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Thermal Investigation of Aluminium – 11.8% Silicon (LM6) Reinforced SiO_2 - Particles

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Abstract. High performance automotive, aerospace, electronics and other industrial and commercial applications are finding tremendous advantages in using metal matrix composites. The reinforcement is very important because it determines the mechanical properties, cost and performance of a given composite. An excellent in mechanical properties, combined with the ease of formability and low cost makes the application of metal matrix composite of aluminium-11.8% silicon reinforced S_iO_2 to increase steadily. This paper investigates the interrelationships between thermal properties and reinforcement content, microstructure and hardness of LM6 reinforced S_iO_2 composites. Specimens were fabricated by casting technique for 5, 10, 15 and 20% weight fractions of S_iO_2 particulate and mesh of: 65 micron. The experimental results show that the thermal diffusivity and thermal conductivity decreases as S_iO_2 wt.% of the composite increases and under hardness test, it was found that the hardness value had increased gradually with the increased addition of quartz particulate by weight fraction percentage.

Introduction

The technology and evolution of metal matrix composite systems has developed over the past 20 years, with primary support from and emphasis on aerospace, airframe requirements, automotive and electronic applications. Wide variety of composite material systems with filament and tow reinforcements is available and produces the anisotropic materials and discontinuously reinforced concepts, including particulate, chopped fiber, and whisker reinforcements to create isotropic properties. Among the many reasons for the recent resurgence of interest in metal matrix composites are the engineering properties of these composites.

The special properties of MMCs can sometimes offset extremely high material costs. The use of the lower weight metal composite can increase load-bearing capabilities, reduce wear, reduce lubrication needs, and also increase output speed, all of which result in cost savings. Some manufacturers which use particulate and discontinuous fiber materials report that their costs were already competitive with those of conventional materials. The success of these composite products could make metal matrix composites a standard material for many industrial applications. Particle reinforced metal matrix composites have higher stiffness, strength and wear resistance compared to the classical alloys. They also show some advantages over other composite types due to their isotropic behaviour and forming ability by conventional methods.

Microstructural and mechanical properties of particle reinforced metal matrix composites are mainly influenced by the amount and distribution of the reinforcing particles. Yield and tensile strengths generally increase with increasing reinforcement content and will resulted in increase of the stiffness. Ductility, fracture toughness, formability and machinability decrease with increasing reinforcement content. The sizes of reinforcing particles and matrix powder decide the uniform distribution of reinforcing particles in the matrix and consequently, strength and the ability to perform secondary deformation and machining [1].

In the literature, particulate reinforcements like silicon carbide, quartz, alumina, aluminosilicates, graphite and fly ash are by products, which are readily available at an affordable cost [2]. Coconut shell char, mica, palm-kernel shell char and zircon are naturally available particulate reinforcement phases used as reinforces in metal matrix composites [3]. Further more, the potential nature of these filler materials is attractive. Silicon carbide has good thermal and chemical stability during synthesis and under severe service conditions. Specific applications of these composites include engine blocks, pistons, brake-system components, seals, wear and abrasion-resistant structures, electromechanical contacts and engine chassis components [4].

Silica sand, the most abundantly available material on the Earth's crust, was found to be a promising ceramic material owing to its high hardness, high compressive strength, good thermal stability and light weight and moreover it is cheap and easily available [5]. Reinforcing quartz particulate in aluminium-11.8 percentage silicon alloy yields a material that displays better physical and mechanical properties of both the alloy matrix and the secondary insoluble phase [6]. For example, the toughness and formability of aluminum -11% silicon alloys (LM6) can be combined with the strength of quartz particulates [7].

On a weight-adjusted basis, many aluminium and aluminium alloy based composite materials can outperform the conventional ferrous and non-ferrous materials like cast iron, steel, magnesium and virtually any other reinforced metal or alloy in a wide variety of applications. Hence, probably, metal matrix composites will replace the conventional materials in many commercial and industrial applications in the near future [8]. Fabrication of particulate and discontinuous fiber-reinforced aluminium and aluminium alloy based metal matrix composite materials can be achieved by standard metallurgical processing methods such as powder metallurgy, metal casting technology, metal-forming processes like rolling, forging and extrusion, and the composite products can be shaped, machined and drilled using conventional machining facilities [9]. Thus, they can be made available in enormous and surplus quantities for automotive and aerospace applications [10].

Since the propagation of thermal properties is sensitive to the variations in the microstructure and mechanical properties, a correlation between thermal properties, reinforcement content and microstructure could be established. In this study, LM6 reinforced S_iO_2 matrix composites were produced by using LM6 ingot and S_iO_2 powder.

Reinforcement of particulates

The improvement in toughness due to the particulate reinforcement depends on the residual stresses surrounding the particles, the weight fraction of the particles and size and shape of the particles [11]. Particles can be spherical, disk-shaped, rod shaped and plate shaped. Each particle forces the crack to go out of plane and can force the crack to deflect in more than one direction and thus increase the fracture surface energy [12]. Plate and rod shaped particles can increase the composite toughness by another mechanism called as 'pullout' and 'bridging'. The residual stress around the particles results from thermal expansion mismatch between the particles and the matrix, which helps to resist the crack propagation. The term 'particulates' is used to distinguish these materials from particle and referred as a large, diverge group of materials that consists of minute particles. The second phase particle can produce small but significant increase in toughness and consequently increases its strength through crack deflection processes. The particles, some times given a proprietary coating can be used for improving strength. When compared to whiskers-reinforcement systems, particle reinforcement systems have less processing difficulties and should permit to add higher weight fractions of the reinforcing phase. The orientation of particles appears as flat plates [13].

Materials selected for processing composites

Aluminium – 11.8% Silicon (LM6)

The materials selected in this research work are aluminium-11.8% silicon alloy containing 85.99% of aluminium, 11-13% of silicon for the matrix and SiO_2-quartz as a particulate reinforcement phase. For preparing the composite, aluminium-11.8% silicon alloy is used because it has excellent castability and fluidity. SiO_2-quartz is used as second phase reinforcement in the alloy matrix with different percentages added on it by weight fraction basis.

Quartz

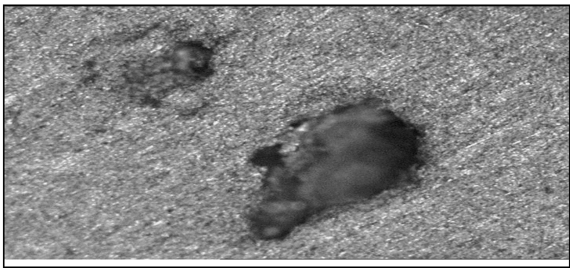
Pure and fused silica is commonly called quartz. Quartz is a hard mineral which is abundantly available as a natural resource. It has a rhombohedra crystal structure with a hardness of 7 on the Mohs scale and has a low specific gravity ranging from 2.50 to 2.66. It provides excellent hardness when incorporated into the soft lead-alloy, thereby making it better suited for applications where hardness is desirable. It also imparts good corrosion resistance and high chemical stability. It is a mineral having a composition SiO_2, which is the most common among all the materials, and occurs in the combined and uncombined states. It is estimated that 60% of the earth's crust contain $SiO_{2.}$ Sand, clays, and rocks are largely composed of small quartz crystals. SiO_2 is white in color in the purest form.

Experimental procedure

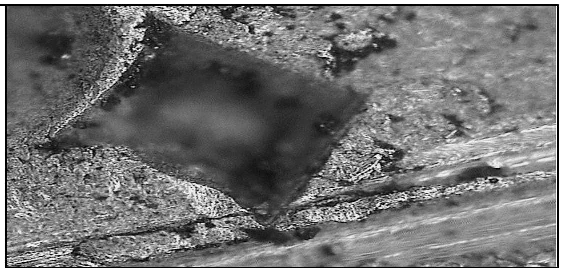
The experimental work is divided into two parts. The first part is the composite slab casting fabrication process. Testing is performed to determine the hardness, thermal properties and metallographic studies have been carried out to identify the presence of the reinforced particulate, distribution uniformity of the particulates in the alloy matrix and hence to characterize the morphological features of the processed four different types of composites. For microstructural studies, standard specimen preparation procedures are followed and Hydrofluoric acid (HF) is used as an etchant to observe the particulate distribution and to reveal the phases present in it. An inverted trinocular metallurgical microscope is used to perform the metallographic studies at different magnifications ranging from 50x and 100x and hence photomicrographs are captured for analysis.

Results and discussion

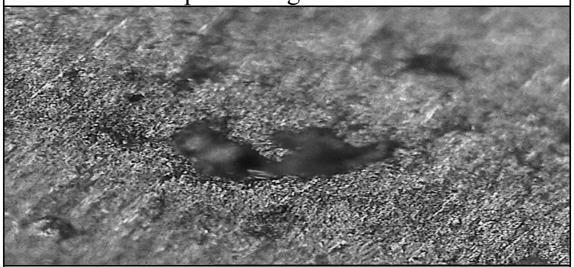
The photomicrographs in Fig. 2 indicate that the S_iO_2 particles in the matrix. A more uniform distribution was obtained when their sizes are close to each other. When coarse LM6 was used, S_iO_2 particles clustered and appeared as a continuous network surrounding the aluminium particles. The clustering tended to increase at higher S_iO_2-contents.



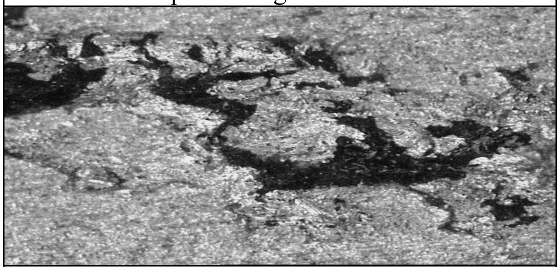
a. 5% Quartz particulate reinforced LM6 alloy composite magnified at 50x



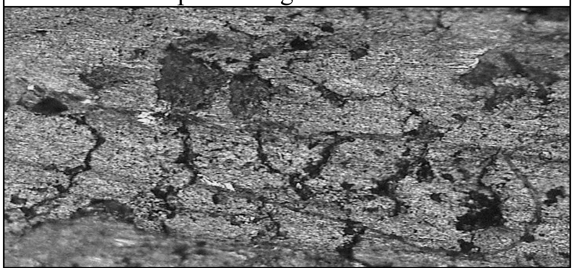
b. 10% Quartz particulate reinforced LM6 alloy composite magnified at 100x



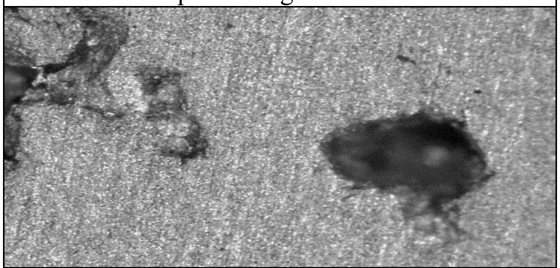
c. 15% Quartz particulate reinforced LM6 composite magnified at 100x



d. 20% Quartz particulate reinforced LM6 alloy composite magnified at 50x



e. 25% Quartz particulate reinforced LM6 alloy composite magnified at 50x



f. 30% Quartz particulate reinforced LM6 alloy composite magnified at 50x

Fig. 2 Figure shows the variation of thermal properties with respect to the SiO2 content for various size combinations of the constituent particles. An increase in the SiO2 content results in a corresponding decrease in the propagation rate of the thermal diffusivity and thermal conductivity.

Similarly, for a given S_iO_2 reinforcement content, some differences in the hardness values were observed depending upon the particle size of the constituents. The hardness value is increased gradually with the increased addition of quartz particulate by weight fraction percentage as shower in the Fig. 3.

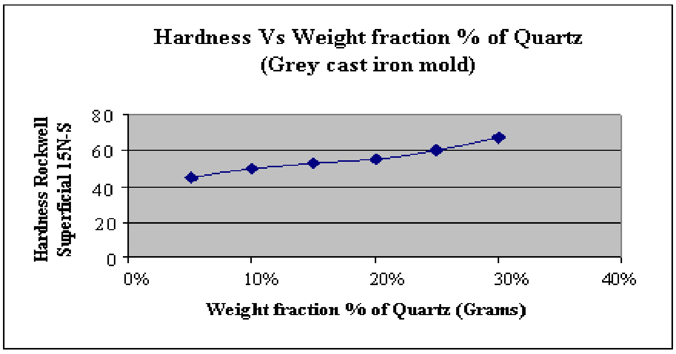


Fig. 3 Hardness Vs Wt Fraction % of quartz

The maximum hardness value obtained was based on the Rockwell superficial 15N-S scale is 67.85 for 30% weight fraction addition. These results indicate the interrelationship between thermal and hardness.

Quartz particulate reinforced composite castings made in grey cast iron mold is tested and analyzed for thermal properties. Graphs are plotted between the weight fraction % addition of quartz and thermal diffusivity and thermal conductivity values. It is found that the thermal diffusivity of the quartz composites is decreased with the increased addition in the alloy matrix. Reversely, the thermal conductivity of the quartz composites is decreased with the increased addition of quartz particulate in the alloy matrix. Quartz particulates are a ceramic reinforcement phase and on addition of this in the alloy matrix reduce the thermal conductivity. These are illustrated in the plotted graphs and are shown in Fig. 5 and 6. The thermal diffusivity and thermal conductivity for 30% weight fraction addition of quartz are 0.2306 cm^2/sec and 52.9543 W/mK respectively and it is well supported from the literature citation [1].

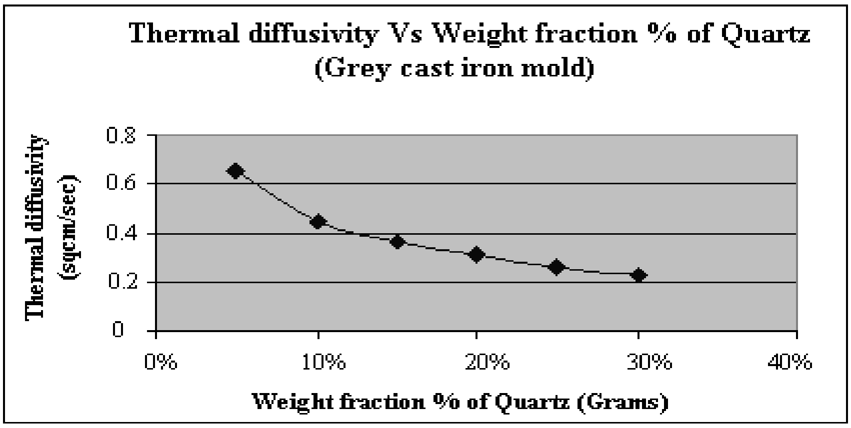


Figure 5 Thermal diffusivity Vs Wt Fraction % of quartz

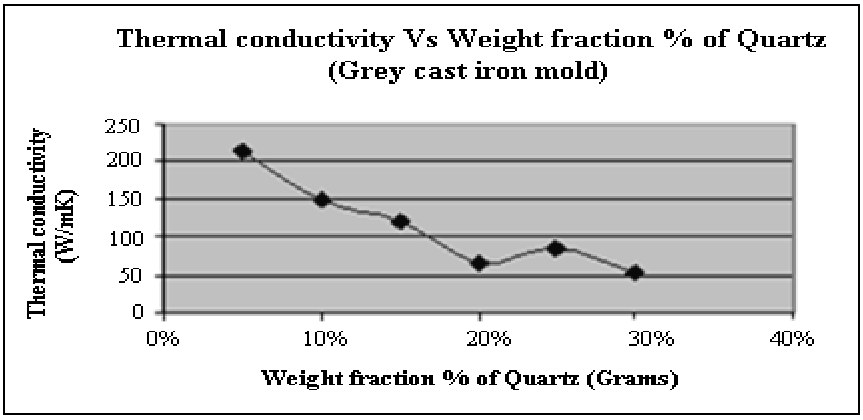


Figure 6 Thermal conductivity Vs Wt Fraction % of quartz

Conclusion

This paper presented that S_iO_2 content can be determined by measuring the thermal properties. For a given particle size combination, the thermal diffusivity and thermal conductivity decreases as S_iO_2 wt.% of the composite increases. The particle size ratio of the constituents becomes an important factor for thermal properties, especially above 10wt.% S_iO_2. A higher Al/ S_iO_2 particle size ratio results in segregation of S_iO_2 particles along the LM6 boundaries. This yields lower thermal conductivity with respect to the homogeneously distributed reinforcement. Therefore, a thermal conductivity value that is less than the expected one might be attributed to the micro-porosity in the segregated structure. Similar tendencies were also observed for the results of hardness tests.

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