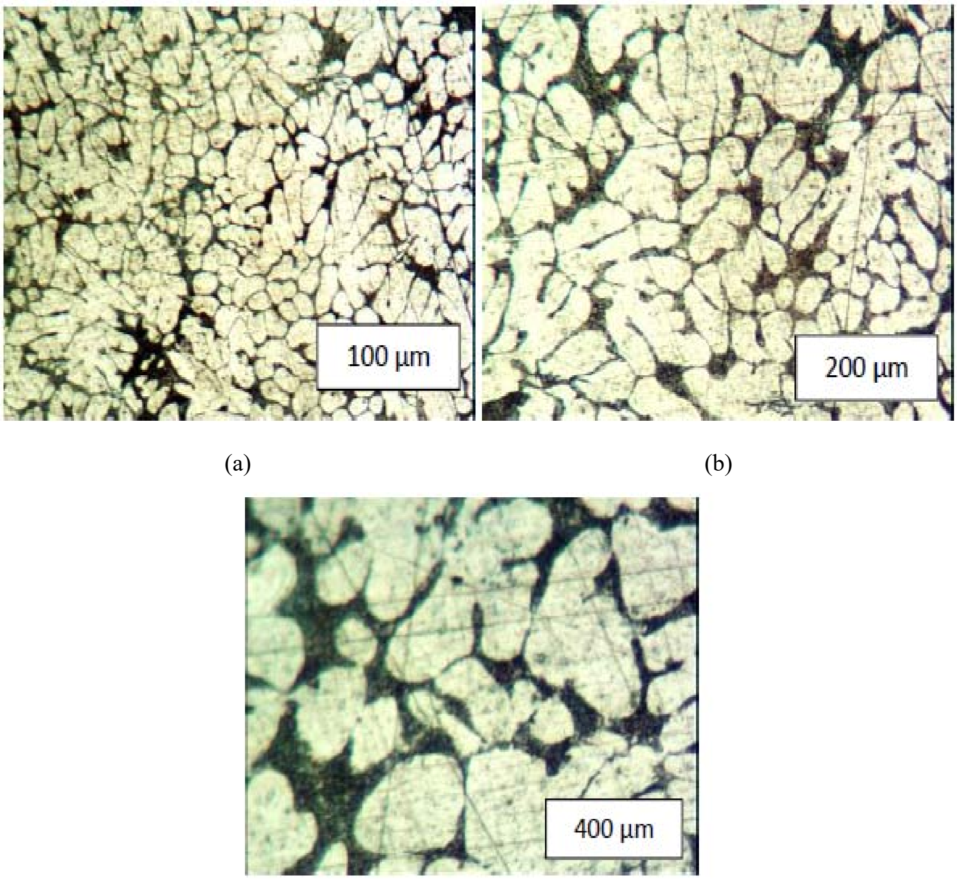


(c)

4.2.2 Microstructure of LM 25 with 4 % of Gr and 3 % of B_4C

The microstructures of pure LM 25 aluminium alloy and reinforcement 4% graphite and 3% boron carbide are shown in Figure 5 at different magnifications 100x, 200x and 400x. Micro structural investigation reveals that the particle distribution in the matrix was uniform. In this case, the presence of 3% boron adds an advantage by reducing the corrosion due to the reaction of aluminium with the graphite.

Figure 5 Optical microstructure of the aluminium alloy LM25 with 4% Gr and 3% B_4C, (a) 100x (b) 200x and (c) 400x (see online version for colours)



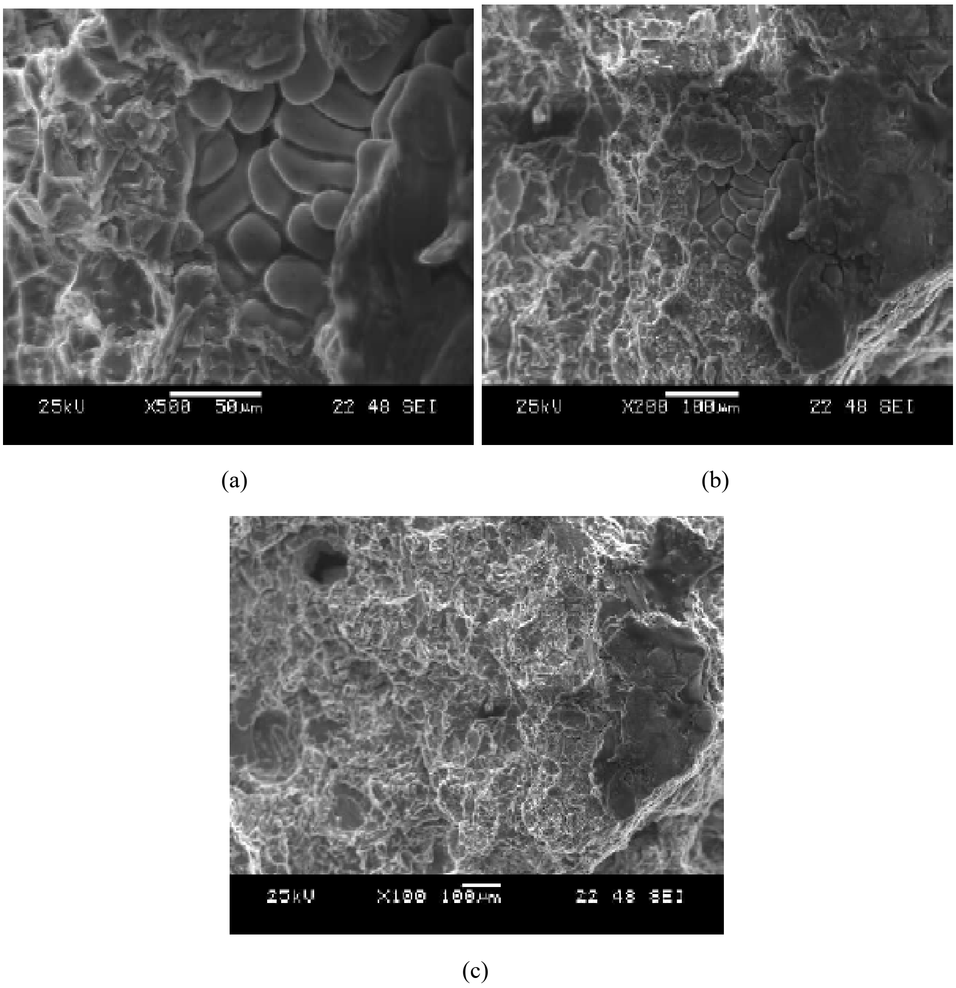
(a) (b)

(c)

4.3 SEM analysis

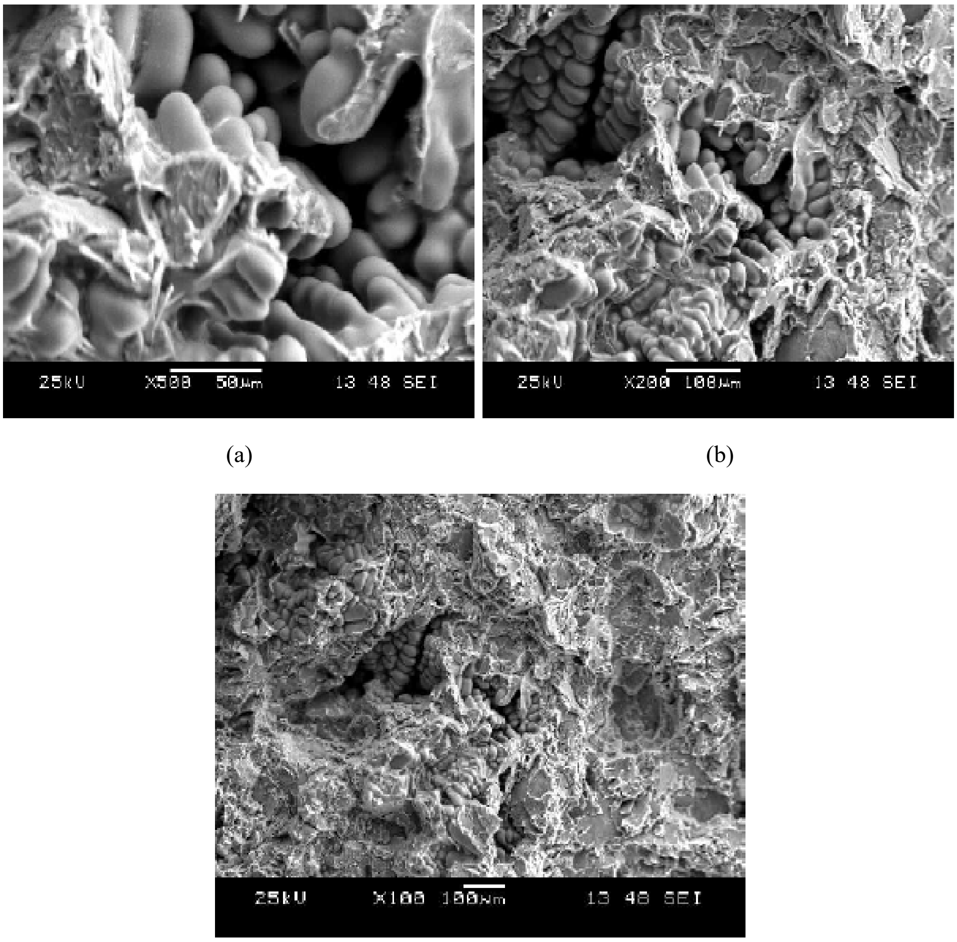
The fracture accessible in Figure 6 demonstrated a graphite flake protruding from the matrix. It seems that the graphite flake with characteristic laminar structure is detained in the matrix. The graphite surface appears to be clean devoid of any reaction products of stuck particles of the matrix material.

Figure 6 SEM micrograph of the tensile test mixture Al/4 % Gr, (a) 500x (b) 200x and (c) 100x



The SEM images of the aluminium composite are shown in Figure 7. It clearly reveals that the fracture is ductile. The grains are clearly visible as well as it is uniformly distributed. From this result, it can be concluded that the fracture initiates at the corroded part which is discussed in optical micrography. When the entitlement of boron carbide was escalating the ductility behaviour of the material is diminished slightly, it results in an increase in hardness significantly.

Figure 7 SEM micrograph of the tensile test mixture Al/4 % Gr and 3 % B_4C, (a) 500x (b) 200x and (c) 100x



(a) (b) (c)

5 Conclusions

- It has been observed that the tensile properties of the composites such as tensile strength, of the composites, are also deeply prejudiced by the adding together of reinforcement.
- The tensile strength of Gr and Gr/B_4C reinforced hybrid particulate aluminium composites was deliberated and the maximum tensile strength observed is 200 N/mm^2 at 4% of Gr and 3% of B_4C.
- The tensile behaviour of SiC/Gr reinforced hybrid composites demonstrated improved results when contrasted with single reinforcement.

- From the studies of microstructure, it divulges that the uniform distribution of reinforcing particulates takes place in the matrix.

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