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INVESTIGATIONS TO STUDY THE MECHANICAL PROPERTIES OF SILICON CARBIDE BLENDED ALUMINIUM

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ABSTRACT

This investigation comprises of the observation of changes in mechanical properties of Aluminium metal matrix when blended with SiC. Aluminium–SiC metal matrix composites (MMCs) are prepared with various weight percentage of SiC using powder metallurgy techniques. The investigation are done using nano powders of pure Aluminium and SiC of sizes 10 μm & 30 μm and blended samples of Al – SiC MMCs with 10%; 20% and 30% of SiC are prepared using ball milling process. With blended MMC powders, cylindrical sample pellets are prepared in a mould with 70% compression by volume using an UTM. Compressed semi solid samples of pure Aluminium and SiC blended Aluminium are prepared for the experiment. These compressed samples were sintered at 250^0C-300^0C temperature in a muffle furnace and cooled in an inert environment. The prepared samples are tested for hardness and compressive strength using Rockwell's hardness testing machine and UTM respectively . The results of this investigation show a positive result and the mechanical properties of Al were found improved with addition of SiC composite compared to pure aluminium. With increase in the volume percentage of SiC in Aluminium the hardness and compressive strength has increased by 10.8 % and 24.6 % respectively.

I. INTRODUCTION

In this new generation of hectic life schedules and living standards , development in the field of material science is the one that plays a crucial role in raising these standards of living. And with this development came the concept of Metal Matrix Composites (MMCs). A normal material might not serve all the intended processes that have been assigned to it and thus a need for improving these base materials had arrived and thus MMCs concept was introduced. MMCs have been regarded as one of the most advantageous material groups in a variety of technical applications and industrial fields.

Metal Matrix Composites (MMCs) are a class of advanced materials that combine a metal matrix with reinforcing materials to achieve enhanced mechanical, thermal and electrical properties [1]. Common metal matrix materials are aluminium, titanium, magnesium and copper as these provide strength , ductility and other useful properties.

Usually MMCs are fabricated using powder metallurgy method but sometimes infiltration or liquid – phase processing can also be used to process these MMCs [2] [3]. The produced MMCs have improved strength and stiffness , thermal conductivity , wear and corrosion resistance properties also being light weighted.

Modern day Aluminium applications use this MMC technique as it helps broaden the various approaches that Aluminium compounds can be used in to achieve a higher number of successful targets.

Researches have been going on to test the behaviour and properties of Aluminium in its base form as well as when it is combined with other compounds to increase its productivity. But newer studies have shown that altering the chemical composition of Al compounds at a micro level can be extremely helpful in altering its properties that have wider range of applications than the compounds that are combined at a macro level. Raw aluminium is a soft, ductile metal that has a variety of applications across many fields of engineering and design.

However reinforced aluminium can be used to replace bronze and cast iron due to their favourable weight ratios. Reinforced Al is used in aircraft wings , pistons , cylinder heads and other components which is a clear

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example that these reinforced Al composites have the ability to be used and as well as replace the existing materials from Automobile industry [4].

The selection of SiC as the reinforcing element for the aluminium alloy is due to it boosts the wear resistance, strength, and hardness of the material to a significant degree while maintaining the ductility of base Aluminium and can provide a wider range of applications in manufacturing and construction sector [5]. Alteration of metal matrix at micro level has taken place before , however previous researches were conducted till the sample size of 50 μm and predictions were made that properties would improve as sample size decreases [6]. Our objective is to test the sample sizes below 50 μm and find out the changes in properties of Aluminium based on the increase in composition of SiC into aluminium metal matrix.

The applications of these SiC blended Aluminium MMCs are that these MMCs are used in;

- Aerospace sector for aircraft components and rocket nozzles, due to their lightweight and high strength properties.
- Automotive sector for brake components, engine parts and transmission systems due to their wear resistance and thermal conductive properties.
- Electronics sector for electronic packaging, heat sinks and substrates to dissipate heat generated by electronic components.
- Defense and military applications for armor materials, missile components, vehicle armor and vehicle weapon system due to their high strength and impact resistance.
- Industrial applications like industrial machinery and industry equipment for their wear resistance and durability factor.
- Renewable Energy applications for the preparation of components for wind turbines and solar panels.

And many other applications due to a variety of properties possessed by them.

The current investigation is being done to understand whether these Al – SiC MMCs can be used for replacing Cast Iron and Cast Steel which are currently used in the discs of Automobile Disc Brake system. Also if these MMCs can be used to replace iron rods used in the construction of buildings and architectural monuments as iron is bound to be affected by rusting and eventually will loose its strength and characteristics overtime [7].

II. METHODOLOGY

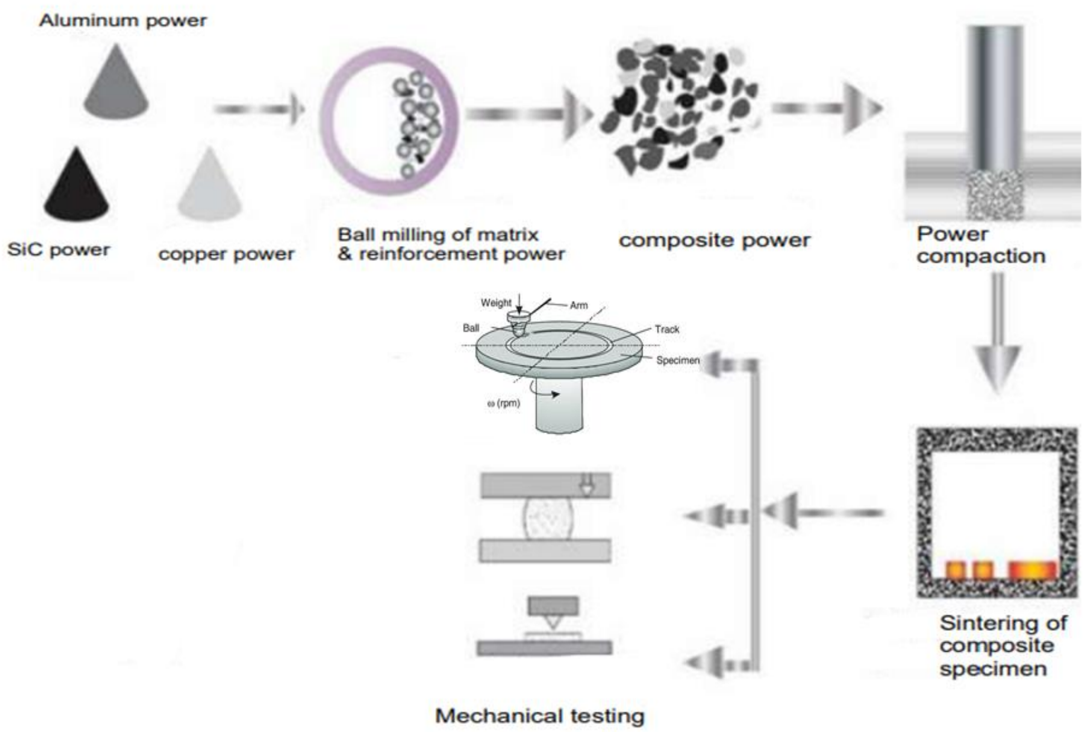

Figure 1: Schematic diagram for powder metallurgy process of Al – SiC metal matrix

The proposed methodology of this project focuses on the production of SiC blended Al MMCs which can be used in Automobile Disc Braking System.

1. Material Selection :

- Aluminium matrix : Aluminium powders of particle size of 10 μm and 30 μm are choosen as particle size of 50 μm have already been studied.
- Silicon Carbide Blend : Silicon Carbide of 10 μm and 30 μm are choosen as the blend material which will improve the properties of Aluminium matrix.
- Bonding material : Copper powders of 10 μm and 30 μm are used as the bonding material of Al-SiC blend.

2. Volumetric Weighing :

- The powders are weighed according to a ball to weight ratio of 10:1 meaning , for every 1 gram of powder 10 balls are to be used. So the 200 balls weighed at 112 grams and thus according to this weight of balls , the weight of individual powders varied on the composition of SiC used for blending.

3. Mixing and Blending :

- The finely produced powders are then blended together using a planetary ball mill to achieve a perfect blend and a homogenous mixture of Al-SiC powders.

4. Compacting :

- It is the process of compacting metal powders using a mould and application of high load using a UTM. Specifically the load applied during this investigation was 75 KN. Doing so semi solid samples of Al – SiC compound are obtained but they are weak and cannot be used to test for their properties.

5. Heat Treatment :

- To improve the strength , hardness of the produced samples and to convert the semi solid samples into solid form , Heat Treatment or Sintering is done so that the porosity of the samples decreases and the samples can be used for testing.

6. Testing :

- The thus produced samples are tested for their properties , so that it can be determined that the product has met its required specifications or not. Tests like Hardness Test , Compression Test and Wear Test are done on the sample to test their Hardness , Compressibility and Wear Rate .

III. EXPERIMENTAL PROCEDURE

PREPARATION OF SAMPLES:

PREPARATION OF METAL MATRIX COMPOSITE POWDERS:

Micro powders of pure aluminium of 10 μm and 30 μm , SiC powders of 10 μm and 30 μm are collected into containers . According to ball to weight of 10:1 used in the ball milling machine Al , SiC , Cu powders are weighed accordingly and varied with the percentage of SiC blended into the Aluminium base powder. Cu powder is used as the bonding material for the Al – SiC composite. For every gram of powder to be worked on 10 balls have to be used. Thus for each varied SiC composition the weighed powder weights are as follows :

- For 10% SiC composition : Al – 20.16 grams , SiC – 1.792 grams , Cu – 0.448 grams
- For 20% SiC composition : Al – 17.92 grams , SiC – 4.052 grams , Cu – 0.448 grams
- For 30% SiC composition : Al – 15.68 grams , SiC – 6.272 grams , Cu – 0.448 grams
- For pure Aluminium : Al – 22.4 grams

The weighed powders are poured into the grinding jar and tightly fixed into the ball milling chamber and the machine is set to operate for 2 hours 30 minutes for every run at 300 RPM. By doing so , fine powders of pure Aluminium and Al – SiC composite are obtained.

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Figure 2: Metal powders and balls in grinding jars

Figure 3: Ball milling Machine Setup

PREPARATION OF SOLID SAMPLES:

The finely produced powders are then transferred into a mould setup for the process of compaction to achieve semi solid metal powder samples. The setup is placed on the UTM and the die containing the powders is pressed with a force of 75 KN and the force pushes the punch into the die and forces the powder inside the die to compress and form into semi solid cylindrical metal billets . But these formed billets are very weak in strength and cannot be used for testing and in any applications , so to provide the billets with strength , hardness and to convert the semi solid samples into tough solid samples , the billets are heat treated inside a muffle furnace at 350^{0}C for 2-3 hours , thus forming strong , hard , solid metal billets.

TESTING THE SAMPLES:

The produced samples are tested for their mechanical properties of Hardness and Compressibility on the Rockwell's Hardness Testing Machine and UTM respectively.

HARDNESS TEST:

To test the hardness of Aluminium samples "Rockwell B Scale" is used as the measuring scale and a force of 100 kgf with 1/16 (1.6 mm) diameter sphere indenter is used as the penetrating indenter. The "Red Dial" of the hardness testing machine is used for the aluminium samples.

Before testing the actual samples , the tester is adjusted to zero point on the dial using a reference block. Position of the anvil of the Rockwell tester is placed so that the indenter will be applied precisely where we want to measure the hardness. Then the preliminary load or minor load is applied to ensure proper seating of the indenter on the specimen's surface . It is a very light load of 10 kgf. By doing so it is made sure that there is no disturbance among the indenter and surface of the specimen and no mismatch would happen between both of them. After the minor load is applied , the major load of 100 kgf is applied . This time rather than just being on the surface of the specimen , the indenter penetrates to some extent into the surface of the specimen.

When the major load is applied on the specimen , the dial on the hardness scale is pointed towards a value. This value is noted. Now major load is removed while keeping the minor applied. The HRB (Rockwell Hardness Scale B) is used to determine the hardness of the specimen as it shows the depth of indentation penetrated into the specimen. After the hardness values are obtained the specimens are removed from the Rockwell Tester.

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COMPRESSION TEST:

To test the compressibility of the produced Al – SiC composite samples a UTM (Universal Testing Machine) is used . Before testing the samples it was made sure that the surface of the specimen was properly machined on all sides and that both the ends of the specimen were flat and parallel to each other , otherwise they would be damaged.

Firstly, Compression platens were installed on the UTM , ensuring they are aligned and parallel to each other. Specimen were placed in the centre of compression platens making sure they were aligned properly with the loading axis. Then Zero displacement measurement was done on the UTM to ensure the intial position of the specimen to be recorded accurately.

A slow , steady compressive load is applied onto the specimen and load and displacement data is recorded continuously during the test. The load is gradually increased till the buckling of the specimen happens so that the compressive limit of the produced specimen can be known. After the compressive load values are obtained and buckling of specimen happens the specimen is removed from the UTM setup ensuring all safety precautions. From the obtained values of compressive loads , the compressive strength of the specimens is calculated by dividing the maximum load applied on the cross - sectional area of specimen.

IV. COMPONENTS USED

The various components used in the investigations are

1. Aluminium powders of 10 µm & 30 µm.
2. Silicon Carbide powder of 10 µm & 30 µm.
3. Planetary Ball Milling Machine.
4. Universal Testing Machine (UTM).
5. Muffle Furnace.
6. Mould setup.
7. Rockwell's Hardness testing machine.

Planetary Ball Milling Machine:

A planetary ball milling machine is a type of grinding machine used to grind and blend materials for various purposes including research , laboratory work , and industrial applications. It operates by rotating the grinding jars o their own axis while also orbiting around the central axis of the machine. This dual motion creates a strong centrifugal force that enhances the grinding and mixing of materials. These machines are generally used in the fields of nanotechnology , material science and sample preparation.

Planetary ball milling machines are versatile tools used in various fields including powder metallurgy, ceramics, pharmaceuticals, and research laboratories. They are particularly valuable for producing finely ground or homogenized materials and for studying materials at the micro and nano scale.

Figure 4: Planetary Ball milling machine

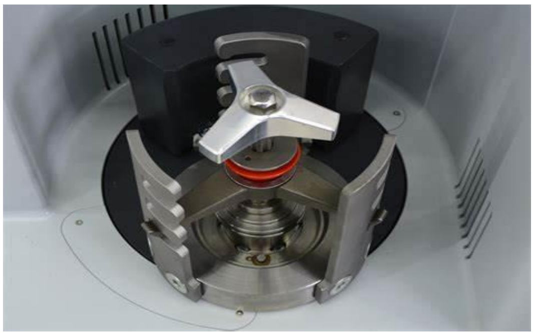

Figure 5: Interior of Ball milling machine

Punch and Mould:

Punch and mould are common tooling components used in various manufacturing processes , particularly in metal working , sheet metal fabrication , and metal forming. They are essential for cutting , shaping or forming materials into specific shapes or sizes. Punch and mould sets come in various sizes , shapes , configurations to accommodate a wide range of manufacturing needs. They are widely used in industries such as automotive , manufacturing , aerospace , electronics where precision and consistency in shaping and cutting materials are crucial.

Punch and mould are used to carry and store powders of Al – SiC till they are compacted and also acts as medium which supports the powders during application of load during Compaction.

Figure 6: Punch and Mould used for compaction

Universal Testing Machine (UTM):

A Universal Testing Machine (UTM) also known as a universal tester , materials testing machine or machine test frame , is a versatile piece of equipment used to test the mechanical properties of materials , components and structures. It can perform a wide range of standardized and custom tests to assess parameters such as tensile strength , compression strength , flexural strength , hardness , elasticity and more. UTMs are commonly used in various industries including aerospace , automotive , construction , materials science and quality control.

Figure 7: Universal Testing Machine

Heat Treatment using Muffle Furnace:

A Muffle furnace is a type of laboratory or industrial furnace designed for high-temperature applications that require controlled heating and precise temperature conditions. The muffle is a separate compartment within the furnace that isolates the sample or material being heated from direct contact with the heating elements. Muffle furnaces are commonly used in various industries, including material science , ceramics , metallurgy and chemistry for processes such as annealing, sintering , ashing and heat treatment.

Sintering is applied to enhance the strength of a material while decreasing porosity. In this process, samples are heated in the furnace at temperature of 250°C - 300^0C for 2-3 hours.

Figure 8: Muffle Furnace

Rockwell's Hardness Testing Machine:

It is a device that indicates the hardness of a material, usually by measuring the effect on its surface of a localized penetration by a standardized rounded or pointed indenter of diamond, carbide, or hard steel. The Rockwell's Hardness Tester utilizes either a steel ball or a conical diamond known as a brale and indicates hardness by determining the depth of penetration of the indenter under a known load. This depth is relative to the position under a minor initial load; the corresponding hardness number is indicated on a dial.

Figure 9: Rockwell's Hardness Testing Machine

The Rockwell hardness testing machine is designed to control and manage the application of the preload , major load , as well as the depth management when the intender penetrates into the surface of specimen. It ensures that the tests that are being conducted are accurate and precise. Modern Rockwell have digital displays for easier reading of values. The selection of the indenter used depends upon the material being used . The Rockwell hardness test is a non-destructive method and is very important for quality control , material selection and evaluating material properties.

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V. RESULTS AND DISCUSSION

The Aluminium (10 & 30 µm) , Al – SiC (30 µm) and Al – SiC (10 µm) were put to test for Hardness and Compressability on Rockwell Hardness Tester and UTM respectively.

HARDNESS RESULTS:

Result obtained from Rockwell Hardness Tester used on pure Aluminium specimen of 30 µm. Average RHN (Rockwell Hardness Number) obtained for Aluminium was found to be 50.36 RHN.

Table 1: Rockwell Hardness Test for Aluminium of 30 µm

Trial No.	Material Used	Scale Reading 'B'	Indenter used	Major load (kgf)	Rockwell hardness number (RHN)	Average RHN
1	Aluminium	Red scale	1/16 inch	100	50	50.36
2	Aluminium	Red scale	1/16 inch	100	50.4	
3	Aluminium	Red scale	1/16 inch	100	50.7	

Result obtained from Rockwell Hardness Tester used on Al – SiC specimen of 30 µm. The volumetric composition of SiC was changed from 10% SiC – 20% SiC – 30% SiC. The average RHN was 52.66 , 53.63 , 54.5 for 10% , 20% , 30% of SiC composition respectively.

Table 2: Rockwell Hardness for Al-SiC MMC of 30 µm of 10% SiC

Trial No.	Material Used	Scale Reading 'B'	Indenter used	Major load (kgf)	Rockwell hardness number (RHN)	Average RHN
1	Al - SiC of 30 µm – 10% SiC	Red scale	1/16 inch	100	52	52.66
2	Al - SiC of 30 µm – 10% SiC	Red scale	1/16 inch	100	52.2	
3	Al - SiC of 30 µm – 10% SiC	Red scale	1/16 inch	100	52.6	

Table 3: Rockwell Hardness for Al-SiC MMC of 30 µm of 20% SiC

Trial No.	Material Used	Scale Reading 'B'	Indenter used	Major load (kgf)	Rockwell hardness number (RHN)	Average RHN
1	Al - SiC of 30 µm – 20% SiC	Red scale	1/16 inch	100	53.4	53.63
2	Al - SiC of 30 µm – 20% SiC	Red scale	1/16 inch	100	53.6	
3	Al - SiC of 30 µm – 20% SiC	Red scale	1/16 inch	100	53.9	

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Table 4: Rockwell Hardness for Al-SiC MMC of 30 µm of 30% SiC

Trial No.	Material Used	Scale Reading 'B'	Indenter used	Major load (kgf)	Rockwell hardness number (RHN)	Average RHN
1	Al - SiC of 30 µm – 30% SiC	Red scale	1/16 inch	100	54.5	54.5
2	Al - SiC of 30 µm – 30% SiC	Red scale	1/16 inch	100	54.3	
3	Al - SiC of 30 µm – 30% SiC	Red scale	1/16 inch	100	54.7	

Result obtained from Rockwell Hardness Tester used on Al – SiC specimen of 10 µm. The volumetric composition of SiC was changed from 10% SiC – 20% SiC – 30% SiC. The average RHN was 53.6 , 54.9 , 55.8 for 10% , 20% , 30% of SiC composition respectively.

Table 5: Rockwell Hardness for Al-SiC MMC of 10 µm of 10% SiC

Trial No.	Material Used	Scale Reading 'B'	Indenter used	Major load (kgf)	Rockwell hardness number (RHN)	Average RHN
1	Al - SiC of 10 µm – 10% SiC	Red scale	1/16 inch	100	53.5	53.6
2	Al - SiC of 10 µm – 10% SiC	Red scale	1/16 inch	100	53.7	
3	Al - SiC of 10 µm – 10% SiC	Red scale	1/16 inch	100	53.8	

Table 6: Rockwell Hardness for Al-SiC MMC of 10 µm of 20% SiC

Trial No.	Material Used	Scale Reading 'B'	Indenter used	Major load (kgf)	Rockwell hardness number (RHN)	Average RHN
1	Al - SiC of 10 µm – 20% SiC	Red scale	1/16 inch	100	54.8	54.9
2	Al - SiC of 10 µm – 20% SiC	Red scale	1/16 inch	100	55	
3	Al - SiC of 10 µm – 20% SiC	Red scale	1/16 inch	100	54.9	

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Table 7: Rockwell Hardness for Al-SiC MMC of 10 µm of 30% SiC

Trial No.	Material Used	Scale Reading 'B'	Indenter used	Major load (kgf)	Rockwell hardness number (RHN)	Average RHN
1	Al - SiC of 10 µm – 30% SiC	Red scale	1/16 inch	100	55.6	55.8
2	Al - SiC of 10 µm – 30% SiC	Red scale	1/16 inch	100	55.9	
3	Al - SiC of 10 µm – 30% SiC	Red scale	1/16 inch	100	55.9	

COMPRESSION RESULTS:

Result obtained from Compression Test conducted on UTM on the specimen of pure aluminium -30 µm , Al – SiC – 30 µm , Al -SiC -10 µm.

The specimen of Al – SiC – 30 µm and Al – SiC - 10 µm were tested based on the composition of SiC which is 10% , 20% , 30% of SiC.

Table 8: Compression Test Results

Trial No.	Material Used	Instrument Used	Failure Load (KN)
1	Aluminium - 30 µm	UTM	28.7
2	Aluminium & SiC 30 µm – 10% SiC	UTM	30.01
3	Aluminium & SiC 30 µm – 20% SiC	UTM	31.87
4	Aluminium & SiC 30 µm – 30% SiC	UTM	33.4
5	Aluminium & SiC 10 µm – 10% SiC	UTM	32.67
6	Aluminium & SiC 10 µm – 20% SiC	UTM	34.21
7	Aluminium & SiC 10 µm – 30% SiC	UTM	35.77

Compressive strength:

Diameter of specimen = 13 mm.

Cross sectional area of the specimen = 132.73 mm^2.

Failure load :

i. Aluminium 30 µm = 28.7 KN , Aluminium 10 µm = 30.12 KN
ii. Al-SiC – 30 µm – 10%SiC = 30.01 KN
iii. Al-SiC – 30 µm – 20%SiC = 31.87 KN
iv. Al-SiC – 30 µm – 30%SiC = 33.40 KN
v. Al-SiC – 10 µm – 10%SiC = 32.67 KN

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vi. Al-SiC – 10 µm – 20%SiC = 34.21 KN
vii. Al-SiC – 10 µm – 30%SiC = 35.77 KN

Now , Compressive strength :

i. Aluminium 30 µm = 216.22 N/mm^2 , Aluminium 10 µm = 224.46 N/mm^2
ii. Al-SiC – 30 µm – 10%SiC = 226.09 N/mm^2.
iii. Al-SiC – 30 µm – 20%SiC = 240.11 N/mm^2.
iv. Al-SiC – 30 µm – 30%SiC = 251.63 N/mm^2.
v. Al-SiC – 10 µm – 10%SiC = 246.13 N/mm^2.
vi. Al-SiC – 10 µm – 20%SiC = 257.74 N/mm^2.
vii. Al-SiC – 10 µm – 30%SiC = 269.49 N/mm^2.

Rockwell Hardness Test clearly shows that blending of SiC in aluminium Matrix does improve the properties of Aluminium as it is seen that pure aluminium (50.36) has an average RHN value less than that of both 30 µm Al-SiC (52.66 , 53.63 , 54.5) & 10 µm Al-SiC (53.6 , 54.9 , 55.8) . And also it is observed that with increase in composition of SiC & decrease in particle size the properties of the MMCs increase meaning that properties of MMCs are directly being affected by particle size as well as chemical composition.

On the other hand Compression Test also shows significant increase in compressive strength from 216.22 N/mm^2 to 269.49 N/mm^2 does mean that SiC is playing an important role in changing the properties and mechanics of Al MMCs.

Graphical Representation:

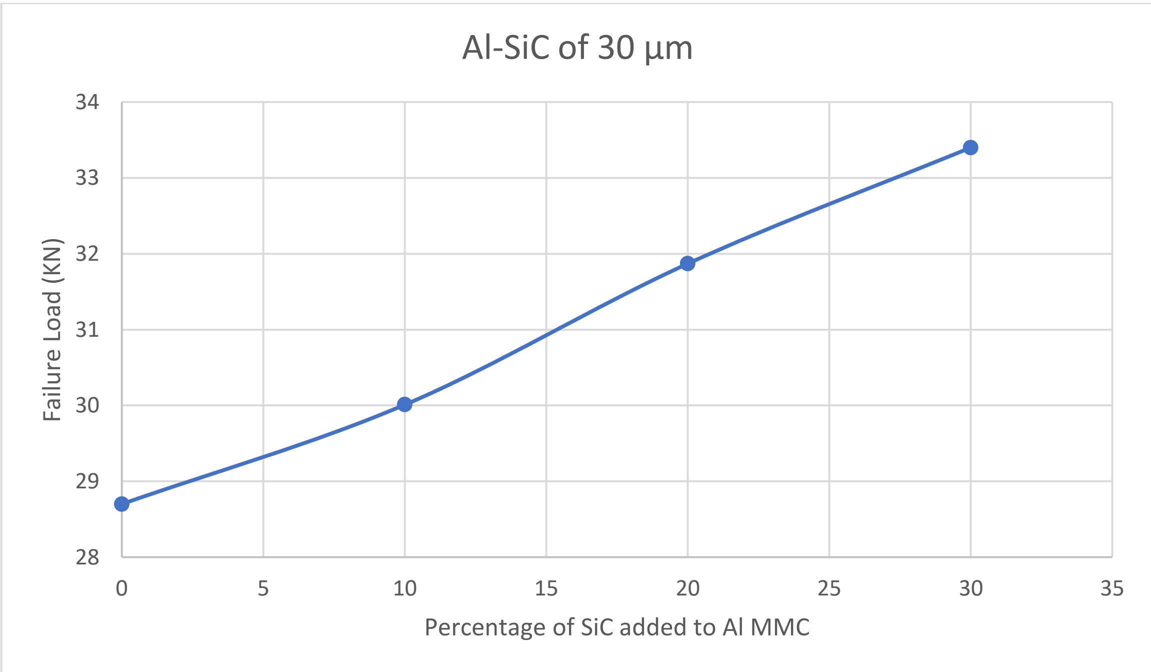

Figure 10: Change in Failure Load with Increase in percentage of SiC in Al MMC - 30 µm

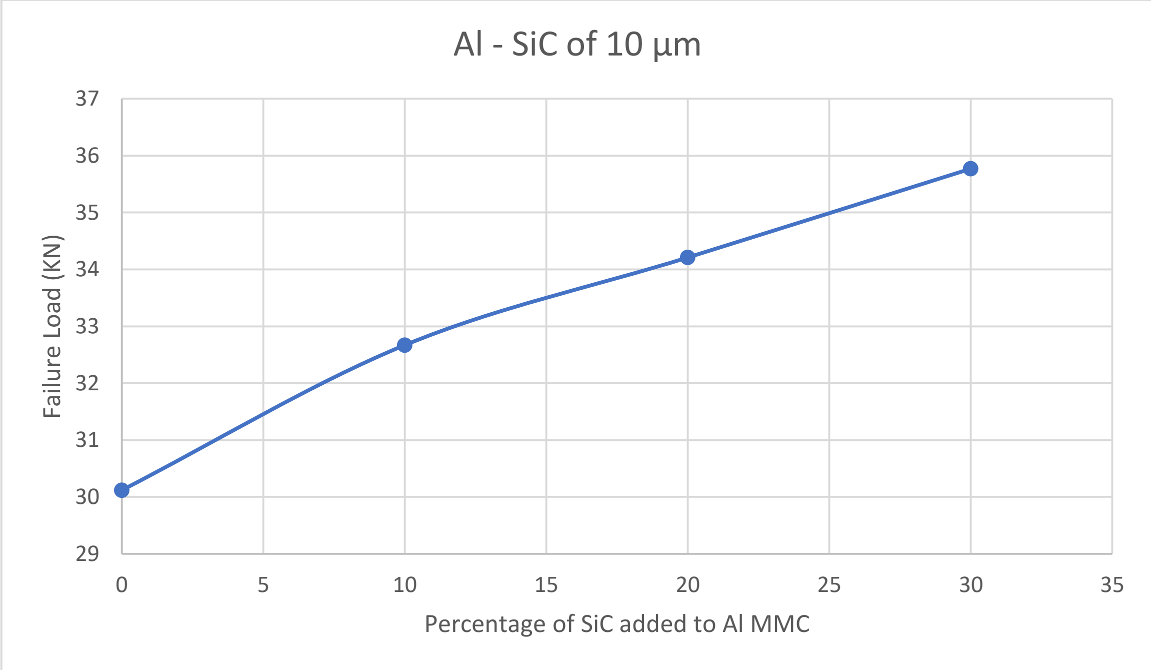

Figure 11: Change in Failure Load with Increase in percentage of SiC in Al MMC - 10 µm

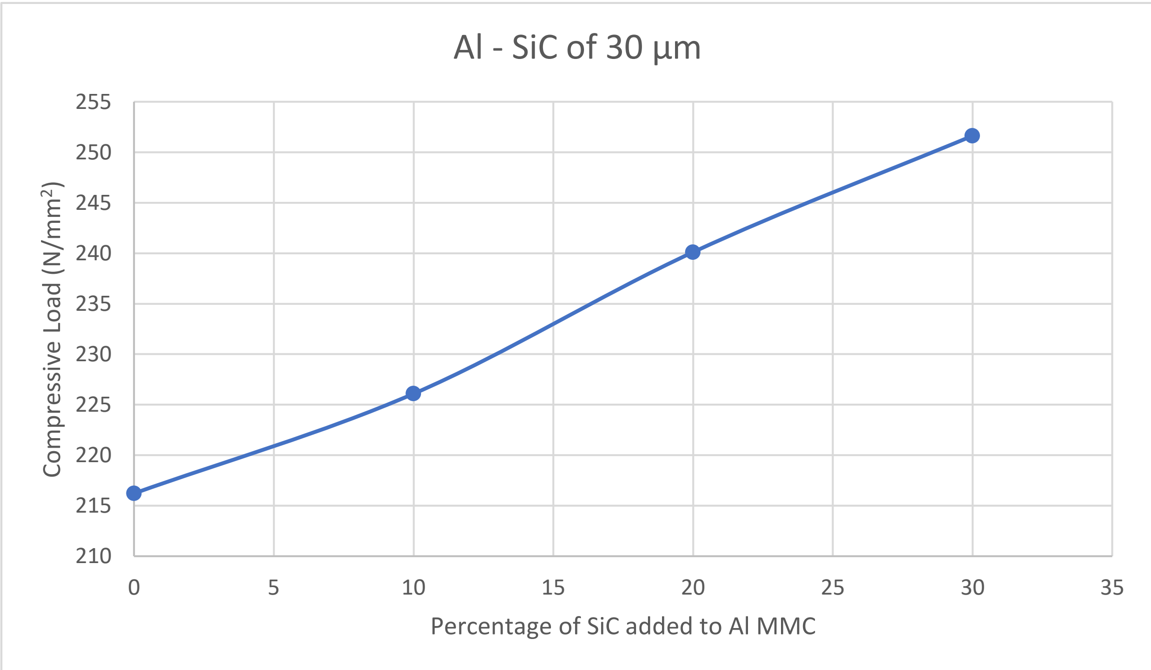

Figure 12: Change in Compressive Load with Increase in percentage of SiC in Al MMC - 30 µm

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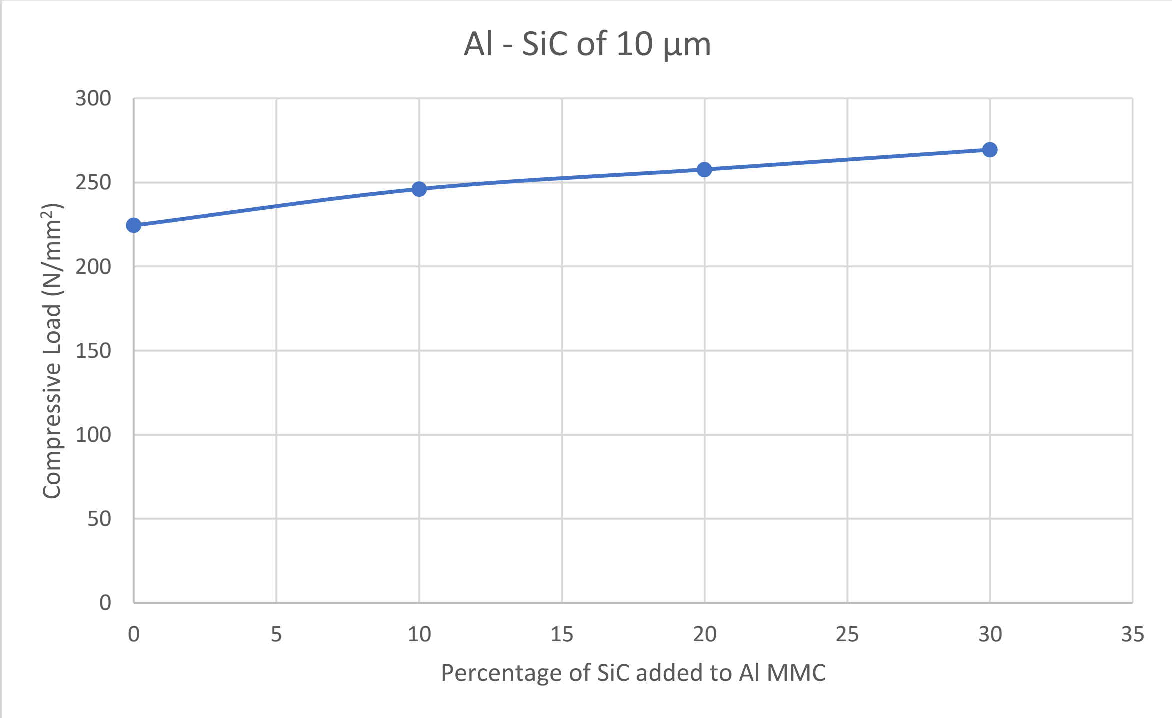

Figure 13: Change in Compressive Load with Increase in percentage of SiC in Al MMC - 10 µm

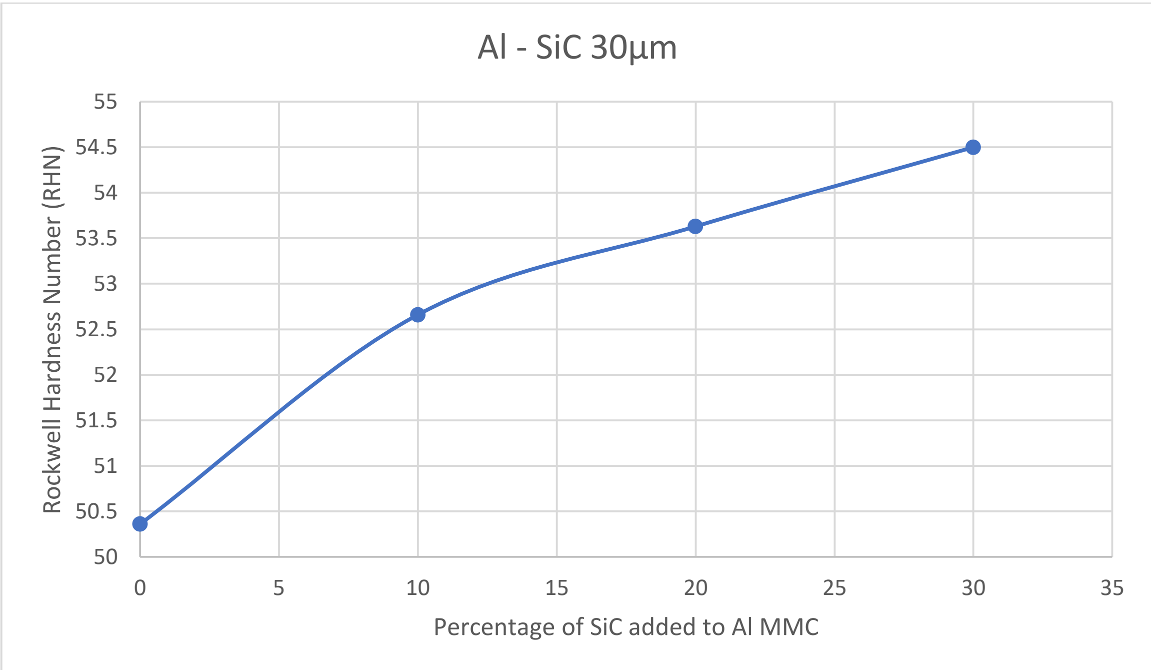

Figure 14: Hardness Number variation with increase in percentage of SiC - 30 µm

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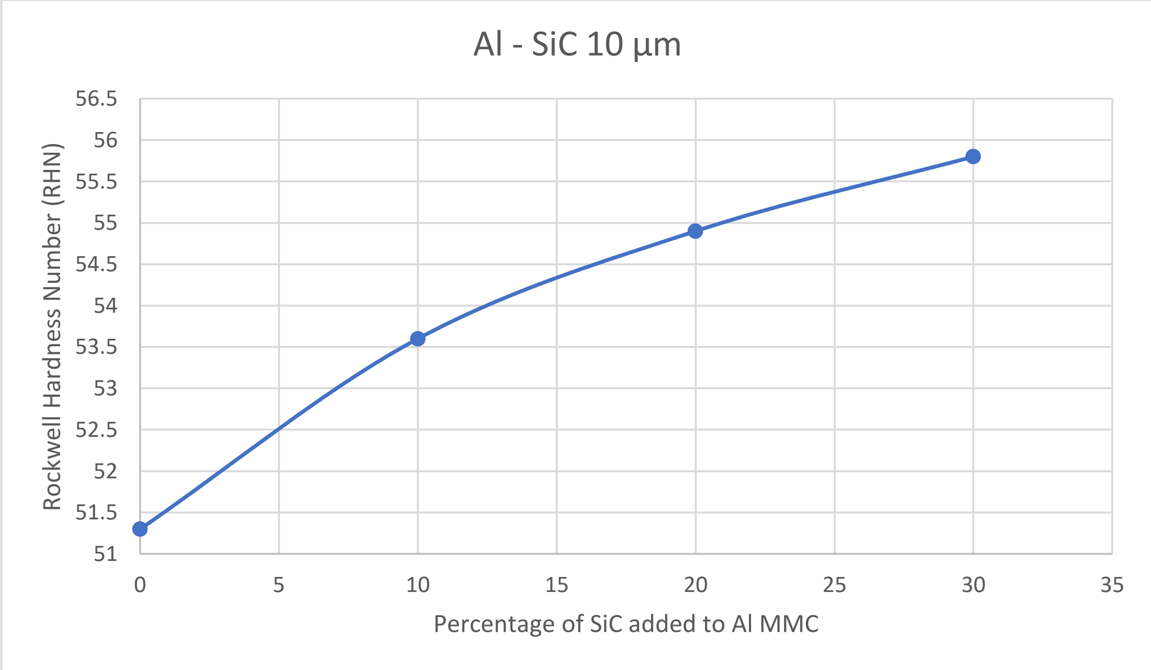

Figure 15: Hardness Number variation with increase in percentage of SiC - 10 µm

VI. CONCLUSION

The testing of SiC blended Aluminium MMCs was carried out for finding the improvement in hardness and compressive strength by the addition of SiC into Aluminium matrix. By the testing it can be concluded that SiC blended Aluminium compounds have improved Hardness , Compressive strength and can be used for many industrial applications due to the improvement of both these crucial mechanical properties. It was observed that with decrease in particle size and increase in volumetric composition of SiC into the metal matrix of Aluminium produced more better results than higher particle size and lower volumetric composed SiC blended Aluminium results. So it can be said that SiC blended Al of lower particle size and higher volumetric composition can be used in various applications that deal with high compression and load bearing works.

For the future the obtained products from these investigations can be tested for their wear resistance and can be used in high wear resistance required applications as well like automobile brakes and mechanical parts dealing with high friction and movement.

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