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ORIGINAL PAPER

SiC Reinforcement in the Synthesis and Characterization of A356/AL_2O_3/Sic/Gr Reinforced Composite- Paving a Way for the Next Generation of Aircraft Applications

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Abstract
A356 aluminum casting alloys are used in fabrication of aircraft components where high strength is a requirement. The requirement of parts with light weight and high strength is constantly increasing. Aluminium matrix composites are considered to be new generation potential materials for many engineering applications. A356 alloy reinforced with Al_2O_3, SiC and Gr particulates with varied wt% was used to fabricate the hybrid composites by using squeeze casting method. The prepared composites were investigated for its structural and mechanical properties such as density, microstructural characterization, hardness, tensile strength, yield strength and elongation%. The composite density increased with increase in wt% of reinforcement. Microstructural examination revealed uniform distribution of reinforcement and XRD identified the presence of A356 matrix alloy and reinforcement Al_2O_3, SiC and Gr. A356/3wt%Al_2O_3/3wt%SiC/3wt%Gr exhibited superior hardness and tensile strength value of 119 BHN and 315 MPa. Gr reinforcement known for its soft characteristics compromised the addition of Al_2O_3 and SiC reinforcement towards the improved mechanical properties. The results obtained encouraged that A356 composite showed 40% improved hardness and 35%. The improved hardness and tensile strength than squeeze cast pure A356 aluminum alloy clearly shows it remains a clear substitute for aircraft components with high strength.

Keywords Silicon carbide composites · Manufacturing · Tensile strength · Hardness · Micro structural characterization · Aircraft applications

1 Introduction

In today's scenario, the aerospace manufacturers are seeking for lightweight materials for its engineering structures with better strength and corrosion resistance. Aluminium (Al) alloys are most preferred due to their high strength to weight ratio, high thermal conductivity, good corrosion resistance, easy to fabricate, and low cost. Among the Al alloys A356, 319 and 242, A356 is one of the alloy used in aerospace applications [1]. The hard particulate reinforcement added enhanced stiffness and strength, improved wear resistance and good thermal conductivity. The reinforcements used are Al_2O_3, B_4C, TiB_2, ZrO_2, SiC, Si_3N_4, TiO_2, TiC, Gr, and MgB_2 [2–12]. Most commonly used are Al_2O_3, ZrO_2, SiC and Gr [13].

The composite Al2024 fabricated using Al_2O_3 reinforcement with particle sizes 16, 32, 66 μm increased the composite hardness and tensile strength at 16 μm particle size for the volume fraction up to 10% [14]. AA2024/Al_2O_3/SiC upto 10 wt% for the 10 μm reinforcement particle size showed maximum hardness and tensile strength [15]. The graphite addition justified the addition of second reinforcement to improve the wear and overcome the machining difficulties resulting as hybrid composites. The graphite (Gr) addition in Al reported superior wear properties than matrix material [16]. A356–10 vol.% SiC composite hardness and modulus of elasticity increase with addition of magnesium exceeding 0.4% [17]. Magnesium addition increased the wettability. The addition of reinforcement to the Al matrix is justified because of ductility and low density [18].

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MMCs can be fabricated by several traditional techniques like centrifugal casting, powder metallurgy, squeeze casting, exothermic reaction process (in situ), stir casting and squeeze casting [19, 20]. Though, the near-net-shape of forming process at molten state by die casting offers the advantage of high productivity and dimensional accuracy. Porosity is the disadvantage with the process. Among these techniques available, squeeze remains the preferred and inexpensive method for development of composites [21]. Squeeze casting known as liquid metal forging solidified the molten metal by application of pressure. The closed die is located between the hydraulic press plates [22–25]. Squeeze casting technique has the advantages of less shrinkage and porosity exhibiting improved mechanical properties. It represents an ideal technique to produce light weight components with high quality and near net shape [26]. Squeeze casting showed 15–40% improvement in mechanical properties [27] with remarkable grain refinement [24].

The mechanical properties of the composites are influenced by wt%, particle size and fabrication technique. The demand from the aircraft manufacturers, seeking lightweight materials with high strength made researchers synthesize the composites in a cost effective process to study the properties of composites. This paper examines the structural characterization and mechanical properties of squeeze cast A356/Al_2O_3/SiO_2/Gr to identify its suitability for aircraft applications.

2 Experimental Procedure

The setup of the squeeze casting method utilized in the fabrication of metal matrix composites is shown in Fig. 1. Matrix material A356 alloy was chosen and reinforcement Al_2O_3 (Sigma Aldrich, 99.9%), Gr (Sigma Aldrich, 98%) and SiC (Sigma Aldrich, 97.5%) 10 μm particle sizes were used. The matrix and reinforcement composition considered for this work is shown in Table 1. A356 alloy was taken according to the given composition in the crucible and heated within the chamber at 750 °C. 1 wt% Mg is added into the liquid melt to improve the wettability of the reinforcement into the matrix. Molten Al is stirred at 250 rpm for 10 min [15] and then reinforcements preheated at 450 °C were added into the molten matrix. Squeeze cast die consists of chrome steel spacers, die, base and chrome steel plunger. The cylindrical shaped die selected minimizes leakage, supply constant pressure and ensure uniform ejection of the solidified samples. The die cavity dimension selected is 250 mm length and 50 mm diameter. The pressure applied is 100 MPa using a hydraulic plunger and at the same time maintaining the die temperature constantly at 150 °C.

Fig. 1 Bottom pouring stir casting machine with squeeze setup

Al molten alloy with reinforcement is poured into the die and squeeze pressure 100 MPa maintained for 30 s by the punch. The interface between die-metal stimulates quick heat transfer to solidify. The cast samples were then ejected from the die. Metal matrix composite heat treated at 493 °C to obtain T6 condition is quenched in the water and aged at the room temperature. According to ASTM standards, the cast samples were prepared and it mechanical properties hardness and tensile strength were studied.

Phase identification of the metal matrix composites was evaluated by studying X-ray diffraction (XRD) analyzer model XRD-3000, SEIFURT. Spectrum was obtained using a graphite monochromatic Cu-Kα radiation (λ = 1.5406 Å) in the 2θ range between 20 and 70 ° scanned at 2 °/min. Mettler Toledo ME204 apparatus (ASTM D792–91) was used to study the sample density using Archimedes principle. The cast samples cut into small pieces were weighed in air and water (Fig. 2). For different weight fractions of Al_2O_3/SiC/Gr particles theoretical density (TD) was calculated using the Eq. 1. Porosity was estimated from the difference between theoretical and observed densities of the samples. Microstructural analysis was performed on the samples to analyze their microstructure.

$$TD = \frac{1}{\frac{wt\%(AA)}{\rho\ AA} + \frac{wt\%(Al_2O_3)}{\rho Al2O3} + \frac{wt\%(SiC)}{\rho\ SiC} + \frac{wt\%(Gr)}{\rho Gr}} \quad (1)$$

Table 1 Composition of A356 composite alloys

Sample Code	A356	Al_2O_3	SiC	Gr
Pure	100	0	0	0
1% each	97	1	1	1
2% each	94	2	2	2
3%each	91	3	3	3
4% each	88	4	4	4
5% each	85	5	5	5

Fig. 2 Mettler Toledo ME204 apparatus

The hardness testing was performed on the sample prepared as per the standard ASTM 23 using a standard load 60 Kgf for the duration of 30 s used to measure the Brinell hardness number (BHN). Using the scale of penetration of an indenter, loaded on a material test-piece indentation is obtained on the specimen [28]. The value of the Brinell hardness number is calculated by using the standard formula. The well-defined indentations that make accurate measurements necessitated the need for the samples to be grinded and polished. The hardness measured at five different locations was averaged for each sample to avoid the effect of segregation of particulates. The mean value was taken to avoid the higher deviation of results not exceeding 2% of the mean value. The tensile test was conducted in a computer-controlled tensile testing machine (Shimadzu JIS Q 17025) at a cross-head speed of 0.5 mms − 1 in Fig. 3(a). Fig. 3(b) shows the test sample loaded in the UTM. The tensile test specimen mechanical behavior was studied as per the standard ASTM E08–8.

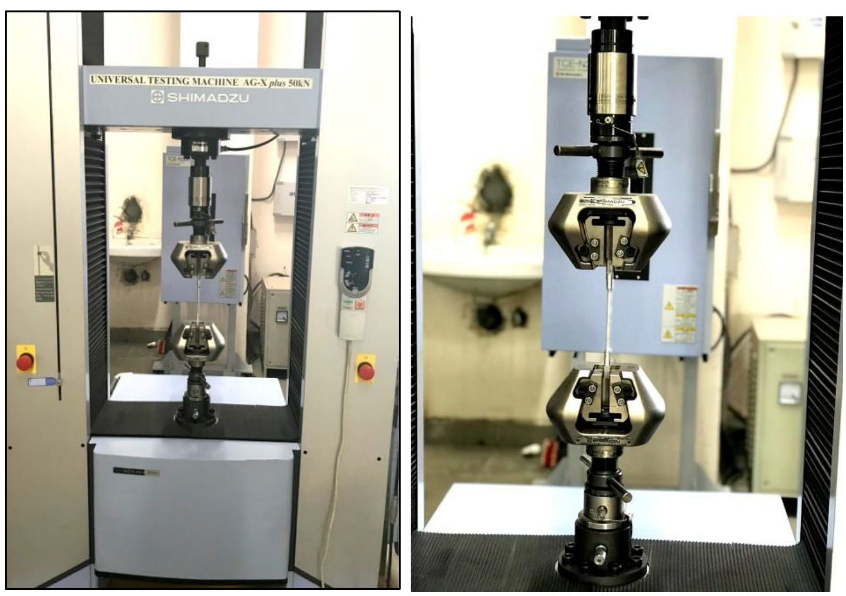
Table 2 Physical properties of composite samples

Sample Code	Density, ρ (g/cm^3)
Pure	2.672
1% each	2.678
2% each	2.687
3%each	2.695
4% each	2.704
5% each	2.712

3 Results and Discussion

3.1 Density

Table 2 shows the physical properties of the samples measured using the Eq.1. The densities of the composites evaluated and measured are shown in Fig. 4. The experimental values of densities were found to be very close to the theoretical values. This confirms the efficiency of the squeeze casting process in the fabrication of the composites. The composite density composites increased with the increase in wt% of reinforcement. The experimental density measured varied between 2.656 and 2.699. The results obtained were well supported by the results of the microstructure which shows uniform distribution with less agglomeration.



(a) Tensile testing machine; (b) Sample S6 loaded in UTM

Fig. 3 (**a**) Tensile testing machine; (**b**) Sample S6 loaded in UTM

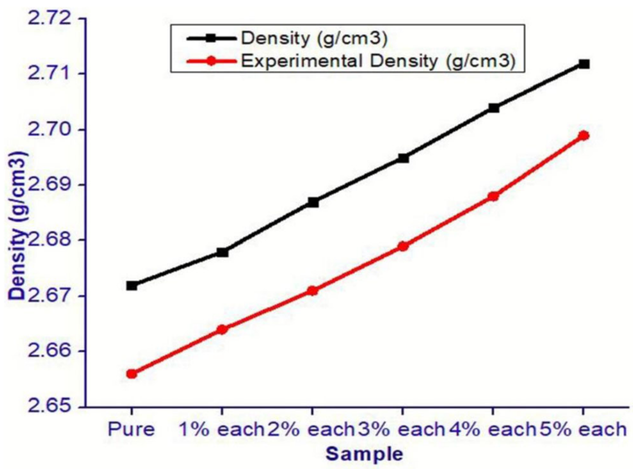


Fig. 4 The variation of density of the composites with different wt% of Al_2O_3/SiC/Gr reinforcement

It is well known that porosity in composites initiates from different processing and fabrications routes. Porosity in materials originates from different processing and synthesis routes. The porosity of the composites produced was estimated from the difference between the theoretical and experimental densities of each sample. The porosity calculated from the theoretical and the experimental densities of each sample exhibited an increase. However, the porosity calculated was found to be less than 5% in all the composite samples. This confirms the composites prepared confirm the preparations standards followed. The results obtained consistent with Alenemi et al. [29], as reported density of the hybrid composites increased with reinforcement content added. The density of the composite materials increased sharply with increase in the Al_2O_3/SiC/Gr content of the composites. This can be attributed to the fact that increasing reinforcement wt% and its agglomerates can strongly retard densification mechanisms by hindering the grain boundary movement. This is the basic difference in

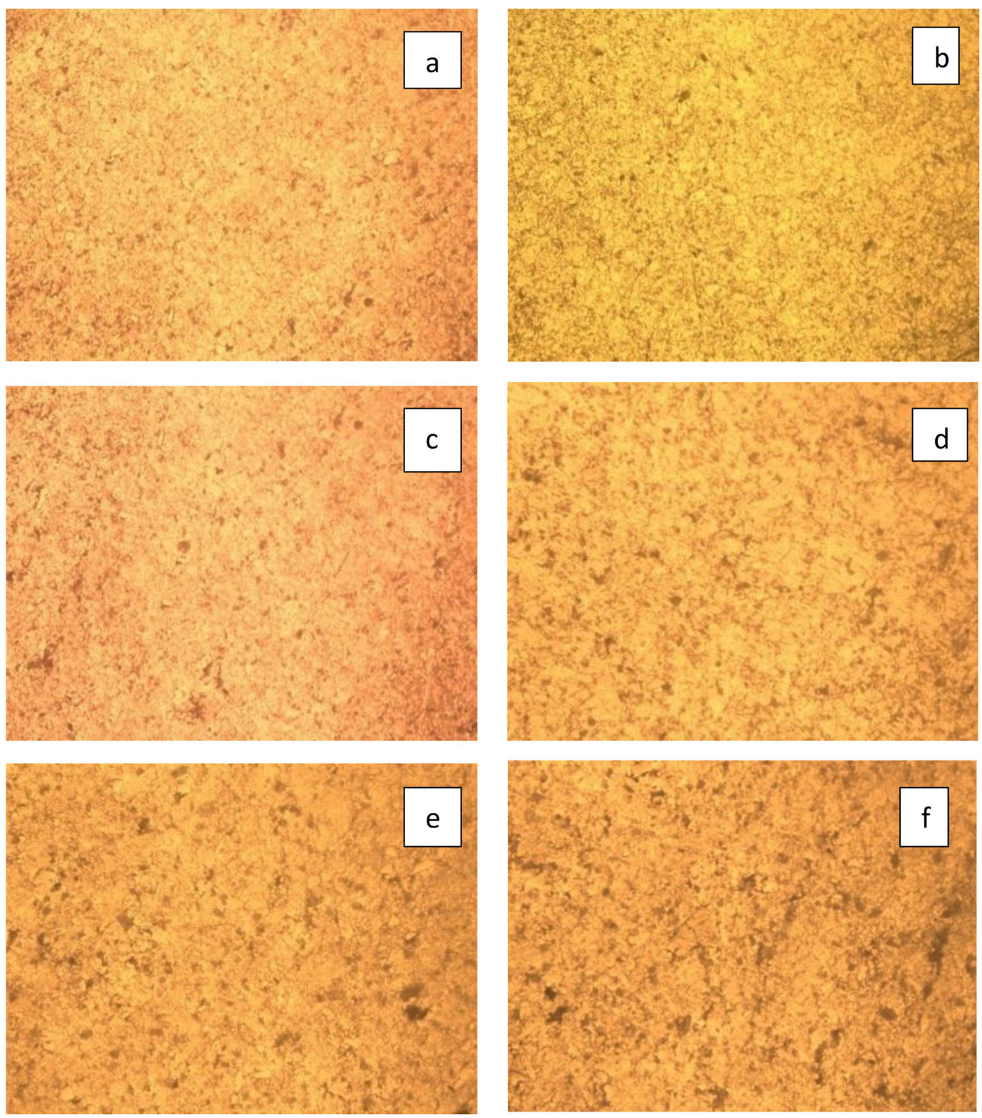


Fig. 5 Microstructure of the composite samples (**a**) Pure A356, (**b**) A356/1 wt% Al_2O_3/1wt%SiC/1wt%Gr, (**c**) A356/2wt%Al_2O_3/2wt%SiC/2wt%Gr, (**d**) A356/3wt%Al_2O_3/3wt%SiC/3wt%Gr, (**e**) A356/4 wt% Al_2O_3/4wt%SiC/4wt%Gr, and (**f**) A356/5wt%Al_2O_3/5wt%SiC/5wt%Gr

densities between theoretical and experimental. However, it must be noted that if it was porosity that was causing the poor densification.

The composite porosity was calculated using the theoretical and the experimental densities measured from the samples. It elucidated that the porosity slightly increases with the increase in wt% reinforcement.

3.2 Microstructural Characterization

It is well known that mechanical properties of hybrid composites is basically influenced by the distribution of reinforcement, size of the reinforcement, reinforcement defects, surface irregularity and reinforcement matrix bonding. This necessitated the study of microscopic analysis to understand the microstructural characteristics. Fig. 5 a –f shows the microstructure of the hybrid composites with various wt% of reinforcement. It is evident from the Fig. 4a–d that shows better bonding between the Al 356 matrix and reinforcement that forms a solid structure. The analysis shows the distribution of reinforcement is uniform, no cracks with good bonding between the reinforcement and matrix. This reveals that sequence of processing is effective in producing the hybrid composites.

3.3 XRD Analysis

In order to identify the phases present in the hybrid composites, XRD study was carried out. Fig. 6 shows the XRD pattern of micrographs of composites. Fig. 6(a-f) shows the XRD pattern for A356/Al_2O_3/SiC/Gr reinforced A356 metal matrix composite (10 m particle size). Diffraction patterns confirmed the presence of aluminium (JCPDS file # 71–4624), Al_2O_3 (JCPDS file # 71–1123), SiC (JCPDS file #29–1127) and Gr (JCPDS file # 41–1487) particles in the hybrid composite. XRD patterns show the peaks with high intensities (111), (200) and (220) for A356. The peaks for Al_2O_3, SiC and Gr increased with increase in wt% of reinforcement. The XRD pattern indicated the occurrence of A356 as the peaks with high intensity and the reinforcement Al_2O_3, SiC and Gr are indicated as minor peaks. However the absence of other peaks is mainly due to the restriction of filtered X-ray to detect the phases with less wt%. However, it is observed that slight peak shift of composites is mainly due to the incorporation of reinforcement with increasing wt%. The XRD patterns indicate the presence of Al, Al_2O_3, SiC, Al_4 C_3 and Al_4 SiC_4 phases due to the reaction between Al and SiC particulates [30, 31].

It is observed that reaction between Al and SiC at high temperatures forms Al_4 C_3 [32] and Al_4 SiC_4 known for their brittle nature tends to deteriorate the composite that affects the mechanical properties. The chemical reaction for the same is as follows.

$$4Al + SiC \rightarrow Al_4C_3 + 3Si$$

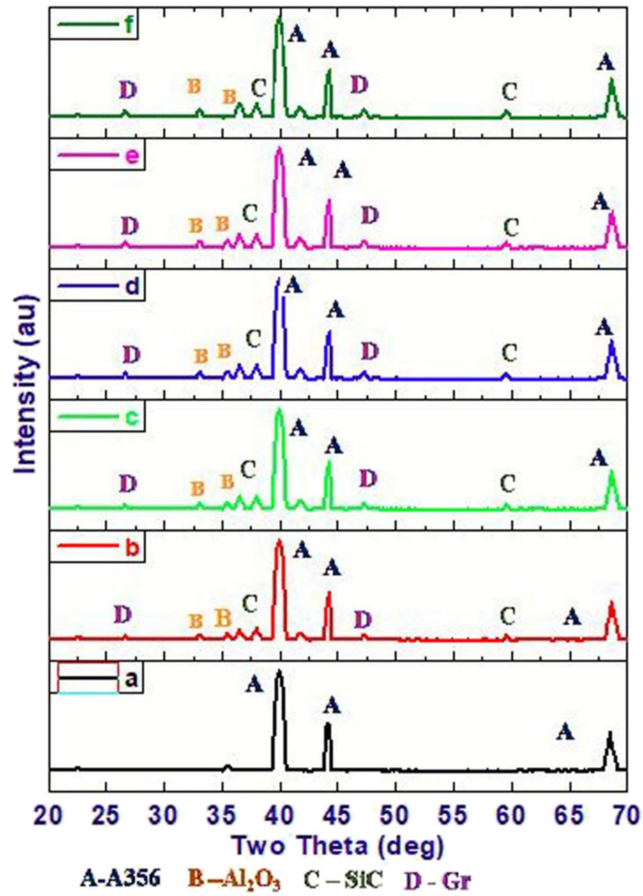


Fig. 6 XRD pattern for the composite samples (**a**) Pure A356, (**b**) A356/1 wt% Al_2O_3/1wt%SiC/1wt%Gr, (**c**) A356/2wt%Al_2O_3/2wt%SiC/2wt%Gr, (**d**) A356/3wt%Al_2O_3/3wt%SiC/3wt%Gr, (**e**) A356/4 wt% Al_2O_3/4wt%SiC/4wt%Gr, and (**f**) A356/5wt%Al_2O_3/5wt%SiC/5wt%Gr

3.4 Mechanical Properties

3.4.1 Hardness

The results of the composite samples Brinell hardness measured is shown in Fig. 7. The observation shows that the hardness varied with variation in reinforcement wt%. The squeeze cast A356 pure alloy hardness was found to be 88 HV. The composite hardness increased with increase in wt% of the reinforcement. The hardness of the composite also increased from 88 to 119 HV up to A356/3 wt% Al_2O_3/3wt%SiC/3wt%Gr. Further increasing the wt% hardness decreased to 98 HV for A356/5 wt% Al_2O_3/5wt%SiC/5wt%Gr.

Reinforcement Al_2O_3, SiC and Gr addition increased the composite hardness [33–35]. The observation shows significant increase in hardness is due to the uniform distribution of reinforcement in the matrix that resulted in the isotropic behavior and high hardness of SiC reinforced composites. This could be justified by the comparison of hardness value of reinforcement that shows noteworthy information that SiC

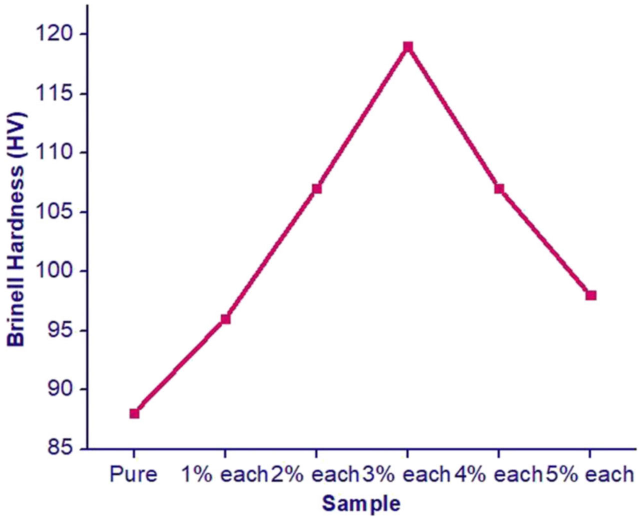


Fig. 7 The variation of hardness of the composites with different wt% of Al_2O_3/SiC/Gr reinforcement

reinforcement is harder than Al_2O_3 and Gr reinforcement. Therefore, SiC is the major contributor for the increased hardness of the composite. The reason being the reinforcement present in the composite prevents the dislocation movement which causes the increase in strain hardening. The heat treatment T4 is also the other reason that forms the precipitates which increase the hardness. The precipitate also acts like reinforcement to form barricades to the dislocation motion [36]. This indicates the hardness of A356/Al2O3/SiC/Gr composite is related to the distribution particles in the A356 alloy.

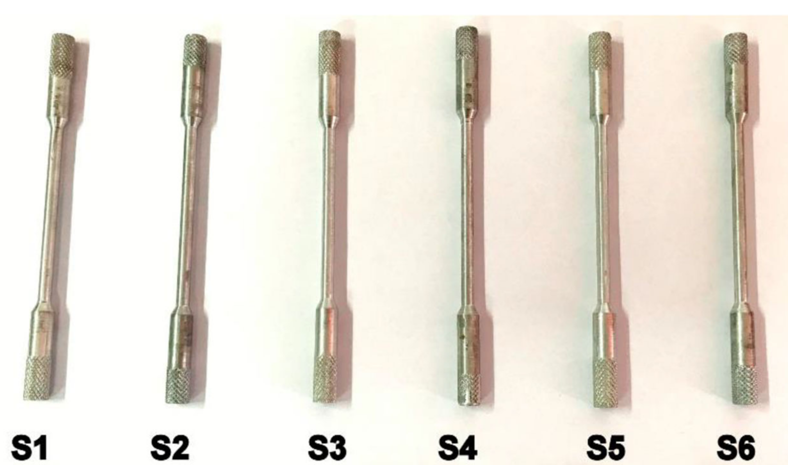
A356/3wt%Al_2O_3/3wt%SiC/3wt%Gr showed the highest hardness with 35% improvement. This shows the good wettability between the matrix and reinforcement phase is achieved. The well-known fact of composites with porosity less than 5% exhibits good mechanical behavior is justified by the hardness obtained in this work. Also the reinforcement SiC significant contribution improved the hardness of the A356/ Al_2O_3/SiC/Gr composites. Gr addition into the matrix which is known to soften the matrix along with its lubricating properties is being compromised by the addition of Al_2O_3 and SiC to improve the mechanical properties. It is due to the fact that addition of Al_2O_3 and SiC in A356 that offers good stiffness and strength to the alloy. It can be concluded A356/3wt%Al_2O_3/3 wt% SiC/3wt%Gr exhibited superior hardness. The results obtained from this research is consistent with the reinforcement SiC and Al_2O_3 in MMCs [37,38] and well supported by the reinforcement SiC contribution to the increase in hardness [39].

3.4.2 Tensile Tests

The tensile test samples for pure A356 and A356 reinforced Al_2O_3/SiC/Gr particles various wt% is shown in Fig. 8. The tensile strength and yield strength of A356 pure alloy estimated is 225 MPa and 192 MPa respectively. A356/3wt%Al_2O_3/3 wt%SiC/3wt%Gr showed highest tensile strength (Fig. 9). The tensile strength variation in the composites is due to the change in wt% of reinforcement in the matrix alloy. The reason for this increase in strength is the rule of mixtures basically accepts that there is a real transfer of the load from the matrix to the reinforcement through the interface. 1 wt% of Mg addition improved the wettability between A356 and Al_2O_3/SiC/Gr reinforcement. Mg reduced the formation of SiO_2 layer on the surface of the SiC. But it lead to the formation of MgO and Mg Al_2O_3 at the matrix-reinforcement interface.

The reinforcement comparison makes it clear that SiC is a strong reinforcement in Al356 alloy compared with Al_2O_3 and Gr. This shows that ceramic reinforcement can withstand the maximum possible tensile load. The composite A356/3wt%Al_2O_3/3wt%SiC/3wt%Gr reinforced composite showed the highest tensile strength and yield strength of 315 MPa and 262 MPa [40]. The wt% of reinforcement added above this reduced the tensile strength and yield strength marginally. Fig. 10 shows the variation in elongation % for the composite samples with different wt% of Al_2O_3/SiC/Gr

Fig. 8 Tensile test samples



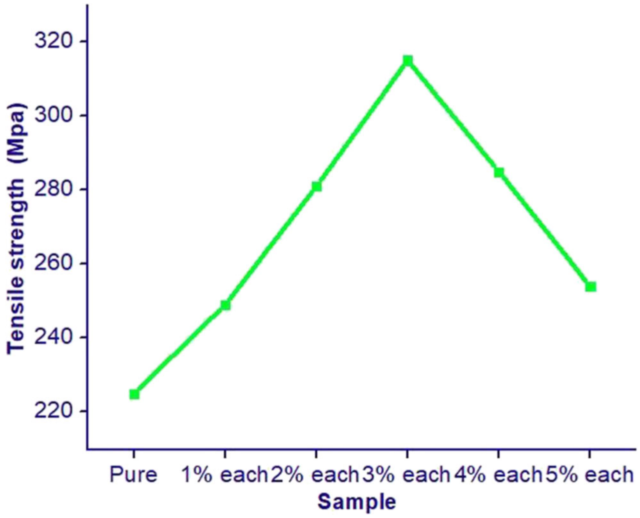


Fig. 9 The variation of tensile strength of the composites with different wt% of Al_2O_3/SiC/Gr reinforcement

reinforcement. It is observed the elongation % decreased with increase in wt% of reinforcement in the matrix alloy [41–43].

This indicated the reliability of the composite and the effectiveness of the reinforcement in strengthening the composite. The composite phenomenon of dislocation is responsible for strengthening mechanism that acts as barriers for dislocation movements. The other reason is the increase in weight fraction of Al_2O_3/ SiC harder particles that forms good bonding of particulates in metal matrix. Thereby, increasing the constraint to plastic deformation and dislocation density increased the hardness of HMMCs. The increased dislocation density was largely due to the wt% increase in SiC that impedes the dislocation motion. Our results are well supported by Lin et al. [44] who reported SiC reinforced Al matrix added strength to the composite which is responsible for increase in the tensile strength. The other reason being increasing SiC the

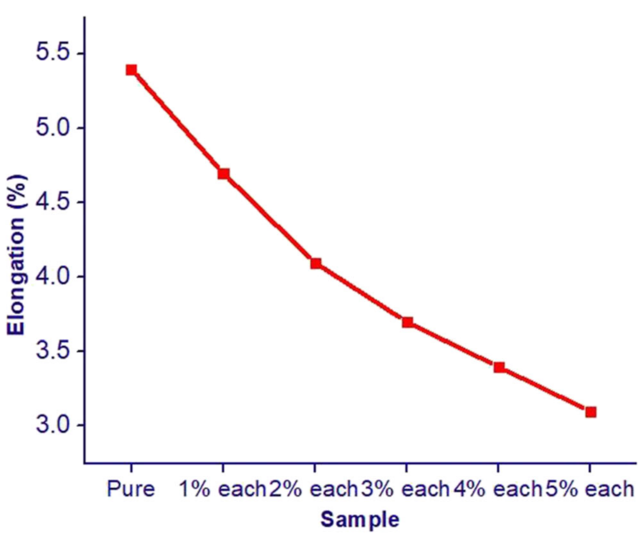


Fig. 10 The variation of elongation % of the composites with different wt% of Al_2O_3/SiC/Gr reinforcement

wt% substantially improved the tensile strength of the hybrid composites, but the ductility of the composite is decreased [45]. The tensile strength of A356/3wt%Al_2O_3/3wt%SiC/3wt%Gr improved by 35%.

4 Conclusion

A356 alloy composite reinforced with Al_2O_3, SiC and Gr particles were successfully fabricated by varying wt% by using squeeze casting process. The MMCs characterized for its density, microstructural characterization, hardness and tensile strength is summarized as follows;

- Composite density increased with increase wt% reinforcement
- Microstructure revealed the uniform distribution of reinforcement
- XRD analysis confirmed the presence of A356 matrix alloy and reinforcement Al_2O_3, SiC and Gr
- A356/3wt%Al_2O_3/3 wt% SiC/3wt%Gr exhibited Brinell hardness of 119 BHN and tensile strength of 315 MPa. The reinforcement SiC with better properties contributed to the improved mechanical properties of the composite.

The A356 composite that showed 40% improved hardness and 35% increased tensile strength than squeeze cast pure A356 aluminum alloy remains a substitute for aerospace applications.

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References

1. Dwivedi SP, Sharma S, Mishra RK (2014) A356 aluminum alloy and applications- a review. Adv Mat Manuf Charac 4:81–86
2. Mahdavi S, Akhlaghi F (2011) Effect of the graphite content on the tribological behavior of Al/gr and Al/30SiC/gr composites processed by in situ powder metallurgy (IPM) method. Tribol Lett 44(1):1–12
3. Hassani A, Bagherpour E, Qods F (2014) Influence of pores on workability of porous Al/SiC composites fabricated through powder metallurgy + mechanical alloying. J Alloys Compd 591:132–142
4. Vedani M, D'Errico FD, Gariboldi E (2006) Mechanical and fracture behaviour of aluminium-based discontinuously reinforced composites at hot working temperatures. Compos Sci Technol 66(2):343–349
5. Nemati N, Khosroshahi R, Emamy M, Zolriasatein A (2011) Investigation of microstructure, hardness and wear properties of

Al–4.5 wt.% cu–TiC nanocomposites produced by mechanical milling. Mater Des 32(7):3718–3729
6. Ruiz-Navas EM, Fogagnolo JB, Velasco F, Ruiz-Prieto JM, Froyen L (2006) One step production of aluminium matrix composite powders by mechanical alloying. Compos Part A: Appl Sci Manuf 37(11):2114–2120
7. Abdoli H, Salahi E, Farnoush H, Pourazrang K (2008) Evolutions during synthesis of Al–AlN-nanostructured composite powder by mechanical alloying. J Alloys Compd 461(1–2):166–172
8. Varol T, Canakci A, Ozsahin S (2013) Artificial neural network modeling to effect of reinforcement properties on the physical and mechanical properties of Al2024–B4C composites produced by powder metallurgy. Compos Part B: Eng 54:224–233
9. Fogagnolo JB, Velasco F, Robert MH, Torralba JM (2003) Effect of mechanical alloying on the morphology, microstructure and properties of aluminium matrix composite powders. Mater Sci Eng A 342(1–2):131–143
10. Cook BA, Peters JS, Harringa JL, Russell AM (2011) Enhanced wear resistance in AlMgB14–TiB2 composites. Wear 271(5–6): 640–646
11. Kubota M, Kaneko J, Sugamata M (2008) Properties of mechanically milled and spark plasma sintered Al–AlB2 and Al–MgB2 nano-composite materials. Mater Sci Eng A 475(1–2):96–100
12. Sivasankaran S, Sivaprasad K, Narayanasamy R, Iyer VK (2010) Synthesis, structure and sinterability of 6061 AA100−x–x wt.% TiO2 composites prepared by high-energy ball milling. J Alloys Compd 491(1–2):712–721
13. Natrayan L, Senthilkumar M, Palanikumar K (2018) Optimization of squeeze cast process parameters on mechanical properties of Al_2O_3/SiC reinforced hybrid metal matrix composites using taguchi technique. Mater Res Exp 5(6):66516
14. Kok M, Ozdin K (2007) Wear resistance of aluminum alloy and its composites reinforced by Al_2O_3 particles. J Mater Proc Technol 183:301–309
15. Senthil Kumar M, Managalaraja RV, Senthil Kumar K, Natrayan L (2019) Processing and characterization of AA2024/Al_2O_3/SiC reinforced hybrid composites using squeeze casting technique. Iranian J Mater Sci Eng 16(2):55–67
16. Rajaram G, Kumar S, Rao TS, Kamaraj M (2010) Studies on high temperature wear and its mechanism of Al-Si/ graphite conditions under dry sliding conditions. Tribol Int 43(11):2152–2158
17. Saravanan RA, Surappa MK, Pramila Bai BN (1997) Erosion of A356 Al-SiCp composites due to multiple particle impact. Wear 202(2):154–164
18. Bains PS, Sidhu SS, Payal HS (2016) Fabrication and machining of metal matrix composites: a review. Mater Manuf Proc 31:553–573
19. Anand SS, Mohan B (2012) Enhanced hardness property in the development of Al-TiC composites through P/M techniques. Adv Mater Res 548:243–249
20. Sajjadi SA, Ezatpour HR, Beygi H (2011) Microstructure and mechanical properties of Al-Al2 O3 micro and nano composites fabricated by stir casting. Mater Sci Eng A 528(29–30):8765–8771
21. Zhong Y, Su G, Yang K (2024) Microsegregation and improved methods of squeeze casting 2024 aluminum alloy. J Mater Sci Technol 19:413–416
22. Murali S, Yong MS (2010) Liquid forging of thin Al-Si structures. J Mater Sci Technol 210:1276–1281
23. Ghomashchi MR, Vikhrov A (2000) Squeeze casting: an overview. J Mater Process Technol 101:1–9
24. Vijian P, Arunachalam VP (2005) Experimental study of squeeze casting of gunmetal. J Mater Process Technol 170:32–36
25. Brito CCD, Magalhaes FD, de Morais Costa AL, Siqueira CA (2010) Microstructural analysis and tensile properties of squeeze cast Al-7%mg alloy. Mater Sci Forum 643:119–123
26. Yue TM, Chadwick GA (1996) Squeeze casting of light alloys and their composites. J Mater Process Technol 58:302–307
27. Kim SW, Durrant G, Lee J-H, Cantor B (1998) The microstructure of direct squeeze cast and gravity die cast 7050 (Al-6.2Zn-2.3Cu-2.3Mg) wrought Al alloy. J Mater Synth Process 6:75–87
28. ASTM E10 - 01E1, Standard Test Method for Brinell Hardness of Metallic Materials
29. Alaneme KK, Ademilua BO, Bodunrin MO (2013) Mechanical properties and corrosion behaviour of Aluminium hybrid composites reinforced with silicon carbide and bamboo leaf ash. Tribol Ind 35:25–35
30. Tham LM, Gupta M, Cheng L (2001) Effect of limited matrix–reinforcement interfacial reaction on enhancing the mechanical properties of aluminium–silicon carbide composites. Acta Mater 49:3243–3253
31. Shorowordi K (2003) Microstructure and interface characteristics of B4C, SiC and Al2O3 reinforced Al matrix composites: a comparative study. J Mater Process Tech 142:738–743
32. Lai SW, Chung DDL (1996) Consumption of SiC whiskers by the Al–SiC reaction in aluminium-matrix SiC whisker composites. J Mater Chem 6:469–477
33. Thakur SK, Dhindaw BK (2001) The influence of interfacial characteristics between SiCp and mg/Al metal matrix on wear coefficient of friction and micro hardness. Wear 247:191–201
34. Suresha S, Sridhara BK (2010) Effect of addition of graphite particulates on the wear behavior in aluminium–silicon carbide–graphite composites. Mater Des 31:1804–1812
35. Natrayan L, Senthil Kumar M 2018 Study on squeeze casting of aluminum matrix composites- a review. Adv Manuf mater Sci. Springer, Cham 75-83
36. Manoj S (2009) Development of aluminium based silicon carbide particulate metal matrix composite. J Miner Mater Charac Eng 8: 455–467
37. Thakur SK, Dhindaw BK (2001) Influence of interfacial characteristics between SiCp and mg/Al metal matrix on wear, coefficient of friction and microhardenss. Wear 247:199–201
38. Suresha S, Sridhara BK (2010) Effect of addition of graphite particulates on the wear behaviour in aluminium–silicon carbide–graphite composites. Mater Des 31:1804–1812
39. Sahin Y (2003) Preparation and some properties of SiC particle reinforced aluminium alloy composites. Mater Des 24:671–679
40. Myriounis DP (2009) Effects of heat treatment on microstructure and the fracture toughness of SiCp/Al alloy metal matrix composites. J Adv Mater 41:18–27
41. Umanath K, Palanikumar K, Selvamani ST (2013) Analysis of dry sliding wear behaviour of Al6061/SiC/Al_2O_3 hybrid metal matrix composites. Compos Part B-Eng 53:159–168
42. Yigezu BS, Mahapatra MM, Jha PK (2013) Infuence of reinforcement type on microstructure, hardness, and tensile properties of an aluminum alloy metal matrix composite. J Miner Mater Charac Eng 1:124–130
43. Tian J, Shobu K (2004) Fracture strength of melt-infiltrated SiC-mullite composite. J Mater Sci 39:3751–3755
44. Lin JT, Bhattacharyya D, Lane C (1995) Machinability of a silicon carbide reinforced aluminium metal matrix composite. Wear 181: 883–888
45. Rao BT (2018) An experimental investigation on mechanical and wear properties of Al7075/SiCp composites: effect of SiC content and particle size. J Tribol 140(3):031601