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Mechanical Study of Aluminium -Silicon Carbide -Tungsten Carbide Hybrid Composite Synthesized Through Powder Metallurgy Technique

A. Jagan Mohana Rao, A. Vivek, A. Raja Sri Charan, B. Srikar Babu, B. Durga Prasad, B. Dinesh
Dr. V. S. S. Venkatesh
Department of Mechanical Engineering
GMR Institute of Technology, Rajam, Andhra Pradesh, India

Abstract: *In this study, powder metallurgy is used to create hybrid metal matrix alloys made of aluminium-silicon carbide -tungsten carbide. Aluminium metal matrix composites are now vastly used in automobile industry due to superior qualities, such as improved corrosion protection, high ductility, and strength to weight ratio is also high too. With individual silicon carbide reinforcement, weight percentages of 5%, 10%, 15% and 20% of composite samples are created using the powder metallurgy method. The manufactured composite samples' physical and mechanical characteristics were examined. By using two analysis(SEM and XRD), aluminium, siliconcarbide, and tungsten carbide are found. Aluminium -10%Silicon Carbide -10%Tungsten Carbide reinforcement was determined to have a higher ultimate tensile strength (UTS) of 263 MPa as well as yield strength (YS) of 202 MPa for composite. Aluminium -10%Silicon Carbide -15 %Tungsten Carbideand Aluminium -10%Silicon Carbide -20%Tungsten Carbide reinforcement showed that the intermetallic specimenis formed(eg: Al_2Cu), which causes a drop in the UTS and YS of manufactured samples. Hybrid composites made of Aluminium, silicon carbide10%, and 10% WC had the greatest combination of mechanical properties. Aluminium, silicon carbide, and WC particles can be seen in the XRD images. Aluminium-silicon carbide 10%-15% WC and aluminium-silicon carbide 10%-20% WC were found to have intermetallic phases present as well. SEM as well as EDS mapping were verified, reinforcements for the 15% and 20% WC reinforcements were distributed uniformly and formed into agglomerations. In comparison to monolithic aluminium, the results revealed that the aluminium-silicon carbide 10%- 10% WC has superior mechanical properties.*

Keywords: Mechanical properties, Silicon Carbide, Tungsten carbide, aluminium

I. INTRODUCTION

A crucial metal matrix component in the creation of composite composites is aluminium (Al). The aerospace and automotive sectors are increasingly requesting a minimal-cost, material weights pretty much less with exceptional properties in mechanical. Since their strength-to-weight ratio, hardness were higher, compressive strength, and wearing resistance, metal matrix composites (AMC) of aluminium have mainly used in the automobile, aerospace as well as marine sectors. Next to magnesium alloy, aluminium alloy has the lowest mass of all metals. Due to its difficult synthesis, high pyrophoric nature, and lesser ductility when compared to aluminium, magnesium has a limited range of applications. Since strength-to-weight ratio is high, outstanding mechanical qualities, simplicity fabrication, aluminium composites have thus been used most frequently in the current situation. The needs of advanced engineering applications may be satisfied by hybrid composites with two or more reinforcements[1].The right choice of materials and processing factors, determine the capabilities of these composite materials. Comparing composite materials to unreinforced alloys revealed superior mechanical properties; additionally, these improved properties can be tailored to meet specific requirements[2].

As reinforcing elements for AMCs, various types of ceramic intermetallic particles have been used, including SiC [8], B4C [9], Ni3Al [10], and Si3N4 [11]. The primary drawbacks of ceramic reinforcing materials are additional abrasion against the countersurface and a decrease in wearing of composites performance made of aluminium [12]. The hardness of aluminium alloys can be increased by adding ceramic particles to the aluminium alloy. This quality has made it challenging to machine such materials. The aluminium alloy's reinforcements must be examined in order to gauge how well it performs in specific uses in order to get around these restrictions[4]. Substance can either be continuous or discontinuous (particles, whiskers, and short fibres). As a dispersed component use of carbides (TiC, SiC, B4C), nitrides (BN, AlN), and reinforced oxides (Al2O3, ZrO2, MgO) metal matrix of aluminium is common[5].

Through the use of powder metallurgy, [14] produced aluminium -kaoline. The study's findings showed that compared to unreinforced aluminum, the tensile strength of the alloy with 20% kaoline reinforcement was increased by 54.8%.It was also noted that intermetallic sample Al3BCformation caused the porosity of the HMMC to rise by more than 3% as a result of the addition of kaoline. In addition to ceramic particulates like silicon carbide, aluminium, tungsten carbide. [3] reported that wastes produced in industry, red mud, fly ash as well as typical agricultural ashes of rice husk, maize stalk, bean shell waste, and corn cob are the commonly used reinforcement. According to a [4]research, the hardness of composites was reduced by 11.1% when graphite granules were stir cast into an aluminium alloy. According to Prashanth Kumar et al. [5], adding SiC and graphine to an alloy of aluminium composite created via sintering in microwave increased the hybrid composites strength of flexural, wearing resistance and toughness. According to [6], adding more ceramic reinforcements improved the density of the hybrid matrix, whereas adding ashes of fly, rice husk, or bamboo leaf decreases composites density. According to Nutt Duva [7], based on TEM findings, the primary cause of failure of SiC whisker-reinforced aluminium composites is the nucleation and development of voids and cracks at the corners of the whiskers, where there is a high stress concentration. In addition, it was noted that intermetallic compound was formed of the Al3BC caused porosity to the HMMC to rise by more than 3% when kaoline was added. A 20% increase in hardness and a 50% increase in compression strength for 8% Si3N4 reinforcement similarity between unreinforced Al 7075 alloy were found, according to [17] analysis of the mechanical as well as wearing characteristics of stir cast Al 7075- Si_3N_4. Following the SiC/Al interface, these cracks would spread and eventually cause the ultimate fracture. There is no one failure mechanism, whereas this mechanism of failure for SiC whisker-reinforced composites of aluminium is commonly accepted.

The synthesis of composite materials with less expensive reinforcements, which enhance the mechanical properties of the composite material, has recently attracted increasing attention. It is well known that since aluminium alloy is primarily used as a structural material, its tribological properties are not a design component. As a result, while the weight percentage of SiC binding agent varied in the current research, the weight percentage of aluminium remained constant. Al-Al alloy has been used as the matrix material in the current research because of its high strength-to-density ratio, higher tensile strength, and maximum yield strength. As a result, the marine, automotive, and aviation sectors are the main users of aluminium alloys. When creating these hybrid composites, the aluminium content was held fixed at 10 weight percent and the reinforcement SiC with a particle size of 10 m was varied by weight percentages of 5%, 10%, 15%, 20%, and 25%[19].

WC particles have not been used to reinforce the matrix material Al-SiC, according to the research. In light of this, the main goal of the study is to use powder metallurgy to produce the Al-SiC matrix for reinforcement with tungsten carbide composites. The composites then undergo SEM testing, hardness, wear, microstructure, and other processes to enhance their mechanical characteristics. A scanning electron microscopy (SEM) with energy dispersive x-ray analysis (EDS) analysis is used to analyse the distribution of reinforcements and the formation of intermetallic compounds. To identify the sort of fracture that happened in the fabricated samples, the fractured tensile samples were subjected to a fractography analysis.

II. MATERIALS

In the current process of fabricating HMMC, aluminium served as the matrix material and silicon carbide (SiC) and tungsten carbide (WC) powders served as the reinforcement phase.When using the powder metallurgy method, H-13 steel is used to construct the punch and die setup.

2.1 Al Matrix Powder

Due to its superior qualities, including a high strength to weight ratio, low density, high stiffness, greater ductility, and improved corrosion resistance, aluminium powder with a size of20m(99.9%purity) is employed as a matrix material[17].

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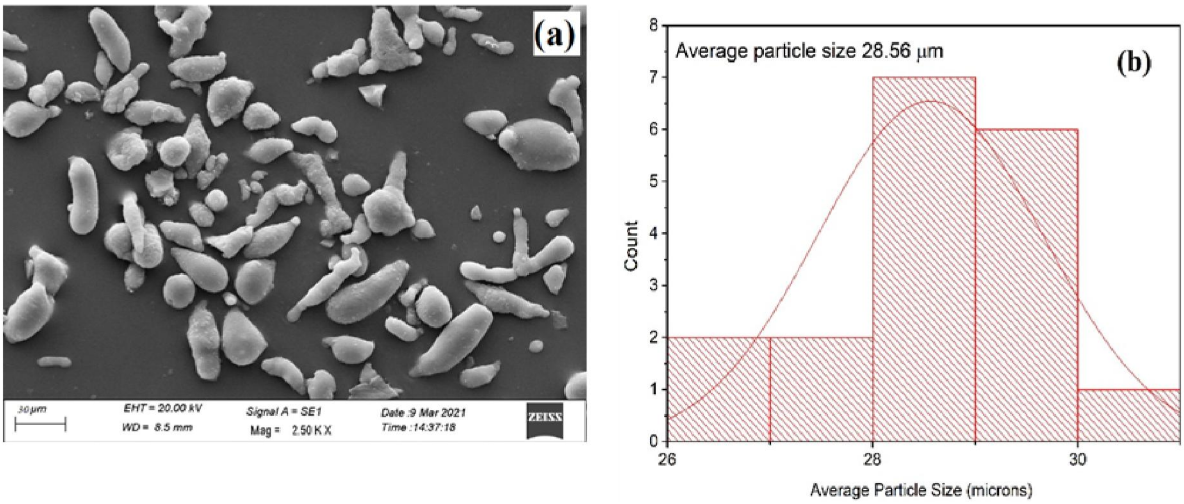

Figure 1. a) Morphology and b) Average Particle Size(ASP) of Aluminium powder

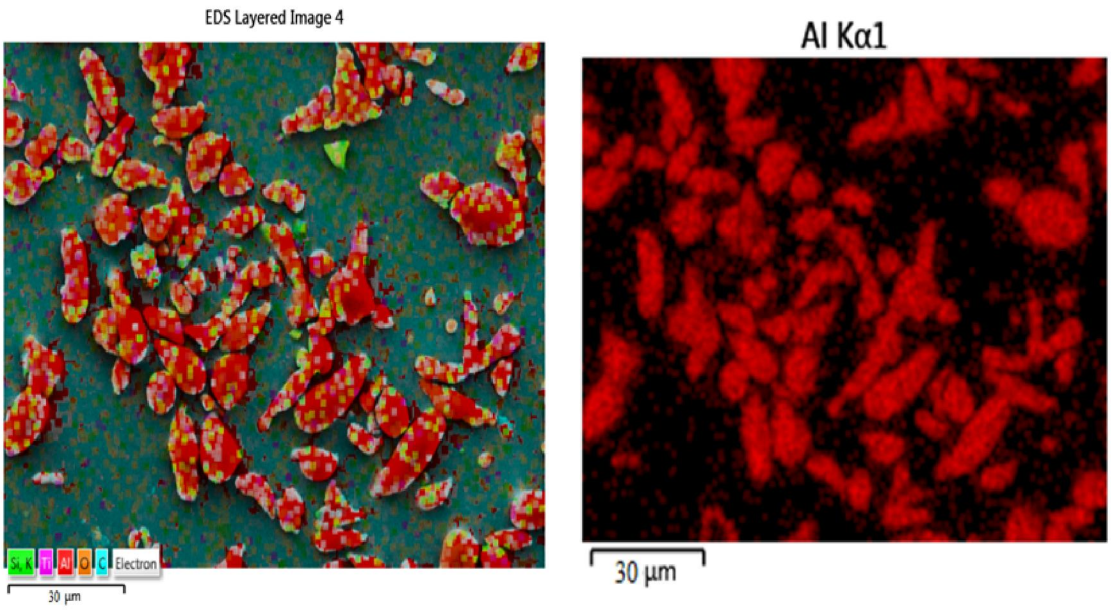

Figure 2. EDS mapping for Aluminium particles

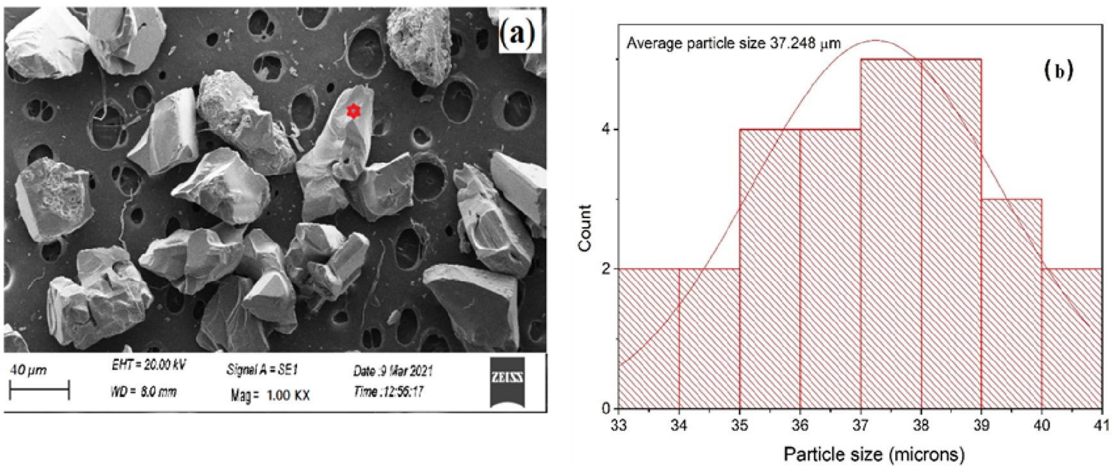

Figure 3. a) Morphology and b) Average Particle Size(ASP) of SiC powder

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2.2 SiC Reinforcement

25 m-sized silicon carbide particles are used as support. Due to its exceptional qualities, including higher hardness (280 BHN), greater compression strength (3900 MPa), higher melting point (2730°C), and reduced density (3.21 g/cm3), silicon carbide is one of the most durable materials. Its hardness is comparable to that of diamonds. The chemical composition of SiC can be observed in the Table1.

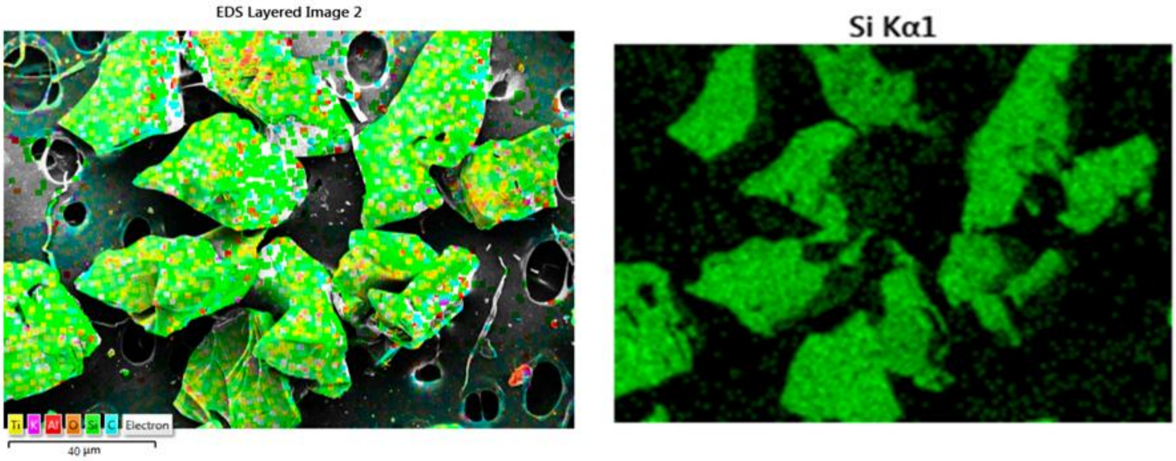

Figure 4. EDS mapping for Silicon carbide particles

Table 1. Composition of Silicon Carbide

Elements	SiC	C
Wt%	79	21

Table 2. Composition of Tungsten Carbide

Elements	W	C	Co
Wt%	73.8	19.7	6.5

2.3 Tungsten Carbide Reinforcement

Tungsten Carbide having the particle size of 30µm contains tungsten, Carbide and Cobalt. It is extremely hard and durable material, with high melting point and good wear resistance, making it an ideal choice for use as a reinforcement in materials where hardness and durability are essential. Tungsten carbide reinforcement offers an efficient method for enhancing efficiency and durability of materials used in a many applications, making it a valuable tool for material scientists and engineers[6].

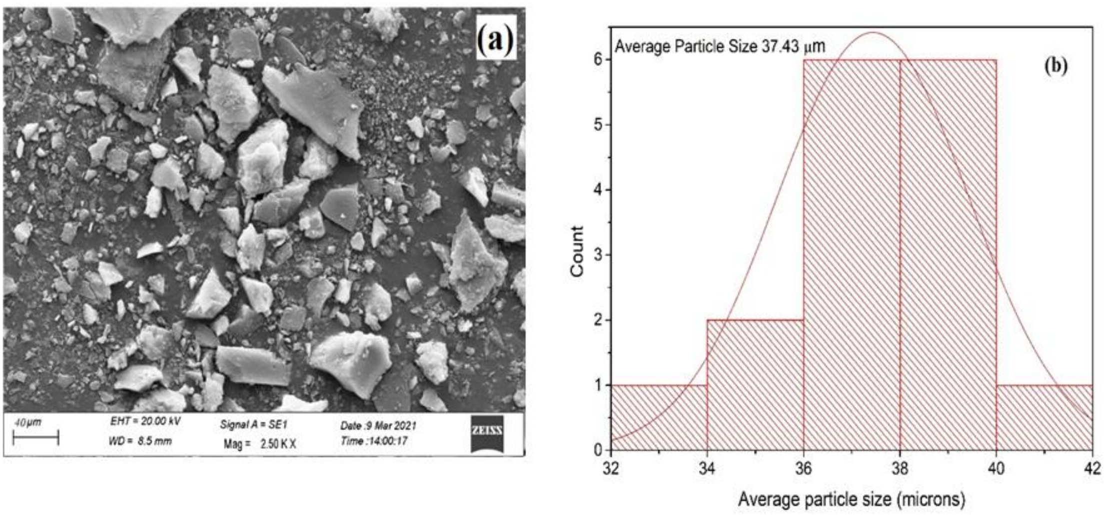

Figure 5. a) Morphology and b) Average Particle Size(ASP) of WC powder

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III. EXPERIMENTAL PROCEDURE

In this experiment, Al, SiC, WC acquired from sources. Aluminium is used as matrix material. During the reinforcement process, SiC and WC are used.

Using powder metallurgy, an Al-10%Sic-X%WC (X=5,10,15,20,25) hybrid alloy was created. Figure 2 depicts the steps taken during the manufacturing process in order. The matrix and reinforcement powder properties that are used to calculate compound percentages. Table 3 displays the different developed HMMC compositions as well as their fabrication sample code. Compacts were created as shown reinforcement shown in Table 4[6].

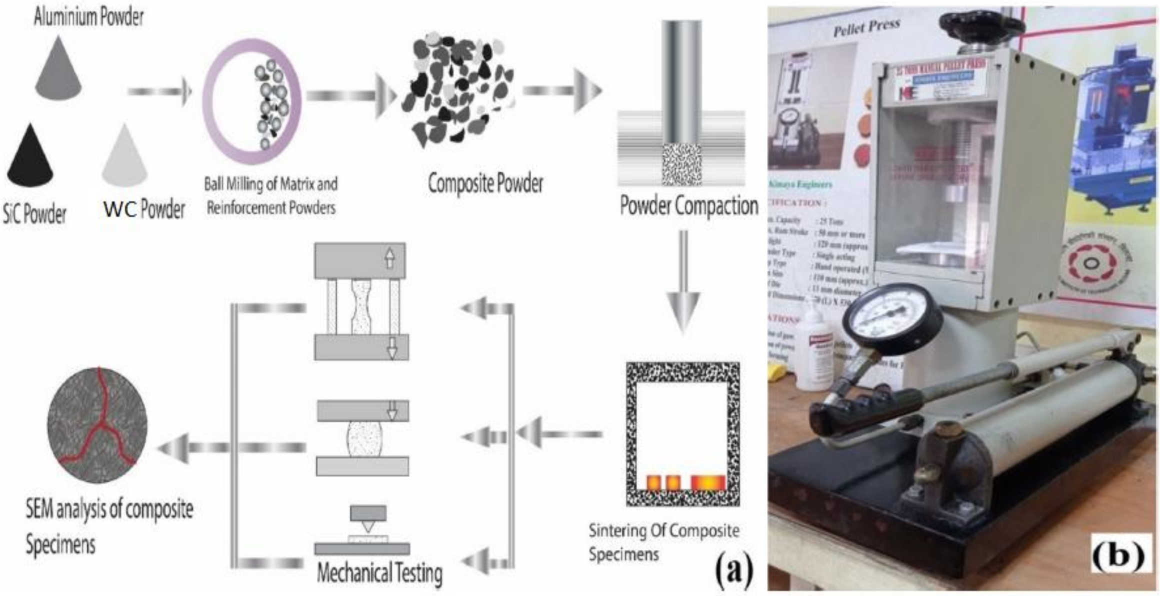

Figure 6. (a) powder metallurgy process diagram, (b) Compaction press

Table 3. Properties of materials.

Material	density(g/c.c)	Coeff. of Thermal expansion(×10−6/°C)	Melting Point(°C)
Aluminium	02.710	024	0660
SiC	3.21	4.0	2730
WC	15.63	4.6 – 5.9	2870

Table 4. Constituents and their compositions.

S. No	**Weight. % reinforcements**	**Codes**
1	Aluminium	a
2	Aluminium – SiC10%	b
3	Aluminium – SiC10% -5% WC	c
4	Aluminium – SiC10% -10% WC	d
5	Aluminium – SiC10% - 15% WC	e
6	Aluminium – SiC10% - 20% WC	f

3.1 Powder Blending

A weight balance with some(in gms)accuracy is used to measure the necessary weight percentage of powders. The ball to powder ratio for these powders is 10:1[4], and they are put into chromium-hardened steel vials. One weight percent of stearic acid was added to the powders to avoid excessive welding between the powders as well as between the powders and tungsten balls. Ball milling was done in a RESTECH 100 ball mill at room temperature for three hrs at 300 rpmspeed in order to make sure that reinforcement particles were distributed evenly to matrix,which causes the powder undergoes hardening along strain.

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3.2 Compaction

Powders which were blended are subjected to compaction process using Universal Testing Machine, where 70kN of load is applied onsetupof punch and die with help of hydraulic press was used as shown in Figure 3. To easily eject the compacted samples from the punch and die, zinc stearate and acetone are used as a lubricant that is added to their contact surfaces[8].

Figure 7. Punch and die setup for compaction

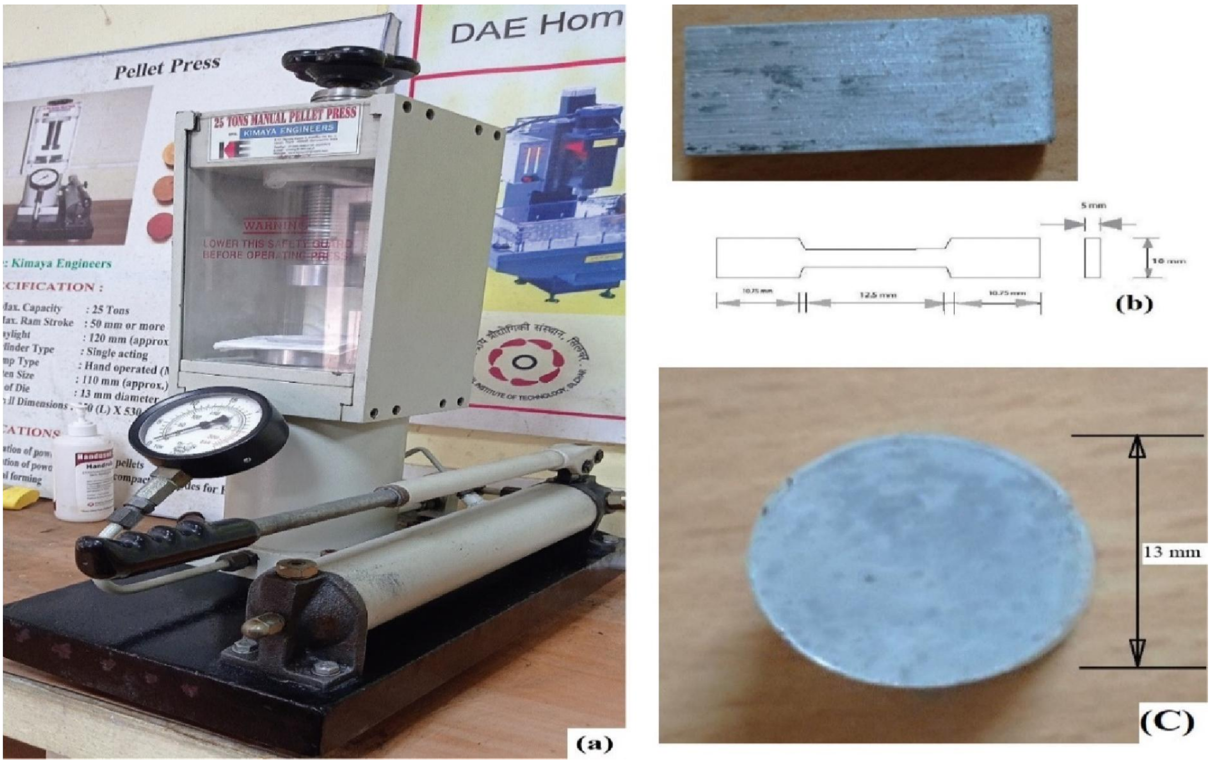

Figure 8. Pallet - Press, dimensions of specimens

3.3 Sintering

In order to prevent oxidation and the development of scale, the compacted samples are put inside a muffle furnace with Ar gas and an inert atmosphere. Samples are heated for 4 hours at 500°C with temperature increases of 10° C/min [17]. These samples are left in the furnace until they are cooled down to the room temperature. During this process, grain bonding will be increased which lends to the strength of the sample.

3.4 Etchant

After sintering, Etchant will be applied to the compacted samples which contains the mixture of 5ml of Nitric acid, 3ml of Hydrochloric acid, 2ml of Hydrofluoric acid and 190ml of distilled water. Samples are etched for 10 to 30 seconds. Etchant is used to make the grains boundaries perfectly visible. This etchant is used for most of aluminium and aluminium alloys[14].

IV. SAMPLES CHARACTERIZATION

To ascertain its mechanical and morphological properties, the developed composite was tested[18]. Below is a discussion of the various experiments that were carried out to characterise the developed composite.

4.1 XRD analysis

XRD is used for identification of various stages that are being involved at the time of fabrication. XRD analysis is performed on the PAN analytical x-ray diffractometer.

4.2 WSEM Analysis

Morphology, elemental makeup of the manufactured object were precisely determined using a carl zeiss EVO 50 high resolution scanning electron microscope. The prepared samples were ground on the belt grinder using abrasive papers with grid sizes of 600, 800, 1200, 1800, and 2400 to verify the distribution of reinforcements in the matrix. These examples are then polished on a twin-disc polisher with 2 m and then 0.5 m diamond paste. In order to expose the grains and microstructure at the micron level, the composite samples are etched using Keller's reagent Mixture of Distilled water (190 ml) with Nitric acid (5 ml), Hydrochloric acid (3 ml), and Hydrofluoric acid (2 ml)) for 30 s. The magnification range used to study specimens is 500X–5000X[18].

4.3 Density of Hybrid Metal Matrix Composites

The Archimedes principle was used to calculate the density of combined samples [6]. A compaction punch and die setup was used to create composite samples measuring 30 mm in diameter and 10 mm in length. The mass of the sample in the air was measured using an electronic weighing device with a 103 g precision [22].The composite's density was calculated using the formula below.

$$\rho = \left(\frac{w}{w - \omega_1}\right)\rho_1$$

ρ = Density of sample
w = Weight of in air
w1 = Weight of sample in distilled water
ρ1= WaterDensity

4.4 Porosity

Porosity is the ratio of a material's overall volume to the number of voids it contains. The porosity of the manufactured samples was determined using the Law of Mixtures concept. The formula for calculating percentage permeability is found in Eq (2).

$$\%\, porosity = \left(\frac{\rho theoritical - \rho measured}{\rho theoritical}\right) * 100$$

$$\rho_{theoretical} = \rho_{matrix} \mathrm{x} v_{matrix} + \rho_{reinforcement} \mathrm{x} v_{reinforcement}$$

4.5 Microhardness

By applying a 25 N load for a dwell period of 10 s, the ASTM E384-16 standards were used to measure the microhardness of fabricated samples [12]. For improved reading precision, each sample receives an average of five readings. Figure 4 depicts the manufactured object for the hardness test.(a). Using a hardness conversion chart, the Vickers hardness value (HV 0.1) received from the ECONOMET VH1MD tester and the corresponding Vickers hardness value were calculated.

4.6 Impact strength

The Charpy impact test was used to evaluate the composite's capacity to absorb energy. Composite samples with specimen dimensions of 10 mm, 12 mm, and 50 mm were created in accordance with ASTM A370 guidelines [10]. the last e2 value that was tallied for each sample throughout the trial. Wire EDM was used to cut a 100 mm2 cross-sectional region from the manufactured sample. By adjusting the apparatus with an energy of 10 kg-m, the original reading e1 was recorded. The following expression was used to determine the value of Charpy impact energy (e).

$$e = e1 - e2(kg - m)$$

$$Charpy\ impact\ strength\ (kg - m/mm^2) = \frac{Charpy\ impact\ value(kg - m)}{Crossectional\ area\ of\ notch(mm^2)}$$

4.7 Ductility % and Tensile test

The micro universal testing machine M-30 model was used to assess the composite material's capacity to resist static tensile loading. The impact of reinforcement on the tensile strength and percent ductility of composite samples was investigated and correlated using a 15kN load applied at a strain rate of 0.001s - 1.

V. RESULT AND DISCUSSION

5.1 XRD analysis

Elements are recognised in the WC reinforcement phase based on the XRD patterns of the unprocessed powders, which are displayed in Figure 5. In samples with up to 10% WC reinforcement, only Al, SiC, and WC showed up as peaks, proving that there was no chemical contact between the matrix and the reinforcement particles.

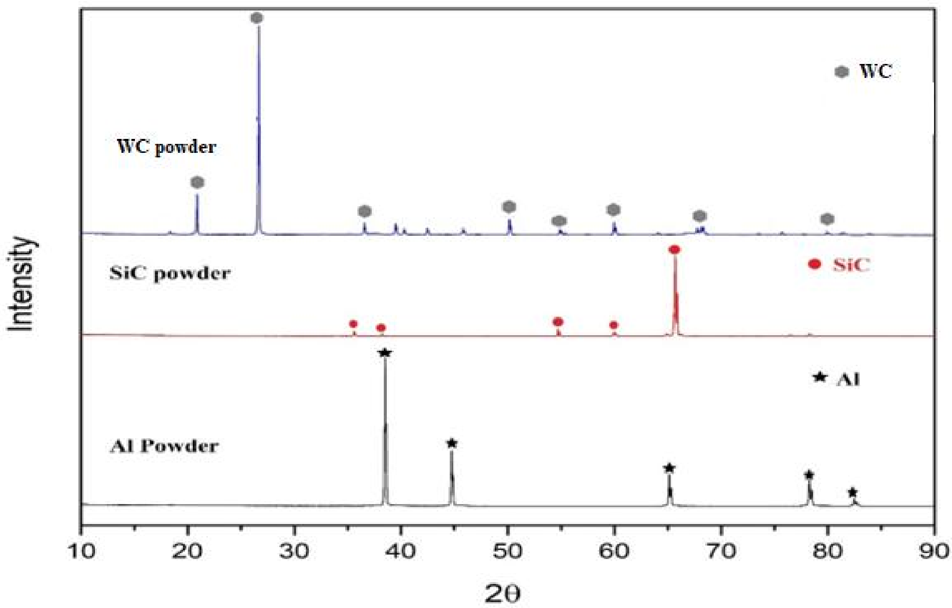

Figure 9: Powders XRD patterns

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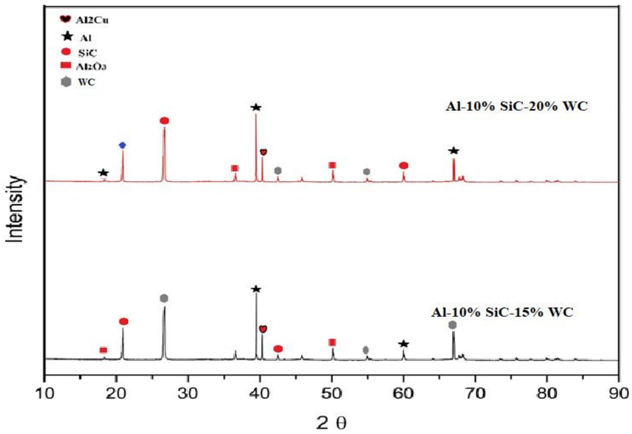

Figure 10. XRD of fabricated composite specimens.

The creation of the brittle intermetallic compounds Al3SiC, phases that may weaken the bonding strength between the matrix and reinforcement particles, is caused by the incorporation of 15% and 20% of WC, respectively. The obtained XRD peaks are found to be reasonably correct with the peaks obtained by K. Shirvanimoghaddam et al. [17] for these intermetallic phases. The kinetic energy of the particles rises during the sintering of composite specimens, resulting in rapid diffusion and bond initiation between the matrix and reinforcements. The strength of the composite specimen is decreased as a result of the creation of secondary intermetallic compounds [19–22].

5.2 Microstructural Analysis

As shown in figure below, SEM analysis of fractured compacted samples depicts that formation of agglomerations in reinforcements are not distributed uniformly, which is the primary causecan influences as well as governs the type of fracture. In aluminium-10% silicon carbide-5% WC micro voids and delamination are found and when comes to aluminium-10% silicon carbide-10% WC microviods and cleavages were found, and for aluminium-10% silicon carbide-15% WC andaluminium-10% silicon carbide-20% WC cleavages are found as shown in figure 5.

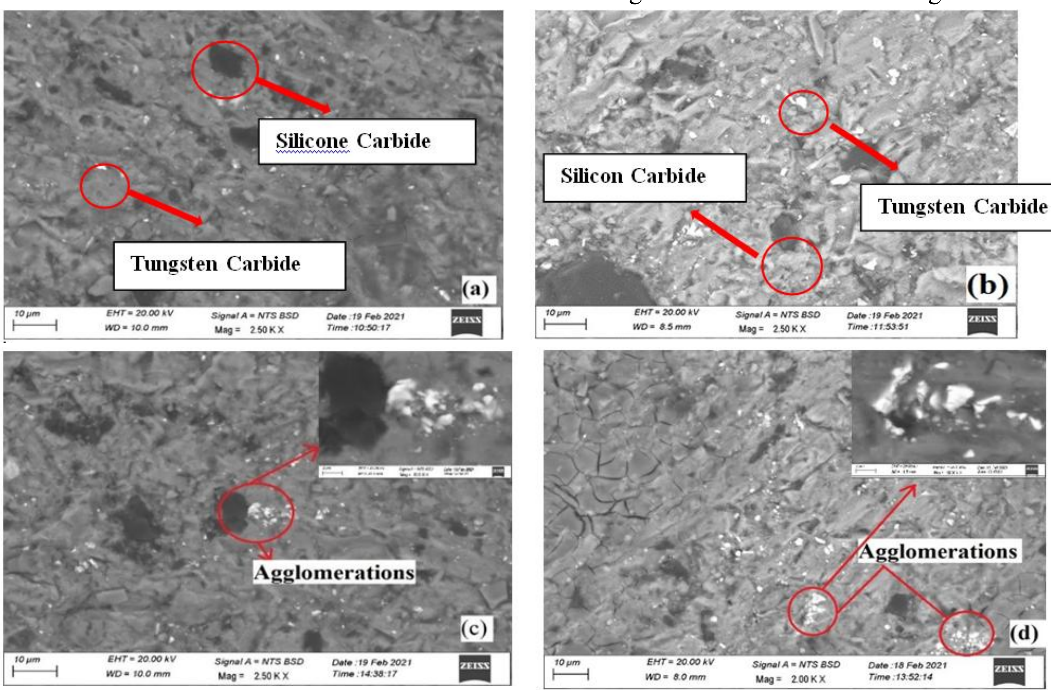

Figure 11. SEM micrographs for (a) aluminium-10% silicon carbide- 5% WC, (b) aluminium-10% silicon carbide- 10% WC, (c) aluminium-10% silicon carbide- 15% WC, (d) aluminium-10% silicon carbide- 20% WC

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5.3 Hybrid Reinforcements Influence on the Hardness

Figure 11 depicts the impact of various weight percentages of silicon carbide and tungsten carbide additives on the hardness of hybrid metal matrix composite. According to the experimental findings, the hardness at 10% Silicon Carbide and 10% WC reinforcement increased by 91.93% when compared to the unreinforced Aluminium specimen. When strengthened with 10% Silicon Carbide and 10% WC, HMMC's hardness rises from 62 VHN for unreinforced aluminium to 119 VHN. Due to the incorporation of harder ceramic reinforcements in the softer aluminium metal, which provides resistance to indenter penetration during the application of pressure, the hardness of HMMC has increased. The increase in wt % of WC reinforcements up to 10 % increases the dislocation density in the composite which eventually retards the plastic deformation, thereby improves the hardness of composite material. The addition of WC reinforcement beyond 10 % leads to a decrease in hardness of composite from 119 VHN to 101VHN for reinforcement wt % of 10 % WC to 15 % WC.

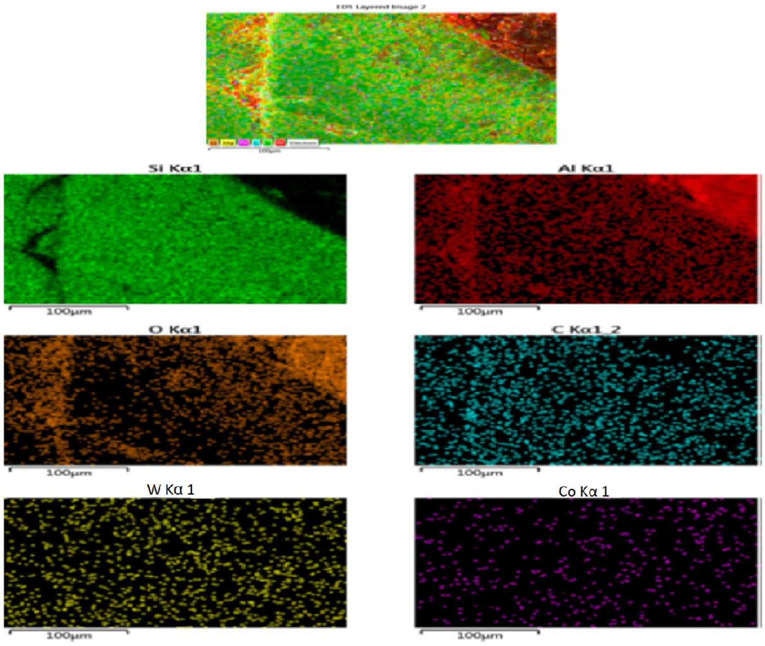


Figure 12. EDS mapping

This result was caused by the WC particles self-lubricating characteristic, which facilitates slipping along the slip planes during the indentation test[18].

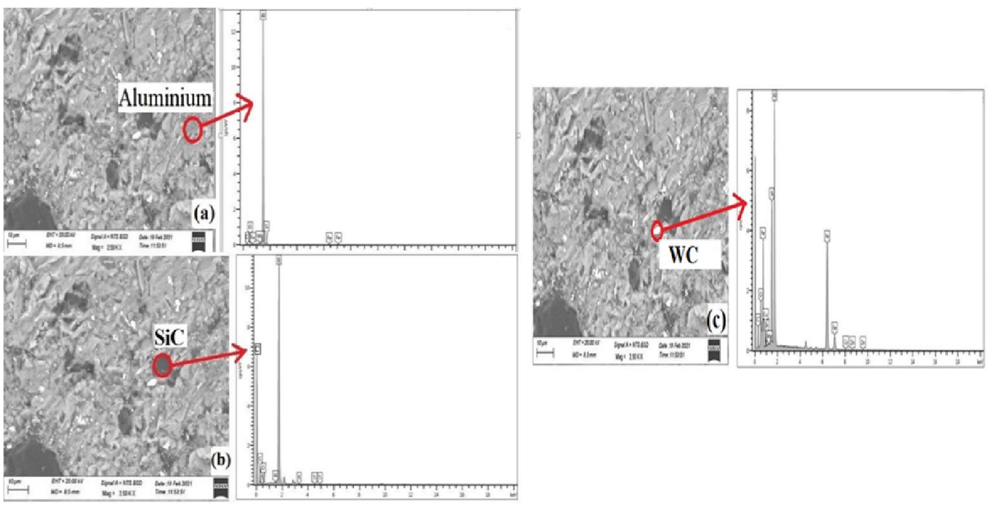


Figure 13. SEM and EDS pattern for (a) matrix aluminium, (b) silicon carbide, (c) WC in fabricated sample

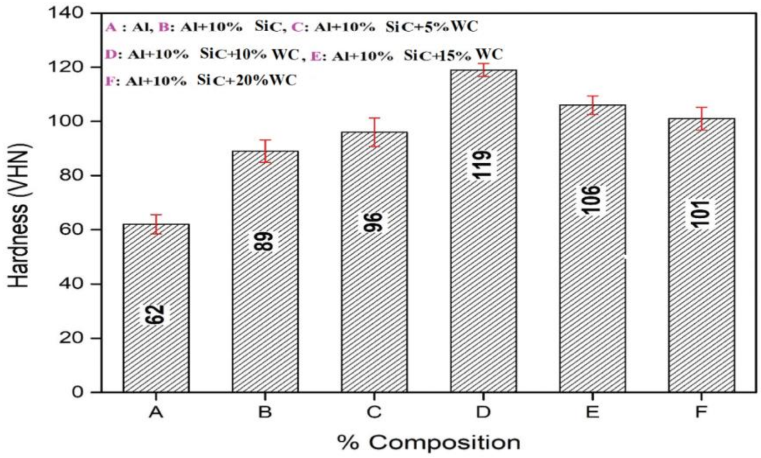


Figure 14. Hardness variation of samples with % reinforcements.

5.4 Influence on Density and Porosity

As shown in Figure 15, the combination of silicon carbide and tungsten carbide hybrid supports reduced the density of composite specimens. The addition of less dense reinforcement granules to the aluminium matrix was blamed for the decrease in density. Additionally, the length of the intermetallic bond between the matrix and reinforcement particles is shortened by the existence of surface cracks and porosities in the constructed composite. which in turn reduces the composite's mass. The experimental densities' standard error bars show that the observed values fall within acceptable bounds. The composite has the fewest porosity defects because the disparity between theoretical densities and measured densities is almost identical. Figure 16 depicts the change in porosity with respect to the composition of the reinforcement. The maximum porosity for unreinforced aluminium was found to be 4.3%, and it was discovered that porosity dropped as tungsten carbide percentage increased from 0% to 20%. Porosity in the samples results from the presence of various deformation tendencies during the sintering, which includes a softer aluminium matrix and harder reinforcements. Additionally, voids are produced at the grain boundary surfaces due to the coefficients of thermal expansion of silicon carbide (3.2 106/°C) and the aluminium matrix (23.6 106/°C). aluminium-10%silicon carbide -20%WC had the lowest porosity measurement, which was 3.1%.This was caused by the formation of intermetallic compounds at greater weight percentages of WC, which tend to cause the porosity of the interfaces to decrease.

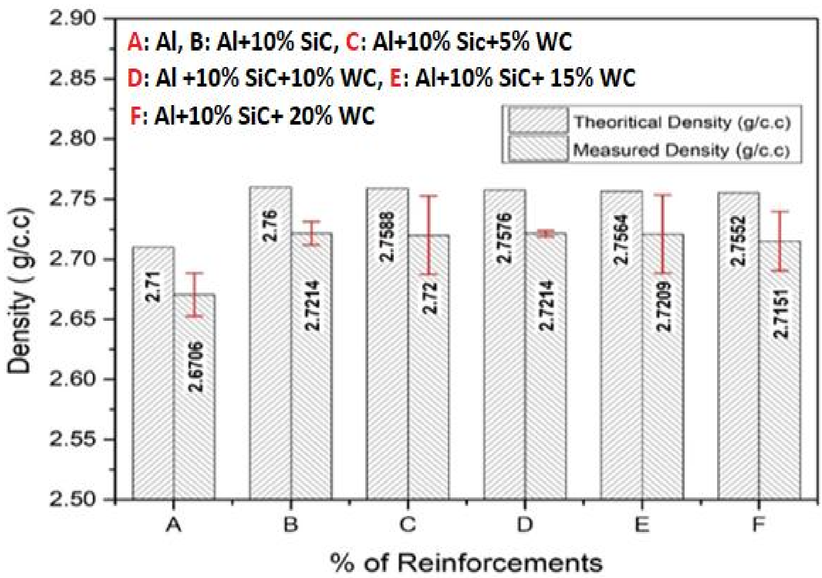


Figure 15.Density variation

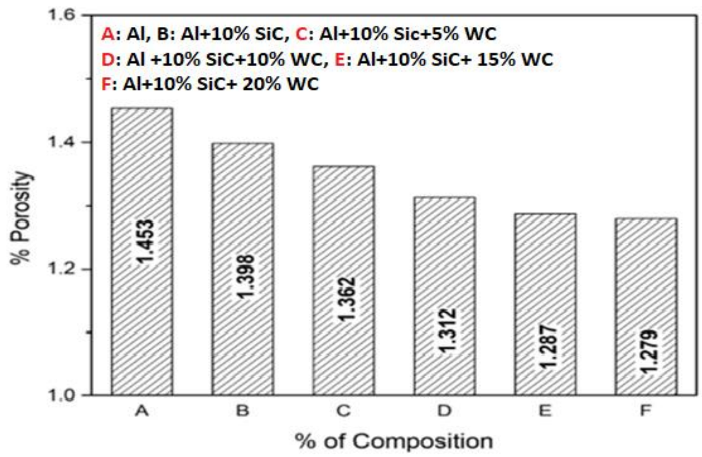


Figure 16. Porosity % variation

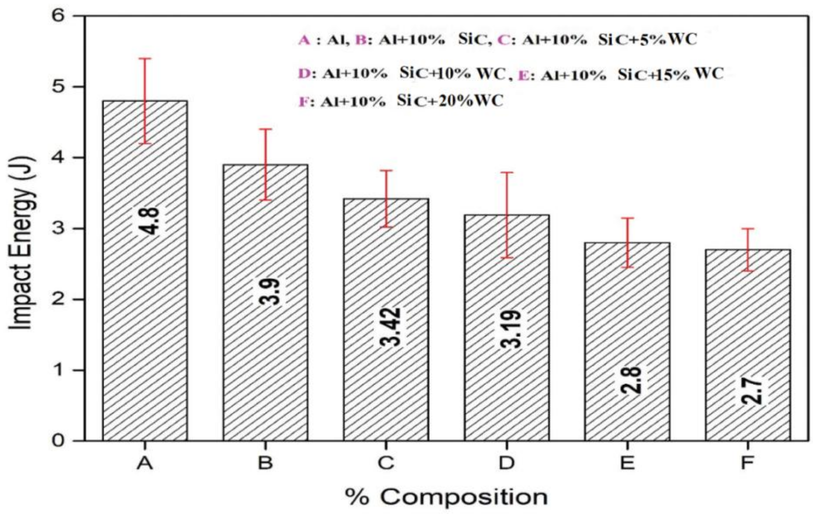


Figure17. Impact energy variation

5.5 Impact Energy Influence

Figure 17 depicts the effect of silicon carbide and WC reinforcements on the impact strength of mixed metal matrix composites. Impact strength of composite specimens dropped from 4.8 J for aluminium that wasn't reinforced to 2.7 J for composite reinforced with 10% silicon carbide and 20% WC. Unreinforced aluminium has a greater impact energy due to the presence of higher plastic deformation energy at the localised stress concentration areas. With the addition of hybrid reinforcements, the impact energy of composite materials reduces, and when compared to aluminum, a reduction in impact energy of 43.75% was seen. Less effective energy absorption and a rise in debonding between the reinforcements and matrix aluminium result from the existence of brittle reinforcements in composite materials. With a rise in reinforcement weight percentage, the non-uniform distribution of reinforcements in the matrix results in cluster formation, which also weakens the bonding strength between the interfaces of the matrix and reinforcements [21,22].

5.6 U.T.S and Y.S Influence

A graphic representation of UTS and YS variance with %wt is shown in the figure. The average number was calculated after five samples of the same composition were tested. Tensile strength increased by 263 MPa for reinforcement made of 10% SiC and 10% WC, which was 75% greater than the alloy of aluminium without reinforcement. By adding 15% more WC reinforcement, the composite's yield strength is increased by 52.2%. According to Figure 5, as WC continues to increase, agglomerations form and the U.T.S. and Y.S. of HMMC tend to decline(c,d). Dislocation strengthening, dispersion strengthening and grain refinement Can leads to the improvement of strength of composite. Formation of dislocations at interfaces are caused because of change that present in thermal expansion coefficient these dislocations at low applied load suppose the deformation of plastic. Transfer of load is better from aluminium to harder composites due to strong bonding between the particles next to each other in uniformly distributed reinforcements. Whenever SiC and WC are added in aluminium this tends to rise in the boundaries of grain which blocks the propagation of microcracks which makes the material strong. Maximum yield strength was obtained at 10% SiC and 10% WC. Then for 10% SiC and 25% WC the yield strength is decreased from 202MPa to 131 MPa. The highest yield strength to U.T.S was discovered to be 0.756. This leads to the inference that material undergoes stage yielding and strain hardening.

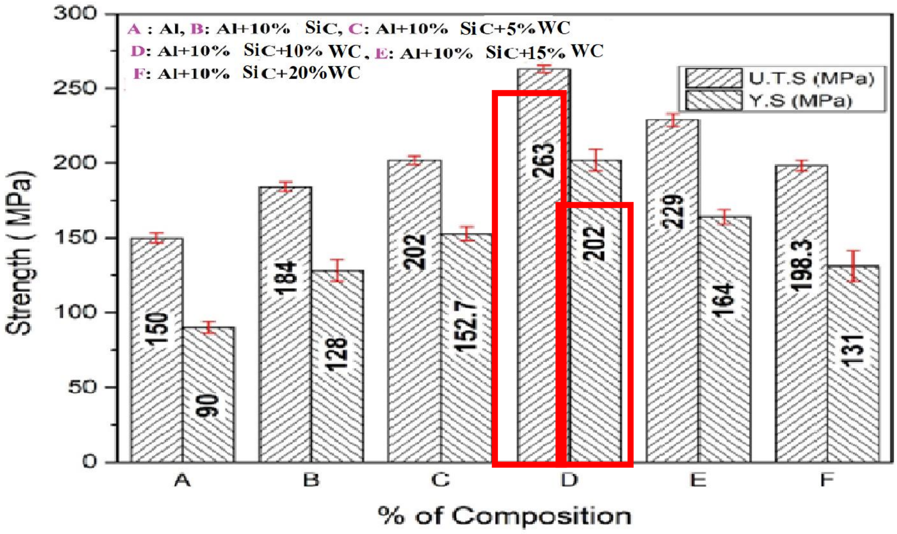
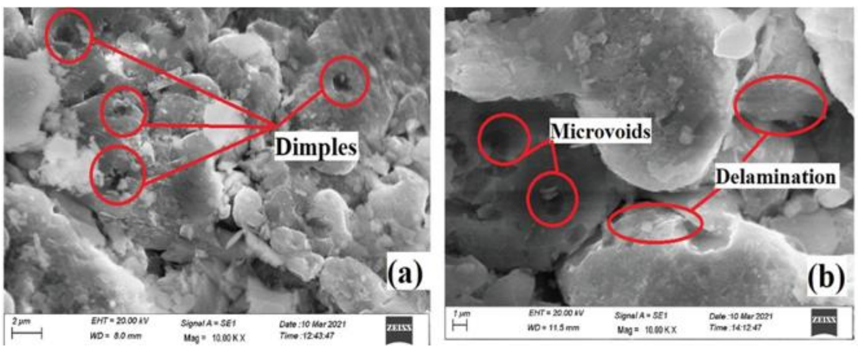


Figure 18. Variation of U.T.S and Y.S of HMMC with % reinforcement

5.7 Fractography

To determine the type of fracture that happened on the fractured surface, the fractured tensile composite specimens are subjected to fractography analysis. Both ductile and brittle fractures can develop in tensile specimens and are classified as such. SEM micrographs were used to determine the character of the fracture patterns, which were either cleavages forming or microvoids coalescing. The trans granular fissure propagation through the grain boundaries in the lesser plastic deformation materials causes cleavage fracture. During the tensile testing of ductile materials, the yield point phenomenon causes necking and microvoids to develop on the fractured surface. The key element that determines and controls the type of fracture is the non-uniform distribution of reinforcements and the creation of agglomerations. When the applied load surpasses the maximum load-carrying capacity, the composite specimen begins to fracture because of the difference between the load-carrying capacity of secondary phase agglomerations and the softer aluminium matrix. Figure 19 displays a scanning electron microscope picture of fractured tensile samples(a–f). Aluminium without reinforcement had broken surfaces.



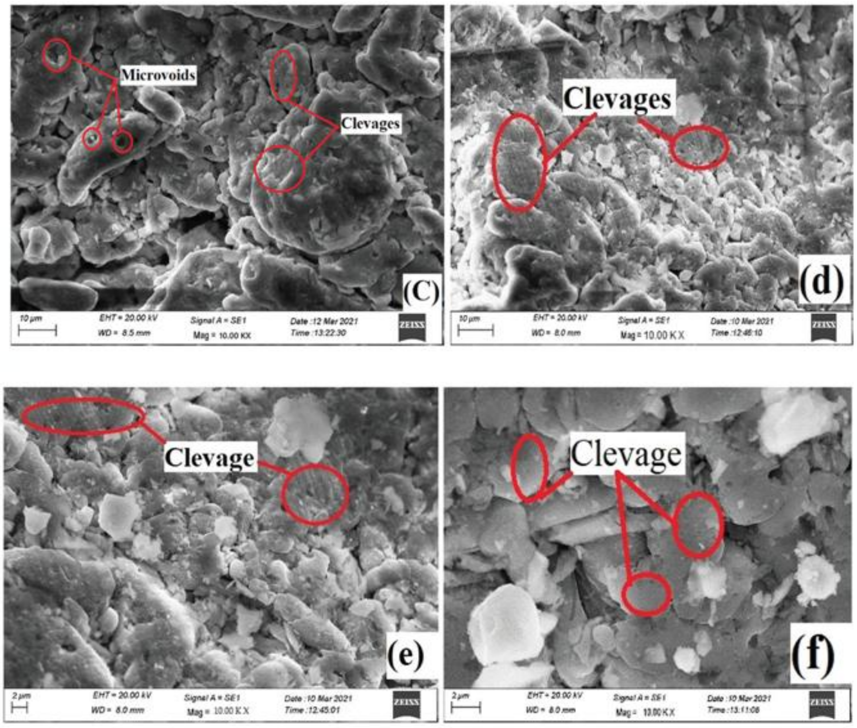


Figure 19. SEM images for Fractured surface (a) unreinforced Al, (b) Al-10% SiC-5% WC, (C) Al-10% SiC-10% WC, (d)Al-10% SiC-15% WC, (e) Al-10% SiC-20% WC, (f) Al-10% SiC-25% WC.

This was ascribed to the presence of harder silicon carbide particles, which prevent the aluminium matrix's reduced ductility from causing the formation of dimples. The fractured surfaces for the samples of aluminum, 10% silicon carbide, and X% WC (X = 5, 10, 15, 20, and 25) shown in figure 6(c-f) are devoid of dimples, and cleavages have developed on the surface.

VI. CONCLUSION

In conclusion, the aluminium – silicon carbide – tungsten carbide composite has shown some mechanical properties.

- Aluminium-10% silicon carbide- 10% WCachieved maximal tensile and yield strengths of 263 MPa and 202 MPa thanks to better interfacial bonding and uniform distribution of reinforcements.
- When more than 10% of WC is added, agglomerates develop, reducing the strength to 209 MPa and 186 MPa for 15% to 25% of WC reinforcement.
- The obtained experimental densities are close to theoretical densities and density declines with increasing reinforcement percentage, indicating lower porosity.
- For composite specimens made of aluminium -10% silicon carbide- 25% WC instead of unreinforced aluminum, the impact energy drops from 4.8 J to 2.7 J. The existence of harder ceramic reinforcements in the aluminium matrix was blamed for this reduction.
- The distribution of reinforcements was uniform up to the addition of 10% WC, according to SEM analysis. However around 15% to 25% assimilation of WC particles, WC agglomerations are evident.
- The greatest hardness value, which was 91.93% higher than pure aluminium, was attained at 10% WC reinforcement. The self-lubricating ability of the WC particles causes the hardness to drop as the amount of WC added increases past 10%.
- Dimples, microvoids, de - laminations, and Cleavages can be seen in SEM micrographs of the cracked surface. In unreinforced aluminium, the presence of dimples leads to ductile fracture, and in aluminium-10% silicon carbide-WC hybrid composites, the presence of cleavages and microvoids leads to brittle fracture.

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