EXPERIMENTAL INVESTIGATION OF METAL MATRIX COMPOSITE USING NATURAL REINFORCEMENT

A Thesis Submitted

In partial fulfillment for the award of the degree of

Master of technology

In

Production Engineering

SUBMITTED BY

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(2k17/PIE/09)

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JULY 2019

<u>CANDIDATE'S DECLARATION</u>

I, PLASH ISSAR, hereby certify that the work which is being presented in this thesis entitled "**EXPERIMENTAL INVESTIGATION OF METAL MATRIX COMPOSITE USING NATURAL REINFORCEMENT**" being submitted by me is an authentic record of my own work carried out under the supervision of **Dr. N. Yuvaraj, Assistant Professor, Department of Mechanical Engineering, Delhi Technological University, Delhi.**

The matter presented in this thesis has not been submitted in any other University/Institute for the award of M.Tech Degree.

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CERTIFICATE

I, PLASH ISSAR, hereby certify that the work which is being presented in this thesis entitled "**EXPERIMENTAL INVESTIGATION OF METAL MATRIX COMPOSITE USING NATURAL REINFORCEMENT**" in the partial fulfillment of requirement for the award of degree of **Masters of Technology in Production Engineering** submitted in the **Department of Mechanical Engineering** at **Delhi College Of Engineering**, **Delhi University**, is an authentic record of my own work carried out during a period from July 2018 to June 2019, under the supervision of **Dr. N. YUVARAJ, Assistant Professor, Department of Mechanical Engineering, Delhi College of Engineering, Delhi.**

The matter presented in this thesis has not been submitted in any other University/Institute for the award of M.Tech. Degree.

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ACKNOWLEDGEMENT

It is a matter of great pleasure for me to present my dissertation report on "**EXPERIMENTAL INVESTIGATION OF METAL MATRIX COMPOSITE USING NATURAL REINFORCEMENT**". First and foremost, I am profoundly grateful to my guide **Dr. N. YUVARAJ, Assistant Professor, Mechanical Engineering Department** for his expert guidance and continuous encouragement during all stages of thesis. I feel lucky to get an opportunity to work with him. Not only understanding the subject, but also interpreting the results drawn thereon from the graphs was very thought provoking. I am thankful to the kindness and generosity shown by him towards me, as it helped me morally complete the project before actually starting it.

Last, but not the least, I would like to thank **my family members** for their help, encouragement and prayers through all these months. I dedicate my work to them.

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ABSTRACT

Aluminium is one of the most common metals in the world and its use is increasing day by day in many industries most significantly in aerospace and automobile industry credited to its comparatively lower weight and higher strength. Aluminium alloy-based metal matrix composites have shown incredible potential for cost saving which can be easily pointed to light weight of the material, high specific strength and corrosion resistance, as well as good cast ability. Aluminium composites are finding application as reinforced piston, driveshafts, break components and many more. Aluminium composites have been produced in the industry by using various techniques such as gravity die casting, hot forging but one process which has shown mass acceptance is stir casting. Stir casting has stood out among all other because of its inexpensive, simple operating and mass production capabilities.

In this report three samples are prepared with the base of aluminium AA6061. First sample is prepared by casting aluminium without any reinforcement. In the second sample SiC particles are added to the aluminium metal matrix, the third sample has two reinforcement, SiC and natural reinforcement (aloe vera), added to aluminium matrix. The reinforcements were preheated to a temperature of 200˚C for one hour before it was added to the molten AA6061 to have uniform distribution in the matrix. XRD analysis of the composite samples shows the presence of reinforcement and the base metal in the composite. The FESEM images of the samples further confirms the presence of reinforcement in the composite samples. Mechanical properties and tribological properties of the prepared composite samples were determined. Tensile strength and microhardness are observed to be maximum in case of SiC reinforced metal matrix composite. Wear loss is minimum in the composite sample having Aloe vera and SiC reinforcement. Percentage elongation is maximum in the as casted sample. Microhardness

Keywords: Aluminium metal matrix composites, Stir casting, Silicon Carbide, Aloe Vera, Wear properties.

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CHAPTER 1: INTRODUCTION

Metal matrix has been generating a lot of interest in the field of research and it is evident by the number of researches pouring in this segment. It is due to the desirable combination of mechanical properties they are able to display. The major strength of attraction in the world is aluminium matrix composite, which is able to depict a plethora of increment in mechanical and tribological aspects of the resulted composite. Reinforcements which are ceramic in nature has found maximum use in the composite research with aluminium as the base. The industry is observing a shift towards more cost-efficient materials like aluminium composite due to its cheaper cost and properties. Composites with the base of aluminium has proved as an attractive replacement option in the aerospace industry as well as automobile industry (Hima Gireesh et al, 2018)

Composites are made with the agglomeration of two components namely, matrix of metal enhanced with reinforcement. The addition of reinforcement into the metal matrix enhances the mechanically oriented properties such as, ultimate tensile strength, ductility, elasticity, hardness etc, tribological governed aspects, such as wear, friction compared to conventionally heavy material such as pure aluminium, steel etc. available for the engineering applications. The reinforcements added to the composite can be classified broadly into four categories, which are,

a) Particle type reinforcement
b) Short fibre type reinforcement
c) Continuous fibre reinforcement
d) Laminated type reinforcement

Particulate type of reinforcement are used widely for various research application because of easy formability and relatively cheaper in terms of cost (M.Taya & R.J. Arsenault, 2016). Short fibre or whisker type of reinforcement found application due to its depiction of strength and thermal stability relatively better then particulate reinforcement. But the research in this section is restricted due to high cost associated with the available whisker reinforcement in the market (I.A.Ibrahim et al, 1991). Continuous fibre type of reinforcement has found usage in military application. The application is reserved to specialized zone due to the very high cost associated with the reinforcement added to the fact that it is a labour-intensive manufacturing process.

The composites produced with the desired components have been consistent with the improvement in the desired properties be it physical, mechanical or tribological. They have been isotropic in nature generally and can be made employing conventional methods that were used for metals. For instance, for high temperature application aluminium composite with reinforcement such as SiC, alumina etc are finding extensive use. Similar efforts are underway to find suitable composition to be used in other industries such as automobile industry. In automobile industry there are various application in which high impact strength is required in some places good wear resistance, good thermal resistance is desired.

Aluminium is perceived as the game change in the industry. With the extensive activity in the particulate reinforced aluminium matrix, particulate used can be further classified into three categories.

a) Ceramic Particulate i.e. SiC, alumina etc.
b) Industrial waste particulate i.e. fly ash.
c) Agriculture waste particulate i.e. Jute ash, egg shells etc. (M.O.Bodunrin et al, 2015)

Agriculture and industrial waste are finding prominent use in the composite to achieve reduction in cost as well as their ability to show satisfactory enhancement in properties. (K.K.Alaneme & K.O.Sanusi, 2015)

We are using a particulate reinforcement rather than whisker reinforcement due to the cost associated with it. Aluminium materials are manufactured by various processes be it gravity die casting, hot forging but one process which dominates the manufacturing industry with around 90% application is stir casting. The material in the stir casting is brought to its melting point and then solidified with leads to inhomogeneous solidification which in turn damages the integrity of the final product. The dendrite formation in the final product lower the strength of the material. Hence other manufacturing techniques are being looked into to find an easy and cheap manufacturing alternative.

In this project we look to make substantial enhancement in the microhardness, tensile strength and wear resistance of the aluminium based matrix, AA6061 by addition of natural and ceramic reinforcement in different composition. With the help of Stir-casting three samples are produced. The samples procured by stir casting are then subjected to various tests to evaluate the change in the properties.

1.1 Aluminium Alloy

Aluminium alloys used as matrix has evolved with the research that is poured into the topic. This led to a lot of various types of aluminium being available for the use as a matrix. Such diversity gave rise to the need of a designation system.

An aluminium alloy is designated as AAXXXX. The first digit (**X**XXX) depicts the major alloying element, which describes the series of the aluminium alloy, for instance, 1000 series, 2000 up to 8000 series. The second digit (X**X**XX) depicts the modification, if any, is done to the alloying element. If the second digit is “0” then no modification has been done. The third and last digit (XX**XX**) are arbitrary number given to help in determining a specific series. In the 1000 series the last two digit describe the percentage of aluminium in the base metal, and no such inference is drawn in any other series.

6000 Series: 6061 Aluminium plate is a precipitation-hardened alloy of aluminium. It has magnesium and silicon as the major contributor as alloying elements, as it is evident in the Table 2. 6061 aluminium plate has proved to have one of the widest ranges of alloys which happens to be heat treatable. AA6061 has found fandom amongst researchers owing to its fabulous medium to high strength, considerable improved toughness and great enhancement in resistance of corrosion.

1.2 Types of Reinforcement

The two different type of reinforcement used in the project are

- Silicon Carbide
- Natural Reinforcement

1.2.1 Silicon carbide

Silicon carbide also known as carborundum is a compound formed from silicon and carbon and has a chemical formula of SiC. It is one of the extremely rare minerals, and has been in mass production since 1893. It has been used in the industry as an abrasive. Sintering of grains of silicon carbide have been known to form very hard ceramic which have very wide application in the area which demand very high endurance such as brakes, clutches in car or bulletproof vests. SiC has also found home at high temperature/high voltage semiconductor electronics (RAY S. ZnO, 1993). Aluminium reinforced with SiC ($Al\text{-}SiC_p$) have shown considerable improvement in the desirable properties and the trend can be seen back over a decade. Light weight, thermal resistance, lower wear rate, high sp. Strength has been the most desirable properties attracting the researchers (HOKAED E & LAVERINYA J, 1999).

1.2.2 Natural Reinforcement

Aloe vera is from Asphodelaceae family which has shown resistance to drought and been everlasting as can be observed from the region in which it is populous (K.Manvitha & B.Bidya, 2014). Aloe Vera is a contribution of Arabic and Latin which roughly translates to shining bitter substance and true, respectively. (E.Tayal et al, 2014). Aloe vera can be described as lance shaped leaves having jagged edges and sharp point which feel into tropical or sub-tropical plant. The plant has found use in medical and cosmetic industry. The origin of aloe vera can be traced back to tropical Africa with the major cultivation can be found in warm climate region. The major production of this crop in India can be credited to Rajasthan, Chhattisgarh, Gujarat etc. The aloe vera cultivation is an economical paradise as it has shown a remarkably good crop with very limited amount of water i.e. it requires 150mL water for good yield. A good yield can be described as a leaf weighing approx. one kg. (T. Mulu et al., 2015).

Easy availability, undemanding cultivation, being eco-friendly that is able to show good wettability has proved to be a good substitute as reinforcement in aluminium based composite. It is evident that not much literature is available on aloe vera as reinforcement material. This project a step undertaken to examine the mechanical and tribological properties of aloe vera as an additive to aluminium based matrix.

1.3 Stir Casting

Composite materials have been employing stir casting as a method of manufacturing for a rather long time now owing to its cost-effectiveness and since the technique is quite simple. The metal is brought to liquid state and stirred with the help of mechanical stirrer. On the formation of vortex, the reinforcements are added to achieve good distribution in the matrix. The set-up of stir casting employed for this experiment is shown in Fig.1. Different combinations of reinforcement are fabricated with aluminum metal matrix. Preheating of the reinforcement, SiC in this case, is done at 200 ˚C for a time period of 1 hour. The procedure of preheating is carried out prior to the addition of the reinforcement into the liquid matrix material. In the case when Aluminium is employed as the base metal and works as matrix the temperature inside the furnace is maintained at 900 ˚C this further helped in controlling chemical reaction between the substance. The stirring action inside the liquid matrix material is done with the use of mechanical stirrer. The stirrer is kept at100-150 rpm from time to time.

Stirring action is continued to mix the reinforcement in molten metal uniformly (Naher et al., 2003).

1.4 Applications

Aluminium is nowadays a most important metal to be used in every industry and its use is increasing day by day due to its less weight and high wear resistant properties. Following are the applications of Aluminium composites:

- Aluminium composites are used in automobile industry selectively reinforced pistons in diesel engines, Al engine blocks employing selectively reinforced cylinder bores, intake and exhaust valves, driveshafts and prop shafts, brake components (discs, rotors and callipers) and power module components for hybrid and electric cars making Pistons, Engine Cylinders and Drum Brakes.

- Aluminium is also widely used in Aerospace industry due to its light weight and high wear resistant properties.

- Aluminium is also finding use in mobiles bodies as to reduce its total overweight.

- Thermal management achieved by aluminium includes, substrates for computer processor chips, power semiconductor devices and packaging for microwave devices used in telecommunications

- Application of aluminium in Recreational and infrastructure industries include cemented carbide and cermet materials, electroplated and impregnated diamond tools, Cu and Ag MMCs for electrical contacts, erosion-resistant cladding for the petrochemical industry. (Miracle & D. B., 2005; S. Das, 2004)

1.5 Advantages

Aluminium matrix composites are finding high technology applications owing to

- Aluminium is light in weight.
- Aluminium Composites is impact resistant and also wear resistant.
- Aluminium is electrically conductible and also magnetically neutral.
- Aluminium can also be recyclable
- High structural efficiency
- Attractive thermal characteristics (Miracle & D. B., 2005)

1.6 Disadvantages

Following are the disadvantages of Aluminium composites:

- Aluminium has low melting point
- Aluminium is difficult to weld and special welding techniques are used o weld them.
- Aluminium is expensive as compared to other metals.
- It exhibits smaller data base of properties
- Aluminium composite technology is under development (Froyen, L., & Verlinden, B., 1994)

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Literature review is scrutinised from last 10 years of papers published to get a clear picture of the work done in the field of metal matrix composite using natural and synthetic reinforcement. Boopathi et al. (2013), noted that addition of 15% fly-ash into AA2024 aluminium matrix has resulted in increased tensile strength, yield strength and hardness and reduction in percentage elongation in comparison to base metal matrix. M.uthayakumar et al. (2013) in their experiment used Al1100 aluminium alloy as the base matrix and reinforced it with SiC and B_4C which shows reduction in wear rate and coefficient of friction up to 4m/s, with increment in load and sliding velocity the wear happens along with plastic deformation. S. Amir khanlou, B. Niroumand (2010) stir casted 356 cast aluminium alloy reinforced with SiC particles. The resulted composite casting has shown improvement in impact energy,10% increase in hardness and 68% decreased porosity. Agriculture and industrial waste are finding prominent use in the composite to achieve reduction in cost as well as their ability to show satisfactory enhancement in properties. (K.K.Alaneme & K.O.Sanusi, 2015). Gireesh et al.,2018 have formed a composite by stir casting aloe vera reinforced aluminium matrix. The resulting composite shows improvement of hardness and tensile strength in respect to fly ash reinforced aluminium matrix. SiC and natural reinforcement in the form of coconut ash has been used as reinforcement material by Surinder Paul & Gora Ram Sharma, 2017. They confirmed presence and distribution of reinforcement by optical microscopy and also reported improvement in tensile strength, impact strength and hardness of the composite in comparison to AA6063. Sani A Salihu & I.Y. Suleiman, 2017 in their research used natural reinforcement in the form of marula seeds cake in AA6061 aluminium metal matrix. The author observed improvement in tensile strength and hardness whereas there was reduction in density, impact and percentage elongation with increasing percentage of reinforcement in the metal matrix. Table 1 contains a full analysis of the literature review done.

Table 1: literature Review

S.no	Source	Matrix Used	Reinforcement	Characteristic	Mechanical Properties	casting technique	Melting Temperature (˚C)	Pouring Temperature (˚C)	Pre-reinforcement temperature	Reinforcement preheat temperature	Stir speed
1	Gireesh et al. (2018)	Aluminium	Aloe Vera powder (2 mm) & Flyash (0.1μm to 100μm)	1. Preheated aloe vera powder of 10% by weight of base metal. 2. 3% Mg to improve wettability of aloe vera	1. brinell hardness was greater for aloe Vera then the specimen with fly ash. 2. there is an increment in UTS while using aloe Vera powder which directs to the suitability of aloe vera composed aluminium matrix for high strength applications	Stir Casting	720	nil	680-720	flyash-100	300

2	Surinder Paul, Gora Ram Sharma (2017)	Al6063	SiC and Coconut shell Ash	1. Optical microstructures were analysed to observe the presence and distribution of reinforcing particles in aluminium alloy and it revealed the presence SiC, CSA particles in alloy matrix in a uniformly distributed manner. 2. SiC and Coconut Shell Ash with weight percentage of 4%, 8%, 12%.	It has been observed that stir formed Al alloy Al6063 with SiC/CSA reinforced composites is superior to base Al alloy Al6063 in terms of tensile strength, Impact strength and Hardness.	Stir Casting	750	nil	nil	1100	250
3	Sani A. Salihu and I. Y. Suleiman (2017)	aluminium alloy (6061)	marula seeds cake	Reinforcements were added in an increment of 2% from 0% till 14%	1. with increase in the volume percentage of additive there is a noted increment in UTS, yield strength and hardness. 2.Dernsity, impact and percentage elongation reduced with increment in reinforcement	Stir casting	710	nil	nil	nil	nil

4	Zahraa Fadhil and Haydar Al-Ethari (2017)	Aluminium metal matrix (AMM)	B_4C (387nm)	1. Composite formed is of sound quality 2. Maximum hardness is recorded in 6%B_4C composite. 3. The strength (tensile and yield) and elasticity are maximum for the 4% B_4C composite instead of the 6% composite- where agglomeration causes poor wettability between the particles.	1. Increment in B_4C percentage has shown increment in hardness. 2. There is a recorded uptake in the value in modulus of elasticity, tensile and yield with increase in B_4C %.	Stir and squeeze casting	750	780	610-620	300	870rpm
5	Ansary Yar et al. (2009)	Aluminium alloy (A356.1)	Nano-particle MgO	1. Density increases with increase in temperature. 2. Hardness decreases with the decrease in temperature. 3. For MgO % > 2% compressive strength decreases with the increase in temperature.	1. Hardness and compressive strength increase with the percentage of MgO. 2. The maximum properties are for the composite containing	stir casting	650	800, 850 and 950	Same as pouring temperature	Room temperature	420 rpm

					1.5 vol%MgO fabricated at 850◦C.						
6	R. Palanivel et al. (2016)	AA6082 Aluminium	TiB_2 (~20 µm), BN (~200 nm)	1. The reinforcement are homogeneously distributed. 2. The iron content in the wear debris of the AA6082/ (TiB_2 + BN) hybrid AMC is less than the AA6082/TiB_2 AMC which is showing reduction in counter face wear. (BN, boron nitride-nanoparticles)	1. wear resistance increases with increase in reinforcement. 2. BN particle result in clean in polished wear surface when put up in comparision to TiB_2.	Friction Stir Processing	nil	nil	nil	nil	nil
7	R. Pérez-Bustamante et al. (2014)	Aluminium powder (99.9% pure, 325	Graphene (less than 10 nm thickness)	1. Graphene Nano Particles were used in amount of 0.25 wt.%, 0.5 wt.% and 1.0 wt.% and distributed using process of milling for 1 h, 3 h and 5 h, respectively.	1. The hardness increases with increase in milling time. 2. Hardness also increases with the	Milled powders were cold consolidated and	nil	nil	nil	nil	nil

		mesh size)		2. with the increase in milling time Aluminium coat on graphene proved to a factor delaying the formation of amorphous structures.	increase in graphene value.	subsequently sintered					
8	Qi Gao et al. (2017)	aluminium (99.8%, wt.%) ingots-Cu alloy	TiB_2 (400-100 nm), flux of K_2TiF_6, KBF_4 and Na_3AlF_6, Na_3AlF_6	1. The application of ultrasonic vibration treatments improves the particle distribution in Al-4.5Cu alloy composites.	1. Ultrasonic vibration treatments improve the distribution in the composite but there is always a higher density at the grain boundaries. 2. Orowan strengthening, grain boundary strengthening, CTE mismatch strengthening and grain refinement are seen in the composites.	Ultrasonic vibration treatment	nil	720	830	nil	nil

9	Xiaoxu Liu et al. (2017)	Nano-aluminium (Al) particles	Polyimide	1Nano-Al reinforcement was homogeneously distributed in the polyimide matrix own to in-situ polymerization. 2. Dielectric permittivity is observed to be four times higher comparison to pure PI matrix.	1. High dielectric permittivity and high-volume resistivity with low dielectric loss, good mechanical properties, and excellent thermal stability is observed in this composite 2. There is also a weak dependence on testing frequency.	in-situ polymerization.	nil	nil	nil	nil	nil
10	M.Uthayakumar et al. (2013)	1100 Aluminium alloy	SiC (10 µm), B_4C (65 µm)	1. Wear rate and coefficient of friction decrease with increasing sliding speed up to 4m/s and increase after that. 2. The composite retains its properties for sliding speed range of 1-4 m/s and load of up to 60N. 3. 5% SiC and 5% B4C (wt.%)	1. The boron tribo oxide layer reduces wear and coefficient of friction. 2. At high loads and high sliding velocity, the wear is accompanied by plastic deformation.	Stir casting	750	720	450	1000	150-300 rpm

11	S. Amir khanlou, B. Niroum and (2010)	356 cast aluminium alloy	SiC particulate (8-3 μm)	1. Milled Al-SiC(p) composite powder instead of untreated one's, enhance the wettability and improves the distribution. 2. Casting in semisolid state instead of liquid state enhances the wettability and distribution. 3. Al-13%Si	1. Addition of Al-SiC(p) composite powder increases the hardness value by 10% and decreases the porosity as recorded by 68%. 2. The impact energy of the composites increase with the addition of Al-SiC(p) composite powder.	Stir casting and compocasting	700	650 or 607	Reinforcement and matrix melted together	Reinforcement and matrix melted together	500 rpm
12	Y. Pazhouhanfar, B. Eghbali (2018)	AA6061 matrix	TiB_2(2–10 μm)	1. Microstructure is uniform distribution of TiB2 without agglomeration. 2. Strong bonding can be attained by adding K2TiF6.	1. Tensile strength of the composite increases without much decrease in elongation to failure. 2. High load bearing capacity, decrease in matrix grain size- are a result of difference in grain size of matrix and reinforcement.	Stir casting	700	700	-	250	350 rpm

					3. The predominant fracture taking place is ductile rupture fracture.						
13	M. Kok (2005)	2024 Aluminium	α-Al_2O_3 (16, 32, 66 μm)	1. It is observed that the Morphology of Al-50 vol% SUS316L and Morphology of Al-80 vol% SUS316L composite powders are same. 2. The advantages with SPS is that there is no drastic melting point difference (the problem with die casting).	1. Al-20 vol% SUS316L composite powder is observed to have larger particles than other composites. 2. Hardness has maximum value in Al-50 vol% SUS316L with 630.4HV. Value in Al-20 vol% SUS316L is 234.3 and in Al-80 vol% SUS316L is 212.3.	Stir Casting	700	720	550	400	900 rpm
14	Reddappa H.N Et al. (2011)	Aluminium (AA6061)	Beryl (53-75μm)	1. The transfer film formed on the surface reduces the wear rate. 2. There was high coefficient of friction in the initial stages	1. Coefficient of friction of AA6061-beryl composites decreases with increasing load.	Stir Casting	nil	710	720		400 rpm

				of sliding (due to the strong interlocking of the rough surfaces).	2. AA6061-10% beryl composites show lower wear rate of wear than AA6061-2% beryl and AA6061-6% beryl composites.						
15	H. Feng et al. (2010)	Aluminium alloy A356	Diamond (91-106 μm), TiC	1. The first heating, results in the plastic deformation of the matrix as the stress could reach yield strength of matrix 2. During the second cycle, the residual strain is found to be reducing.	1. The values of CTE of the composites are considerably decreased into the range of 4–8 × 10−6 K−1 in combination with an enhancement of the boundary conductance. 2. Thermal conductivity increases and thermal expansion decreases in the composite.	Gas pressure infiltration	nil	nil	nil	nil	nil

16	S. Baskaran et al.(2014)	High strength 7075 aluminium.	TiC (halide salt K2TiF6 and graphite powder)	1. Uniform distribution of TiC particles along grain boundaries. 2. The optimal level combination for minimum wear rate was identified as 4 wt.% Tic reinforcement, 9.81 N load, 3 m/s sliding velocity and 1500 m sliding distance.	1. The TiC layer improves the wear resistance of the composite. 2. The wear depends upon the sliding velocity and weight applied.	in situ casting technique	900	900	nil	250	
17	Boopathi et al. (2013)	Aluminium alloy 2024	15% SiC-fly ash	1. Wetting of reinforcements with the aluminium matrix is improved by the addition of magnesium. 2. Both the SiC and fly ash particles are well distributed in aluminium matrix	1. The density of the composite is decreased by increasing the amount of reinforcement. 2. with the Increase in area fraction of reinforcement, the matrix shows improvement in tensile	Stir casting	720	680	700	300	200 rpm

					strength, yield strength and hardness. 3. The increase in tensile strength was also observed but elongation of the hybrid metal matrix composites in comparison with unreinforced aluminium was decreased						
18	ZHAO Yu-tao et al. (2010)	Aluminium A356 alloy	Al_2O_3, Al_3Zr	1. The observed morphologies of the in-situ particles comes out to be ball-shaped and the distributions are uniform in the matrix. 2. Dislocation accumulation effect is responsible for the cracks recorded as observed in tensile resuls.	1. The values of tensile strength, yield strength and hardness for the composite prepared in assistance of pulsed magnetic field shows improved results.		nil	nil	nil	nil	nil

19	Z.Y.Liu et al. (2014)	2009Al powders	Carbon nanotubes (CNT) (outer diameter of 10–20 nm and a length of 5 µm)	1. More FSP passes Increase the uniformity of distribution of CNT. 2. It also reduces grain size and hence the uniformity of the composite.	1. The mechanical strengths of the CNT/2009Al composites were improved significantly after FSP and the maximum strength increase was obtained with three-pass FSP.	Friction Stir Processing	nil	nil	nil	nil	nil
20	B.Chen et al. (2016)	Aluminium metal composite (Al)	Carbon nanotube (CNT)	1. The grain size of Al/CNT composites is almost same for different sintering temperatures. 2. CNTs detection is very difficult for sample prepared at 900K.	1. The ductility, yield strength, ultimate strength, all improve with the increase in temperature of sintering. 2. The elongation of composite sintered at 900 K has shown an improvement of 82% with respect to that sintered at 800 K.		nil	nil	nil	nil	nil

21	Kovtunov et al. (2017)	Aluminium AM5 and A7	Molten lead, Babbit B16	1. The density of the composite is lower than that of the aluminium alloys. 2. Friction coefficient of both the composites is almost same.	1. Density of Aluminium A7 – lead composite is higher than that of Aluminium alloy AM5 – Babbit B16 composite. 2. The ultimate compressive strength and yield strength of AM5 – Babbit B16 composite is higher than A7- lead /Babbit B16 composite. 3. Presence of Aluminium phase in the above composites increases their wear resistance.		nil	nil	nil	nil	nil

22	Kwangjae Park et al. (2017)	Aluminium powder	Stainless steel-SUS316L	1. The advantages with SPS is that there is no drastic melting point difference as opposed to die casting	1. Al-20 vol% SUS316L composite powder has larger particles than other composites. 2. Hardness has maximum value in Al-50 vol% SUS316L with 630.4HV. Value in Al-20 vol% SUS316L is 234.3 and in Al-80 vol% SUS316L is 212.3.	spark plasma sintering process	nil	nil	nil	nil	nil
23	Chinawad DHADSANADHEP et al. (2008)	Aluminium powder (106 μm)	Copper powder (70 μm), Silica powder (250 μm)	1. The density of compound decreases with the addition of silica. 2. During heat treatment, Aluminium and Silica react to form Alumina and Silicon. 3. There are different phases- silicon rich, containing gamma aluminium, pure Al,	1. Increase in heat treatment temperature increases the porosity of the composite. 2. The hardness increases with the amount of silica.	Powder Metallurgy Method	nil	nil	nil	nil	nil

				Al2Cu distributed all over and non-reacted silica.							
24	Oddone et al. (2017)	Al7075, Alumix 431 and 231, Al2024, AZ31	Magnesium, Graphite	1. Density of Aluminium – graphite composites decrease when 50 vol% graphite is added. Whereas, the density of Magnesium-graphite composites increase when graphite is added.	1. There is increase in density, thermal conductivity- but more increase is in magnesium alloy. 2. The coefficient of thermal expansion decreases with the increase in the amount of graphite added, but there is a slightly more decrease in Aluminium-graphite composite.	spark plasma sintering process	nil	nil	nil	nil	nil

					3. Both hardness and thermal stress decrease with the amount of graphite added.						
25	Longlong Dong et al. (2016)	QAl9-4 aluminium bronze alloy	304 stainless steel.	1. Because of tightly bond interface of steel, defects/strips do not get revealed to the surface. 2. Mesophases like AlCrFe2, AlNi3, and Al4Cu9 are formed.	1. Mesophases result in the brittleness of the compound. 2.Shear bonding strength of the composited is less than the individual alloys (because of micro phases).	vacuum smelting-casting	nil	nil	nil	nil	nil
26	Ehsan Ghasali et al. (2015)	Aluminium (1056-merck) powder	B_4C (Aldrich-378100)	1. The properties can be further enhanced by adding 1 wt.% Co. 2. Time and energy consumed in the microwave sintering process is less than other methods of fabrication.	1. For sintering temperature more than 850◦C there is a significant increase in structural and mechanical properties.		nil	nil	nil	nil	nil

					2. The microhardness and compressive strength values increased with increasing the weight fraction of B4C.						

2.2 Summarisation of Literature

2.2.1 Effects of Aloe-Vera

a) Aloe Vera composed aluminium composite has shown good strength to weight ratio.

b) The ultimate tensile strength of Aloe Vera composed matrix are significantly higher compared to 1000 series aluminium.

c) Yield strength has shown comparatively better results in aloe vera composed aluminium composite.

d) Impact strength, wear and hardness in case of aloe vera composed composite was more or less the similar to fly-ash.

e) The fabrication of agriculture particulate aluminium composite is eco-friendly i.e. powder form of aloe vera in place of fly-ash in the form of ash (Hima Gireesh et al., 2018).

2.2.2 Effect of SiC

a) Vickers hardness number and the tensile test has shown increment due to the enhancement of the matrix with the use of SiC maximum improvement can be observed when 20 wt.% SiC is added.

b) Wear resistance is one among other properties to shown enhancement on addition of SiC to the mix of aluminium alloy matrix (Amirkhanlou, S. & Niroumand, B., 2010)

c) Better hardness, tensile strength and wear resistance are easily spotted on addition of SiC to aluminium based matrix.

d) Increase in hardness and decreases in porosity is evident.

e) The impact energy of the composites increases with the addition of Al-SiC(p) composite powder. (Rahman, M. H., & Al Rashed, H. M., 2014)

2.3 Research Gap

On the thorough scrutiny of the published work on the Aluminium matrix composite, the following observations have been made:

1. There is very little information available in the direction of using Aloe Vera as natural reinforcement.
2. There is no research done in the pairing of SiC and Aloe Vera particles.

CHAPTER 3: EXPERIMENTAL SETUP

3.1 Materials and Methods

In this study, the material selected is Aluminium of series 6061. The material is designated as AA6061. The Reinforcements used are SiC and natural reinforcement (Aloe Vera) for preparation of aluminium matrix.

3.5 Base Matrix Material-AA6061

Aluminium is assigned by a four-digit code in numeric. The principal digit speaks to the primary alloying component. For this situation, the initial six demonstrates that it is alloyed with magnesium and silicon. The second digit, on the off chance that it is a 0, similar to this case, implies it is a standard combination, its arrangement has not been adjusted. At last the last two digits, 61, remain for the particular compound.

The selected base matrix of AA6061 has chemical composition as per ASTM E 1251:2011 and is given in Table 2. Mechanical tests were performed on base material. The test performed give the results as tensile strength of 284 MPa and 24.9% total elongation which can be viewed in fig. 1. Average Vickers microhardness of 116.1Hv with 97.76 GPa modulus of elasticity.

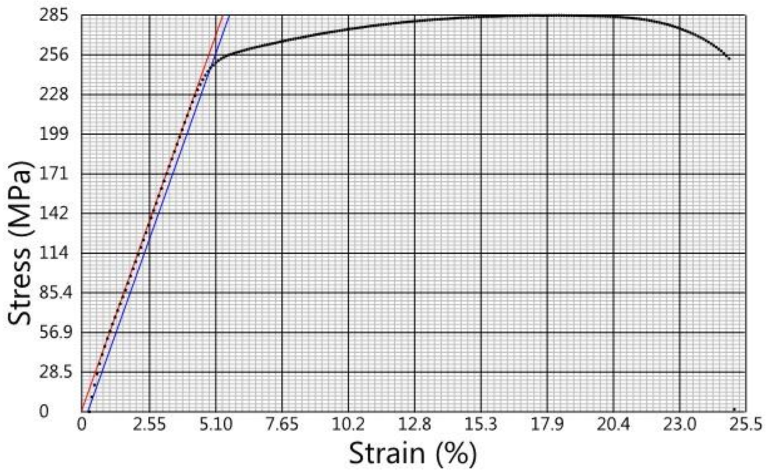

Fig. 1. Stress Vs Strain Plot of Base Metal

Table 2: Chemical properties of AA 6061 (wt%)

Composition	**Al**	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Cr**	**Ti**
AA6061-T6	97.75	0.665	0.253	0.153	0.0676	0.840	0.0226	0.178	0.0225

3.6 Reinforcements

a) Silicon Carbide
b) Natural reinforcement

(a) Silicon Carbide.

Silicon carbide is a compound made from silicon and carbon (SiC). Its particle size od SiC used in this study is 38 microns. Table 3 constituting a chemical composition of SiC tested with the help of chemical spectroscopy.

Table 3. Chemical Composition of SiC (wt.%):

SiC	Si	SiO_2	Fe	Al	C
98.5	0.3	0.5	0.08	0.1	0.3

(b) Natural Reinforcement

Natural reinforcement used in this study is aloe vera. Table 4 consist of the chemical composition of Aloe Vera. Aloe Vera powder is made by chopping the aloe Vera leaves into very small parts i.e. 5 mm. The leaves are washed with the use of hot water kept at 80-100˚C which helped in removing undesired dirt. The chopped of leaves are then dried with the help of hot oven for eight hours at 150˚C to remove excess of moisture content. Then with the help of ball mill dried leaves were grounded into powder of about 44-53 microns in size. Thus, the aloe Vera powder is ready as shown in Fig.2 for preparing the specimen of AMC.

Table 4. Chemical Composition of Aloe Vera (wt.%) (T.Mulu et al., 2015)

Ca	Mg	Na^+	K	P	Fe	Cu	Zn
3.58	1.22	3.66	4.06	0.02	0.1	0.06	0.02

Fig. 2. Dried Aloe Vera Powder

3.3 Process Parameters

Based on the literature review and number of trials performed, following parameters were considered during Stir Casting to obtain the matrix without any formation of defects:

3.3.1 Rotational Speed

In a paper published by Naher, S. et al. (2003) it has been observed that on varying the speed of rotation of the blade the dispersion of the particles can be controlled effectively. It has been concluded that maximum dispersion of particles can be achieved by keeping the stirring speed in between 100-200 rpm. And the reinforcement settles within 60 to 180 seconds of seizing of rotation. Based on these discussions the stirring speed had been kept 100-150 rpm and is kept stirring after addition of reinforcement.

3.3.2 Temperature

The wetting of the reinforcement is liquid aluminium alloy can be greatly influenced by the temperature of addition of reinforcement in the melt. Higher temperature provides better wettability and also the time of contact need to be monitored (Froyen, L., & Verlinden, B.,1994). Hence, the temperature of the aluminium melt was kept constantly at 900˚C in the furnace.

3.3.3 Preheating of reinforcement

Preheating of reinforcement has been a rather common practise as it serves two purposes. Firstly, it helps in getting rid of any moisture content, absorbed gases etc in the reinforcement sample and secondly it increases the reinforcements wettability with the molten aluminium. There has also been noticed improvement in interfacial strength and dispersion of reinforcement particle (Razzaq, A.M. et al., 2017). Adhering to these results the reinforcements added to the composite in this project where preheated at 200 ˚C for two hours.

3.4 Experimental Methods

In this experimental work commercially available AA6061 is used as base matrix material for the composite. In order to procure three sets of samples with different percentage of reinforcement material. Stir casting method is used for the manufacturing of composite samples.

The setup used for the fabrication of sample consists mainly of electric furnace and mechanical stirrer. The electric furnace used in this process is equipped with a crucible, the maximum temperature for operation of the furnace is 1200ºC. The current rating as mentioned of furnace is single phase 230V AC, 50Hz. AA6061, an aluminium alloy, is used. AA6061 is available in the plates form of thickness 5mm. It amounts to 1 kg per sample. The metal plates are kept inside the crucible which in turn was placed into the furnace. The furnace is further heated by electric coils just above the liquidus temperature of the aluminium matrix converting it in semi liquid form at around 900ºC. The mixing is done uniformly with the help of mechanical stirring of aluminium alloy. The reinforcement that is to be added is measured beforehand and preheated to a temperature of 200°C. With the help of a mechanical stirrer, rotating at a speed of 150 rpm, a vortex is created and, in this vortex, additives are added to liquidous aluminium alloy inside the furnace. Again, reheating of the aluminium matrix composite is done. Mechanical stirrer is in continuous stirring action during reheating at 100 rpm. Aluminium composite reaches melting point at a temperature of about 700ºC so the temperature is maintained at 800°C. This liquid aluminium metal matrix is poured into permanent mould that gave us the required specimen for further experiment.

Fig. 3. Stir Casting Setup

Table 5: Sample Composition

Sample	AL Alloy (AA 6061) (wt.%)	SiC (wt.%)	Aloe Vera (Wt.%)
1	100	0	0
2	96	4	0
3	96	2	2

3.5 Composite Sample Preparation

Three sample are prepared through stir casting. The Die used is of permanent type as shown in Fig 4.

Fig. 4. Sample Preparation using Permanent Die

3.5.1 Sample 1 (AC)

Sample 1 is of Aluminium 6061 without any additives is shown in fig 5(a).

3.5.2 Sample 2 (SiC-AA)

Sample 2 is prepared by mixing the SiC particles with AA6061. SiC particle size is 38 microns. The SiC particles are subjected to preheated at 200˚C for two hours before adding to base matrix AA6061. The SiC was taken 4% by weight. It is shown in fig 5(b).

3.5.3 Sample 3 (AV-AA)

Sample 3 is prepared by mixing the Aloe Vera powder and SiC with AA6061. SiC of 38 microns and Aloe Vera powder of 44-53 microns are taken. Aloe Vera is taken 2% by weight and SiC is also taken 2% by weight. It is shown in fig 5(c).

All three samples collectively are shown in fig 5.

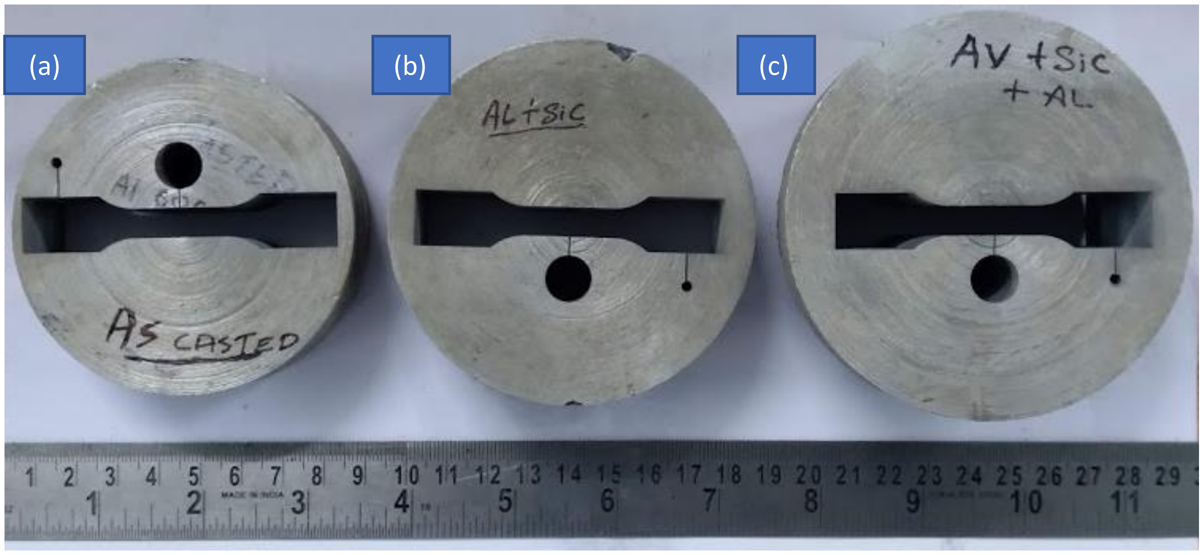

Fig. 5. Casting (a) As Casted (b) AA6061 + SiC (c) AA6061 + SiC + AV

3.6 X- Ray Diffraction

Diffraction pattern are observed due to scattering of light by a periodic array with long range order thus producing an interference constructive in nature. Such constructive interference is observed only on some specific angles. The analysis of the XRD driven data is done to spot trends which correspond to the directionality in the crystal structure, which is further analysed by the miller indices of the peaks in diffraction pattern. The scattering of light is done due to the electron in an atom. The arrangement of atoms in a crystal are periodic hence when the light interacts with the periodic array of atoms diffraction is observed. The wavelength used for the X-ray and the distance between the atoms is almost similar. A diffraction pattern is observed when X-rays are scattered on interacting with the atoms, this pattern helps us with the information regarding the atomic arrangement in the crystal.

Diffraction peaks observed on the XRD are associated with the plans of atoms. Diffraction peaks formed are related to the planes of atoms, which assist in analysing of the atomic structure and microstructure. Now the determination the position of the diffraction peaks is done with the help of Bragg's law ($\lambda=2\ d_{hkl}Sin\theta$). d_{hkl} is the distance between the parallel planes of atom. Bragg's law helps in identification of the angle at which diffraction peaks are observed due to constructive interference formed by the scattered X-ray from the parallel planes of atoms. The intensity of the diffraction peaks and their position are dependent on the crystal structure, i.e. the arrangement of atoms in periodic array in the entire crystal.

3.6 Field Emission Scanning Electron Microscopy

Field Emission Scanning electron microscopy (FESEM) is done with the help of electron-optical column. The electron beam, or electron probe, that is employed to pursue the image should be as small as possible, typically it is kept around 10nm. The electron probe diameter is directly influencing the resolution of the image obtained by FESEM process. The process by which the electron probe covers the whole specimen is known as raster scanning. During the scanning the accelerated electrons are bombarded on the specimen, on interaction with the specimen they are scattered. The scattering phenomena is observed as elastic and inelastic in nature of electron interaction.

The image formed after the scanning can be of differing brightness in response to the electron bombardment. Secondary electrons and backscattered electrons are responsible for the differing brightness, which can be easily differentiated according to their kinetic energy and the latter having greater energy. Images generated using the secondary electron are showing only the surface structure and nothing regarding the underlying structure is known only topographical contrast is displayed. Backscattered electron images on the other hand has depth, providing information under the topography of the specimen, as the information is generated by the signals coming from half the penetration depth. They are known to show contrast in the images on the basis of the chemical composition of the specimen (Egerton, R. F.,2005).

3.7 Tensile, Wear & Microhardness sample Preparation

3.7.1 Microhardness sample preparation

Microhardness Testing is a technique used to determine hardness or resistance to penetration of the material under study. When test samples are very small or thin, or when small regions in a composite sample are to be measured, microhardness is tested. During microhardness testing, a Vickers diamond indenter is pressed into the material’s surface with a penetrator and a light load. When a load is applied on the material it penetrates on indentation causing permanent deformation on the surface if the material in the shape of the indenter. The test is performed under controlled condition by monitoring pressure for a given time segment, for a diamond indenter that is square in shape. The resulting diagonal due to indentation on the material surface is measured and with the help of formula to calculate the Vickers hardness value. For many types of samples, the contact depth is not identical to the displacement depth due to surrounding material getting elastically deflected during the indentation (Fisher, 2004).

The microhardness analysis is done on an instrumented indentation tester. The dimensions of the specimens for the microhardness test are 10mm diameter cylinder which is carved through the Wire EDM process as shown in Fig.1. During this process, the indentation depth is measured continuously.

Fig. 6. Microhardness sample cut by Wire EDM

3.7.2 Tensile Sample Preparation

The material used for engagement in engineering applications are advised on the basis of their mechanical properties such as tensile strength, percentage elongation etc. Such properties are induced by tensile testing. The tensile properties are always documented for a new material as they help in stabilising the new material against the available options in the market. The tensile strength of a material is governed by various attributes, some of the prominent attributes are listed below.

(i) Molecular structure: intermolecular forces are directly dependent on the molecular structure hence even a slightest change in the molecular arrangement will affect the outcome of tensile strength.

(ii) Temperature: with the increase in temperature, tensile strength of the metal increases up to a point beyond which the properties start depreciating.

(iii) Composition: Different composition leads to different arrangement of molecular structure and there is difference in the level of molecular binding hence effecting the UTS of the material.

The tensile strength of the material can only be quantified by the performance of testing on the material. Tensile testing of a material is done by subjecting the material on Universal Testing Machine (UTM). The specimen for the same is prepared according to the standard specified in ASTM-E8, to procure the sample help of wire EDM was taken. The dimension according to which the sample for tensile testing was prepared are gauge length – 20mm, gauge width- 6mm, and gauge thickness- 4mm, the sample when produced look like dog bone in shape as it can be seen in Fig 7 along with procured tensile sample in Fig. 8.

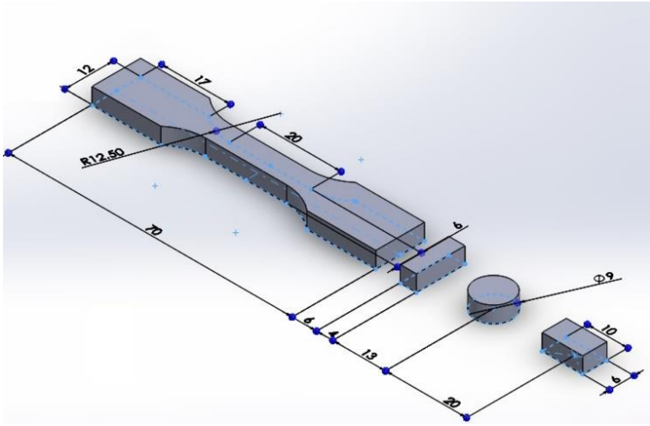

Fig. 7 Specification of Tensile specimen

Fig. 8 Tensile Specimen

3.7.3 Wear Test

Wear can be described as an action of erosion of the solid surface pertaining to the action of another surface, the need of action in mechanical form, which results in relative motion between the two bodies in contact. Wear leads to a lot of loss of material thus making the wear rate a point to look after before deciding on the usability of the material.

In this discussion three samples are prepared with the help of Wire EDM that will be subjected to sliding under dry condition and the objective is achieved with the help of High Temperature Rotary Tribometer. The test specimen for the wear testing are prepared cylindrical in shape of diameter of 10mm as can be seen in Fig. 9. The wear testing is carried on by rubbing the pin on a harder rotating disc which is made of EN31 Steel having a Rockwell Hardness number of 55-58, the disc can be seen in Fig.10.

Fig. 9 Wear Specimen

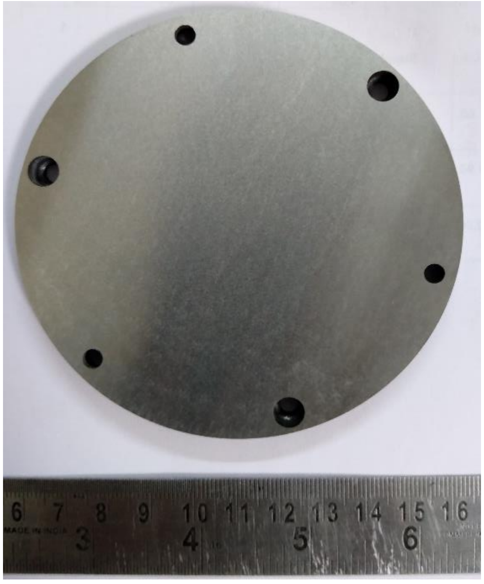

Fig. 10 Wear Disc EN 31

CHAPTER 4: MICROSTRUCTURAL PROPERTIES

4.1 X-Ray Diffraction

The samples are subjected to X ray diffraction for the identification of the formation of intermetallic. A 2θ range of 10˚ - 80˚ is maintained during XRD analysis for all the samples. Primary peaks are identified in the result of the XRD procured. Fig 21-24 gives XRD of the base metal, reinforced samples and the powdered form of aloe vera. XRD help us to understand weather the objective of achieving a composite by adding additive and matrix is achieved or not. XRD results establishes a fact that additives and the matrix retained their identity without forming any intermetallic bonds thus producing a composite as desired with the depiction of clear peaks (Vedabouriswaran, G., & Aravindan, S., 2019).

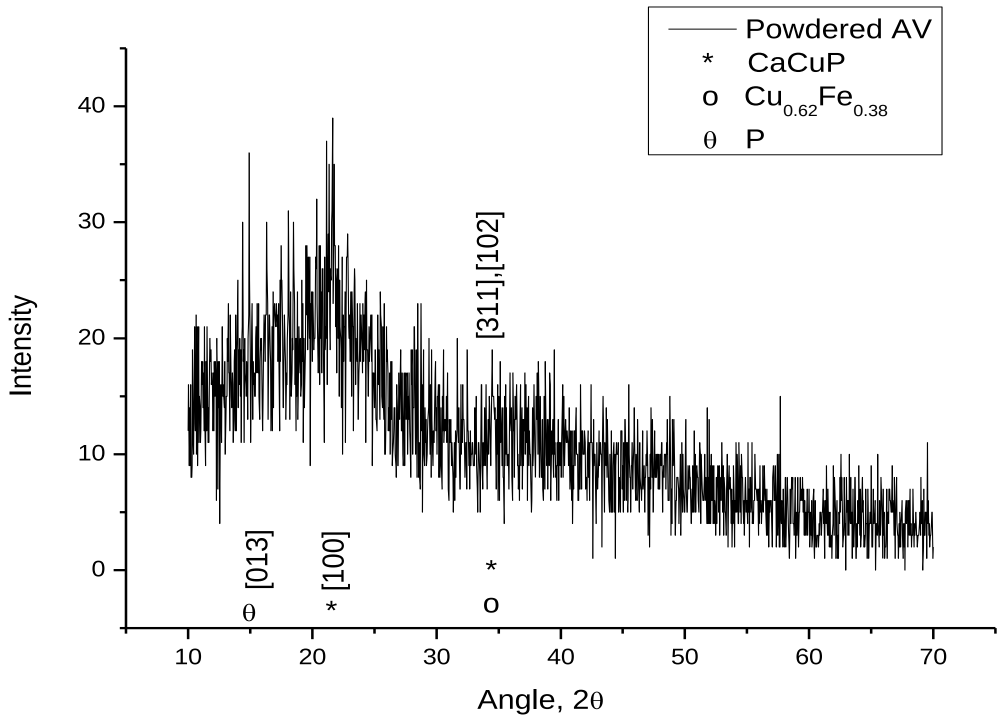

Fig. 11 XRD pattern of Aloe vera Powder

Fig. 11 is the XRD analysis of powdered aloe vera used in this study. The analysis shows the presence of elements such as calcium, iron, phosphorous which are similar to the chemical composition given by T.Mulu et al., 2015.

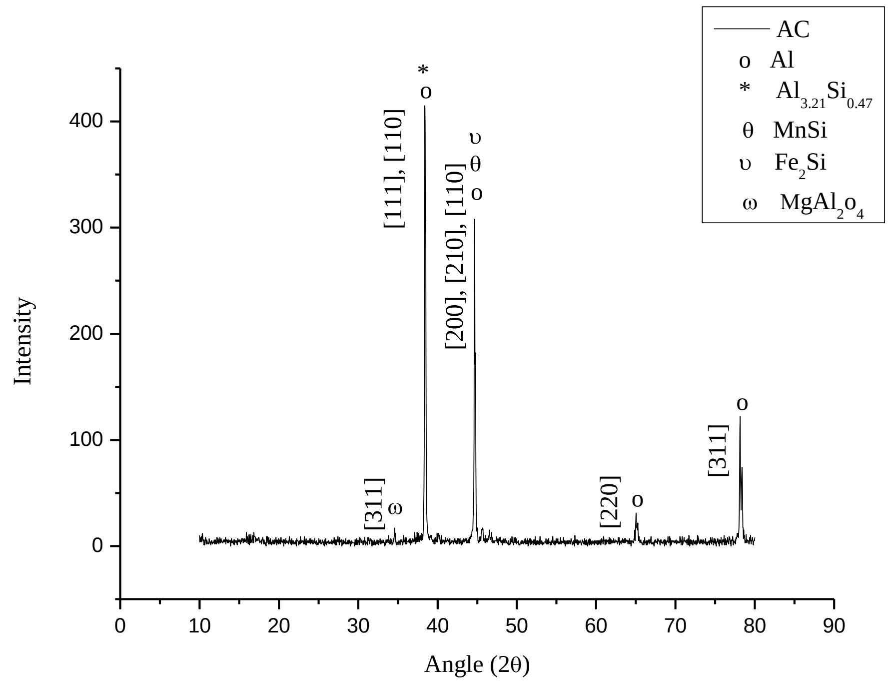

Fig. 12 XRD pattern of Stir Casted AA6061

There are four peaks in Fig. 12 is analysis by XRD which is clearly showing aluminium as the majority element and followed by very little composition of Si, Mg and Fe. These elements are similar to the elements present in the chemical spectroscopy of the base metal.

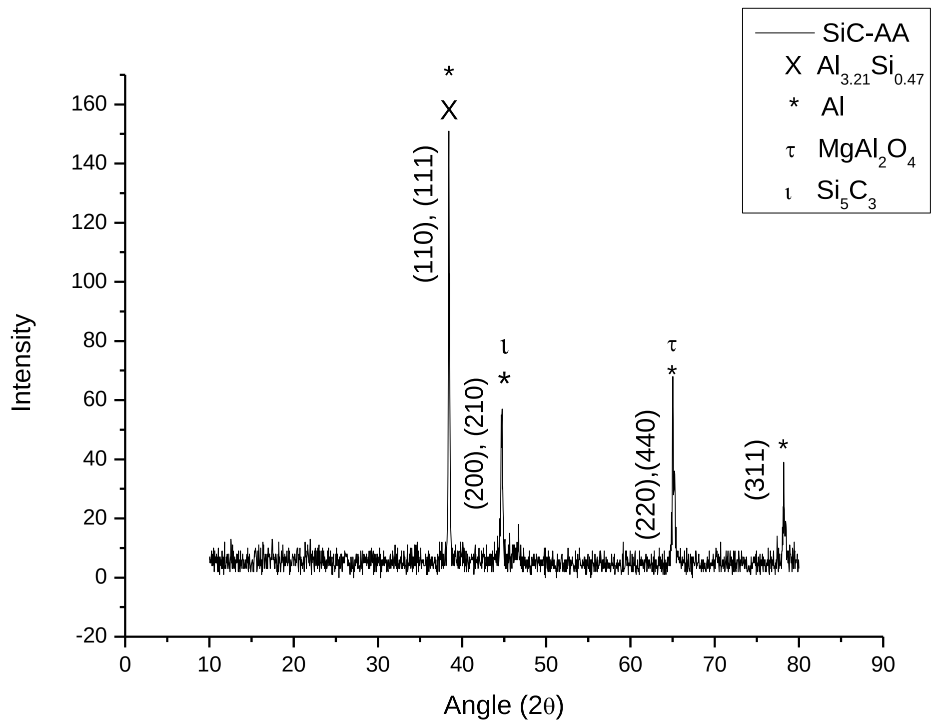

Fig. 13 XRD pattern of SiC-AA composite

Elements appearing in the XRD analysis of SiC reinforced metal matrix composite in Fig. 13 are similar to the results published by Nieh, T.G.,1984. The paper also shows a presence of magnesium, silicon carbide in the AA6061 matrix reinforced by SiC. Silicon carbide composition can be observed at a peak on 44 degree.

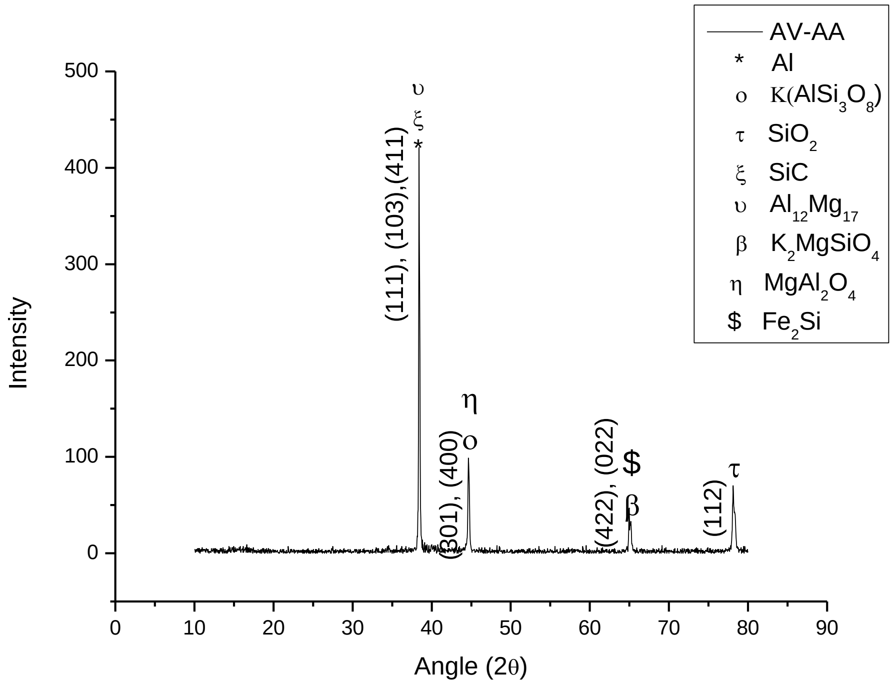

Fig. 14 XRD pattern of AV-AA composite

The chemical composition as observed by T.Mulu et al., 2015 in their paper can be observed in this XRD plot. All the peaks are showing the intensity of the constituents which is supporting the existence of aloe vera along with SiC in the composite prepared by stir casting with aluminium as its base metal

4.2 Field Emission Scanning Electron Microscopy

The FESEM images obtained are governed by number of independent parameters such as electron accelerating voltage, working distance and also (sometimes) the aperture of the objective lens. All these parameters have the potential to influence performance of the FESEM images. The accelerating voltage determine the kinetic energy of the primary electron, controlling the depth of penetration of the electron beam thus effecting the backscatter electron images. The accelerating voltage also has effect on the transparency of the secondary electron images. On reducing the accelerating voltage below 1kV only surface features can be observed and no in-depth information can be gathered. Aperture plays a role in the controlling the spherical aberration (Egerton, R. F.,2005).

FESEM help us examine the morphology, particle size and microstructure. It is done with the help of FEI Quanta 200F in IIT Delhi. The images of the processed samples are taken under suitable accelerating voltage, with constant working distance, with the help of secondary electrons to get an image with best resolution possible.

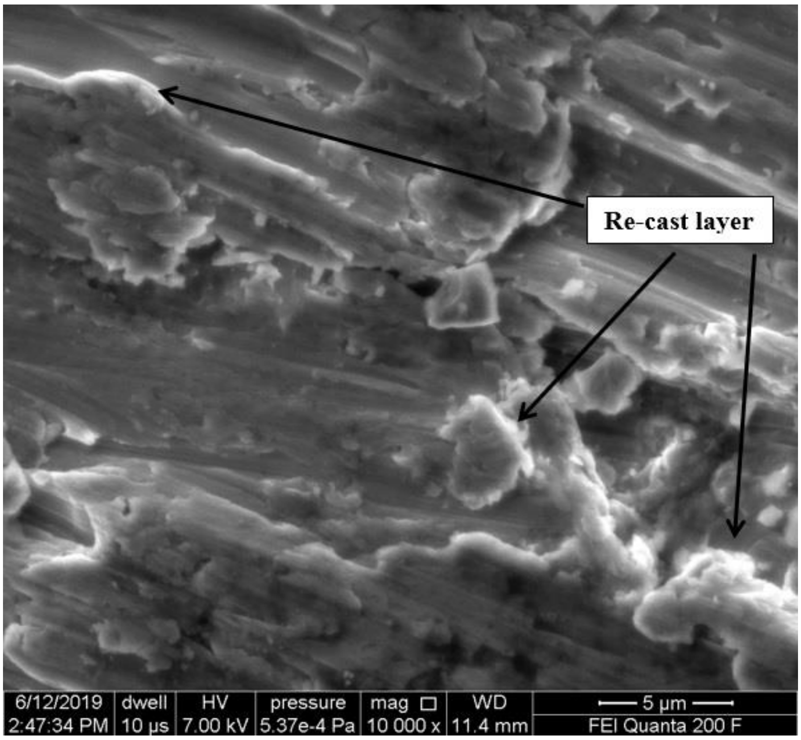

Fig. 15 As Casted AA6061

When the aluminium is solidified in the furnace there is a formation of a new layer onto the aluminium surface which is due to the formation aluminium oxide on the surface of the solidified casting. This new solidified layer is clearly visible in the SEM image (Fig 15)

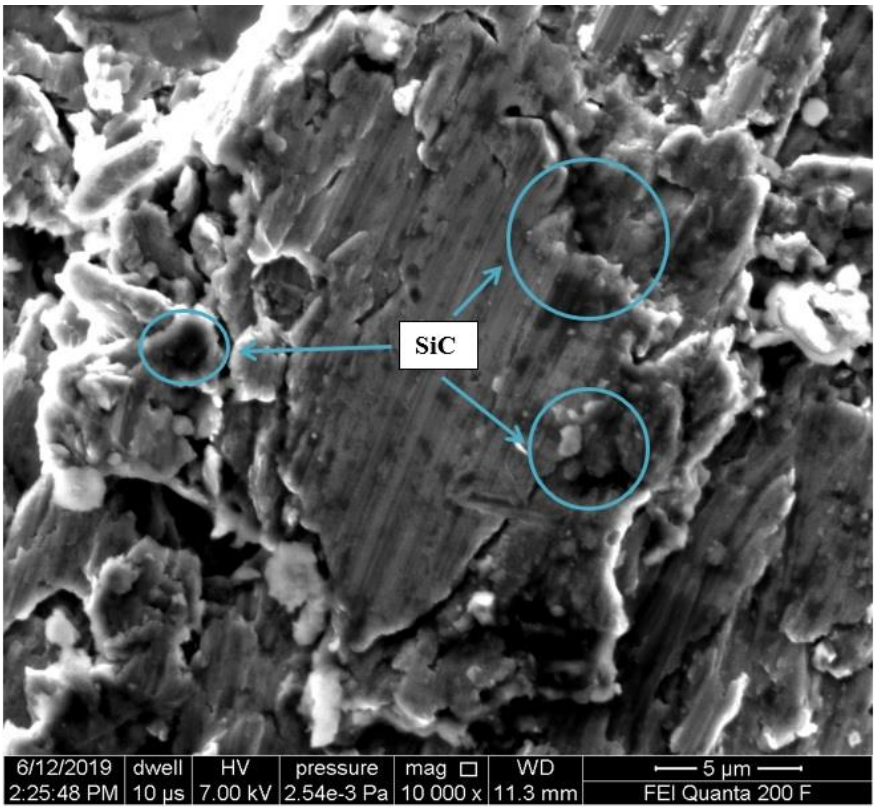

Fig. 16 SiC-AA composite

SiC particles can be observed in the FESEM image in Fig. 16. These are the small black mark on the base matrix. The similar kind of black spots were observed on the base metal matrix in a paper by Das, S. et al. (2018) in which a study is conducted on SiC reinforced with AA6061. Al-Rubaie et al. (1999) also shows SiC in SEM images as small black spots on the base metal.

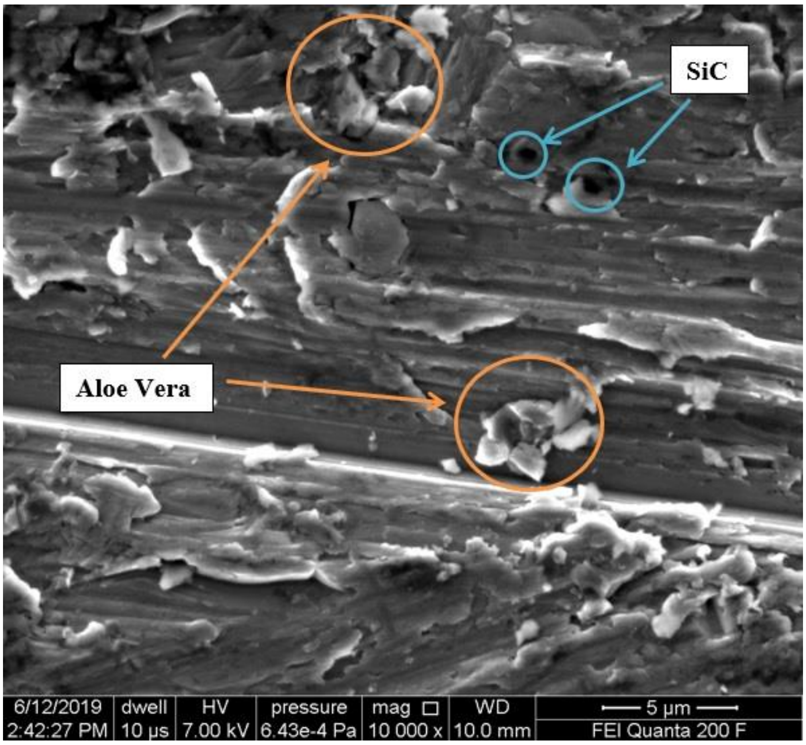

Fig. 17 AV-AA composite

Fig. 17 depicts the presence of both aloe vera and SiC in the base matrix. SiC can be easily spotted as the small black entity on the base metal. Aloe vera is also marked in the fig. 26, it pattern is similar to the one shown by Gieesh et al. 2018, in their published paper.

CHAPTER 5: MECHANICAL AND TRIBOLOGICAL PROPERTIES

This chapter concerns with finding the mechanical and tribological behaviour of composite prepared by adding natural and synthetic reinforcements with the help of stir casting method.

5.1 Microhardness Properties

The microhardness analysis is done by FISCHERSCOPE HM2000 S (Fig. 18) at room temperature with at least six indentation of each sample and then the average values were utilized to calculate hardness number. The indenter penetrates the specimen using a load of 300.000mN/20s with the dwell time of 5 seconds. During this process, the indentation depth is measured continuously (Fisher, 2004).

Fig. 18 Microhardness Tester

Aluminium AA6061 used as base metal in this experiment is showing a hardness of 87.12 HV. For experimentation, six hardness values were recorded at six different points and then an average was calculated form the readings. Table 8 below shows the microhardness results of stir casted aluminium alloy composite. Microhardness test result clearly depicts an increase in the composite hardness in the presence of the SiC particles, in sample 2. Equal weight percentage of SiC and aloe vera, in sample 3, also show considerable increase in the hardness even though it is not able to mimic the hardness results precured by sample 2.

The hardness added to the sample of reinforcement can be attributed to the fact that due to change in the value of thermal expansion coefficient for SiC particle and aluminium alloy 6061, strain fields are formed around SiC particles when the solidification of the composite melt happens. The strain fields pie up dislocation. The propagating cracks during tensile loading encounter resistance due to interaction between dislocation and SiC particle (J.Jebeen Moses et al., 2014). Therefore, microhardness properties and tensile strength properties of the SiC reinforced aluminium-based matrix are showing improved results.

Table 6: Mechanical properties of stir casted AA composite

	Vickers Hardness (HV)	UTM (MPa)	Elongation (%)
Base Metal (AA6061)	87.12	139	7.33
SiC-AA composite	116.74	181	6.45
AV-AA composite	109.31	175	6.37

5.2 Tensile Properties

The tensile test was performed on UTM. In a tensile test, a sample prepared by wire EDM is carefully loaded, the load applied and elongation of the loaded sample are measured in a very controlled manner. The major output out of the tensile test is a Load vs Elongation curve, this information with little alteration is transformed into stress vs strain curve. The achieved curve is very specific to a material, as the curve gives a relation between the applied stress and the corresponding resulting strain in the sample. The sample subjected to the machine for the tensile test are loaded until they break down as shown in Fig. 18(a),(b),(c). Three tensile dog bone type sample were prepared from each composite sample and subjected to a pulling force at a speed of 1mm/min for the composite sample and 2.5 mm/min for the as casted sample. The average of the results for percentage elongations and ultimate tensile test were taken for each composite sample, respectively.

(a) Before Test

(b) After Test

(i): Tensile Test Specimen of As Casted AA6061 (a) Before Test (b) After Test

(a) Before Test

(b) After Test

(ii)Tensile Test Specimen of AA6061-SiC alloy (a) Before Test (b) After Test

(a) Before Test

(b) After Test

(iii) Tensile test Specimen of Al6061-SiC-Natural reinforcement (a) before test (b) after test

Fig. 19 Tensile test specimen of (i) As Cast AA6061 (ii) AA6061-SiC alloy (iii) AA6061-SiC-natural reinforcement

A stress-strain curves from the tensile test are formed for the composite samples as shown in Fig. 20. Table 06 depicts results of hardness and tensile test of stir casted aluminium composites. The tensile strength properties of the composite are recorded higher than the base metal, though the percentage elongation of the base metal is observed to be maximum among all the composite prepared. SiC reinforced composite sample has shown maximum value of 181 MPa and addition of Aloe Vera has also recorded considerable increase in the material strength. Though it is evident from the graph that there is noticeable fall in the percentage elongation due to the addition of the additives.

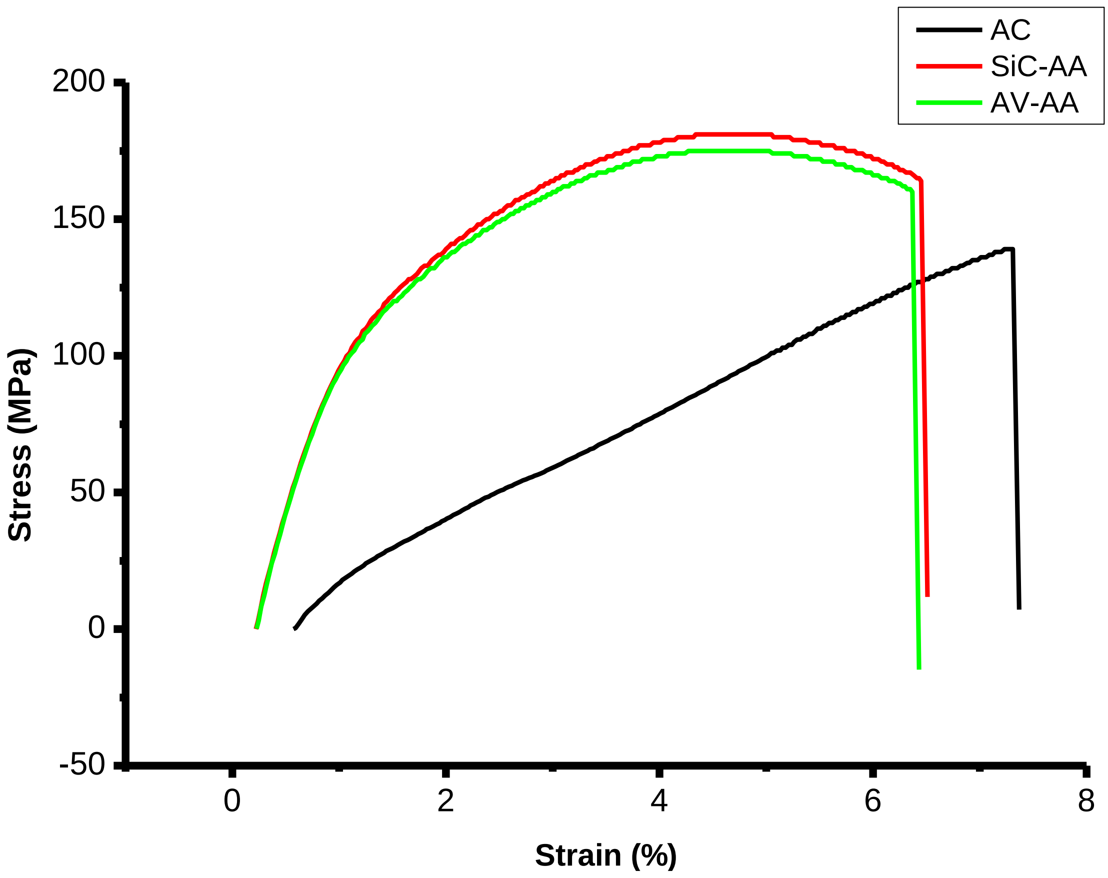

Fig. 20 Stress- strain Curves of composite specimen

The resulted increase of ultimate tensile strength in aluminium composite can be credited to the transfer of applied tension load to the strongly bonded SiC reinforcements in aluminium based composite. With the increase in the dislocation density near the interface of metal matrix-reinforcement and grain refining results in strengthening effect. The crack propagation, in composite with additive in the matrix, has to cross both the matrix and additive. Which in turn results into stronger interfacial bond thus enhancing the tensile strength (Rahman, M. H., & Al Rashed, H. M., 2014)

5.3 Wear Properties

The wear test was done by sliding the sample in dry condition using a High Temperature Tribometer (DUCOM). The conditions for the test were arranged according to ASTM G99 standard. The setup used for the wear test is shown in the Fig. 21. The cylindrical pin wear sample was tested against a hardened disc made of EN-31 steel. The disc's hardness is maintained around 55-58 HRC, with surface roughness (Ra) of 0.2µm. the sliding speed of the sample on the disc was kept constant at 1m/s with the load on the pin being managed from 20N to 40N, the distance of sliding was kept in incremental form of 50m i.e. starting from 50m to 3000m.

Fig. 21 High Temperature Rotary Tribometer

Fig. 22 shows the arrangement of the experiment. The tip of pin to be in contact was polished using an emery paper of grit size of 1600 then the sample and the disc was cleaned using an acetone once before the test and once after the proper sliding distance was completed. The pin sample procured for the test were weighed to an accuracy of 0.01mg with the help of precision electronic weighing balance. To ensure repeatability and reproducibility all the test was performed three times. The coefficient of friction that is recorded between the hardened disc and under study sample was measured with the help of recorded frictional force and the applied load.

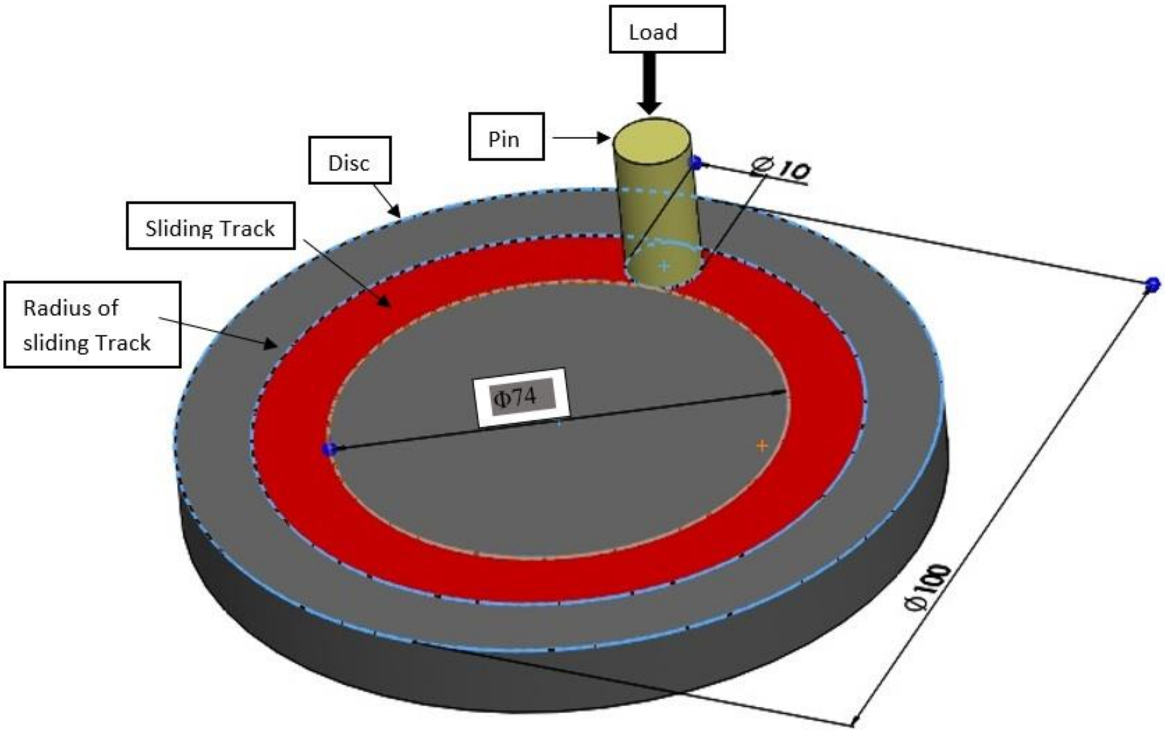

Fig. 22 Pin on disc diagram

Fig. 23 shows the effect of reinforcement particles on microhardness and wear rate used in making composite compound. SiC-AA composite provides highest hardness when compared to another composite and base metal. It can be inferred from the readings that hardness of AV-AA composite is considerably lower as compared to SiC-AA composite, but it is showing enhanced wear resistance then the SiC-AA matrix which can be observed in the reduced wear rate trend in Fig 23.

The properties of aluminium reinforced composite depend upon number of attributes such as shape of reinforcement, size of reinforcement and the distribution of the additives in the base alloy matrix chosen. The presence of hard additive particles in the prepared samples of composites, behave like the load bearing members thus resulting in the enhancement in wear resistance and also shows greater hardness then the base matrix They result in greater resistance in the cutting action in the specimen prepared for wear measurement, hence lower metal removal therefore lower wear rate (Yuvaraj, N., & Aravindan, S., 2016). This results in composites containing higher percentage of SiC particles exhibiting lower wear rate in comparison to the composite with lower weight percentage or no additives.

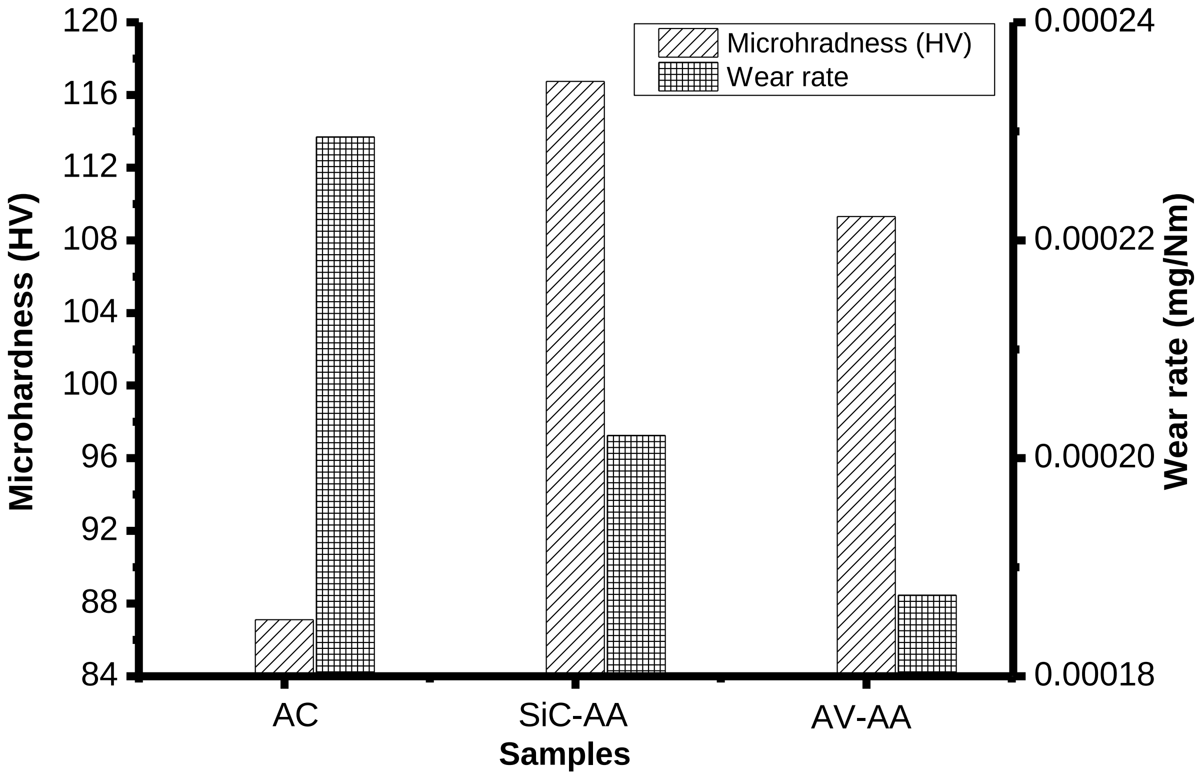

Fig. 23 Microhardness and wear rate at a sliding load of 20N

5.3.1 Wear rate

According to the experiments conducted the wear rates observed for the base material and AA composite are attached below in Fig. 24. This reveals that the wear resistance of the composite sample has improved significantly with addition of the reinforcement particles. The difference in deduced wear rate of the specimen is more clearly visible thus indicating that the Aloe Vera reinforcement is working as a useful additive in reducing the wear loss of the metal.

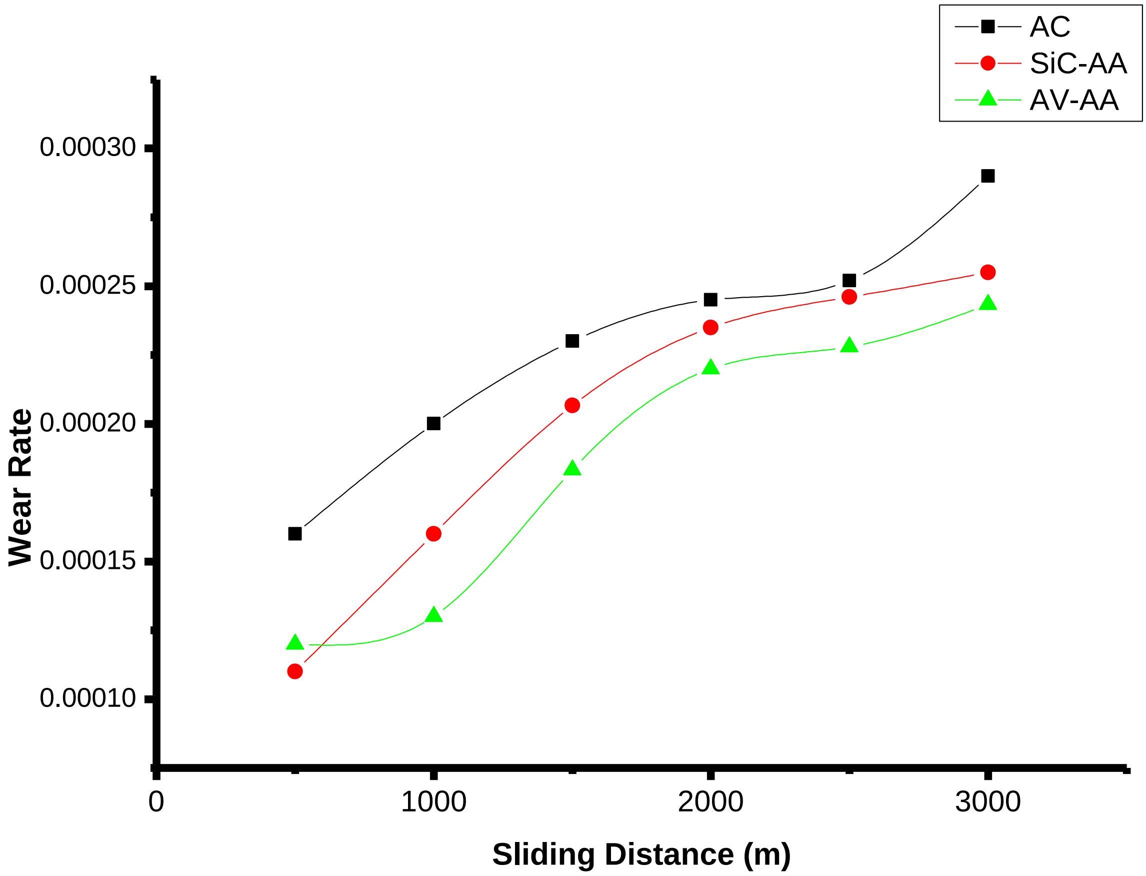

Fig. 24 Effect of Sliding distance on wear rate of AA6061

Table 7. Wear Properties of composite sample

Wear Properties	AC	SiC-AA	AV-AA
Wear Rate (10^{-3}g N^{-1} m^{-1})	0.0002295	0.000202111	0.000187444
Coefficient of friction	0.242	0.302	0.284

5.3.2 Coefficient of Friction

It is observed from the results that the coefficients of friction in the composite sample are higher than those recorded in the base matrix. This is due to abrasive wear mechanism. This deduction is inclined to the fact that the steel disc surface on which the pin is sliding is having higher hardness then the sample sliding over it, scratching of the softer sample will happen, hence wear is observed. Average coefficient of friction for the base metal sample is 0.242 which is lower than the sample of composite as SiC as additives which depicted a coefficient of friction to be 0.302. Addition of Aloe vera in the composite has leads to considerable reduction in friction of the sample thus resulting in 0.282 as the COF. Fig. 25 shows the coefficient of friction along with the sliding distance.

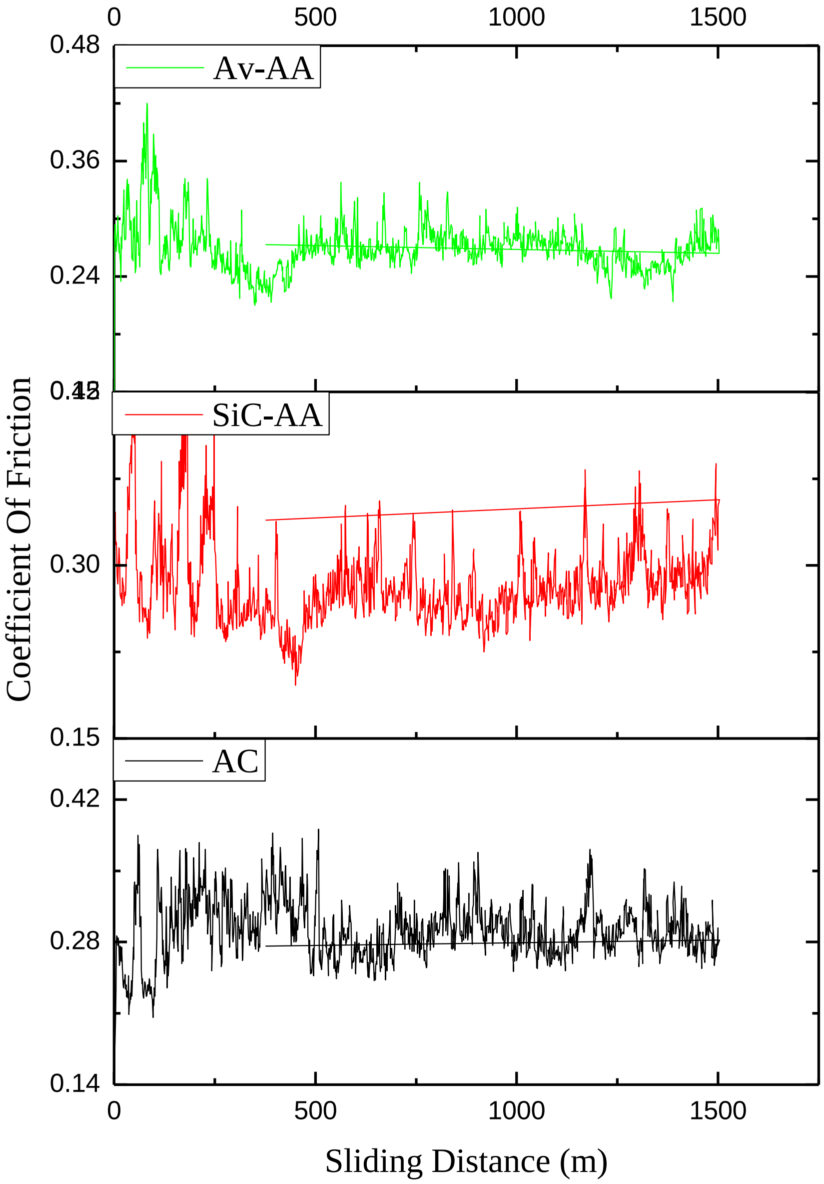

Fig. 25 COF graph of composite at 20N load and 1m/s sliding velocity

CHAPTER 6: CONCLUSION & SCOPE FOR FUTURE WORK

AA6061 with SiC and aloe vera powder Particle composite was successfully prepared using the Stir Casting process. Effect of additives on the tensile, microhardness and wear properties of the surface composite produced was investigated by performing various tests on the sample. Following were the major findings:

(a) Casted Aluminium exhibited increased tensile strength up to 181MPa with SiC particle and tensile strength increased to 175 MPa when fabricated with both SiC and Aloe Vera powdered particles compared to 139 MPa for the parent metal.

(b) SiC composed composite has shown 30.2% increase from the base metal whereas aloe vera composed composite also has shown considerable improvement of 25.89 % from the base matrix.

(c) Elongation has reduced by the addition of reinforcement into the matrix, maximum reduction is observed in the case of mono reinforcement i.e. SiC, sample 2.

(d) Casted aluminium has shown reduced wear rate of 0.000202 mg/Nm with SiC additives for sample 2, wear rate with the addition of aloe vera and SiC as additives has shown wear rate of 0.0001874 mg/Nm for sample 3 as compared to wear rate of 0.0002295 mg/Nm for the casted AA6061 base sample. The addition of reinforcement was successful to reduce the wear for base metal by 2.73×10^{-5} mg/Nm & $4.205\times10^{-5,}$ respectively, for sample 2 and 3.

(e) Both Microhardness and Tensile strength increasing with the addition of Reinforcement in the parent metal and wear rate is decreasing with increase in hardness.

(f) XRD analysis helped to recognize the results as composite with no intermetallic bonds.

On the thorough scrutiny of the published work on the Aluminium matrix composite, the following observations have been made:

1. Researches on the sidelines of using ultrasonic stirrer which can contribute to improving particulate distribution in nano-particles reinforced aluminum metal matrix composites can be a step-in right direction.

2. Sufficient efforts have not been undertaken towards the improvement of Metal Matrix Composite Using natural reinforcements in nano-particulate form.

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