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An Experimental Investigation of Mechanical Properties on Aluminium / Diamond Composite Using Powder Metallurgy

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ABSTRACT: Aluminum is a material having lower strength compared to its own aluminum composites (alloys), so in order to gain the higher strength than pure aluminum we made a composite material of aluminum. We choose Synthetic diamond as a composite material in aluminum to increase its strength. Metal Matrix based Composites are chosen when the applications need metals with the improved characters like high strength to density ratio, high-temperature resistance, high resistance to wear and resistance to corrosion. We produced the composite of pure aluminum by adding the weight percentage of 1% and 3% weight of synthetic powder and produced by powder metallurgy. In the present work, pure aluminum and aluminum metal matrix reinforced with diamond particle to form the composites of aluminum+1% diamond and aluminum+3wt.% diamond combinations are produced through powder metallurgy technique. The metallurgical studies for mechanical properties such as Wear behaviour, Compression test, hardness test and scanning electron microscopic analysis have done to confirm the occurrence of reinforcements. The mechanical properties were considered as per the ASTM standards.

KEYWORDS: Aluminium, Diamond, Metal Matrix Composite, Powder Metallurgy, Wear Behaviour, Scanning electron microscopic analysis.

I. INTRODUCTION

Aluminium occupies eight percent of the earth crust next to iron. It is one of the metals which have low density and weight as of magnesium. Aluminium is the 2nd most Ductile metal and is being lightweight. Composite materials of aluminium being more lighter and more flexible than aluminium with a much higher elasticity, causing many changes the way we use aluminium. With aluminium, highly tension loaded applications increase fatigue failure and maintenance. Composites are better at controlling tension compared to aluminium because the fibres in composite matrix can be originated to transfer loads in well-organized manner which helps to dissolve stress get in material. Composites have the design flexibility to distribute the strength and weight accurately to create a more precise design than aluminium. Aluminium does have some of the bending properties, however when bending the material too much it is snap, or in some cases takes a permanent deformation.

Aluminium Alloys are widely used in satellite components, airframes, engines, engineering structures, missile bodies, packing, fuel cells, transportation, sports and parts where high strength to weight ratio or resistance to corrosion is required. Aluminium Alloys are classified as cast Aluminium Alloy and wrought Aluminium Alloy. Wrought Alloy has the more tensile strength compared to cast Alloy which attracts more engineering applications. The first 1XXX series is 99% pure Aluminium with very high resistance to corrosion, high conductivity both electrical and thermal, reasonable formability, with reasonably low strength, and not heat treatable characters. In 2XXX series, the primary Alloying element is copper and poses the Characteristics of high strength-to-density ratio, low resistance to corrosion, and temperature curable. For 3XXX series, Manganese is the principal Alloying element and has excellent formability, moderate strength, and cannot be heat treated. Silicon act as a prime element for the 4XXX series shows a low melting

point compared to other Alloy series, and this series is not heat treatable. The fifth 5XXX series has magnesium as the primary Alloying element which poses an excellent corrosion resistance, better weldability, moderate to high strength, and not heat treatable characters. Further, 6XXX series has magnesium and silicon as virtual Alloying elements and shows excellent formability, weldability, machinability, heat treatable, corrosion resistant and medium strength properties. The 7XXX is the high strength Alloy series which has Zinc as the primary Alloying element and Also, it is heat treatable and prone to fatigue. Finally, 8XXX series constitute of All other Aluminium Alloys which have elements like lithium, iron, zirconium, molybdenum, and etc. as a primary Alloying element. In spite of these Alloys, the industrial growth demands the enhancement of its properties which further leads to the development of the composites.

II. MATERIALS SELECTION

Aluminium is employed in a very large kind of merchandise as well as cans, foils, room utensils, window frames, brewage kegs and airplane elements. metallic element may be a sensible electrical conductor and is usually utilized in electrical transmission lines. It's cheaper than copper and weight for weight is sort of double pretty much as good a conductor. Aluminium is used as the matrix material in the present investigation, and details of its physical properties are given below. Powders used in micron level study were element Aluminium powders of Aluminium, zinc, magnesium, copper, silica, manganese, chromium, iron, and Titanium. Aluminium metal rod was supplied by M/s Perumal Engineering Works., Tirunelveli, India. The matrix powder was sieved and a sieve fraction of average sizes of 50 μ m was used. The SEM micrographs of the received Aluminium powders exposed the spherical shape.

Property	Value in metric unit
Density	2.70g/cm ³
Young's modulus	68 GPa
Thermal expansion	2.32 x 10 ⁻⁵ K ⁻¹
Specific heat capacity	897 J/(kgK)
Thermal conductivity	151 – 202 W/(mK)
Poisson ratio	0.33
Tensile strength	124 - 300 MPa
Melting temperature	585 ⁰ C (1085F)
Elongation	12 - 25 %

Table 1. Physical Composition of Aluminium 6061

Synthetic Diamond is type of diamond made of the same materials as of that of natural diamonds which is pure carbon, crystallized and is form of Isotropic 3D form and could be a with its atoms organized during a crystal structure known as diamond blockish. at temperature and pressure, another solid kind of carbon referred to as plumbago is that the with chemicals stable kind, however Diamond virtually never converts to that. Diamond has the best hardness and thermal physical phenomenon of any natural material, properties that square measure used in major industrial applications like cutting and sprucing tools. They're additionally the explanation that Diamond anvil cells will subject materials to pressures found deep within the earth.

Property	Value in metric unit
Density	3.54 g/cm ³
Young's modulus	1220 GPa
Thermal expansion	0.11 x 10 ⁻⁶ K ⁻¹
Elongation	9 %
Thermal conductivity	20 W/(cmK)
Poisson ratio	0.2
Tensile strength	1.2 GPa
Melting temperature	585 ⁰ C (1085F)

Table 2. Physical properties of the Synthetic Diamond

Powder Metallurgy:-

It involves mixing elemental or alloy powders, compacting the mixture in a die, and then sintering, or heating, the resultant shapes in an atmosphere-controlled furnace to metallurgically bond the particles. In the process the al/diamond composite which is placed in a die and gives compression mechanical load by universal testing machine (UTM). The below images is the aluminum powder and industrial diamond powder.



(a)



(b)

Figure 1.(a) Aluminum 6061 (b) Synthetic Powder

Ratio of Aluminum/Diamond Composite:-

In the ball milling process, the mixing of aluminium and diamond to combine the al/diamond composite component. The ratio of the aluminium and diamond is vary for the analyzing of the component.

Component	% of aluminium	% of diamond
1	100	0
2	99	1
3	97	3

Table 3 Ratio of Al/Diamond components

In the above combination of the components has three separate component pieces of the testing of wear characteristics and compressive test of al/diamond composite. Hence SEM analysis was also performed on these component. There is three separate pieces and also each of the component has three separate pieces.

III. METHODOLOGY

Making of Aluminium/Diamond Composite:-

The component Aluminium 6061 was purchased as rod were the size material of 30 mm diameter and 500 mm length. The same piece was hence held up with metal cutting to the size of around 30 mm length of which resulted in 26 pieces each. Hence next the process of casting starts. The held pieces of aluminium 6061 was set-up and usage are detailed in a test method, often published by a standards organization. This specifies the sample preparation, fixturing, gauge length (the length which is under study or observation), analysis, etc.

1. Casting of Pure Aluminium:-

Process 1:- The Al6061 was is placed in the Sonicator furnace at a temperature of 800°C in order the melt the piece of aluminium rod into a solid to liquid form. The actual melting point is 585°C as of the specimen is of rod type the furnace is placed in 800°C . The weight of aluminium Al6061 is placed as 243.2 gm.

Process 2:- The Al6061 was is placed in the Sonicator furnace at a temperature of 800°C it begins to melt and it took around 2 hours for the process to finish in order the melt the piece of aluminium rod into a solid to liquid form. By that time the die for casting was also placed in another furnace named Muffle furnace at the temperature of around 500°C for preheating the die for casting. After the heating was done the solid begins to turn to liquid form and hence with a help of a mechanical stirrer which is set at a speed of 500rpm was stirred and the same is poured and moulded into a die for settling and cooling.

2. Casting of Aluminium 97% + 3% Diamond:-

Process 1:- The Al6061 was is placed in the Sonicator furnace at a temperature of 800°C in order the melt the piece of aluminium rod into a solid to liquid form. The actual melting point is 585°C as of the specimen is of rod type the furnace is placed in 800°C . The weight of aluminium Al6061 is placed as 252.38gm.

Process 2:- The Al6061 was is placed in the Sonicator furnace at a temperature of 800°C it begins to melt and it took around 2 hours for the process to finish in order the melt the piece of aluminium rod into a solid to liquid form. By that time the die for casting was also placed in another furnace named Muffle furnace at the temperature of around 500°C for preheating the die for casting. After the heating was done the solid begins to turn to liquid form and then a around 3% of wight percentage of AL6061 i.e around 7.56gm (3% of Al added (252.38gm)= 7.56%) of diamond powder was taken into account and added into alumnium liquid with a help of a mechanical stirrer which is set at a speed of 500 rpm was stirred and the same is poured and moulded into a die for settling and cooling.

3. Casting of Aluminium 99% + 1% Diamond

Process 1:- The Al6061 was is placed in the Sonicator furnace at a temperature of 800°C in order the melt the piece of aluminium rod into a solid to liquid form. The actual melting point is 585°C as of the specimen is of rod type the furnace is placed in 800°C . The weight of aluminium Al6061 is placed as 244.1 gm.

Process 2:- The Al6061 was is placed in the Sonicator furnace at a temperature of 800°C it begins to melt and it took around 2 hours for the process to finish in order the melt the piece of aluminium rod into a solid to liquid form. By that time the die for casting was also placed in another furnace named Muffle furnace at the temperature of around 500°C for preheating the die for casting. After the heating was done the solid begins to turn to liquid form and then a around 1% of wight percentage of AL6061 i.e around 2.4gm (1% of Al added (244gm)= 2.44%) of diamond powder was taken into account and added into alumnium liquid with a help of a mechanical stirrer which is set at a speed of 500 rpm was stirred and the same is poured and moulded into a die for settling and cooling.



Figure 2.Process of Stir Casting

IV. MECHANICAL PROPERTIES TESTING AND RESULTS

Dry Slide Wear Test :-

The pin-on-disc wear tests was carried out with loads of 50 and 70 N, sliding speeds of 500rpm and sliding distance of 500m. It is observed that the weight loss of Al/diamond composites is increased load sliding distance. The wear resistance of the composites increased with the increase in weight percentage of diamond reinforcement.

Calculation Of Sliding Time :-

The sliding time is to be calculated in order to determine the time required by the sliding disc to complete the time for sliding distance of 500m.

Load (N):- 50N,70 N Speed RPM :- 500.00

WTD (mm) :- 100 Samples/ Min

Sliding Disatnce :- 500m

Sliding Velocity $V = (\pi \times \text{WTD} \times \text{Speed}) / 60$

$V = (\pi \times 100 \times 500) / 60 = 2.617\text{m/s}$

Time = Sliding Distance / Sliding velocity = $500 / 2.617 = 191.05$ seconds = 3.184 min

Hence the timing was set to 3.184 minutes for the sliding speed of 500rpm and sliding distance of 500m and load attaining 50 N and 70 N.



Figure 3.Wear Rate of Pure Aluminum

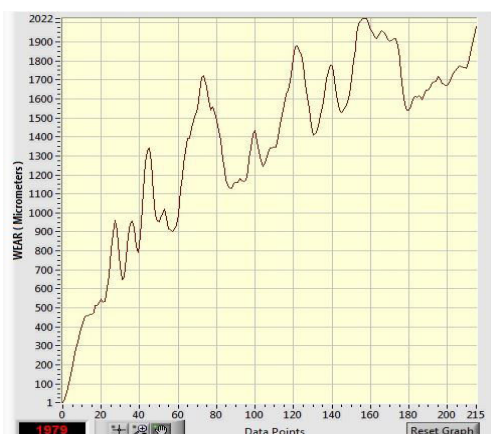


Figure 4. Wear Rate of Aluminium 99 % + 1% Diamond



Figure 5. Wear Rate of Pure Aluminium 97% + 3% Diamond

		Wear (mm)
Sl.no	Materials	Sliding distance 500m
	Load = 50N	
1	Pure Aluminium Al6061	276.4
2	Al 99% + 1%diamond	197.78
3	Al 97% + 3%diamond	108.72
	Load = 70N	
4	Pure Aluminium Al6061	303.4
5	Al 99% + 1% diamond	208.45
6	Al 97% + 3% diamond	128.35

Table 4. Results for Variation of wear with sliding speed 500 rpm

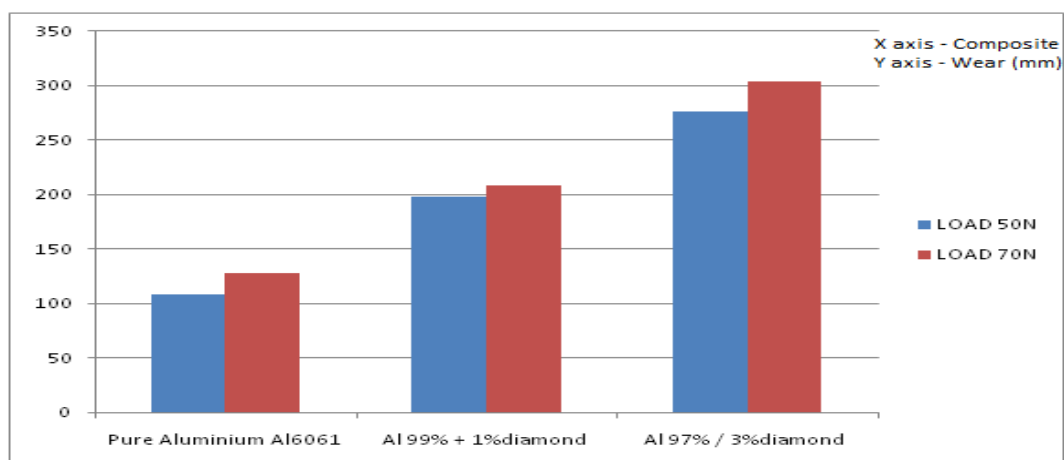


Figure 6. Effect of load on Influence of Wear for the Composite

It is observed that the wear rates of Al/diamond composites increased with load. The Al/diamond composites exhibit better wear resistance than base alloy. In the case of base alloy, adhesion is the wear mechanism, however,

in Al/diamond composites; abrasion is the main wear mechanism along with the adhesion. At higher loads, due to excessive frictional heat generated the pin surfaces become quite soft and plastic enough to deform and finally fracture such that the wear debris formed and dislodged consists of large shining metallic particles. It is also observed that there was a gross material transfer from pin to the disc, at these high loads. The wear rate of Al/diamond - 3wt % composites is lower than Al/diamond -1% due to its higher hardness and particle reinforcement.



Figure 7. Pin on Disc Wear Testing Equipment

Scanning Electron Microscope Analysis(SEM):-

The scanning electron microscopic analysis image of aluminium, aluminium composites with 1 wt. % DIAMOND and aluminium composites with 3wt.% DIAMOND Content. The Structure of the produced composites through the scanning electron microscope is shown in Figure 4.4. From the microscopic examination, it is found that the reinforcement particles are distributed uniformly over the matrix material and it also confirms the presence of DIAMOND and the absence of inclusions and segregations. The hexagonal shape confirms the occurrence of the DIAMOND particles in the magnified view. Taken as a whole from the microscopic examination the image visualises and differentiates the aluminium matrix phase and reinforcement phase and shows the homogenous distribution of reinforcements in the aluminium matrix. The SEM image ALUMINIUM+3Wt.% DIAMOND composite which reveals the presence of DIAMOND particles uniformly distributed in the matrix but with different size due to agglomeration of particles formed with in the composite structure is shown below.

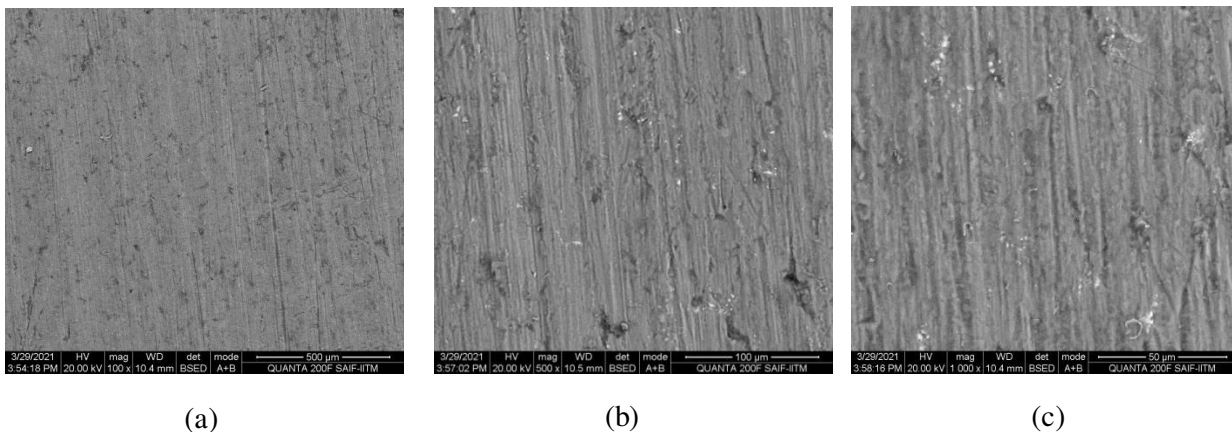


Figure 8. SEM data of polished surface of reference sample of Pure Aluminium (a) Magnitude 100x (b) Magnitude 500x (c) Magnitude 1000x.

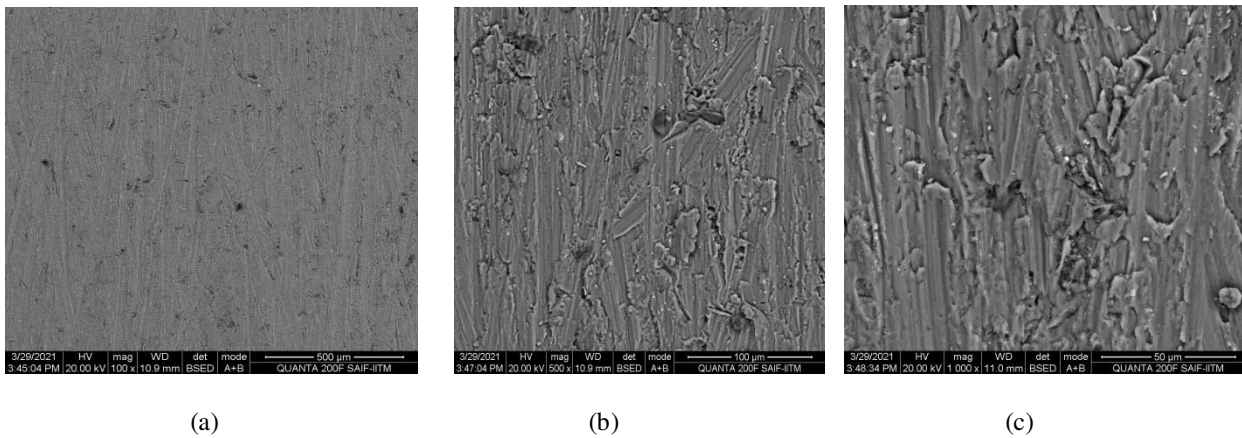


Figure 9. SEM data of polished surface of reference sample of Aluminium 99% + Diamond 1% (a) Magnitude 100x (b) Magnitude 500x (c) Magnitude 1000x

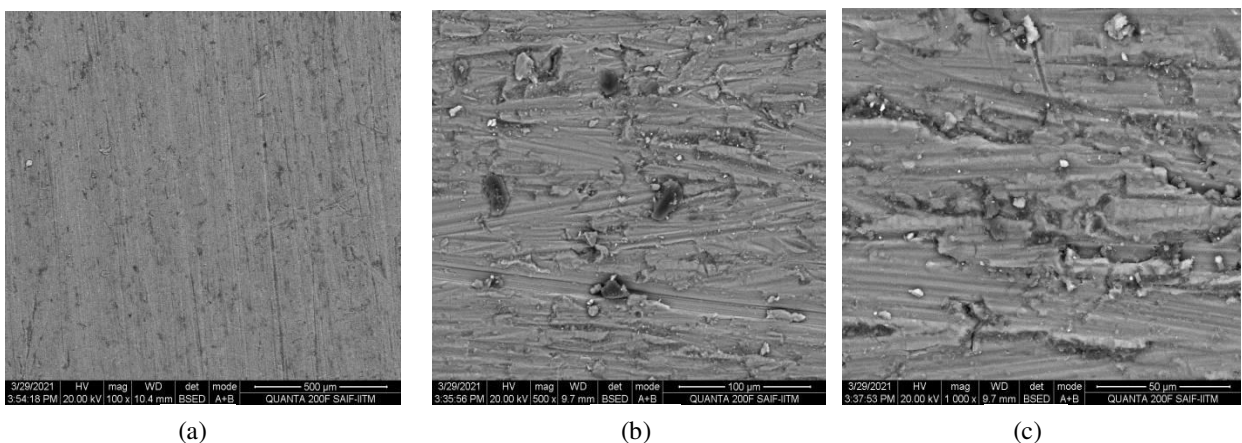


Figure 10. SEM data of polished surface of reference sample of Aluminium 99% + Diamond 3% (a) Magnitude 100x (b) Magnitude 500x (c) Magnitude 1000x.

TEST OF COMPRESSIVE STRENGTH:-

Compressive test was performed for the pure aluminium, Al+ 1 % diamond, Al + 3% diamond on computerised Ultimate Testing Machine machine – 60 Ton Capacity. These components were taken in dimension of 10 mm diameter and 10 mm length of consecutive peices

SLNo	Composite Materials	Compressive Load
1	Pure Aluminum-Al 6061	283KN
2	Al 99% + Diamond 1%	400KN
3	Al 97 % + Diamond 3%	530KN

Table 5. Results for test on Compression Strength

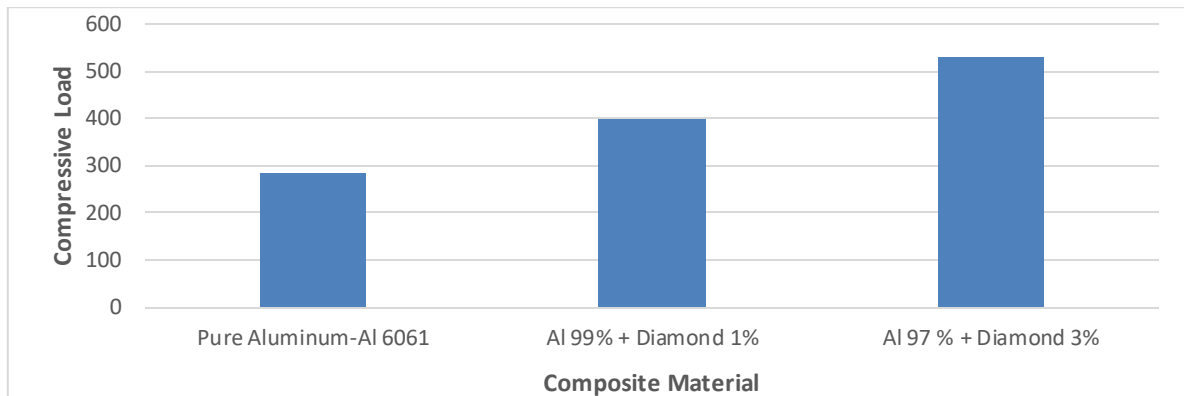


Figure 11. Results for test on Compression Strength.

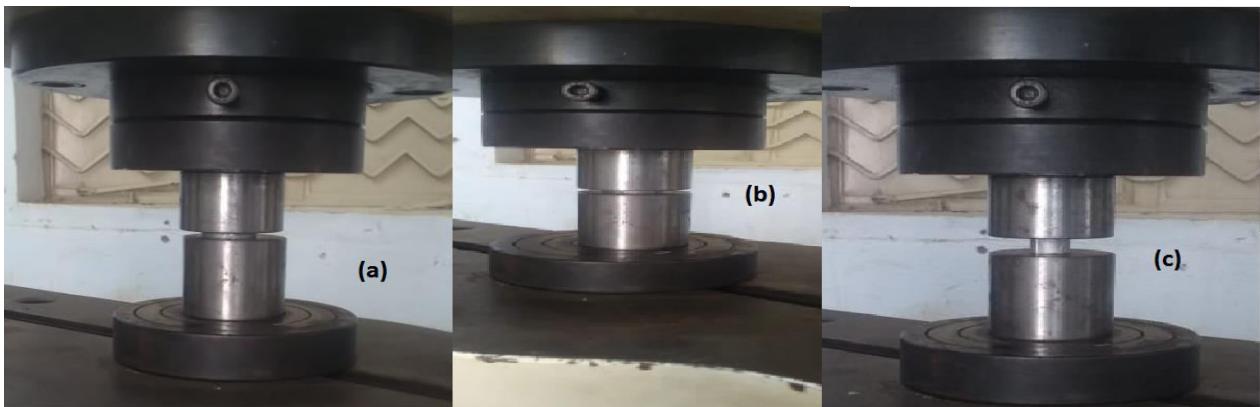


Figure 12. Universal Testing Machine Compression Testing (a) Pure Aluminum (b) Aluminium 99% + Diamond 1% (c) Aluminium 99% + Diamond 3%

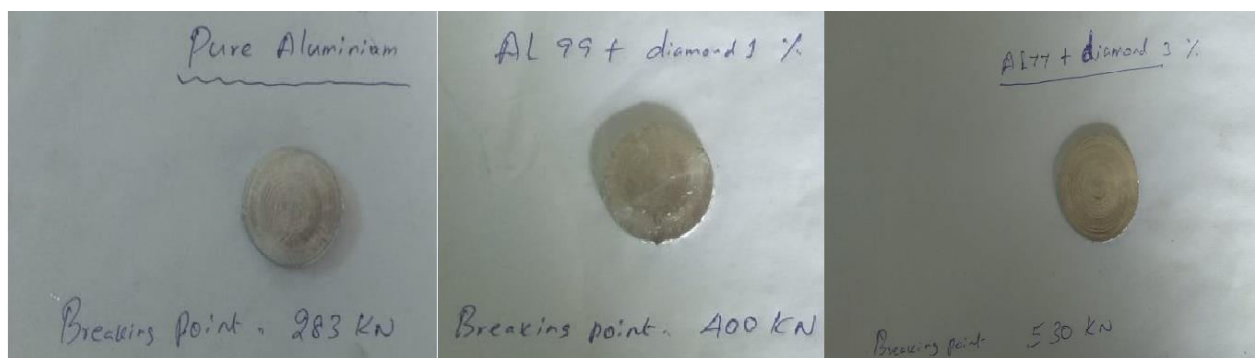


Figure 12. Universal Testing Machine Breaking Point for all the components

HARDNESS TEST:-

The hardness test is done as a property of material that enables it to resist plastic deformation, penetration, indentation and scratching. In the present work the hardness was compared and result are induced. Dimensions of the specimens are 10mm length and 15 mm diameter.

Material	Load in Kgf	Indenter used	Scale	RHN	Average
Pure Aluminum-Al 6061	100	1/16" Ball	B	87	84.667
				85	
				82	
Al 99% + Diamond 1%	100	1/16" Ball	B	91	88.333
				88	
				86	
Al 99% + Diamond 3%	100	1/16" Ball	B	92	90.16
				88.5	
				90	

Table 6 Hardness Test Readings

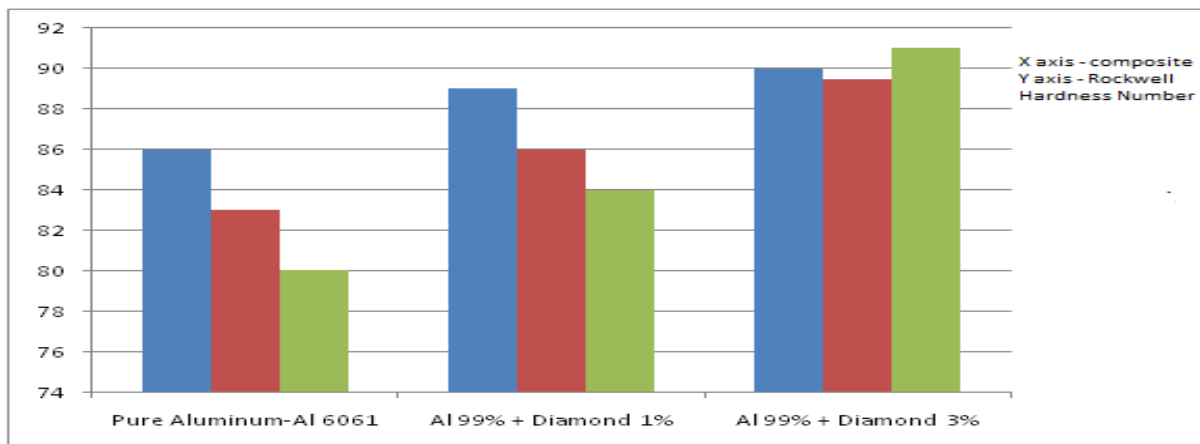


Figure 13. Rockwell Hardness Number for Composites

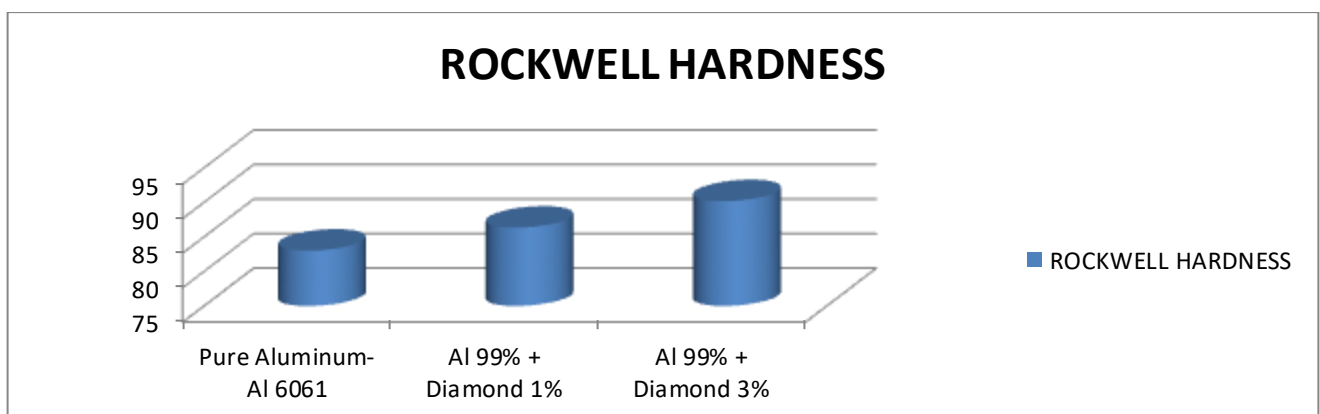


Figure 14. Average Rockwell Hardness Number for Composites

V. CONCLUSIONS

Aluminium metal matrix composite ALUMINIUM, ALUMINIUM + 1 wt.% DIAMOND and ALUMINIUM + 3 wt.% DIAMOND is effectively manufactured by the powder metallurgy route. The presence of the reinforcements is confirmed through the scanning electron microscopic analysis. The composites hardness increases with the increasing

of titanium carbide particles for both sintered and cold upset samples with a maximum hardness of 88.16 RHN for ALUMINIUM + 1 wt.% DIAMOND and 90.16 RHN respectively for the ALUMINIUM + 3 wt.% DIAMOND. When compared with the sintered samples, the increase in density are observed for coldupsetted samples. An aluminium diamond composites of different proportions were manufactured by powder metallurgy process and its behaviour was analyzed. The wear rate of Al/diamond -3 % composites is lower than Al/diamond - 1% than pure aluminum due to its higher hardness and particle reinforcement. At higher sliding speeds, the increase in temperature induces a thermal softening beneath the worn surface and results in the change of wear mechanism. Also at higher sliding speeds an oxide layer forms on the pin surface and reduces the coefficient of friction. In the above work the aluminium diamond composite of 3% diamond reduces the wear rate and less friction of the aluminium diamond composite component.

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