

EVALUATION OF MECHANICAL BEHAVIOUR AND EFFECT OF PARTICLE SIZE ON LM26/Gr METAL MATRIX COMPOSITE

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Abstract

In automotive industries, Aluminium cast alloy (LM26) is well-renowned material in the fabrication of pistons for both diesel and petrol engines for its superior casting and mechanical properties. However, diminishing strength at higher temperatures drives metal matrix composites in cast alloys. The present study focused on the impact of naturally available ceramic particles Garnet on the microstructure and mechanical properties of Aluminium cast alloy (LM26). Samples were fabricated with varied Garnet (Wt. % of 3, 6, 9, and 12) by dual step stir casting technique. Two different particle sizes (400µm and 250µm) were incorporated to determine the effect of particle size on composite mechanical behaviour. Scanning electron microscope images unveiled the dissemination of ceramic particles inside the cast alloy matrix. It was found that ultimate tensile strength, yield strength, and impact strength were increased up to a certain Garnet percentage and started diminishing with the rise in particulate fraction for both particle sizes. However, the increase in hardness value indicates the brittleness of Metal matrix composite with the increase in ceramic reinforcement. Validation of Experimental results with theoretical values was also discussed.

Keywords: MMC, Al-Alloys, Garnet, Stir casting, Mechanical properties

Introduction

Possessing unique properties such as a high strength-to-weight ratio, high hardness and wear resistance made Aluminium alloys a material of choice for all industries (Lumley, 2011). Here is vast research going on these Al metal matrix composites to improve the material properties to meet the requirements of the present scenario. Aluminium alloy-based metal matrix composites have spread their usage significantly with different reinforcement materials such as TiC, Al₂O₃, B₄C, and SiC which resulted in improved properties

of composite over conventional alloys (Velmurugan, *et al.*, 2011; Vijaya and Srinivas, 2019). Cast aluminium alloys are extensively used in the automotive and aerospace industries for various accessories and engine components. Especially high cast ability with good fluidity, low dissolving point, and moderately low propensity for hot cracking leads the researchers to look to aluminium cast alloys. Ongoing improvements show that the body's weight decreased by 30% of vehicle weight with the substitution of steel by

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aluminium (Cole and Sherma, 1995). There is a wide assortment of LM alloys use in major engine retrofits. The vital engine component piston was manufactured by LM13 alloy which is the substitute material for LM26 by variation in silicon percentage. It is also used a wide range aluminium alloy in the piston fabrication. However the performance of LM26 at elevated temperatures is good, there is a need to improve its properties to further extension.

Superior functioning, high working temperatures, and better Tribological properties leads conventional cast alloys to metal matrix composites. (Vadghule and Kale, 2018) Has investigated the properties of LM26 Reinforced with SiC and WS₂ and found that the resistance to wear increased with increase in Silicon Carbide. (Dev and Aherwar, 2016) Studied properties of LM26 with Porcelain reinforcement stated that there is a great improvement in mechanical properties of tensile modulus and micro hardness with increase weight percent of reinforcement.

Ceramic (Kaolin particles) reinforcement in aluminium alloy composite had been fabricated and investigated by (V.S.S Venkatesh, 2020) and found the increase in mechanical by 55% than base metal. Ceramic material Garnet is the unrivalled reinforcement because of its incredible Concoction with AMC's (Schileo *et al.* 2016). Particle size is the one of Major aspect which is to be consider with garnet fortification that influence composite performance.

(Taylor *et al.*, 2015) Has characterized the Al-Si MMC reinforced with garnet of varying particle sizes and reinforcement, Inferred that the wear obstruction of the material increments with expanding in supporting element with a reduced amount of particle size. The corrosion behavior of garnet-reinforced Aluminium cast alloy was studied and found that corrosion resistance increased with garnet content. (Seah *et al.*, 2002; Mishra and Kumar, 2019) had investigated garnet properties in hybrid MMC's and concluded that Garnet is a better decision of support as far as mechanical properties are concerned. Bonding between ceramic particles and the metal matrix was influenced by particle size irrespective of composite material and preparation methods (Jarzabek *et al.*, 2016). Focusing on the dielectric and thermal properties of garnet (Sibi and Subodh, 2017) recommended garnet/HDPE composites is ideal for microwave application.

Based on previous studies only a limited amount of research has been done in the area of MMCs for piston material. Lightweight metal aluminium alloy LM26 plays a predominant role as piston material which also used as an alternate material for LM13. It also have superior thermal

conductivity than LM13. Incorporating naturally obtained freely available mineral garnet particles as reinforcement tends to improve in mechanical properties because of its chemical composition. It also proven that existing stronger reinforcements, such as SiC, TiC can be replaced by garnet. Though the density of composite increases with garnet particle size the composite provides good Tribological properties (Oh *et al.*, 2019) that are very much useful in piston application. So far major studies have been made by different researchers on piston design, piston Coatings and improving thermal properties. Fewer works have been done so far in composite materials to enhance piston material properties.

The foremost goal of this research paper is "To develop a suitable Aluminium-based material that best ensembles a Piston application" An attempt have been made in this paper to enhance the material properties of the piston by innovating the new composite material. No work has been reported so far considering LM26 as base metal fortified with non-metallic ceramic inclusion Almandine Garnet. Which is easily available, less cost mineral. Though LM26 is used as material in piston application, anticipating the impact of Almandine garnet particles and their sizes as reinforcement in LM 26 composite gives novelty to this research work. Fine Garnet particles of two varying sizes (200-250 µm) and (400-450 µm) are intricate in the procedure. Hence, a standardized method is carried out to contemplate the impact of particle size and weight percent of reinforcement on the mechanical characteristics of the composites. Samples with both particle sizes ranging weight fractions (3, 6, 9 and 12) of garnet were produced and its different mechanical properties were investigated in later sections.

Experimentation

Methodology

Figure 1. describes experimental procedures involved in this study. In the first phase the material determination is done by decision theories to select base material and in other phase experimentation is done on the prepared composite material in two sizes of particles. physical and mechanical properties were investigated as well as effect of particle size on the above properties were examined.

Materials

The material determination is a prime factor in improving the properties of composite material. Many researcher's (Kumar and Suman, 2014) implemented Decision theories in selecting the

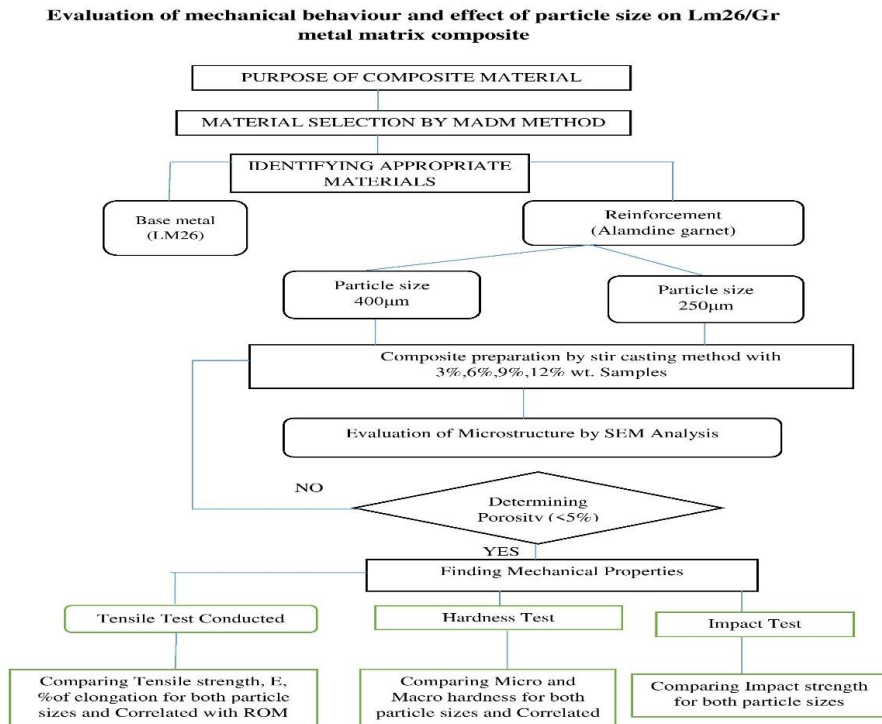


Figure 1. Proposed Methodology

Table 1. Chemical Composition of LM26 (Elements maximum wt %)

Cu	Mg	Si	Fe	Mn
2.0	0.5	8.5	1.2	0.5
Ni	Zn	Ti	Al	
1.0	1.0	0.2	rest	

Table 2. Chemical Composition of Almandine Gr

SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃
37.3	0.16	20.72	0.83
FeO	MnO	MgO	CaO
36.3	0.8	3.8	0.41

appropriate base material in automobile parts (Chaitanya and Srinivas, 2019). Among all the piston alloy materials, it is recognized that LM26 is a reliable material with good chemical and thermal stability. It was available in the form of half-kilogram cylindrical bars from a variety of aluminium sources. Vizag industry provided Almandine garnet as a granular powder made up of finely divided garnet particles of different sizes that were utilized as a reinforcement. The garnet particles were sieved into sizes of 60 and 40 mesh. Specimens with varying weights of 3, 6, 9, and 12 volumes fractions were prepared with an average particle size of 400µm and 250µm. The chemical

compositions of the base metal and reinforcement are shown in Table 1. and Table 2.

Experimental Procedure

LM26 and Almandine garnet Composite was prepared through stir casting process which was mostly used to fabricate Aluminium Metal Matrix Composites to attain better me-mechanical properties. Two steps stir casting method is employed for better blending be-tween the elements. When compared to con-ventional stirring, the resulting microstructure has been shown to be more uniform in this process. The matrix material is heated above its liquidus temperature after that, mechanical stirring is used to mix the composite particles into the melt (Bhandare and Sonawane, 2013). Samples are shown in Figure 2. At first, LM26 was melted above its melting point in an electrical furnace. And then preheated al-mandine garnet particles of two particle sizes (250µm, 400µm) at 3% of weight were added to molten LM26 slowly. Preheating process builds the wettability among matrix and reinforcement by improving the surface energy of the Strengthening molecules. Optimised pro-cess parameters are considered from (Rao, 2013). Stirring speed is one of the foremost parameters that obtains effective bonding among composite materials. The blended is driven by ½ HP AC motor at 300 rpm. The stirring temperature is maintained at around 720°C for 20 minutes. It is also a major



Figure 2. Aluminium Stir Casting Furnace



Figure 3. Composite Samples

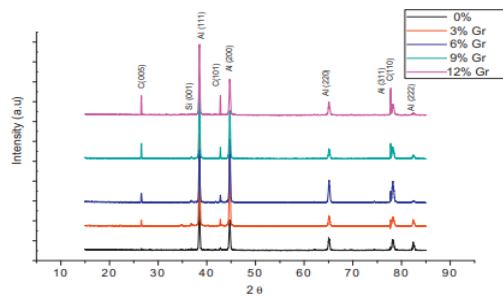


Figure 4. XRD of Composites

vari-able to be considered as it influences the viscosity of the AL matrix. Blades of two num-bers at an angle of 45° are taken during stir-ring. As given above certain optimized varia-bles should be maintained to during the pro-cedure to avoid agglomeration of particles. Workpieces that are cast for each particle size with different weight percentages shown in the underneath Figure 3.

Density and Porosity Measurement

Density and porosity measurements were done on the processed samples by Archimedes' theory. Theoretical calculations for density have been done through the rule of mixtures by immersing the samples in distilled water for every single composition from equation 1.

$$Den_c = Den_m * Vol_m + Den_p * Vol_p \quad (1)$$

Where Den_c is the density of the composite sample, Den_m - density of matrix (LM26) and Den_p - density of reinforcement particle (GARNET). Porosity in the composite material can be calculated as a ratio of bulk matrix volume that is not occupied by any of the solid particles.

$$\% \text{ porosity} = 1 - (\text{Tested Density} / \text{Empirical density}) \times 100 \quad (2)$$

Microstructural examination

The fundamental aspect that effect the composite properties is its microstructure. Microstructural delineate was done for alloy as for reinforced composites. This microscopic analysis helps in determining particle size, shape, distribution, porosity and the chemical reaction among matrix and reinforcement. Samples for this microstructural analysis were prepared by utilizing an automatic polisher to produce reflect like surface. The scanning electron microscopy (model:VEGA3 TESCA) used for analysis.

Mechanical properties evaluation

Mechanical Properties of the composite with various weight fractions of strengthening element were assessed regarding Micro hardness, Macro Hardness, Tensile properties, and impact strength. Micro hardness and Macro hardness were determined for load of 200gf and 50kg separately with a loading time of 15 sec (Broitman, 2017). Five readings were estimated on each sample at various areas and normal of all the readings were taken as hardness value. Tensile testing was done according to ASTM B 557 Standard (ASTM E8 2010) on UTM 40, FIE machine. The average reading of three values for all compositions was noted as conclusive perusing. Impact tests were conducted on composite samples as per IS:1757 standards (Leis, 2013) with v-notch for the procedure.

Results and Discussions

X Ray Diffraction Analysis

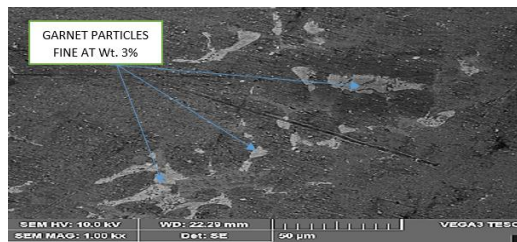
XRD Results of base metal with reinforcement can be seen in above Figure 4. The elements like Si, Al and FeO in garnet particles can be identified at the peaks. Low dispersion is observed at 12% Gr. were as cluster formation is low at remaining compositions. Porosity, non-uniform distribution may tend the properties decrease at maximum weight percent.

Composite density and porosity estimation

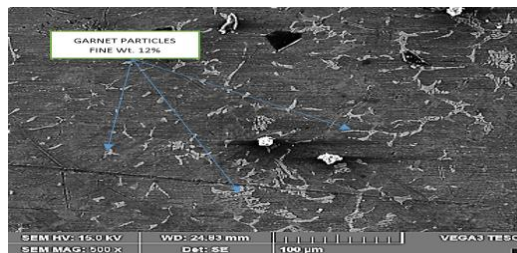
Table 3. shows the densities and porosities of prepared composite samples. The experimental

Table 3. Density and Porosity of samples with different particle sizes

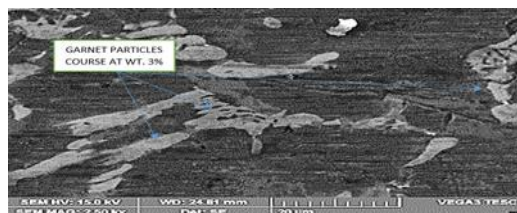
Particle Size(μm)	Reinforcement content (%)	Theoretical density (g/cm^3)	Experimental density (g/cm^3)	Porosity (%)
400	LM26	2.77	2.73	2.74
	3	2.80	2.69	3.92
	6	2.84	2.74	3.58
	9	2.88	2.79	3.14
	12	2.93	2.83	3.30
250	3	2.80	2.73	3.17
	6	2.84	2.76	3.68
	9	2.88	2.83	2.94
	12	2.93	2.87	3.10



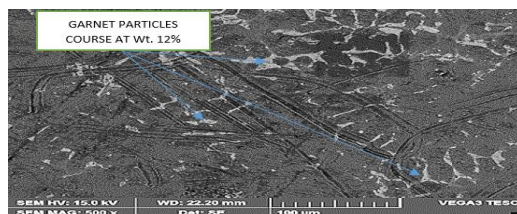
(a)



(b)



(c)



(d)

Figure 5. SEM images of composite containing different Particle sizes and Wt.% of Garnet (a) 250 μm at 3wt.% (b) 250 μm at 12wt.% (c) 400 μm at 3wt.% (d) 400 μm at 12wt.%

densities of composites with fine particles is seen to be nearer to the theoretical values (Aqida, and Hashim, 2004). The densities enhances with increment in weight percent of garnet particles. This finding can be predicted as the density of garnet particle ($4.3 \text{ g}/\text{cm}^3$) is greater than that of aluminium ($2.77 \text{ g}/\text{cm}^3$).

The effect of support (ceramic particles) and molecule size on porosity can correspond from the above Table 3. Porosity reduces with decreasing in particle size and extends with an increase in the level of reinforcement. Ob-tained samples under 4% porosity indicate few void contents in the sample. These also show the superior wettability of garnet particles toward base metals. Since porosity is the critical influencing parameter in determining the mechanical properties of MMC's more attention is required in stir casting technique in monitoring the process parameters to obtain sound casting (Kala and Sandeep, 2014).

Microstructural characterization

Figure 5. Shows the scanning electron images of fabricated MMC. Different sizes and shapes of reinforced particles can be seen on the Al matrix. Normally garnet particles sized between 400 μm and 250 μm were seen.

Figures 5(a). indicates the expansion in Particle fixation from 3 to 12 wt. % in matrix. Particles distributed were consistent along the matrix up to a certain Wt. % is noticed. Garnet particles start accumulations at 9% and above can be seen in Figure 5(b). It was observed that an increase in particle size minimizes the pileup of garnet particles at the boundaries of the matrix in Figure 5(c). and Figure 5(d).

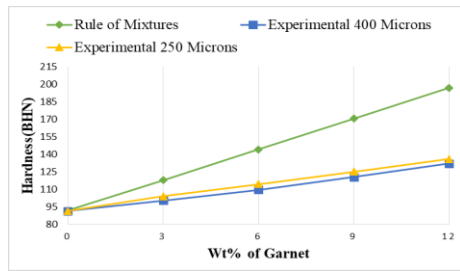
Mechanical Properties

1. Hardness

The influence of molecule size and weight level of Ceramic support on hardness can be seen in the underneath results for both hardness tests. The hardness of LM26 composite increased with an increase in wt. % of garnet particles for both particle

Table 4. Hardness behavior of Al-Gr composites produced

Wt. % of Gr	Micro Hardness (HV)		Macro Hardness (BHN)	
	400 μ m	250 μ m	400 μ m	250 μ m
0	104.4 $\pm$ 1	104.4 $\pm$ 1	91.45 $\pm$ 2	91.45 $\pm$ 2
3	113.2 $\pm$ 1	111.9 $\pm$ 2	100.33 $\pm$ 1	103.93 $\pm$ 2
6	124.8 $\pm$ 2	123.6 $\pm$ 1	109.47 $\pm$ 2	114.43 $\pm$ 4
9	131.7 $\pm$ 4	134.8 $\pm$ 3	120.53 $\pm$ 3	125.14 $\pm$ 3
12	145.4 $\pm$ 2	148.6 $\pm$ 1	132.33 $\pm$ 3	136.11 $\pm$ 4

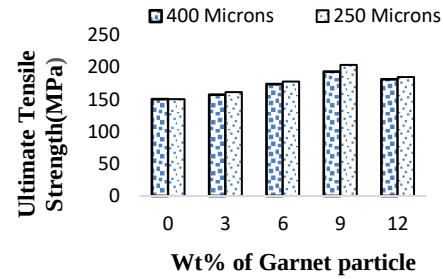
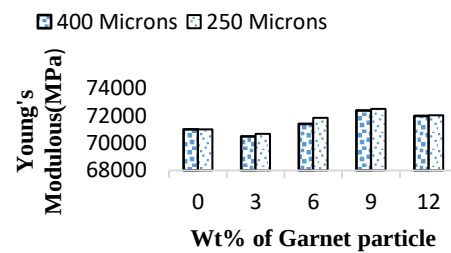
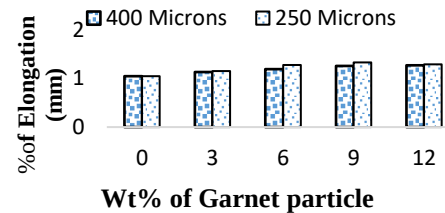
**Figure 6. Variation of Hardness by Experimental and ROM**

sizes. Table 4. clearly shows that growth in reinforced particles supports the hardness improvement in the composite as the intergranular microstructure causes hardness improvement (Venkatesh and Deoghare, 2021b). Hardness occurs as a result of an inhomogeneity between particles and the interface product, which leads to distortion at the boundaries. as the fine particles have more surface area than coarse particles they provide large interface between matrix and particles so the hardness impart by fine particles are relatively high when compared to coarse particles. Thereby inclusion of stiff ceramic particles increased the hardness value of composite up to 148HV at 12wt. % with particle size 250 μ m fortification (Rahimian *et al.*, 2010).

Section 2.4 discussed the principal rule of mixtures. By analogizing the experimental results with ROM, the accuracy of the results can be estimate. Figure 6. looks at the Brinell hardness esteems experimentally and hypothetically to guarantee the limits for the obtained qualities.

2. Mechanical behaviour: Tensile Testing

By examining the behaviour of each prepared composite sample, the test result showed that the elasticity of the as-cast MMCs produced is of a higher degree than that of the non-reinforced metal. Composite tensile strength improves with the expansion in filler content up to a 9% weight. Slightly diminishing in Elongation percentage with maximal fortification happened because of cluster formations.

**(a)****(b)****(c)****Figure 7. (a) Ultimate Tensile Strength (b) Young's Modulus (c) % of Elongation of different particle sizes reinforced with Garnet**

The presence of hard ceramic constituents such as SiO₂ and FeO accounts in approximately 70% of the reinforcement constitution, which contribute in improving the tensile strength property. These ceramic particles may serve as barriers for dislocation motion between the matrix and reinforcement grain boundaries. Tensile fracture test samples obtained indicate the brittleness of the composite showing the fracture without necking as the percentage of Ceramic content increases.

The binding between matrix and reinforcement, particle size and shape, metal constituents influence considerably on young's mod.

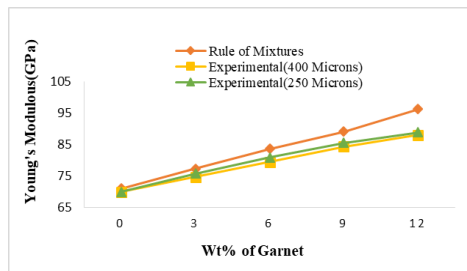


Figure 8. Comparison of Elastic modulus Experimentally and Theoretically

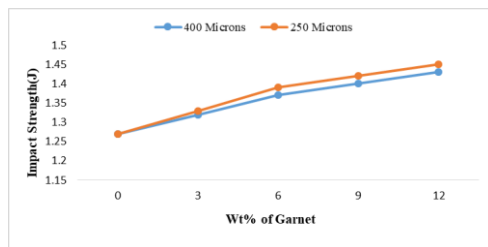


Figure 9. Impact Strength of composite

ulus (E), ultimate tensile strength (UTS), ductility (elongation, %) and yield strength of the MMC (Ahmad *et al.*, 2005).

The outcomes show that porosity and different deformities lower the yield strength of LM26/GrP400 μ m. (Venkatesh and Deoghare, 2021a) Depletion in tensile strength with the increase in weight percent of supporting particles because of the poor binding edges seen in Figure 7(a). Lopsided dispersion of particles occurs with more particle size that lower the ductility of composite.

The comparison of UTS and % elongation values can be seen in Table 5. Tensile Strength for casted LM26 is 150.59MPa. At 9% strengthening, the tensile strength increases to 193.23MPa for coarse particle size and 203.93MPa for fine grain size. Diminishing strength to 181.64MPa and 185.11MPa for both particle sizes at 12% strengthening occurs because of Cluster formations, wettability, and insufficient binding at the interface. The above factors may lead to a decrease in tensile strength at maximal weight percentage.

Usually, the load transmitting limit of the material increases with the expansion in the filler material. But in Figure 7(b). there is slight change in young's modulus at 3% reinforcement. This indicates that the binding strength is lower for the ceramic particle at that weight percentage. Though the elastic modulus of the garnet particles (Mishra, and Kumar, 2019) was more than LM26. As the load move of the burden from the framework amalgam to the hard ceramic particles.

Table 5. UTS and elongation values of Al-Gr composites produced

Wt. % of Gr	Ultimate Tensile Strength (Mpa)		% of Elongation (mm)	
	400 μ m	250 μ m	400 μ m	250 μ m
0	150.59	150.59	1.05	1.05
3	157.58	161.55	1.13	1.15
6	173.85	178.12	1.19	1.28
9	193.23	203.93	1.26	1.33
12	181.64	185.11	1.27	1.29

Ductility is one of the most significant mechanical properties of aluminium metal, which helps in making complicated motor parts in many automobile applications. It is measured by the percentage of elongation under tensile loading.

Figure 7(c). depicts the effect of the supporting element on the ductility property. It is seen that for both molecule sizes, the prolongation rate improves up to a certain weight percentage, then the prolongation rate starts to decline for both molecule sizes, though the filler content increases. This is because garnet particles impart brittleness to the base material, as garnet falls under the category of ceramic materials. The other reason may be inadequate bonding between the matrix and the reinforcement.

Experimental values of Young's modulus were compared with theoretical values to attain calibration of the obtained results in Figure 8. The vulnerability in the elastic behaviour of the strengthening element is also responsible for the difference in both practicable and determining quality.

Impact Strength

Impact test of metals gives data on failure mode under high-velocity loading conditions. It has typically been observed that the LM26 composite shows more toughness for fewer particle sizes with varying reinforcement (Das *et al.*, 2014). Though base metal falls under the category of ductile material, the failure of the composite occurs in a brittle manner because of the hard particle fortification. Reported that as a single reinforcement ceramic particles when distributed in aluminium matrix forms the stronger bonding at interfacial areas during fracture failure in impact testing. The size of the specimen at the fracture remains the same indicates that this composite material sustains impact resistance.

The impact strength of the metal matrix composite is higher than base metal due to the existence of hard and brittle garnet particles. Variations in toughness values with a change in reinforcement percentage are shown in Figure 9. Impact Strength of 1.47J happen at outrageous fortification with fine grain size.

Conclusions

In this paper, density, hardness, tensile properties, and impact strength Characteristics of Al cast alloy LM26 reinforced with 3, 6, 9, and 12 wt. % of Garnet particles were examined. Reinforcement effects on two different particle sizes (400µm and 250µm) have been established:

Inclusion of Ceramic (Garnet) particles in Al cast alloy brought an about the slight increase in the densities of the fabricated composites, and extremely low porosity level for less particle size in the composites is reminiscent of good wettability

The presence of Garnet reinforcements in the produced samples is confirmed by XRD peaks. The less porosity percentage in the samples indicate the sound castings.

The hardness of the LM26 composite increases about 40.08% as the garnet particles in the composite increment 12% by weight. This is because of hard garnet particle which causes a compact holding of the matrix.

By expanding the reinforcement ratio ultimate tensile strength, young's modulus, and ductility of the composite increased about 27.4% when the garnet content increased by 9% and by further increase decrement in the values are observed

The fine garnet particle size has more UTS and Young's modulus with maximum values of 185.1 MPa and 72 MPa. There is also an increase in the percentage of elongation by 33% for the sample containing 9% of weight fractions.

Impact strength increases for both particle sizes. Maximum strength was obtained at 12% reinforcement. As hard garnet particles impart good binding capacity towards the base metal which leads to impact strength increase.

Acknowledgement

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