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Influence of Ceramic Particulate Reinforcements on Fly Ash Dispersion Strengthened Composites for Aircraft Structures

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Abstract

The present work is a comprehensive research carried out to fabricate and characterize the hybrid metal matrix composite materials by reinforcing the metal matrix of Aluminum 5083 (Al 5083), with ceramics and industrial wastes. More often than not, when no less than two reinforcements are available, it is known as a hybrid metal matrix composite and our work relevantly focuses on portrayal of these "hybrid metal matrix composites" for aerospace applications, especially for aircraft components. Aluminum metal matrix composites with ceramic particles especially "Silicon carbide particulate reinforcements" are finding expanded applications in aircraft industry. In the present work, Aluminum 5083 is utilized as the matrix material into which SiCp and fly ash particulates are included as the reinforcements. The consequences of an exploratory examination of the mechanical properties of reinforced aluminium matrix (Al 5083) composites, synthesized by stir casting are accounted in this paper. Each set decided for present work had five kinds of composite specimens with 3, 5, 7, 9 and 11 Wt. % of silicon carbide and 4 Wt. % of fly ash that is kept consistent all through, since the reinforcements in the matrix phase should not surpass 15 Wt.% . A graphite crucible and a cast iron die are utilized to prepare the composite specimens. The mechanical properties examined are the tensile strength, compressive strength, ductility and hardness. It is discovered that the tensile strength, compressive strength and hardness of the aluminum combination (Al 5083) composites increased with the increase in weight percentage of silicon carbide up, while the ductility steadily diminished with the increment in weight percentage of silicon carbide reinforcements. Morphology of the composites and dissemination of the reinforcements are explored by optical microscopy and scanning electron micrographs. The aluminium metal matrix hybrid composite, thus fabricated is characterized for its use in aircraft components, since aircraft components requires better tensile strength, compressive strength and wear resistance.

Keywords: *Aluminium, silicon, carbide, fly ash, metal, matrix, composite, hardness, wear tensile, compressive, strength*

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INTRODUCTION

A composite is a 'material' made out of a mix of at least two or more constituents at macroscopic level with distinct properties. The constituents are brought together at macroscopic level and are basically insoluble in each other [1]. "One of the constituents is called as matrix phase and the other is called reinforcement phase". Reinforcements are dispersed in the matrix phase to give the coveted attributes. The inclusions of "high strength, high modulus reinforcement particles to a ductile metal matrix deliver a material whose mechanical properties are in between the matrix and the reinforcements. "Metal matrix composites (MMCs) are the harbingers among various classes of composites". In the course of recent decades, metal matrix composites (MMCs) have been changed from a subject of logical and scholarly enthusiasm to a material of expansive mechanical and business noteworthiness. MMCs offer a one of a kind of balance between the physical and mechanical properties. It is notable that the versatile properties of the metal matrix composites are emphatically impacted by miniaturized scale auxiliary parameters of the reinforcements, for example, "shape, size, orientation, dispersion and volume or weight fraction [2]". Among the assortment of fabrication methodologies accessible for handling of discontinuous metal matrix composites, stir casting is for the most part acknowledged a role as an especially encouraging route, at present practiced worldwide economically. Its favorable circumstances lie in its effortlessness, adaptability and appropriateness to vast quantity production. It is likewise appealing in light of the fact that, on a fundamental level, it permits a traditional metal processing methodology to be utilized, and consequently limits the cost of the item [3]. 5XXX series aluminum alloys contain high level of magnesium in HCP structure at 650°C. Magnesium acts as a strengthening agent, enhances wettability of aluminum and has "high corrosion resistant" properties [4]. The difficulties and chances of aluminum matrix composites have been accounted for much better to that of its unreinforced alloy system. The introduction of reinforcements essentially enhances the tribological properties of aluminum and its alloy systems. The reasoning behind the advancement of hybrid metal matrix composites is to bring together the attractive properties of aluminum, silicon carbide and fly ash reinforcements. Aluminum alloys have valuable properties, for example, high quality, malleability, high thermal and electrical conductivity however they have low stiffness, though silicon carbide and fly ash reinforcements are stiffer and stronger and have high temperature resistance yet they are brittle in nature. Silicon carbide (SiC) particulates have achieved a prime position among the different spasmodic dispersions accessible for the combination of MMC. This is because of the way the particulates of SiC get reinforced with the aluminum matrix and the dispersions generously improve the strength, the modulus, the wear resistance and thermal stability. The density of SiCp (3.2 g/cm^3) is closer to that of aluminum alloy AA6061 (2.7g/cm^3). The protection of SiC particulates to acids, soluble bases or liquid salts up to 800°C makes it a decent support contender for aluminum based MMC. Moreover, SiCp is effortlessly accessible and has great wettability with aluminum combinations [5–11]. The product of combustion of coal in thermal power plants namely fly ash, is an undeniably critical issue related with their "storage and disposal". Then again, fly ash particulates exhibit a novel regular wellspring of the particulate material for light-weight minimal effort composites. This is a result of the blend of its low cost alongside low density, appealing physical and mechanical properties, and spheroidal shape, which is extremely costly to create in a simulated way. Along these lines, literature on the reactivity of fly ash remains with different liquid metal is of high functional significance [12]. The application of ceramic particulate reinforced composites in aerospace applications is rapidly increasing [13] due to the excellent properties in regard to strength characteristics, stiffness and wear resistance [14, 15]. The evolution of composite materials in regard to applications in aircraft components has incorporated the use of ceramics as the reinforcements to the aluminium alloys and has led to further strengthening of the structural elements of the wings and fuselages [16–18].

MATERIALS AND METHODS

Selection of Material and Composition

Aluminium 5083 is a corrosion resistant alloy with magnesium as the major alloying constituent alongside traces of "Silicon, copper, manganese, titanium, chromium and zinc", It has the highest strength among all the non-heat treatable alloys, The required amount of "metallurgical grade 99.7% pure" Al 5083 alloy in the form of billets were sourced from perfect metal corporation, Bangalore and further it was discretized into small sized pieces for facilitating the easy melting of the alloy in the graphite crucible in the stir casting furnace. Silicon carbide particulates of 25–40 micron size were sourced from "Snam Abrasives" and analyzed for the particle size in the particle size analyzer, while the "C – type fly ash with lower bulk specific gravity designated as ASTM C618" was sourced from Raichur Thermal Power Station (RTPS). A vast review of available literature on the aluminium metal matrix composites has given sufficient rationale for proportionately fixing the composition, such that the reinforcements doesn't exceed 15% by weight (Table 1).

Table 1: *Weight Composition of the Different Composite Specimens.*

Specimen	Al 5083	SiC	Fly ash
A1	92	3	4
A2	90	5	4
A3	88	7	4
A4	86	9	4
A5	84	11	4

Processing of Composite Rods

Composites were synthesized in electrical resistance heater setup with vortex generator that is casually alluded to as stir casting furnace. The graphite crucible was stacked with ascertained amount of Al 5083 alloy and the temperature was kept up at 850°C which is 200°C more than the melting temperature of Al 5083 alloy. After Al 5083 alloy was melted, successful de-gassification was accomplished by including hexachloroethane tablets in the liquid metal. The slag formed on the surface of liquid metal was scooped out. This liquid metal with all the slag removed was later strengthened with preheated blend of silicon carbide and fly ash reinforcements. The high degree of dispersion of weighted amount of the preheated reinforcement particles in the liquid metal was accomplished by steady blending of the blend utilizing a vortex generator i.e. aggregate sum of reinforcements required was computed and brought into dissolved state in 3 stages for ensuring better wettability of the reinforcements. At each stage, when reinforcement particles are dispersed, the mechanical mixing of the liquid metal was carried out for duration of 20 minutes by utilizing zirconium-covered steel impeller. The stirrer was preheated before inundating into the molten metal, and then immersed roughly to the profundity of 2/3 of the level of the liquid metal from the base and stirred continuously at a speed of 400 rpm. The liquid metal matrix composite thus obtained was poured into the die and allowed to solidify. The dies were initially preheated to facilitate easy removal of the composite rods. The composite rods thus obtained had a diameter of 22 mm and length of 220 mm.

ASTM Specimens

The specimens for tensile, compression and hardness tests were machined as per ASTM standards. The specimen for tensile test was prepared as per the ASTM E8-95 standards. The specimens were machined to a diameter 12.5 mm and gauge length of 62.5 mm from the cast composites with the "gauge length of the specimens parallel to the longitudinal axis of the casting". The compression specimens were machined to ASTM E9 standards. The specimens selected for compression test were having a diameter of 15 mm and length 20mm. The Brinell hardness test was carried out as per ASTM E10 standards on the specimens of the dimensions of 15 mm diameter and 20 mm length (i.e. compression test specimens). The typical drawings of tensile test and compression test specimens are as shown in Figures 1 and 2.

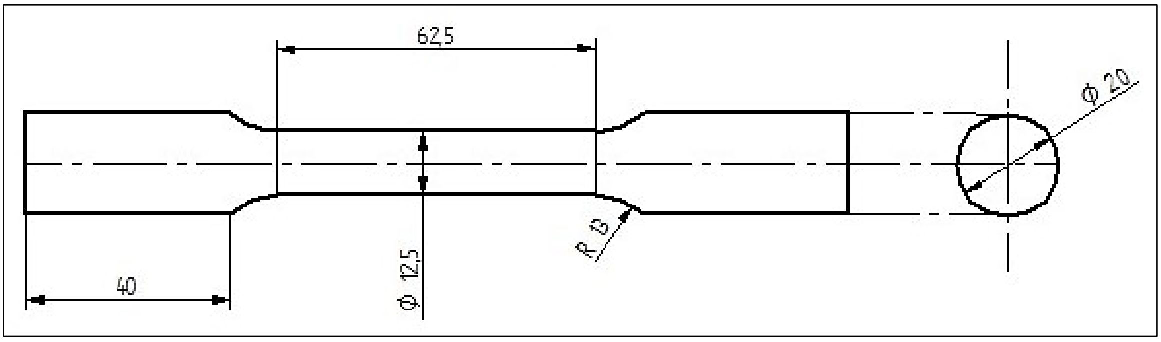

Fig. 1: *Draft of Tensile Test Specimen.*

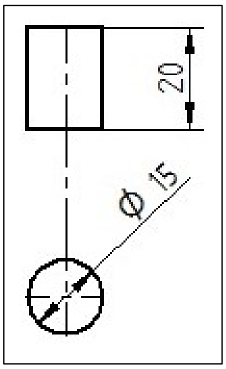

Fig. 2: *Draft of Compression Test Specimen.*

RESULTS AND DISCUSSIONS

The following is discussed as under:

Tensile Tests

Tensile testing, otherwise called strain testing, is a fundamental type of material testing in which the specimen is subjected to controlled loading conditions. Properties that are straightforward estimated through a tensile test are "ultimate tensile strength, breaking strength, maximum elongation and reduction in area". From these estimations, the accompanying properties that can likewise be resolved are "Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics". Uniaxial and Biaxial tensile testing are the most normally utilized tests for getting the mechanical attributes of isotropic materials. The tensile tests are carried out on Instron make 600 kN hydraulic operated universal testing machine as per ASTM E8-95 standards. The results of tensile tests are tabulated and plotted as a graph to obtain the graph of weight percentage of silicon carbide versus tensile strength in MPa and weight percentage of silicon carbide versus ductility in % elongation, The tensile strength for the specimens varies between 238 MPa and 379 MPa, while the ductility decreases from 9.7–4.7% for the variation of Wt. % of silicon carbide from 3–12, The results obtained on the graph are curve fitted for linear interpolation and the "Slope, Residual sum of squares, Pearson's r, R – Square(COD) and Adj. R – Square" are obtained which are as shown in the Figures 3 and 4.

Compression Tests

A compression test is a type of characteristic material testing in which a material encounters restricting inward forces, thus getting compressed, squashed, crushed or flattened. The specimen is for the most part placed in between two plates that distribute the load over the whole surface of two opposite faces of the specimens and the plates are pushed together by a universal testing machine applying a crushing load. A compressed test specimen is generally shortened along the direction of applied loads and is opposite to that of the tensile tests. The compression tests are carried out as per ASTM E9 standards on an Instron make 600 kN hydraulic operated universal testing machine.

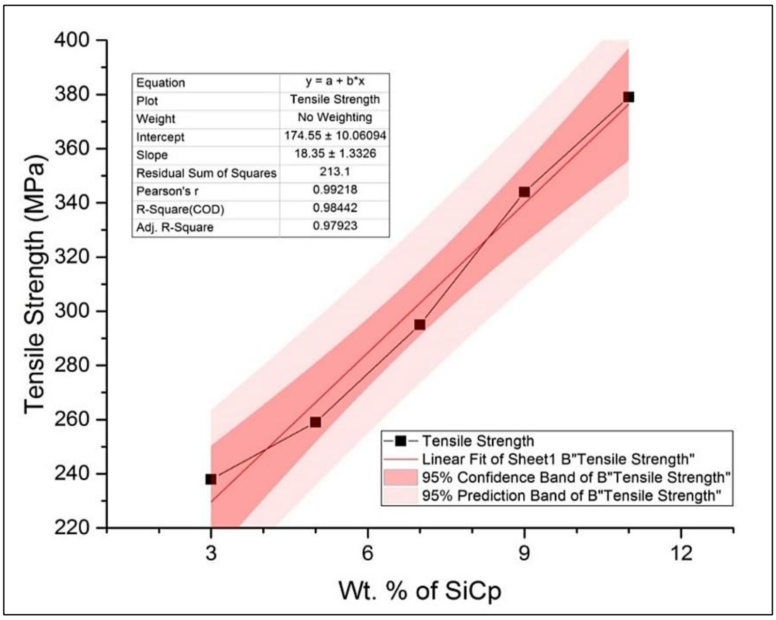

Fig. 3: *Variation of Tensile Strength versus Wt. % of SiCp.*

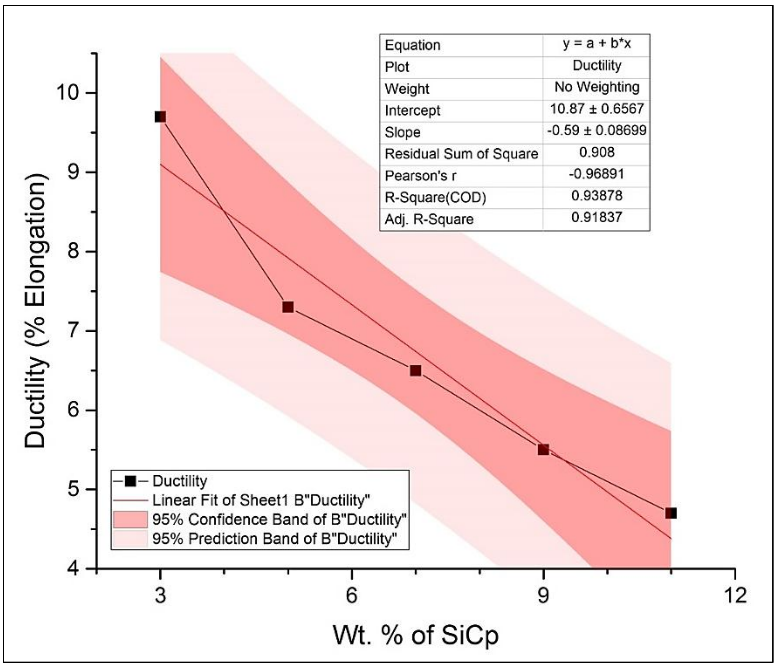

Fig. 4: *Variation of Ductility vs. Wt. % of SiCp.*

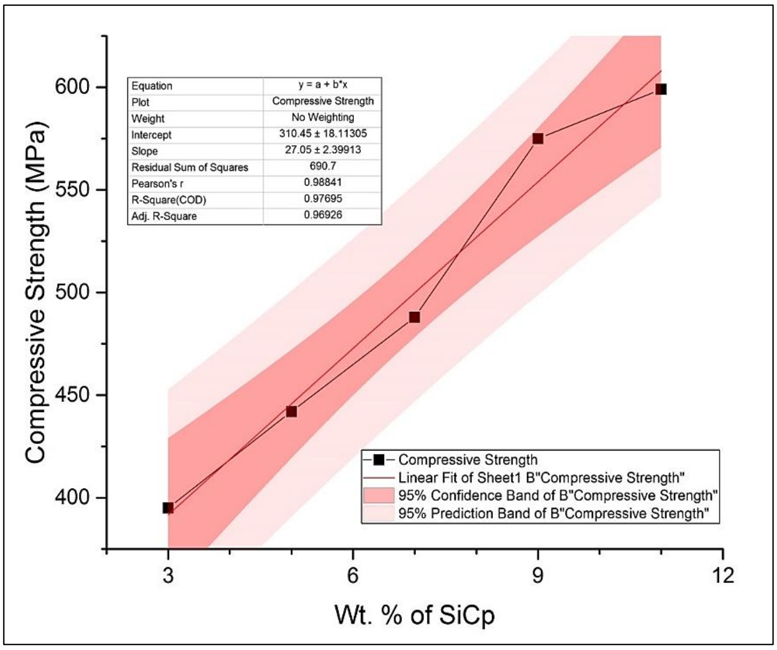

Fig. 5: *Variation of Compressive Strength versus Wt. % of SiCp.*

The results of compression tests are tabulated and plotted as a graph to obtain the graph of weight percentage of silicon carbide Vs. compression strength in MPa, The compressive strength for the specimens varies between 395 MPa and 599 MPa for the variation of Wt. % of silicon carbide from 3 to 12, The results obtained on the graph are curve fitted for linear interpolation and the “slope, residual sum of squares, Pearson’s r, R – Square(COD) and Adj. R – Square” are obtained which are as shown in the Figure 5.

Hardness Test

“The Brinell hardness test method is used to determine Brinell hardness, as characterized in ASTM E10. Most often it is utilized to test materials that have a structure that is excessively coarse or that have a surface that is too harsh to ever be tried utilizing another test technique, e.g., castings and forgings. Brinell testing frequently utilize a high test load (3000 kgf) and a 10 mm breadth indenter with the goal that the subsequent space midpoints cover the most of surface and sub-surface irregularities. The Brinell technique applies a test load (F) to a carbide indenter of diameter (D) which is held for a predetermined time period and removed. The subsequent impression is estimated with a Brinell magnifying lens or optical system across the two opposite diameters usually at right angles to each other and averaged for the value of d. In spite of the fact that the Eqn 1 can be utilized to obtain the Brinell number, frequently a chart is used to convert the averaged diameter measurement to a Brinell Hardness Number (BHN). The load applied on the specimen ranges from 500 kgf regularly utilized for non-ferrous materials to 3000kgf typically utilized for steels and cast iron. There are other Brinell scales with loads as low as 1kgf and 1 mm distance across indenters, however these are rarely utilized".

$$\text{BHN} = \frac{2F}{\Pi D(D-\sqrt{D^2-D_i^2})} \qquad \text{Eqn 1}$$

The hardness values for the specimens varies between 58 BHN and 97 BHN for the variation of Wt. % of silicon carbide from 3 to 12, The results obtained on the graph are curve fitted for linear interpolation and the "slope, residual sum of squares, pearson's r, R – Square (COD) and Adj. R – Square" are obtained which are as shown in the Figure 6.

Microstructure

The microstructure of the specimens was studied from scanning electron micrographs using a Hitachi make S-3400N scanning electron microscope. The specimens were initially polished on 1/0, 2/0, 3/0 and 4/0 emery papers for getting a flat surface and further finished using alumina suspension a velvet cloth and final polish was given using diamond paste on a very special velvet cloth, the specimens were then etched using the standard etchants of Keller's reagent before observing the microstructure. The instrument used for microstructural evaluation had a resolution of 3 nm at 30 KV. The scanning electron microscope (SEM) used both the principle of secondary electron detection and back-scattered electron detection. The SEM images (Figure 7) of the specimens clearly depicted the dispersions of the reinforcements in the matrix phase and also it gave the evidence for the formation of intermetallic particles due to the reaction between silicon carbide and fly ash particulates in the aluminium matrix composites (AMC).

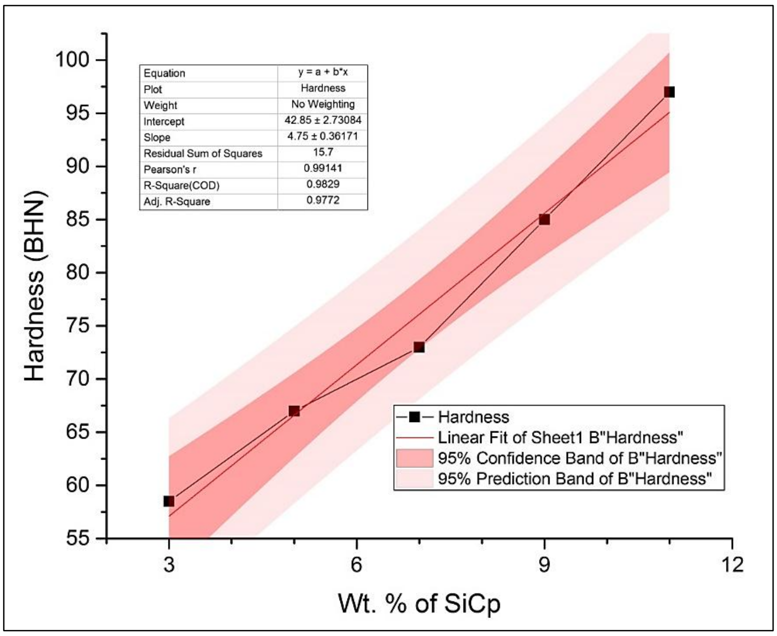

Fig. 6: *Variation of Hardness versus Wt. % of SiCp.*

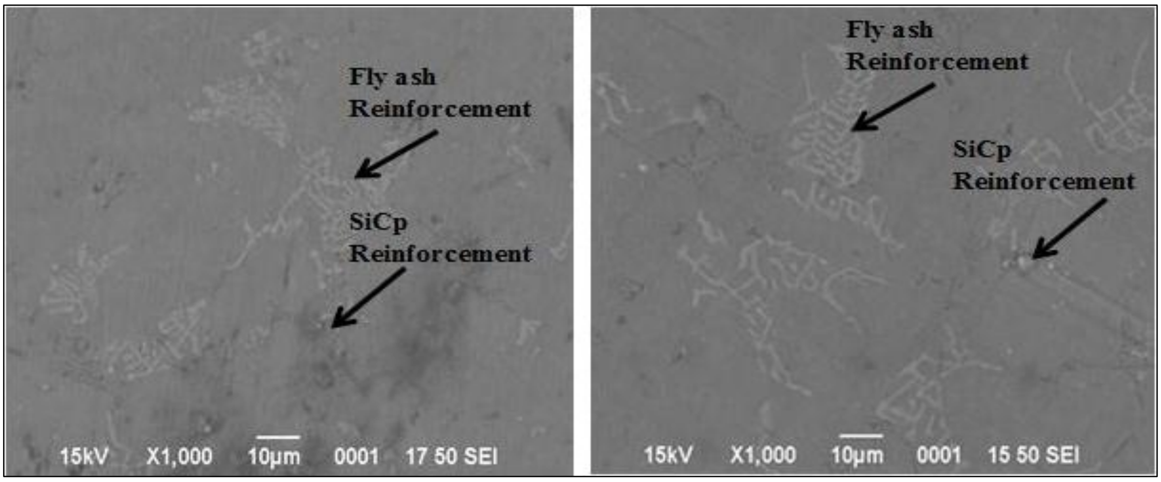

Fig. 7: *SEM Images of Ceramic Particulates Dispersion Strengthened AMC.*

CONCLUSION

The critical inferences drawn from the results obtained en – route characterization of the cast specimens of different composition of the reinforcements clearly give the following conclusions pertaining to the dispersion of ceramic particulates in the aluminium matrix composites.

1. The tensile properties of the composites is observed to increase with the increase in the Weight percentage of silicon carbide and is found to be maximum at 12 Wt. % of silicon carbide. This is majorly due to the formation of intermetallic bonds between the aluminium grains and the silicon carbide particulates around the periphery of the fly ash particulates.
2. The tensile strength increases from 238 MPa to 379 MPa, while the percentage elongation reduces from 9.7% to 4.7% with the increase in the Wt. % of silicon carbide.
3. The compressive strength of the composites is observed to increase with the incrase in the weight percentage of silicon carbide; this is majorly due to the inclusions of ceramic particulate reinforcements that impart resistance to compressive forces acting towards each other.
4. The compressive strength increases from 395 MPa to 599 MPa for the increase in weight percentage of silicon carbide reinforcements.
5. The hardness significantly improves with the addition of silicon carbide reinforcements; this is majorly attributed to the fact that the addition of ceramic reinforcements considerably improves the hardness characteristics of the composite specimens.

From the above conclusions, it is evident that the addition of ceramic reinforcements considerably improves the properties such as basic mechanical strength and wear resistance, thereby facilitating the use of aluminium 5083 alloy matrix composites for aerospace applications which requires better strength to weight ratio and resistance to wear and abrasion. Thus, the composite developed can be effectively used for aircraft components such as wing structure, fuselage and bracket mounting frames.

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