Synthesis and Comparative Analysis of Hybrid Al-6063/SiC/B_4C Metal Matrix Composites

Dr. Gagandeep Chawla[1a*], Sahil Kumar[1b], Aditya Sharma[1c], Krishna[1d] Aseem Gulati[1e], Sunil Setia[2f]

[1]*Department of Mechanical Engineering, Seth Jai Parkash Mukand Lal Institute of Engineering and Technology (JMIT) Radaur-135133, Yamunanagar (Haryana), India*

[2]*Department of Mechanical Engineering, National Institute of Technology, Hamirpur-177005 (Himachal Pradesh), India*

[*a]*gagan1984mech@gmail.com*, [b]*sahilrana230901@gmail.com*, [c]*adityasharma042001@gmail.com*, [d]*krishnachaudhary2002s@gmail.com*, [e]*aseemgulati22072001@gmail.com*, [f]*sunilsetia@nith.ac.in*

Abstract

Metal Matrix Composites (MMCs) are gaining popularity among scientists, engineers, and industrialists owing to their greater strength, improved elastic modulus, excellent micro-plastic strain resistance, superior fatigue resistance, improved thermal/electrical conductivity, and expansibility. In the current study, four different samples of Al-6063/SiC/B_4C hybrid MMCs were developed using the stir casting technique, containing 0%, 9%, 8%, and 7% volume of SiC and 0%, 1%, 2%, and 3% volume of B_4C. Mechanical properties of Al-6063/SiC/B_4C hybrid composites including tensile test, impact test, hardness test, and chemical test, were investigated. Test results show that sample-4 has maximum tensile strength (163.41 N/mm^2), maximum % elongation (23.89%), maximum impact strength (34.00J) and maximum hardness (66.76 HV) as compared with other samples while sample-3 has the maximum yield strength (150.81 N/mm^2).

Keywords: *Al/SiC/B_4C, MMCs, Stir casting, Mechanical properties*

1. Introduction

COMPOSITE refers to a combination of at least two separate materials. The qualities of these materials are the sum of their constituent particles. Metal matrix composites are gaining popularity among scientists, engineers, and industrialists owing to their greater strength, improved elastic modulus, excellent micro-plastic strain resistance, superior fatigue resistance, improved thermal/electrical conductivity, and expansibility. Among the various matrix materials available, such as Al, Cu, Mg, Ti, Ni, Pb, Co, and Zn metal and alloys, Al metal and alloys are the most commonly used. This is due to their readily available light weight, and has high heat conductivity. The second phase of these composites is the reinforcing phase. The resulting composites are called aluminium matrix composites (AMCs) or simply metal matrix composites (MMCs). The commonly used reinforcing materials are silicon carbide (SiC), boron carbide (B_4C), aluminium oxide (Al_2O_3), fly ash, red mud, bamboo leaf ash (BLA), rolled homogeneous armor (RHA), copper clad aluminium (CCA), Magnesia or magnesium oxide (MgO), Titanium carbide (TiC), Silicon nitride ($Si3N_4$), Titanium Diboride (TiB_2), Molybdenum disulfide (MoS_2), and Nickel (Ni) etc. These can be used individually or in combinations. When MMCs contain more than one reinforcing element, they are called hybrid MMCs.

The addition of refractory particles with high strength and modulus to a ductile metal matrix results in a material. This material is endowed with mechanical characteristics midway between the matrix alloy and the ceramic reinforcement. MMCs are either in use or in prototyping for the space shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs, and avariety of other applications. Hemalatha *et al.* [1] examined three samples of MMCs in which Al-6063 was reinforced with different compositions of alumina (3, 6 and 9) percent. It was concluded that Al-6063 + 9% Al_2O_3 has the highest hardness. With an increase of 6% Al_2O_3 concentration in Al-6063, the porosity decreases. Poovazhagan *et al.* [2] worked on metal matrix nano-composites (MMNCs) having Al-6061 as matrix with reinforcement concentration of B_4C as 0.5% (fixed) and of SiC as 0.5%, 1%, 1.5% (variable). It was found that 1% SiC sample has superior tensile strength whereas 1.5% SiC has maximum hardness but it is unstable along the length. Kisasoz *et al.* [3] prepared samples by infiltration of Al-6063 in preform of SiC and B_4C and analyzed that hardness of sample quadruples that of the Al-6063 alloy with a homogeneous distribution of particulates in the matrix by occupying maximum porosity space. Rino *et al.* [4] synthesized MMCs by reinforcing 8% by wt. zircon sand and alumina in Al-6063 with different combinations of particulate concentration and found that the 4%+4% combination showed optimum results with minimum pore formation. Singla *et al.* [5] conducted experiments on Al/SiC- MMCs prepared a two- step mixing method of stir casting. It provided homogeneous dispersion of particulates in the Al matrix and concluded that Al+25% by wt. SiC gave maximum hardness and impact strength. Chawla *et al.* [6] worked on the MAFM of Al-6063/SiC/B_4C and found that the effect of change in percentage of reinforcement B_4C and SiC in Al-6063, the MRR was increased by 51.52%. Kumar *et al.* [7] prepared Al/SiC/Mo aluminium matrix composites (AMCs) by stir casting and obtained that Al+10%SiC+4%Mo indicates a significant improvement in the hardness value. While a marginal effect on the tensile strength due to clustering resulted in increased porosity level. Sekar *et al.* [8] performed tests on Al-7075/SiC/B_4C prepared by stir and squeeze casting. It was found the hardness of Al-7075 increased from 102 HV to 120 HV for a 1% SiC and 1.5% B_4C combination, whereas impact strength decreases. Mahmoud Hassaballa *et al.* [9] tested Al-7075/SiC/B_4C and affirmed that increasing the weight percent of reinforcement decreases percentage elongation, impact strength, and density while increasing tensile strength and porosity. Jindal *et al.* [10] carried MAFM on Al/SiC/B_4C and observed MRR increase with increase in magnetic field strength. The observed MRR decreases with increase in hardness MMCs used. Karakoc *et al.* [11] synthesized MMCs by reinforcing 12% by wt. SiC and B_4C in Al-6061 with different combinations of particulate concentration. It is concluded that 12% B4C + 0% SiC has the highest hardness and high degree of agglomeration with the lowest coefficient of friction. Jindal *et al.* [12] performed MAFM and roughness measurement on Al/SiC/B_4C. Authors found at 0.4 Tesla MRR is maximum and surface roughness is minimum and these decrease and increase afterwards respectively. Hosamani *et al.* [13] worked on three samples viz. pure Al alloy, Al+3%SiC, and Al+7%SiC. It has been observed wear resistance, tensile strength, and hardness increase with an increase in wt. % of SiC in Al matrix. Uthayakumar *et al.* [14] tested Al+5%SiC+5%B_4C and found that the hybrid composite retains the wear resistance properties up to 60N. A sliding range of 1-4 m/s and the bigger B_4C particulate sizeshows a more homogeneous composite microstructure compared to the smaller size due to agglomeration. Kumar *et al.* [15] investigated 1kg Al-6351+50gm SiC+50gm B_4C. It is concluded that strength and hardness increases with addition of reinforcement. Green *et al.* [16] prepared three samples of MMCs viz. Al-6063+SiC (5, 7 and 9) percent. The results showed that yield strength, hardness, and degree of refinement of eutectic silicon increase, percentage elongation decreases with an increase in wt. % of SiC. Kumar *et al.* [17] performed tests on Al-6063+5% SiC and there were higher values of hardness, tensile strength, and impact strength than the base Al-6063 alloy. Clustering and non-homogeneous distribution of SiC particles were seen in the Al matrix and this resulted in increased porosity. Kingston *et al.* [18] investigated three Al/C/SiC/B_4C samples. It is revealed that a hybrid with a composition of 90%Al+2%C+2%SiC+6%B_4C has high tensile, compressive, and hardness compared to other samples with a lower increase in brittleness. Gomez *et al.* [19] prepared Al/B_4C/SiC-MMCs by hot extrusion. It was observed that hardness increases up to 95HV to 150HV whereas coefficient of friction increases from 0.5 to 0.8. Karthibeyan *et al.* [20] prepared three samples of Al-MMCs with different concentrations of SiC (5%, 7%, and 9% by wt.). The tests showed that wear losses decrease with an increase in wt. % of SiC. In the present investigation, an attempt has been made to prepare hybrid Al-6063/SiC/B_4C MMCs with different compositions of SiC and B_4C reinforcements with Al-6063 as base material using stir casting technique. These MMCs were examined and comparatively analyzed on their mechanical properties viz. tensile strength, impact strength, hardness test and chemical test.

2. Material and Methods

In the present research work, four different samples of hybrid MMCs have been prepared like {sample-1: 100 % of Al-6063 with 0 % of SiC and 0 % of B_4C}, {sample-2: 90 % of Al-6063 with 9 % of SiC and 1% of B_4C}, {sample-3: 90 % of Al-6063 with 8 % of SiC and 2 % of B_4C} and {sample-4: 90 % of Al-6063 with 7 % of SiC and 3 % of B_4C}. The MMCs were fabricated using a stir casting technique in which a rectangular muffle furnace with a temperature controlling device and graphite stirrer was used for melting and stirring purposes respectively. Table 1 shows the samples of MMCs at different proportionate compositions.

Table 1. Weight ratios of four different samples of Al/SiC/B_4C-MMCs

Sample No.	Weight Ratios		
	Al-6063	**SiC**	**B_4C**
1	100%	-	-
2	90%	9%	1%
3	90%	8%	2%
4	90%	7%	3%

Figure 1 depicts the flow chart for the fabrication procedure of hybrid Al-6063/SiC/B_4C-MMCs. Before proceeding further in the experimentation work of casting, a brief description of stir casting is given. Stir casting is a sort of casting method in which a mechanical stirrer is used to create a vortex in the matrix material to combine reinforcement. It is an appropriate technique for the fabrication of MMCs because of its cost effectiveness, mass production application, simplicity, nearly net shaping, and simpler control of composite structure. Figure 2 and Figure 3 depict the schematic arrangement and pictorial view of stir casting setup that includes a furnace, reinforcement feeder, and mechanical stirrer. The furnace is used to heat up and melt materials. The bottom pouring furnace is better suited for stir casting because quick poring is necessary after stirring the combined slurry to avoid solid particles settling at the bottom of the crucible. The mechanical stirrer is used to create a vortex that leads to the mixing of the reinforcing materials that are put into the melt. The stirring rod and the impeller blade make up the stirrer.

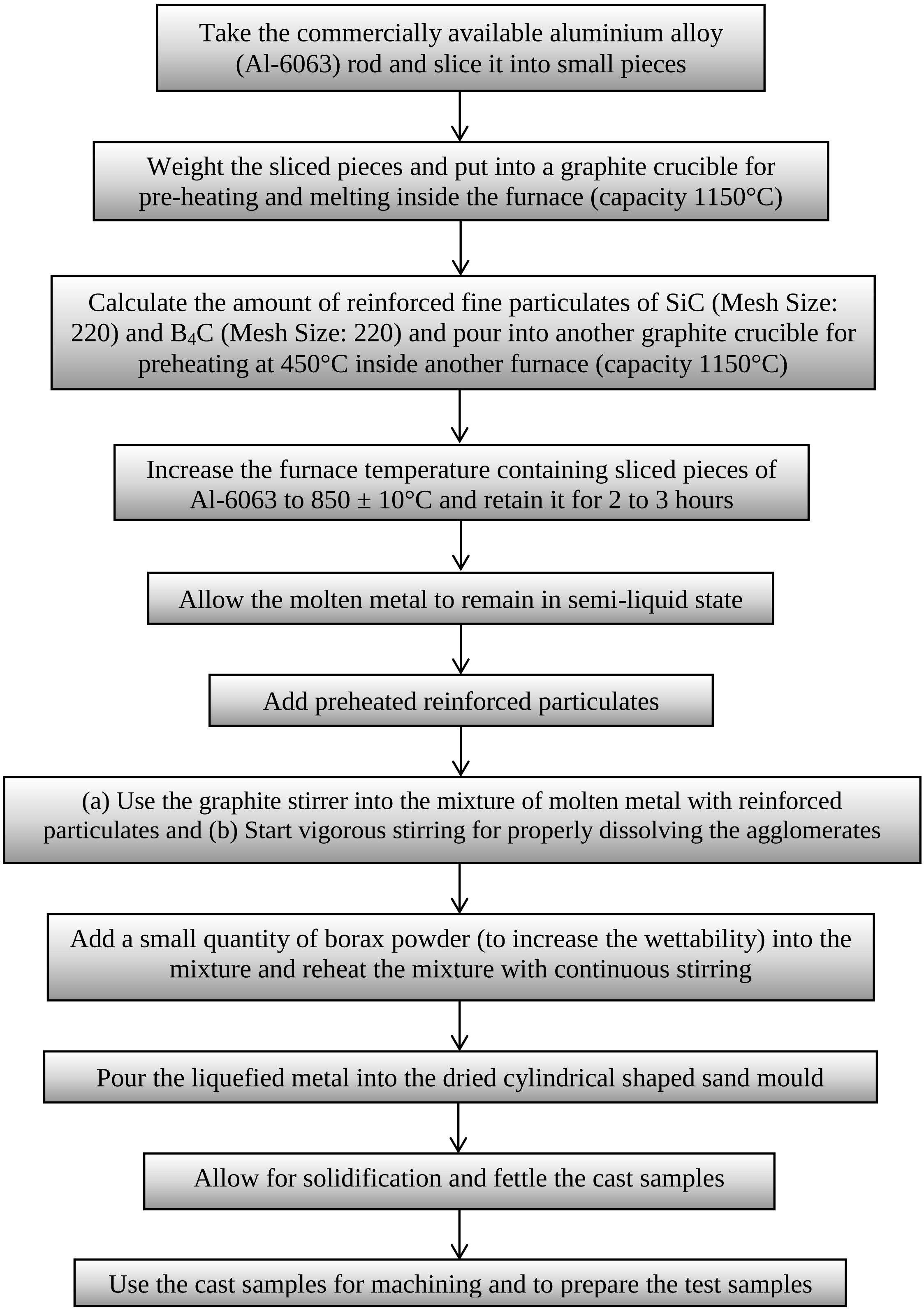

Figure 1. Flow chart of metal matrix composite (Al-6063/SiC/B_4C) preparation [6]

The impeller blade can be of different geometry and number of blades. Flat blades with three numbers are chosen because they provide an axial flow pattern in the crucible while using less power. This stirrer is connected to variable speed motors, and the rotation speed of the stirrer is regulated by a regulator attached to the motor. Furthermore, the feeder is connected to the furnace and is used to feed the reinforcing powder into the melt. Pouring of mixed slurry in the mould can be done using a permanent mould, a sand mould, or a lost-wax mould.

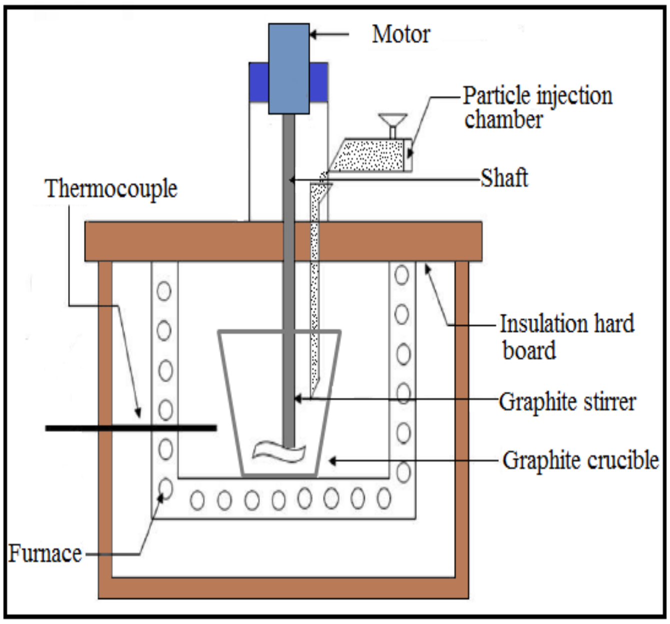

Figure 2. Schematic illustration of stir casting setup

Figure 3. Pictorial view of stir casting setup

Figure 4 depicts the several phases involved in the stir casting process. Figure 5 and Figure 6 depict the Al-6063 rods and SiC and B_4C reinforcements used for the preparation of hybrid MMCs. The matrix ingredients are melted in the bottom pouring furnace at a temperature of 850 ± 10°C. Simultaneously, reinforcements are preheated in a separate furnace at 450 ± 10°C temperature to eliminate moisture, impurities, and other contaminants. After melting the matrix material, mechanical stirring is started to form a vortex for a certain time period, then reinforcement particles are poured at a constant feed rate by the feeder provided in the setup at the centre of the vortex, and the stirring process is continued for a certain time period after the reinforcement particles have been completely fed. The molten mixture is then poured in preheated metal mold and kept for natural cooling and solidification. Further, post casting process such as machining, testing, inspection etc. has been done.

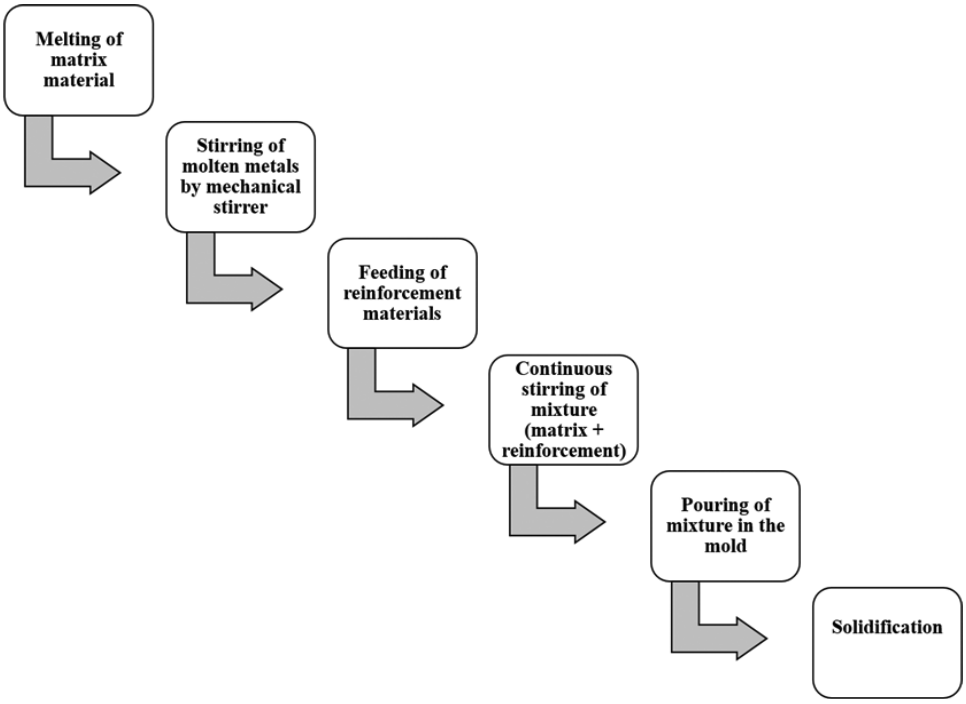

Figure 4. Process of stir casting

Figure 5. Al-6063 rods

Figure 6. SiC & B_4C powder

2.1 Material calculations

The calculations of the material required for the casting of four sample compositions of metal matrix composites (MMCs) has been conducted. For the calculations consultation with the testing agency that has performed the various tests on the casted samples was done. Yamunanagar Engineering Cluster Pvt. Ltd., Yamunanagar, Haryana, India has performed the tests.

The various tests performed are as follows:

1. Tensile Strength Test
2. Impact Strength Test
3. Hardness Test
4. Chemical Test

As per the discussions with the testing agencies, three cylindrical rods of OD (Outer Diameter) = 2 cm and length 12 cm (total length 36 cm) for the tensile strength test; two square bar of cross-section 1 × 1 cm^2 and length 10 cm (total length 20cm) for the impact strength tests were prepared. Remaining tests are to be performed on the above bar specimens.

For the calculations, density of aluminium is taken as 2.719 gm/cm^3.

Approx. Weight of Al-6063, SiC (220 Mesh) and B_4C (220 Mesh) is calculated as follow:

Weight of aluminium cylindrical rod for tensile test = Volume of cylindrical Rod × Density

$$= \frac{\pi \times OD^2 \times L}{4} \times 2.719$$

$$= \frac{\pi \times (2)^2 \times 36}{4} \times 2.719$$

= 0.307 Kg

Weight of aluminium square bar required for impact test = Volume of square bar × Density

$$= (1 \times 1 \times 20) \times 2.719$$

= 0.054 Kg

Weight of Aluminium per sample = 00.307 + 0.054 = 0.361 Kg

To account for the losses in casting like solidification shrinkage etc. allowance of 30% was taken.

So, net weight of aluminium after adding allowance = 1.30 × 0.361 = 0.469Kg

Total weight of aluminium for all 4 samples = Wt. of aluminium per sample + 3 × (90% of wt. of aluminium per sample)

$$W_{Al} = 0.469 + 3 \times 0.90 \times 0.469$$

$$W_{Al} = 1.735 \text{ Kg}$$

Total weight of SiC for all 4 samples = (0% +9% +8% +7%) of wt. of aluminium per sample

$$W_{SiC} = (0+0.09+0.08+0.07) \times 0.469$$

$$W_{SiC} = 112.56 \text{ gm}$$

Total weight of B_4C for all 4 samples = (0% +1% +2% +3%) of wt. of aluminium per sample

$$W_{B4C} = (0+0.01+0.02+0.03) \times 0.469$$

$$W_{B4C} = 28.14 \text{ gm (approx.)}$$

2.2 Synthesis of Al-6063/SiC/B_4C MMCs

2.2.1 Slicing of Al-6063 rods into small pieces

The cylindrical and square bar is sliced into several pieces; each piece has a length of 40 mm and 50 mm with weight 50 gms respectively. Figure 7 and Figure 8 show the cutting of rods and cut pieces of Al-6063 respectively. These cut pieces ease the melting in a shorter time.

Figure 7. Cutting of Al-6063 rods

Figure 8. Cut pieces of Al-6063 rods

2.2.2 Preheating of sliced pieces of Al-6063 rods

The sliced pieces were weighted and put into a graphite crucible for pre-heating and melting inside the furnace (capacity 1,150 °C) as shown in Figure 9. Time required for preheating and melting was reduced due to increased exposed area for heat.

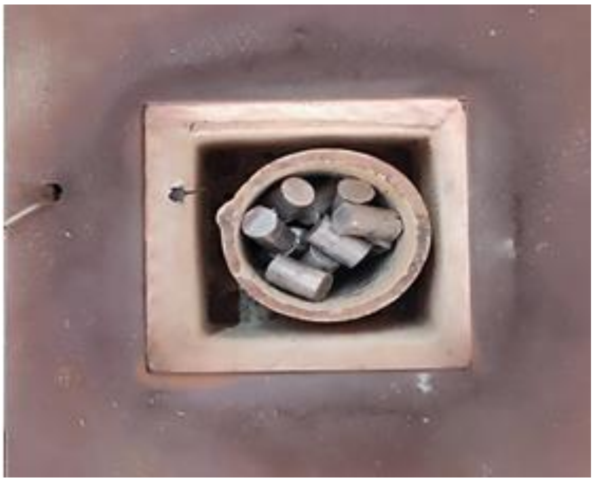

Figure 9. Preheating the cut pieces of Al-6063 in furnace

2.2.3 Preheating of SiC & B_4C reinforcements

The amount of reinforced fine particulates of SiC (Mesh Size: 220) and B_4C (Mesh Size: 220) is calculated and poured into another graphite crucible for pre-heating at 450 ± 10°C inside another furnace (capacity 1,150°C) as shown in Figure 10. Essentially, the reinforcements are preheated for two reasons: firstly to remove moisture and secondly to make them compatible with molten Al. In order to enhance wettability with the liquid alloy or metal matrix material, it is essential to preheat the reinforcement phase.

Figure 10. Preheating the reinforcements in furnace

2.2.4 Melting of Al-6063 pieces and adding reinforcements

The furnace temperature containing sliced pieces of Al-6063 to 850 ± 10 °C was increased and retained for 2 to 3 hours. The molten metal was allowed to remain in semi-liquid state. The preheated reinforced particulates of SiC and B_4C were added simultaneously with the vortex by stirring action to form the molten metal matrix. Figure 11 depicts the melting of Al-6063 pieces and Figure 14 shows the addition of reinforcements with continuous stirring.

Figure 11. Melting the cut pieces of Al-6063 in furnace

2.2.5 Stirring of metal matrix and adding borax powder

The distinguishing point about the stir casting is the use of stirrer. The graphite stirrer was used to mix the molten metal with reinforced particulates for properly dissolving the agglomerates. Also vortex flow created by the stirring action helped in the circulation of reinforcements at the bottom of the crucible. Because of the density difference between the heavier aluminium matrix and the reinforcement particles, sedimentation of reinforcement particulates occurred at the bottom of the stirrer. Stirrer rotations disturbed it and redistributed it uniformly in the matrix. Small quantity of borax powder (to increase the wettability) was added into the mixture and reheated the mixture with continuous stirring. Figure 12 shows addition of reinforcements with continuous stirring.

Figure 12. Adding the reinforcement particle in the molten metal with continuous stirring

2.2.6 Pouring the molten matrix into the moulds

For the tensile test specimen of OD 20 mm and length 120 mm was considered and for impact test specimen dimensions were 10 × 10 × 100 mm^3. So two mild steel moulds were fabricated which provided the above dimensions. Figure 13 and 14 shows the moulds for tensile and impact test respectively. In Figure 15 CAD model of mould for impact test is shown. These moulds were designed and fabricated using SolidWorks software. The dimensional accuracy of the moulds were checked by performing the trail casting with wax. Small pieces of wax (cut from the candle) were melted and the liquified wax was poured into the mould (Impact test specimen mould) as shown in Figure 16. Then it was allowed to solidify for some time as shown in Figure 17 and the two wax specimens of 10 × 10 × 100 mm^3 volume required for impact test are depicted in Figure 18. The wax specimens were found within the required dimensions. Hence the moulds were found to be dimensionally accurate for specimen casting. Molten metal matrix was then poured into the moulds. Care should be taken while pouring the molten metal. Pouring should neither be too fast nor be too slow but should be quick enough to avoid pre-solidification. Figure 19 shows the preheating of the moulds in the furnace which helped in removing moisture from the moulds. Making the mould dried is very essential as it can cause porosity defects in the cast samples. Flow of molten metal should be directed into the pouring basin of the mould as shown in Figure 20.

Figure 13: Mould for tensile test

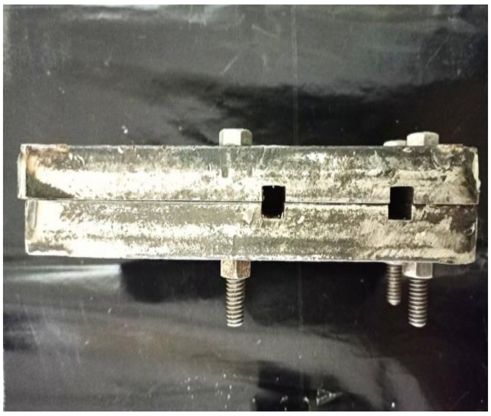

Figure 14: Mould for impact test

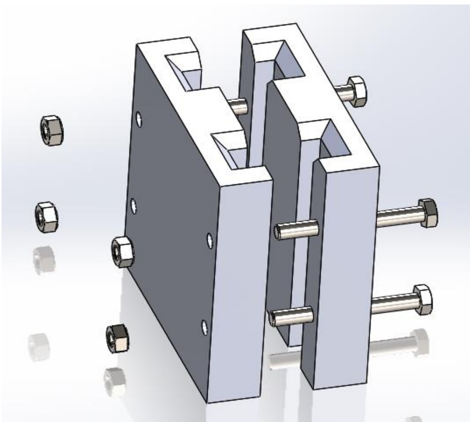

Figure 15. CAD model of mould for impact test

Figure 16. Pouring of molten wax in mould

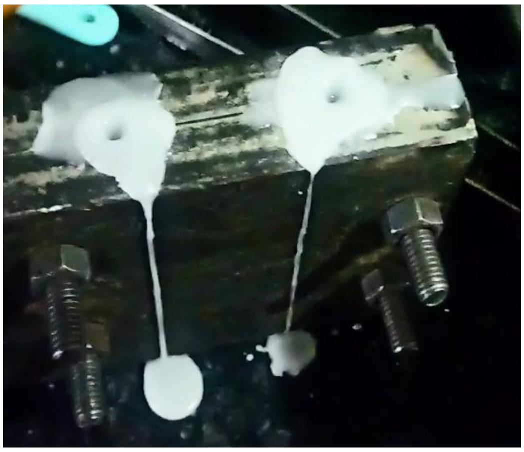

Figure 17. Wax solidification

Figure 18:Wax specimens for impact test

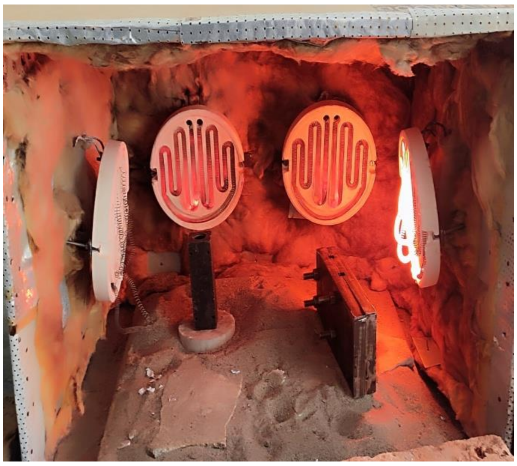

Figure 19. Preheating the moulds

Figure 20. Pouring the molten mixture into the dried mould

2.2.7 Allowing solidification and removing the cast sample

After the solidification of molten MMCs in the mould, casted samples for each composition were taken out. These samples were ready to get machined for required shape as per the code standard. The same steps were repeated for each composition. A total of five specimens for each sample composition were casted as shown in Figure 21.

Figure 21. Removing the casted samples from the moulds after solidification

2.3 Specimen preparation for testing

The casted samples were then machined in accordance with the specific code. Machined specimens and their corresponding dimensions are given in the following sub-sections.

2.3.1 Specimen preparation for tensile strength testing

For tensile strength testing dumble shape specimens were machined. ASTM E8/E8M:22 standard codes were used for testing specimens. Figure 22 shows the dimensional plot of tensile test specimens and machined samples with these dimensions is shown in Figure 23.

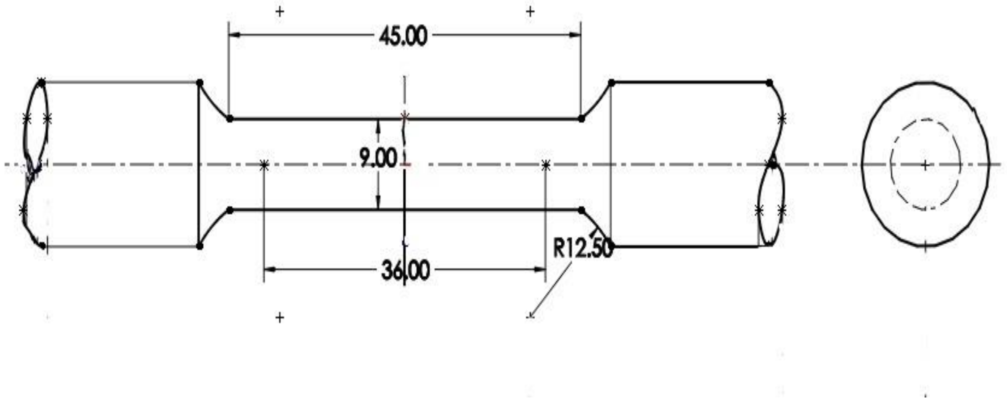

Figure 22. ASTM E8/E8M:22 tensile test specimen dimensions

Sample 1: 100 % of Al-6063 with 0 % of SiC and 0 % of B_4C

Sample 2: 100 % of Al-6063 with 9 % of SiC and 1 % of B_4C

Sample 3: 100 % of Al-6063 with 8 % of SiC and 2 % of B_4C

Sample 4: 100 % of Al-6063 with 7 % of SiC and 3 % of B_4C

Figure 23. ASTM E8/E8M:22 tensile test machined specimens

2.3.2 Specimen preparation for impact strength testing

For impact strength testing, square bar shape specimens were machined. IS 1757 (Part 1): 2020 standard code was used for testing specimens. Figure 24 shows the dimensional plot of impact test specimens and machined samples with these dimensions are shown in Figure 25.

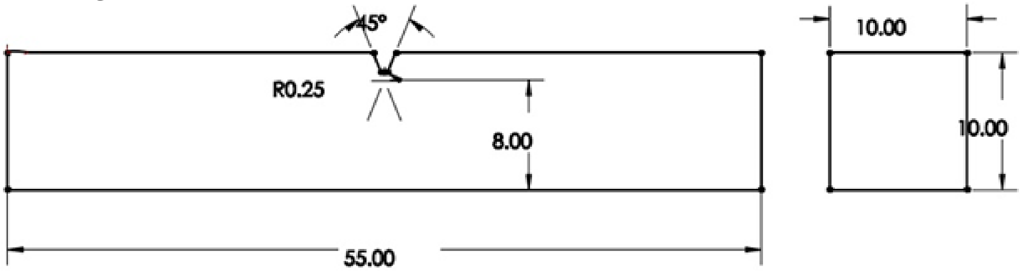

Figure 24. IS 1757 (Part 1): 2020 impact test specimen dimensions

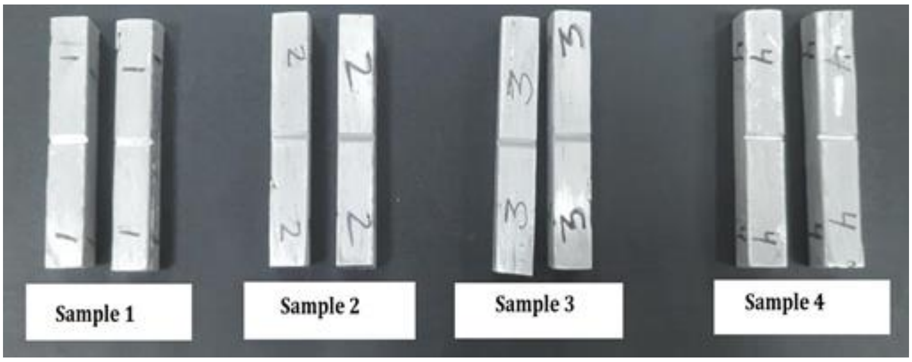

Figure 25. IS 1757 (Part 1): 2020 impact test machined specimens

2.3.3 Specimen preparation for hardness testing

For hardness testing cylindrical disc shaped specimens were machined. ASTM E384:22 standard codes were used for testing specimens. Hardness is measured on Micro Vickers Scale. Cylindrical disc shaped machined samples are shown in Figure 26.

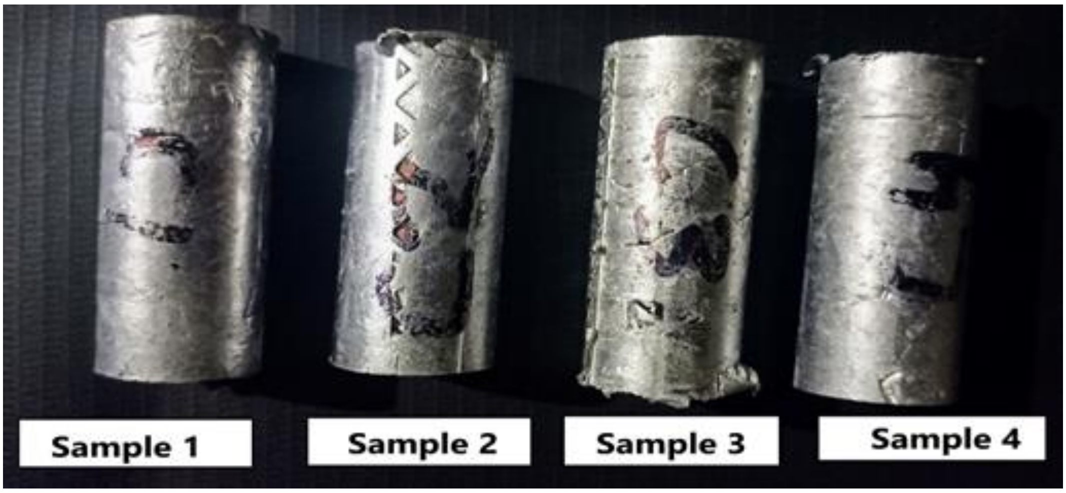

Figure 26. Machined specimens for hardness and chemical test

2.3.4 Specimen preparation for chemical testing

For chemical testing cylindrical disc shaped specimens were machined. ASTM E1251-17a standard code was used for testing specimens. Cylindrical disc shaped machined samples are shown in Figure 26. Single cylindrical disc shaped specimen was used for hardness and chemical testing by utilizing end faces of the disc.

3. Result and Discussion

In order to predict the mechanical properties of the samples, various tests were performed. Standards and specifications of each test specimen is elaborated in section 2.3. This section deals with the results obtained from the testing of different sample specimens and their analysis.

3.1 Analysis of testing results

The results obtained from different tests for different sample compositions were compared. The different tests which were performed on four different samples include:

1. Tensile Strength Test
2. Impact Strength Test
3. Hardness Test
4. Chemical Test

3.1.1 Tensile strength testing

Tensile strength is the ability of material to withstand a maximum amount of tensile stress without failure. The stress occurs when the material is being pulled or stretched. It is the point when a material goes from elastic to plastic deformation. The tensile test provided the tensile strength for different sample compositions having two specimens each. Average value of the tensile strength in N/mm^2 for the two specimens was used for the analysis as shown in Table 2.

Table 2. Average value of tensile strength for different samples

Sample No.	Average value of tensile strength (N/mm^2)
1	133.28
2	135.66
3	158.74
4	163.41

Figure 27 shows the variation of the tensile strength for the different samples graphically. From the results it was observed that the tensile strength increases from sample-1 to sample-4 and sample-4 have the maximum tensile strength of 163.41 N/mm^2.

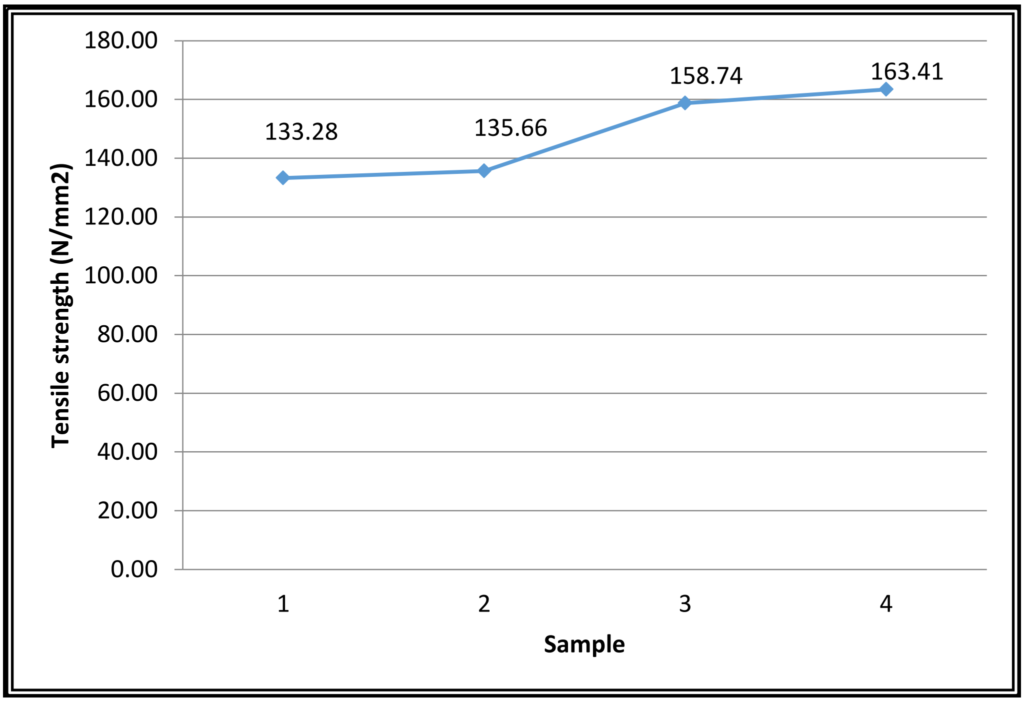

Figure 27. Plot for average value of tensile strength for different samples

Table 3 shows the average value of the yield strength in N/mm^2 for the different samples and its graphical variation is shown in Figure 28. This shows that yield strength increases from sample-1 to sample-3 then decreases for sample-4 where maximum yield strength for sample-3 is 150.81 N/mm^2. Average value of the % elongation is shown in Table 4. Figure 29 shows graphical variation of % elongation for different samples. It was observed that % elongation showed nearly the increasing trend from sample-1 to sample-4 with the maximum value of 23.89% for sample-4. Figure 30 shows the broken specimens of different samples after the tensile strength test.

Table 3. Average value of yield strength for different samples

Sample No.	Average value of yield strength (N/mm^2)
1	69.02
2	121.08
3	150.81
4	112.20

Table 4: Average value of % elongation for different samples

Sample No.	Average value of % elongation
1	12.39
2	12.26
3	14.72
4	23.89

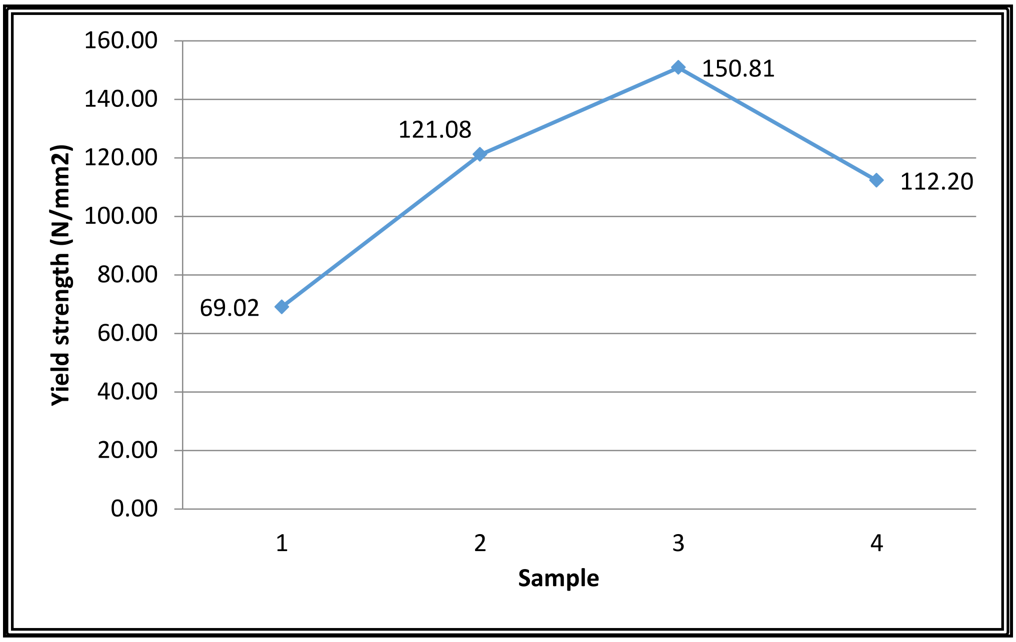

Figure 28. Plot for average value of yield strength for different samples

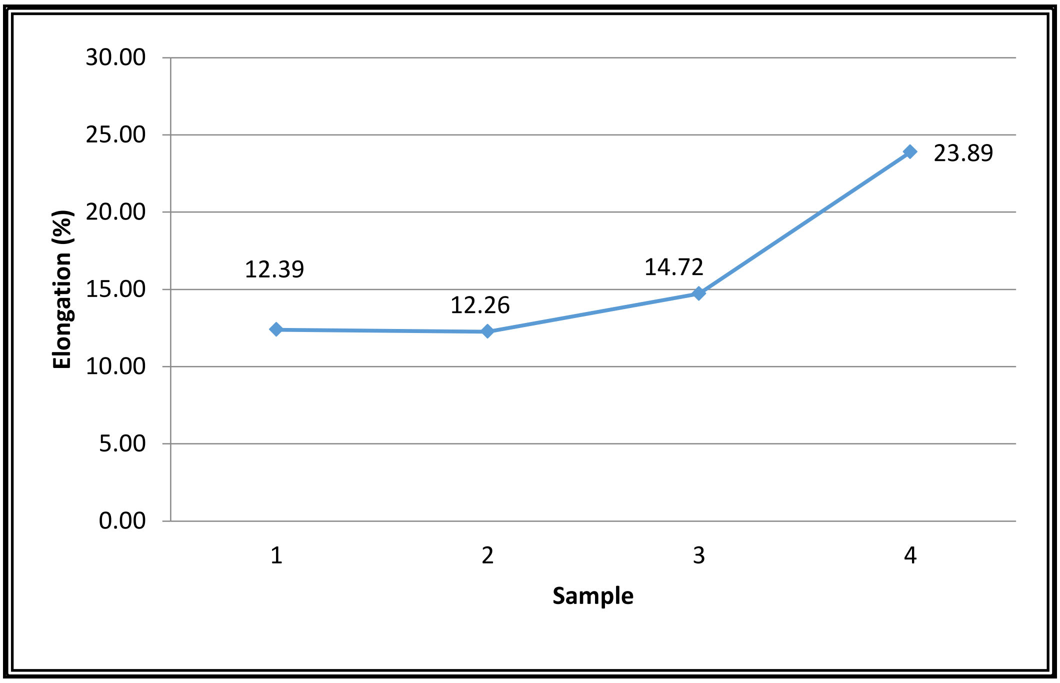

Figure 29. Plot for average value of % elongation for different samples

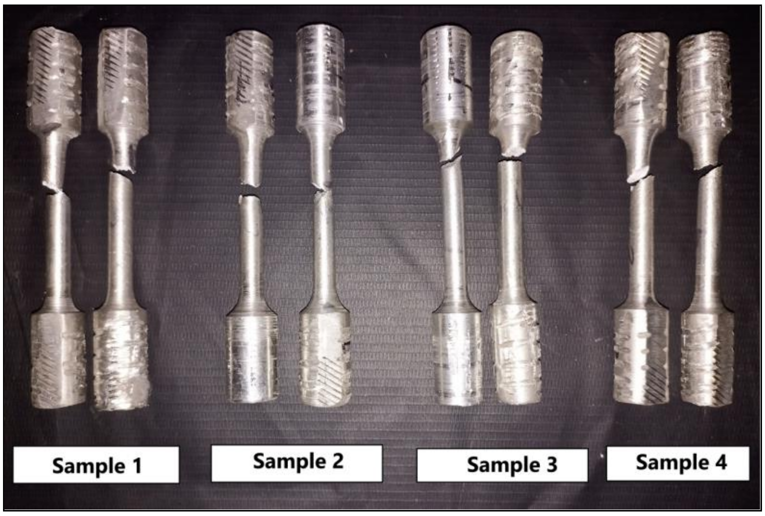

Figure 30. Specimens of different samples after the tensile strength test

3.1.2 Impact strength testing

Impact tests are used to study the toughness of the material. A material's toughness is a factor of its ability to absorb energy during plastic deformation. Two specimens per sample composition were tested for impact test and their average value of impact energy in Joules (J) for different samples is tabulated in Table 5. Figure 31 shows the graphical variation of impact energy for different samples. From the Figure it was observed that impact energy decreases from sample-1 to sample-3 and increases for sample-4. Maximum impact energy obtained was 34 J for sample-4. Figure 32 shows the broken specimens of different samples after the impact strength test.

Table 5. Average value of impact energy (J) for different samples

Sample No.	Average impact energy (J)
1	29.50
2	27.00
3	22.00
4	34.00

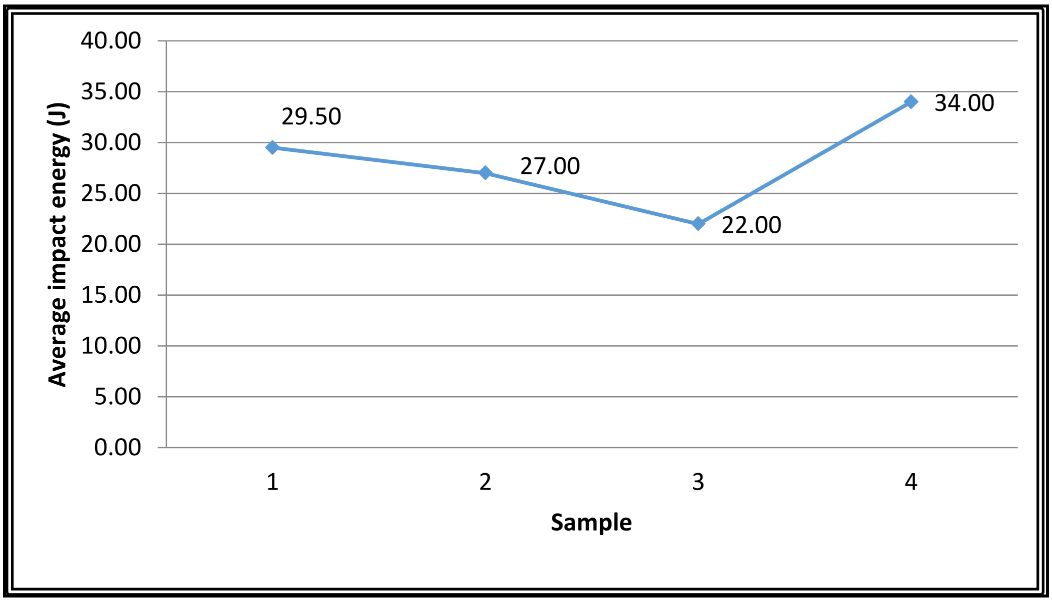

Figure 31. Plot for average value of impact energy (J) for different samples

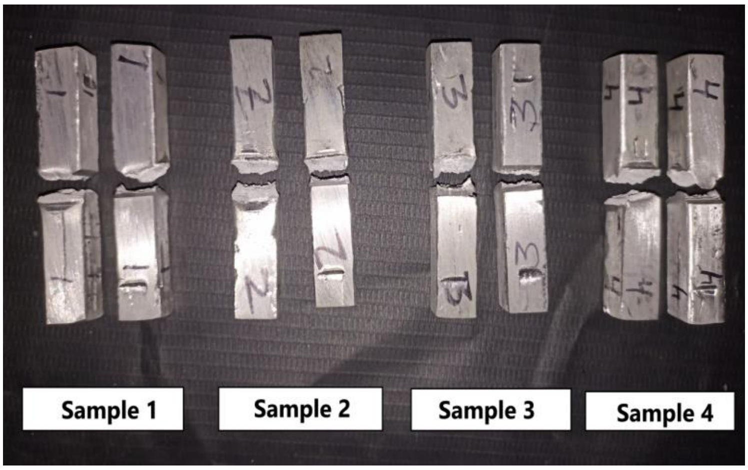

Figure 32. Specimens of different samples after the impact strength test

3.1.3 Hardness testing

Hardness is the characteristic of a material, defined as the resistance to indentation and is determined by measuring permanent depth of indentation. Table 6 shows the micro hardness test results for different samples on HV scale. Figure 33 represents the variation of average hardness (HV) for different samples. From the results it was observed that hardness increases from sample-1 to sample-4 with a maximum value of 66.76 HV for sample-4. Figure 34 shows different specimens after the hardness test.

Table 6: Average value of micro Vickers Hardness (HV 0.5) for different samples

Sample No.	Average micro Vickers hardness (HV 0.5)
1	53.46
2	58.80
3	62.00
4	66.76

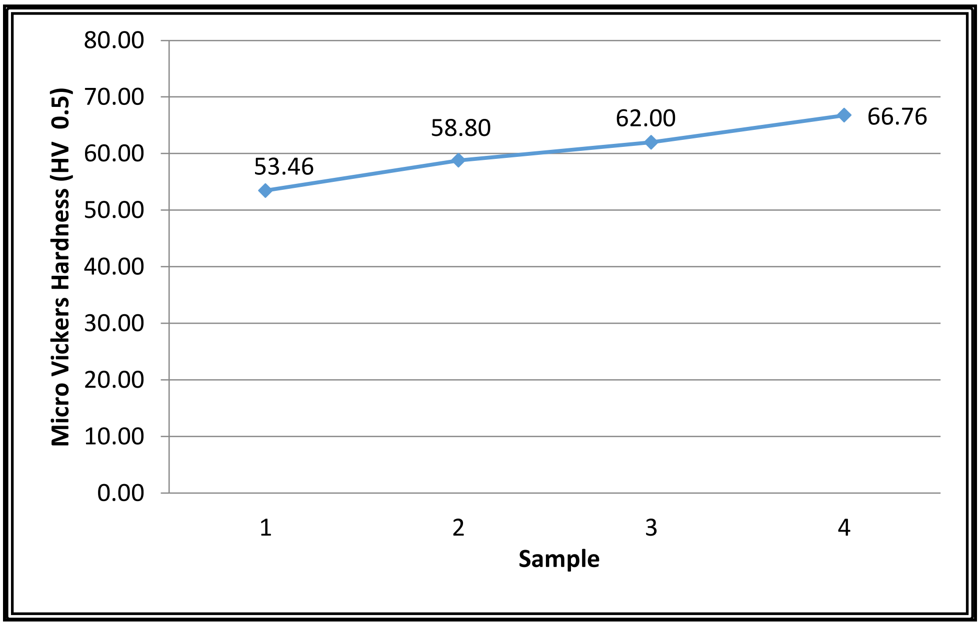

Figure 33. Plot for average value of micro vickers hardness (HV 0.5) for different samples

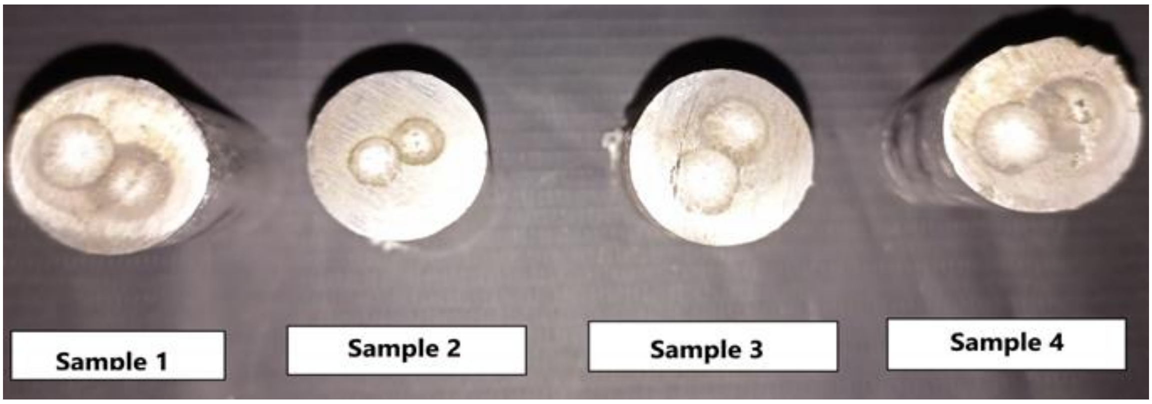

Figure 34. Specimens of different samples after the hardness and chemical test

3.1.4 Chemical testing

Chemical testing was carried out to investigate the percentage of different elements present in each sample. Results of the chemical test are shown in Table 7. Figure 34 shows different specimens after the chemical test.

Table 7. Chemical analysis testing results

Elements	Al	Si	Fe	Cu	Mn	Mg	Zn	Ti	V
Sample-1	98.98	0.377	0.142	<0.03	0.496	<0.01	<0.02	<0.005	<0.01
Sample-2	95.97	3.33	0.203	<0.03	<0.01	<0.399	<0.02	<0.05	0.026
Sample-3	98.42	0.983	0.169	<0.03	<0.01	0.423	<0.02	<0.005	<0.01
Sample-4	98.78	0.54	0.191	<0.03	<0.01	0.475	<0.02	<0.005	<0.01

4. Conclusion

Following conclusions are derived from the results:-

1. From the tensile test it was concluded that tensile strength increases with increase in percentage of reinforcements added with the maximum tensile strength of 163.41 N/mm^2 for sample-4.
2. Yield strength revealed that sample-3 had the maximum (150.51 N/mm^2) and sample-1 had the minimum (69.02 N/mm^2) yield strength.
3. The results from Figure 29 shows that percentage elongation nearly increases with increase in percentage of reinforcements added and hence ductility also increases in the same manner.
4. Impact energy absorbed by the samples initially showed the decreasing trend from sample-1 to sample-3 and then increased for sample-4. Therefore, sample-3 and sample-4 have the minimum and maximum toughness respectively.
5. Hardness increases with increase in the addition of reinforcement particles. Thus sample-4 was the hardest one having a hardness of 66.76 HV.
6. Results of the chemical test for the investigation of elements present in the different samples were not satisfactory as per the composition of samples decided. Reasons identified for the above mismatch in the composition may be the location where the chemical test was performed doesn't have the distributions of reinforcements. This shows that there was a lack of uniform distribution of reinforcement particles in the samples, which is the casting defect.

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