Visual Abstract

Impact of nano sized SiC and Gr on mechanical properties of aerospace grade Al7075 composites

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ABSTRACT. Aluminum composites exhibit high resistance to wear and corrosion, possess high strength, offer durability and more such properties. In this study, Al7075, reinforced with nano size SiC - Gr was produced by a stir casting technique and its microstructure and mechanical behavior were evaluated. Reinforcements were added in the range of 0 - 3 wt. %. The microstructure study, tensile and compression strength of the developed hybrid Metal Matrix Composites have been analyzed and examined. From the investigational study, it was found that the reinforcements are evenly dispersed in the base material. The porosity and density of the developed composites were found to be enhanced. The mechanical properties such as ultimate tensile and compressive strength of the developed MMCs could be improved by addition of SiC particulates compared to base material. Further, the strength of developed hybrid composites was found to be decreased by adding of solid lubricant such as graphite (Gr) particulates along with hard ceramic particulates. Finally, fractured surface of the tensile test specimens were analysed using a SEM analysis.

KEYWORDS. Al7075; SiC; Gr; Stircasting; Microstructure; Tensile strength; Compression strength; SEM analysis.

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INTRODUCTION

Composites have been the subjects of a competitive and stimulating field for research from past 2-3 decades. Nowadays, instead of other engineering materials, Al is extensively used in various industries like aerospace, automobile and defence, due to its lower density, better resistance to wear and corrosion, high strength with better thermal conductivity and better machinability. As technology progresses, requirement for a stronger, harder, inexpensive and lightweight materials in the industries [1-3]. Among the different types of Al alloys, Al6061 alloy possesses better corrosion resistance and exhibits the excellent strength and also finds a lot of material applications in the areas such as commercial, automotive, and structural applications. Presently, less weight materials such as Al alloys are chosen as better material for marine industries and as well as aerospace due to better thermal and physical characteristics. MMCs from Al alloys have attracted lot of attention due to higher strength and high wear resistance. Particulates reinforced MMCs consist of uniform dispersal of strengthening hard ceramic particles embedded within a base matrix [4]. In general, these materials show better strength and good stiffness and low density, when it is compared to the matrix. The addition of hard particulates in Al MMCs can enhance the tensile strength and resistance to wear in soft Al matrix. The enhancement in mechanical characteristics is generally influenced by uniform dispersal of reinforcements and the interfacial bonding between the reinforced particulates and matrix. Generally, hard ceramic particulates such as SiC, Al_2O_3, B_4C, TiC and marble dust are used as reinforcement for several engineering applications. It is found that most of the researcher/s has studied the wear characteristics of hard ceramic reinforced Al composites. But yet the mechanical and wear behavior of Al is not adequate for the practical applications. Further, this type of Al composites exhibits enhanced mechanical properties with low-coefficient of thermal expansions. The soft particulates (Gr) impart better machinability to the base material. This provides for a wide usage of composites in automotive, aeronautical and also in thermal management applications [5-10]. The manufacture of Al matrix composites is undertaken through squeeze casting, stircasting and powder metallurgy methods. The most often used production method is the stircasting route. When considering the stircasting method, the parameters like speed of the stirrer, geometry of stirrer and stirring time are considered. The stirring must be accurate vigorous so as to ensure a uniform mixing of the reinforcements with in the matrix which in turn to increases their material properties. Suitable selection of parameters is essential to attain the end properties failing which will be resulting in reduction of material properties. From literature survey it was observed that when improper parameters were chosen and there was a decreased in the resulting materials properties. The stircasting method is cost effective and least expensive. In this method, the hard particles are added at the melting point of the matrix. The development of MMCs is very less expensive with particulates reinforcement in comparison with fiber reinforcement [11-14]. Dipankar Dey et al [15] evaluated the mechanical strength of Al 2024/SiC hybrid MMC's produced by stircasting technique. From the outcomes it was observed that the mechanical properties of hybrid composites were enhanced when compared with the base alloy. Ali M [16] conducted the experiments trials on mechanical characteristics of nano sized SiC reinforced MMCs. It was observed that the mechanical strength of the composites increased with the increase in SiC content, whereas ductility of composites decreased. Song M [17] studied the mechanical behavior of SiC/Al MMCs. It was found that the strength of material showed an increase with increasing wt. % of SiC content. Alaneme [18] investigated the mechanical characteristics of Al reinforced with hard ceramic particulates. The outcomes shown that the material properties improved and fracture was reduced by increase of wt. % of ceramic particulates content. Murlidhar Patel et al. [19] in their study, made efforts to develop an Al composite reinforced with SiC by using liquid stircasting technique. It was observed that, composites mechanical behavior improved by the adding of SiC. It is also observed that, by adding of SiC particles leds to reduction in ductility. Hashim Sh. Hammood [20] evaluated mechanical strength of MMCs reinforced with Gr. From the outcomes it was observed that the hardness and compression strength were increased upto 4% of Gr and further it is decreased significantly due to the addition of Gr content from 4% - 8% by weight. The reduction of strength may be caused by various mechanisms like the crack propagation and particle pull-out, which are instigated by the existence of solid lubricant particulates content. Lokesh K S [21] evaluated the hardness of MMCs reinforced with SiC-Gr. The hardness improved by increase in wt. % of reinforcement content. The increase in the strength of hybrid MMCs may be due to the existence of hard ceramic particulates. However, previous researcher/s have carried out material characteristics such as mechanical, wear behavior and machinability of Al metal matrix composites with SiC or Gr content as reinforcing materials. Whereas, in the case of research on Al7075 reinforced with SiC-Gr hybrid composites, inadequate literature survey is available. So effort was made to study the tensile, compression strength and fractography of Al7075 / SiC-Gr reinforced hybrid composites.

MATERIAL AND FABRICATION OF THE COMPOSITES

Reinforcements and instruments

Stircasting method is presently the simple and effective technique available for the fabrication of hybrid MMCs [22-24]. So, stircasting method has been successfully used for the production of hybrid composites. In the present research work, Al7075 was used as base matrix material and two different reinforcements such as SiC and Gr of wt. % of 1, 2 and 3 with particulates size of 75 μm mesh were used for the development of hybrid MMCs. Electric furnace was used to melt the matrix material at 800ºC. When the molten melt was ready, preheated reinforcements were added in to the melt on the required content. The stirring process was carried out continuously with speed of 100 rpm for the duration of 2 min were used during the development of MMCs. Continuous stirring process was maintained to achieve uniform distribution of reinforcements within the matrix. Latter the ready molten metal was poured in to pre-heated metallic die. After solidification, castings were removed from the die. The test samples were pre-machined by using CNC machining. Tensile test samples were prepared as per the ASTM E8 standards. Compression test sample were prepared as per the E9 standards [4, 6 & 11]. These test samples were subjected to study the micro-structure and mechanical strength. The test samples of hybrid composites are shown in the Fig. 1.

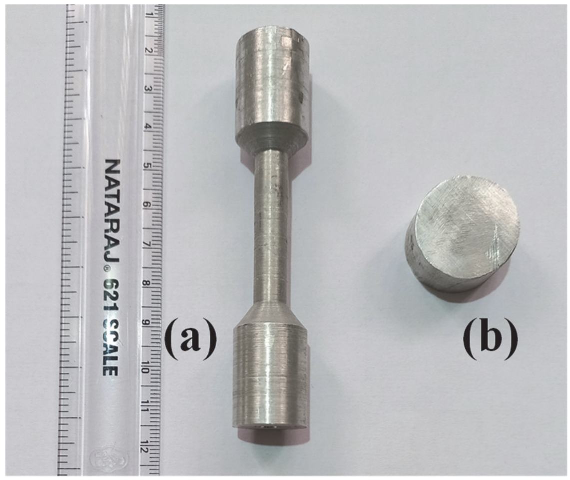

Figure 1: (a) Tensile specimen (b) Compression specimen

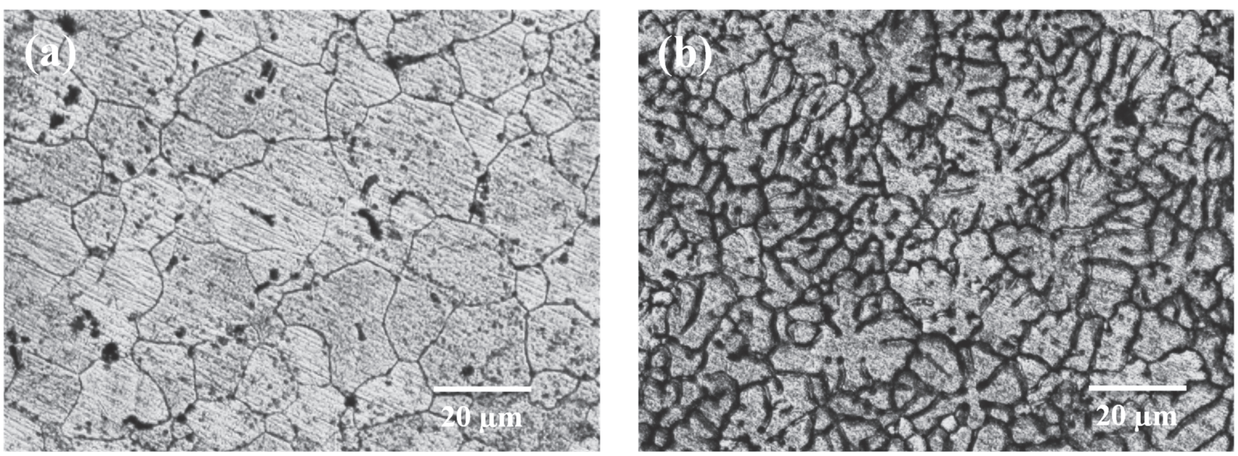

Figure 2: Optical Micrograph of (a) Pure Al alloy in as-cast condition (b) Al 7075 reinforced with 3% SiC – 1% Gr with uniform dispersal.

RESULTS AND DISCUSSION

Microstructure analysis

The microstructure depicted in Fig. 2(a) base alloy. The Fig. 2(b) shows the optical micrograph of Al 7075 reinforced with nano sized 3% SiC - 1% Gr with uniform dispersal. The reinforced particles in the MMCs are evidently resolute near the grain boundaries. It is found that, the particles are free from clustering and agglomeration due to the stircasting method adopted to fabricate the hybrid composites. Fig. 2(b) indicates the microstructure of the 3% SiC – 1% Gr indicates the grain refinement of the hybrid composites. It is due to the SiC - Gr particles free from the oxide surface which exhibits improved interfacial properties in developed hybrid composites. It can be revealed that, the grain refining in Al-7075 alloys requires the inclusion of hard ceramic particles. Consequently, developed hybrid composite production may be identified to the grain refinement process of the Al alloy caused by the addition of SiC and Gr particulates. The dispersal of hard particles in Al matrix is a vital requirement for enhancement of the mechanical strength of the hybrid composites [25-27]. The microscopic study shows that the grain around hard reinforcements is much finer when compared to the grains around reinforcements free matrix alloy. So, hard particulates can induce the recrystallization of the Al alloy by accelerating particles nucleation among the matrix and reinforcement phase. Similar outcomes have been found by other researchers [28, 29] and they concluded that, aluminium grain solidifies near by the reinforced particulates which are execution the nucleation center generally which compromises the resistance to the grain growth.

Density and porosity

Density of the samples was measured to know the level of porosity, which affect the reliability of the casting technique. The influence of reinforcements on the hybrid composite material density is given in the Eqn. (1). The density of composite samples calculated with Archimedes' principle (water displacement method).

$$\varrho_{exp} = \frac{m}{V} \ (kg/mm^3) \qquad (1)$$

where:
m = mass (kg)
V = volume of the test samples (mm^3).
Porosity can be calculated by differentiating the density values of theoretical (ϱ_{th}) and experimental (ϱ_{exp}) by Eqn. (2). Porosity level in the developed composites normally appears, due to the entrapment of air while casting. Porosity can affect the mechanical and other properties of the composite material, which cannot be removed entirely, but can be reduced by controlling the casting process.

$$\text{Porosity (\%)} = \left(\frac{\varrho th - \varrho exp}{\varrho th} \right) * 100 \qquad (2)$$

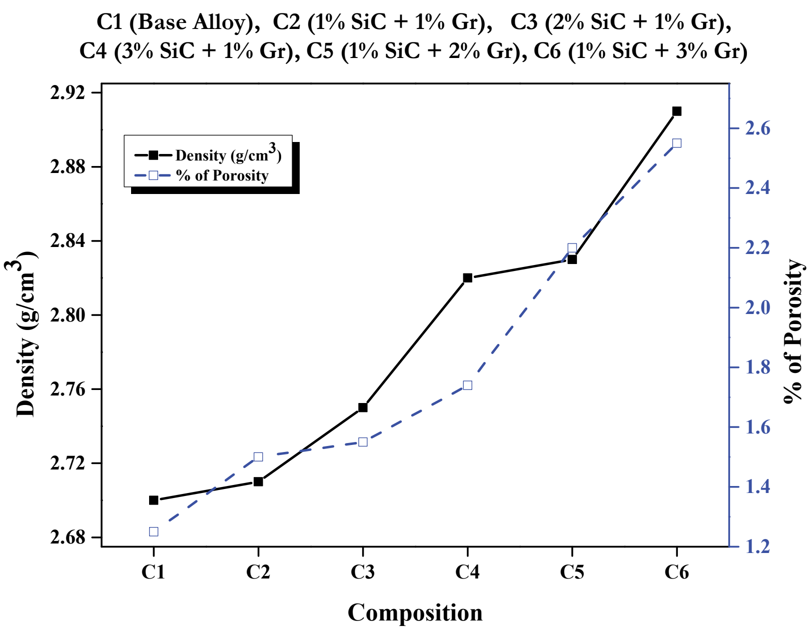

Figure 3: Effect on Density and porosity.

Fig. 3 shows the density and porosity of SiC and Gr reinforced hybrid Al composites. The outcome indicates good interface between the matrix and the reinforcements. As SiC was added to the Al mixture, it increased the sintered density. Though, density is not proportional to quantity of SiC since addition of SiC caused development of pores. Density is a measure of assessing a composites compactness and porosity. Further, density of the developed MMCs was enhanced due to the existence of Gr particulates. In developed composites, further due to adding of Gr content, it was observed that there was an increase in density when compared to matrix alloy. The enhancement of density is generally due to the existence of the denser particulates in the composites. The porosity of the developed composites was studied. The presence of porosity in the developed hybrid MMCs was because of formation of gasses with in the molten melt. It was observed that, there was absorbing of air bubbles in the molten melt and also some amount of bubbles due to the diffusion of the gas at the time of the stirring. High porosity was found at higher wt. % of reinforcement composites. This investigation results are in line with other researchers [30, 31] who developed Al MMCs reinforced with hard ceramic particles and Gr content by a stircasting method and it was observed that the porosity and density increased by increasing wt. % of Gr particulates.

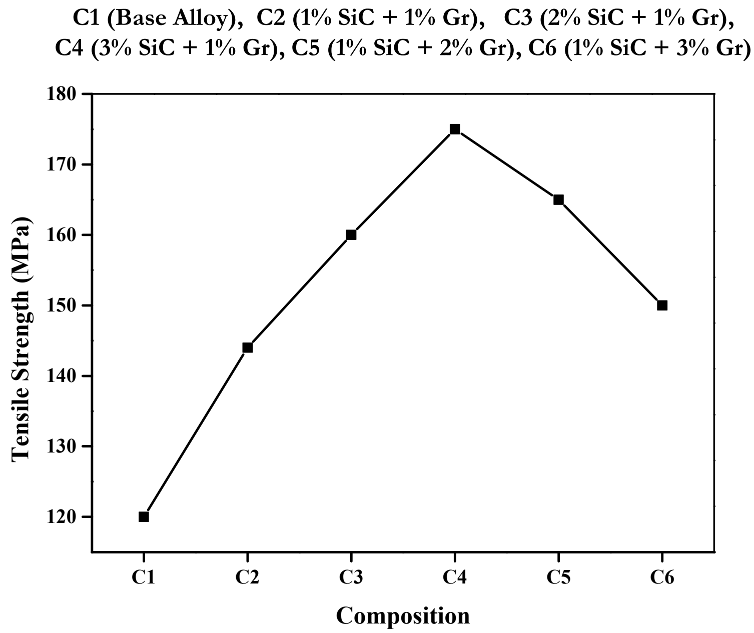

Figure 4: Tensile strength test results of monolithic and hybrid composites.

Tensile strength

Fig. 4 depicts that the tensile strength of the hybrid composites enhanced with increasing in the wt. % of SiC content. The observed results are in conformity with observations in most hard ceramic particulate reinforced MMCs [32]. The strengthening mechanisms were reported by other researcher [33] who attributed it to increased load sustaining capacity of the developed composite by increasing the wt. % of the ceramic particulates and the enhanced resistance to dislocation of movement by the particles. The strength of the developed MMCs increased because of the resistance of the dislocations and hence the MMCs strength was enhanced by increasing the content of ceramic particles. The nature of hard particulates caused an improvement in material strength. Ceramic particulates compare with the dislocations which led to enhancement in the ultimate tensile strength. Similar results were witnessed by various other investigators [34, 35]. The ultimate tensile strength improved with an increase in the SiC content which is generally ascribed to less degree of porosity and also uniform distribution of reinforced hard ceramic particles. This observation is the witnessed in the results of most ceramic particles reinforced hybrid composites. The solidification of the MMCs was higher due to the amount of reinforcement's present in matrix. Usually, this is due to the complexity involved because of addition hard particles which hinders the dislocation movements over the base matrix [36]. Further, it is seen that the decrease in tensile strength may be caused due to several mechanisms like crack propagation and the particle pull-out which are instigated by the existence of lubricant particulates. Because of Gr particles, high porosity & interfacial de-bonding of hybrid composites may result in the reduction of ultimate tensile strength. Similar results were observed by other researcher/s [37, 38] who stated that, decrease in the strength of developed MMCs may be because of porosity and presence of higher wt. % of Gr in the developed MMCs. Also, increase in wt. % Gr and reduce in wt. % of SiC particulates leads to reduction of tensile strength of developed hybrid composites. It is due to the increase of Gr reinforcement leads to adverse effect on the tensile strength of the hybrid composites. However, Gr is one of the lubricating agent materials and it helps to improve machinability characteristics of composites.

The tensile test of MMCs sample results indicated the deformations with different wt. % of ceramic reinforcement's shows the different behavior of failures. The MMCs with 3 % of SiC and 1 % of Gr shows the highest % of elongation and tensile strength when compared to the base alloy and all also other developed MMCs. After tensile tests, surface fracture tests were performed to characterize the fracture behavior as well as the relationship of the interface among the reinforcement and the matrix. SEM images of fractured surface were captured at uniform magnifications for both non-reinforced matrix and hybrid MMCs. This study enables analysis of the microstructural effects on tensile properties of developed hybrid composites. In case of hybrid MMC, it is always a brittle when compared to the base alloys. Subsequent growth of voids causes dimple rupture is related with in the fracture progression. Since ceramic particles are introduced as a reinforcing material the fracture process changes markedly. This micro-mechanism is because of change in particulates fracture and cracking along with the interface from the formation of shear crash and voids in base matrix. Fig. 5 depicts the SEM analysis of fractured samples of matrix and hybrid MMCs. Extreme ductility is desired in the fabrication of MMCs caused by micro pores on the surfaces of fractured materials. More number of dimples formations was seen on the fractured surface non-reinforced base material, which results in higher ductile strength when compared to hybrid composites. The fractographic study shows that increase in the wt. % of the SiC & Gr content changed the kind of failure from ductile to brittle. Generally, this could be clearly observed from the deformed region and dimples present within the fractured area. Due to increased hard reinforcement content, it is found that more number of micro cracks have occurred signifying decreased ductility. Generally, the topology of the fractured surfaces appears with more number of cracks and voids. The formation of voids is caused by the presence of hard particulates with soft matrix initiating the triaxial state of stress in the vicinity of a particulates. It specifies good bonding the reinforcements and matrix. Usually, the grain size and shape of reinforcements determine the bonding ability. Generally, dimple size indicates the directly proportional relationship with the composite strength. The fractured surface of tensile specimens indicates the combination of hard particulates at the interface. The combination of hard particles fracture and pullout was stated to be a fracture mechanism. The existence of hard ceramic particles on the fracture surface and as well as in micro voids also enhance the mechanical properties by improving the bonding of the matrix and decreased in the ductility. The voids at the interfaces between the particulates and matrix increased the crack propagations from their center [39-41].

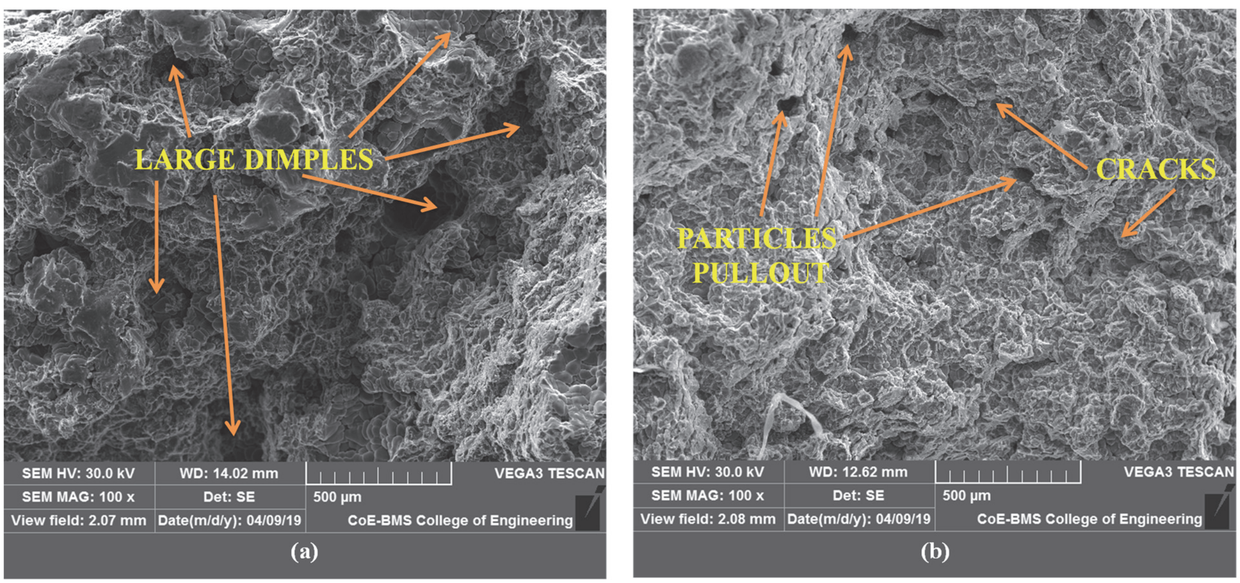

Figure 5: SEM images of fractured surface of tensile test samples (a) as-cast condition (b) Al7075 with 3% SiC - 1% Gr.

Compressive strength

It was found that, the compressive strength enhanced by increasing the wt. % of reinforcement. However, the presence of SiC content contributes to improved compressive strength as compared to base alloy (Fig. 6). Compression tests of the developed hybrid composites were done as per ASTM-E8 standards. It is concluded that the strength improved owing to the interface among the matrix and the reinforcement. The presence of stiffer reinforcement particulates in the base matrix acts like an obstacle which resists the plastic flow and motion-of-dislocations with in the base alloy. Compressive strength of developed hybrid MMCs is higher compared to monolithic owing to the homogenous distribution of reinforcing particles in Al alloy. The compressive strength of developed hybrid MMCs reduced when Gr (solid lubricant) content was increased. Researcher [6, 21] has confirmed that the solid lubricant effectively affects compression stability, though the negative results impact the robustness. The observed reduction in compressive strength may be due to the various mechanisms such as particulates pull-out and crack propagations, which are initiated by the existence of Gr content.

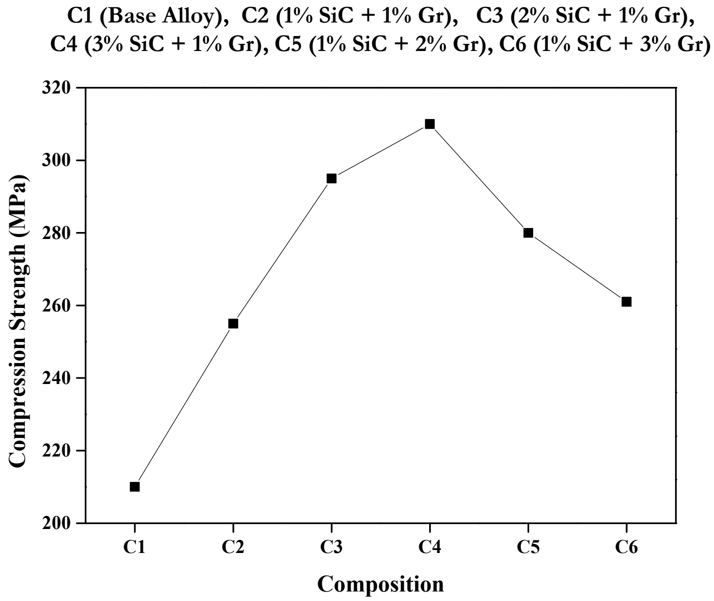

Figure 6: Compressive strength results of monolithic and hybrid composites

Conclusions

The main outcomes are shown below:

- The hybrid composite were successfully developed through stircasting process.
- Uniform dispersal of reinforcements was consistently observed from micro-structure study.
- The addition of SiC and Gr particulates helps to grain refinements of developed hybrid composites.
- Mechanical properties of hybrid MMCs increased with addition of SiC content. But on further increase in wt. % of Gr particulates decrease in mechanical strength was observed. It is confirmed that by increase in the dislocation of density, the strength of the composites can be improved.
- The reduction of ultimate tensile strength observed while increasing in Gr particles is due to high porosity & interfacial de-bonding of hybrid composites.
- Fracture mechanism shown in SEM pictures indicates higher size of dimples in base alloy. Dimples size decreased by adding of SiC-Gr particulates. Reduced dimple size is due to the grain refinement.

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