International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Research Article

Preparation of Aluminium Matrix Composite by using Stir Casting Method & it's Characterization

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Accepted 12 March 2014, Available online 01 April 2014, **Special Issue-3, (April 2014)**

Abstract

Driven by energy conservation and environment protection, modern engine are require to have higher power capacity accompanied by reduction in fuel consumption. Now day's engines are more often operated at high speed and high temperature. Consequently all new engine development should meet stringent emission regulation. Therefore engine and engine components are require to be tighter and lighter with minimum intertie force. Therefore need arises to develop new material which will satisfy the requirement of modern engine. In present study we aim to manufacture composite material by reinforcing Al alloy with SiC, Al_2O_3, and graphite particles. The wetability between all these materials is assured by stir casting process. The fabricated composite material is tested for its mechanical, metallurgical and tribological properties. The properties of fabricated material are much superior to the base matrix Al alloy.

Keywords: *Stir casting process, aluminium matrix composite, mechanical & tribological testing.*

1. Introduction

Now days the need of advanced engineering materials for various engineering applications goes on increasing. To meet such demands metal matrix composite is one of reliable source. In composites materials are combined in such a way as to enable us to make better use of their parent material properties while minimizing to some extent the effects of their deficiencies. In the past few years, materials development has shifted from monolithic to composite materials for adjusting to the global need for reduced weight, specific strength and high performance in structural materials. Driving force for the utilization of AMCs in areas of aerospace and automotive industries include performance, economic and environmental benefits.

In AMC one of the constituent is aluminium, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminium and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC, Al_2O_3 etc. These advantages can be used to achieve better properties. For example, elastic modulus of pure aluminium can be enhanced from 70GPa to 240GPa by reinforcing with 60 vol% continuous carbon fiber. On the other hand incorporation of 60 vol% alumina fiber in pure aluminium leads to decrease in the coefficient of expansion from 24 ppm/°C to 7 ppm/°C. Similarly it is possible to process Al-9% Si-20 vol% SiCp composites having wear resistance equivalent or better than that of grey cast iron (Surappa, et al, 2003) these examples illustrate that it is possible to alter several physical properties of aluminium or aluminium alloy by adding two or three appropriate reinforcement in suitable volume fraction.

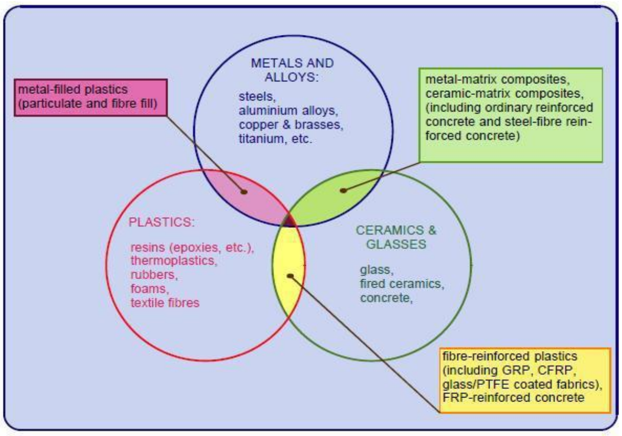

Fig. 1 Composite material

In AMC one of the constituent is aluminium, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminium and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC, Al_2O_3 etc. These advantages can be used to achieve better properties. For example, elastic modulus of pure aluminium can be

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enhanced from 70GPa to 240GPa by reinforcing with 60 vol. % continuous carbon fiber. On the other hand incorporation of 60 vol% alumina fiber in pure aluminium leads to decrease in the coefficient of expansion from 24 ppm/°C to 7 ppm/°C. Similarly it is possible to process Al-9% Si-20 vol% SiCp composites having wear resistance equivalent or better than that of grey cast iron (Surappa, et al, 2003). All these examples illustrate that it is possible to alter several physical properties of aluminium or aluminium alloy by adding two or three appropriate reinforcement in suitable volume fraction.

Reinforcing the matrix with whiskers, short fibers or particulates of ceramics could give a composite and improved properties compared to monolithic base alloy. Further, the attractive feature is the isotropic nature of the properties. Even though the property improvements are not as high as those achievable with continuous fiber ones, they are sufficiently attractive enough for most of the intended engineering applications.

The commonly used reinforcement is silicon carbide particulates (SiCp) in cast alloy matrix (modified compositions of 356 and 357 Al alloys) and alumina particulates in wrought alloy matrix (6061/2024). Even though the possibilities of using different kinds of reinforcement in Al alloys as reinforcements, except SiCp and $A1_20_3$ others have not shown any commercial potential (Pai, et al, 2001).

Jokhio, Panhwar & Mukhtiar Ali investigate the effect of elemental metal such as Cu-Zn-Mg in aluminium matrix on mechanical properties of stir casting of aluminium composite materials reinforced with alpha Al_2O_3 particles using stir casting they found increase in tensile strength. Also they found that Mg has pronounced effect on aluminium cast composites up to 2.77% Mg contents which increases wetability, reduces porosity and develops very good bonding with Al_2O_3 (Jokhio, et al, 2001).

Preparation and characterization of aluminium metal matrix composites reinforced with aluminium nitride was carried out by M. N. Wahab, A. R. Daud and M. J. Ghazali they found considerable significant increase in hardness of the alloy matrix (Wahab, et al, 2009).Cast A356/SiCp composites were produced using a conventional stir casting technique by S. Tzamtzis, N. S. Barekar, N. Hari Babu, J. Patel, B. K. Dhindaw they found a good combination of improved Ultimate Tensile Strength(UTS) and tensile elongation is obtained (Sozhamannan, et al, 2003).Experiments have been conducted by varying weight fraction of SiC, graphite by Dunia Abdul Saheb and they found that an increasing of hardness and with increase in weight percentage of ceramic materials (Saheb, et al, 2011)

Among the variety of manufacturing processes available for discontinuous metal matrix composites, stir casting is generally accepted as a particularly promising route, currently practiced commercially. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product.

2. Objective of the paper

The main purpose of this paper is to manufacture the particulate aluminium metal matrix composite (PAMC) with varying compositions of reinforcement particles of graphite, Al_2O_3 and SiC by using stir casting method. Testing of PAMC material to carried out to evaluate its mechanical and tribological properties.

2.1. Matrix

Aluminium alloy 2000, 6000 and 7000 series are used for fabrication of the automotive part. PAMC under study consist of matrix material of aluminium alloy Al6061 whose chemical composition is shown in the Table 1. An advantage of using aluminium as matrix material is its casting technology is well established, and most important it is light weight material. Aluminium alloy is associated with some disadvantages such as bonding is more challenging than steel, low strength than steel and price is 200% of that of steel. But with proper reinforcement and treatment the strength can be increased to required level.

Table1. Chemical composition of Al (6061)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4-0.8	0.0-0.7	0.15-0.4	0-0.15	0.8-1.2	0.04-0.35	0.0-0.25	0.0-0.15	Bal

2.2 Reinforcement

Table 2. Properties of Matrix and Reinforcement

Property	Unit	Al(6061)	Al_2O_3	SiC	Graphite
Density (at 20°C)	g/cm^3	2.7	3.97	3.22	2.09–2.23
Melting point	°C	650	2,288	2973	3915
Coefficient of thermal expansion	µm/m°C	23.4	7.1	4	2.0-6.0
Thermal conductivity	W/mK	166	35.6	126	85
Young's modulus	GPa	70	370	410	10

Particles of Al_2O_3, SiC and graphite of mesh size 320 are used as reinforcement.

SiC:-Silicon carbide particulates have attained a prime position among the various PAMC. This is due to the fact that introduction of SiC to the aluminium matrix substantially enhances the strength, the modulus, the abrasive wear resistance and thermal stability. The density of SiC (3.2g/cm_3) is nearer to that of aluminium alloy Al 6061 (2.7g/cm_3). The resistance of SiC to acids, alkalis or molten salts up to 800_0 C makes it a good reinforcement candidate for aluminium based MMC. Addition of Silicon carbide particle results in excellent mechanical properties this produces a very hard and strong material.

Alumina (Al_2O_3): - Addition of alumina particle has shown increase in tensile strength and it has good compatibility with aluminium alloy.

Graphite:- Addition of graphite particle results in low friction of composite as it is good dry lubricant hence reduces wear and abrasion.

Initially, aim of the study was to decide optimum combination of the reinforcements in the matrix for best tribological and mechanical properties. From previous study different combinations of reinforcements are prepared as shown in Table. 3

Table.3 PAMC Combination

PAMC No.	Al_2O_3	SiC	Graphite	Mg	Al	Total reinforcement
1	1	3	0	1	95	5
2	1	3	4	1	91	9
3	2.5	5	4	1	87.5	12.5
4	4	7	4	1	84	16
5	2.5	5	0	1	91.5	8.5
6	2.5	5	2.5	1	89	11
7	2.5	5	6	1	85.5	14.5
8	4	7	0	1	88	12
9	4	7	4	1	84	16
10	4	7	6	1	82	18

3. Experimental setup and procedure

The experimental setup consist of conical shaped graphite crucible for melting of aluminium alloy, as it withstands high temperature up to [2400°C]. This crucible is placed in muffle made up of high ceramic alumina around which heating element is wound. The coil which acts as heating element is Kanthol-A1. This type of furnace is known as resistance heating furnace. It can reach the temperature of 900°C within 45 minute. Aluminium, at liquid stage is very reactive with atmospheric oxygen. Oxide formation occurs when it comes in contact with the open air.

Fig. 2 Stir cast apparatus

Therefore all the process of stirring is carried out in closed chamber with nitrogen gas as inert gas in order to avoid oxidation. Closed chamber is formed with help of steel sheet. K type Temperature thermocouple whose working range is -200°C to 1250°C is used to record the current temperature of the liquid. Due to corrosion resistance to atmosphere EN 24 is selected as stirrer shaft material. One end of shaft is connected to 0.5 HP PMDC motor with flange coupling. While at the other end blades are welded. 4 blades are welded to the shaft at 45°C. Blades are made up of SS316 in order to stir reinforcement like SiC. It also consists of perment mould of CI for pouring molten metal.

3.1 Procedure

Graphite crucible is placed in muffle. At first heater temperature is set to 500°C and then it is gradually increased up to 900°C. Aluminium alloy is cleaned to remove impurities, weighed and then kept in the crucible for melting. Nitrogen gas is used as inert gas to avoid oxidation. Pure magnesium powder is used 1% by weight as wetting agent. Required quantities of reinforcement powder and magnesium powder are weighed thoroughly mixed with the help of blending machine for 24 hour.

Reinforcements are preheated for half hour and at temperature of 500°C. When matrix was in the fully molten condition, stirring is started after 2 minutes. Stirrer rpm is gradually increased from 0 to 300 RPM with the help of speed controller. Temperature of the heater is set to 630°C which is below the melting temperature of the matrix. A uniform semisolid stage of the molten matrix was achieved by stirring it at 630°C. Pouring of preheated reinforcements at the semisolid stage of the matrix enhance the wetability of the reinforcement, reduces the particle settling at the bottom of the crucible (Hashim, et al, 2001). The flow rate of reinforcements measured was 0.5 gram per second. Dispersion time was taken as 5 minutes. After stirring 5 minutes at semisolid stage slurry was reheated and hold at a temperature 900°C to make sure slurry was fully liquid. Composite slurry is poured in the metallic mould. Mould is preheated at temperature 500°C before pouring of the molten slurry in the mould.

Fig. 3 Test Specimen

4. Result

We had successfully manufactured PAMC by using stir cast apparatus. We come to know that process parameter is playing a major role for uniform distribution of reinforcement. In order to determine its mechanical and tribological properties we had conducted some test and its result are illustrated as follows.

4.1Testing the Tribological Properties

For suitability of the present PAMC as IC engine component material tribological properties are most important. Tribological properties such as wear rate and coefficient of friction between PAMC and steel were determined. Thus test of fabricated PAMC was conducted on Pin on disc machine. Figure 4 represents one of the test results showing variation of the average coefficient of friction of the PAMC with time. Time for test is plotted along horizontal axis. Average coefficient of friction is plotted on the vertical axis.

Figure 5 represents one of the test results, showing variation of the average wear rate of the PAMC with time. Time for test is plotted along horizontal axis. Average wear rate is plotted on the vertical axis. Unit of the wear rate is mm^3/Nm. Table 4 represents the value of the average coefficient of friction and wear rate for test conducted at two different sliding velocities.

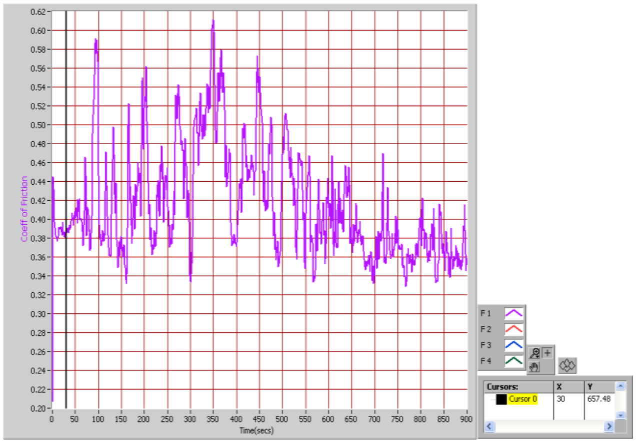

Fig. 4 Coefficient of friction Vs Time for PAMC

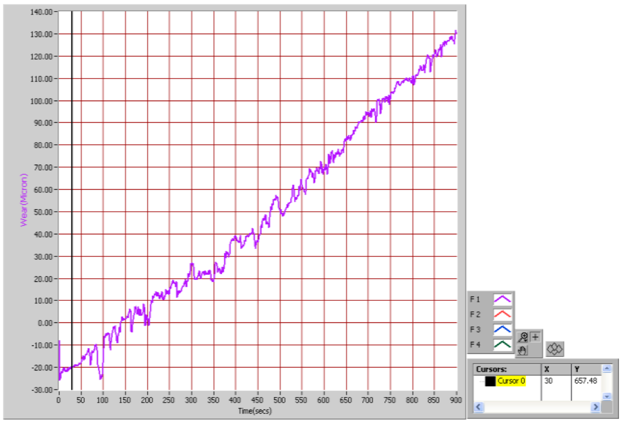

Fig. 5 Wear Vs Time for PAMC

Figure 6 represents test analysis data in which we directly get reading for the operating parameter like test speed, load applied, pin dia, track radius. Also we get information about average wear rate, sliding distances, sliding velocity and average COF of PAMC specimen.

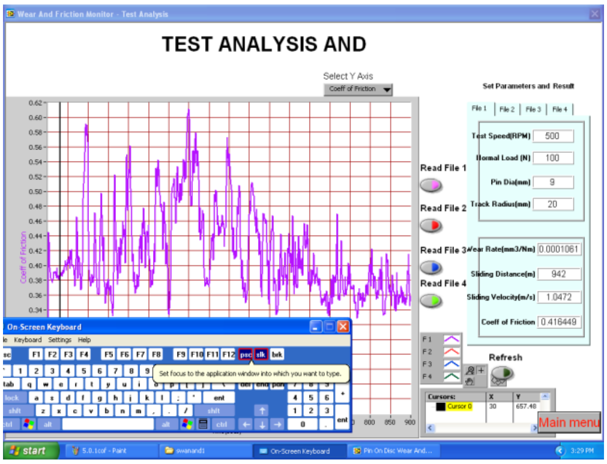

Fig. 6 Test Analysis of PAMC

Table.4 Coefficient of friction and wear rate of PAMC

PAMC	Sliding Velocity 1.0446 m/sec		Sliding Velocity 1.832 m/sec	
	COF	Wear rate mm^3/Nm	COF	Wear rate mm^3/Nm
Al 6061	0.384621	0.0002473	0.394612	0.0001982
PAMC 1	0.333117	0.0001221	0.347515	0.0000482
PAMC 2	0.330234	0.0000764	0.339172	0.0001067
PAMC 3	0.324812	0.0001439	0.3597	0.0001212
PAMC 4	0.344132	0.0000982	0.3382	0.0000771
PAMC 5	0.39214	0.0001012	0.402614	0.000167
PAMC 6	0.336874	0.0001588	0.352246	0.0000557
PAMC 7	0.316425	0.0001061	0.421462	0.0001121
PAMC 8	0.402431	0.0000989	0.413612	0.000152
PAMC 9	0.373012	0.0003588	0.394232	0.000168
PAMC 10	0.337851	0.0000897	0.346415	0.0001146

4.1.1 Effect of increasing percentage Graphite on the Coefficient of Friction

The graph shown in the Figure 7, 8, 9 and 10 represents variation of coefficient of friction of the PAMC with change in percentage of the graphite in as cast conditions. Percentage of reinforcement is plotted on horizontal axis. Coefficient of friction is plotted along vertical axis.

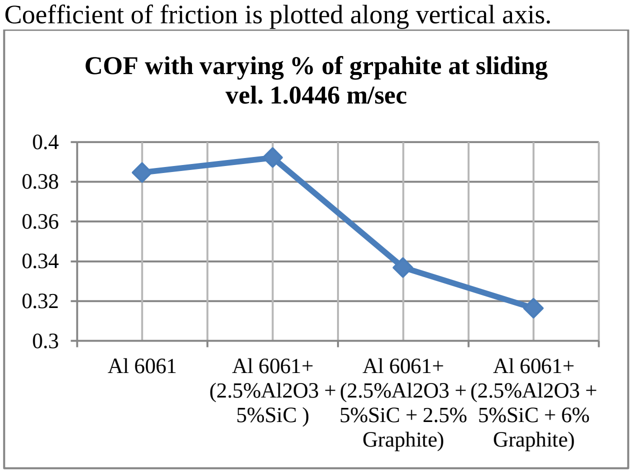

Fig. 7 COF with varying % of graphite at sliding vel. 1.0446 m/sec

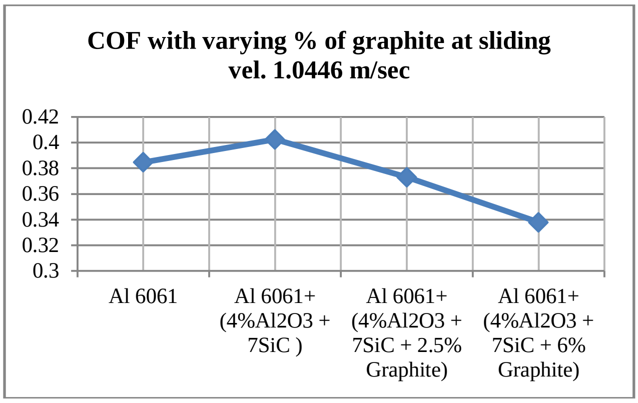

Fig. 8 COF with varying % of graphite at sliding vel. 1.0446 m/sec

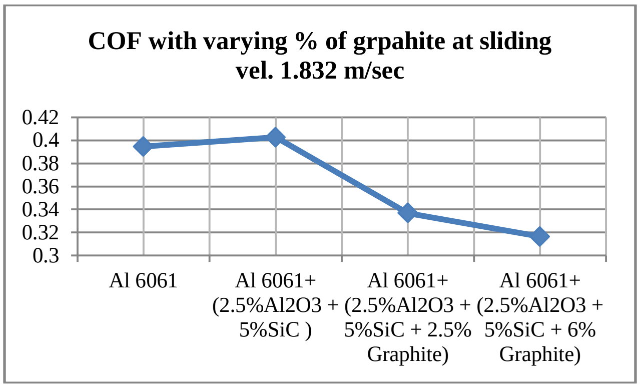

Fig. 9 COF with varying % of graphite at sliding vel. 1.832m/sec

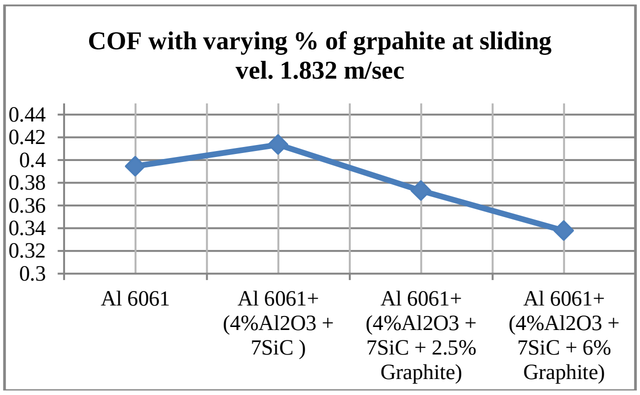

Fig. 10 COF with varying % of graphite at sliding vel. 1.832m/se

Matrix alloy Al6061 has coefficient of friction 0.384621. Coefficient of friction of PAMC decreases with increase in the percentage of graphite reinforcement. The least value of coefficient of friction noted is 0.316425. This value corresponds to PAMC (Al 6061+ (2.5%Al_2O_3 + 5%SiC + 6% Graphite).

Initially SiC reinforcement increases COF to its hard nature. Coefficient of friction of PAMC decreases with increase in the percentage of graphite reinforcement. Graphite acts as solid surface lubricant, which results in reduction of the coefficient of friction between pin made of PAMC and disc made of steel.

4.12 Effect of Increasing Graphite Concentration on the Wear Rate

The graph shown in Figure 11, 12 and 13 represents the wear rate of the PAMC for increasing concentration of the graphite in as cast conditions. Percentage of reinforcement is plotted on horizontal axis.

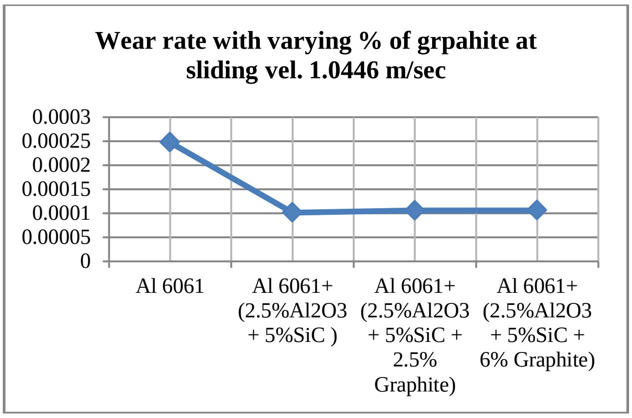

Fig. 11 wear rate with varying % of graphite at sliding vel. 1.0446 m/sec

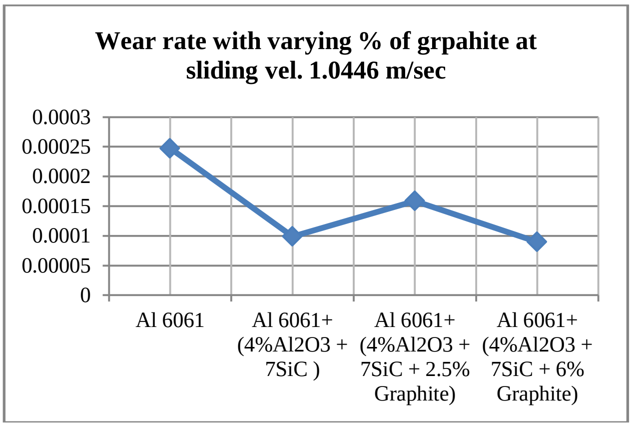

Fig. 12 wear rate with varying % of graphite at sliding vel. 1.0446 m/sec

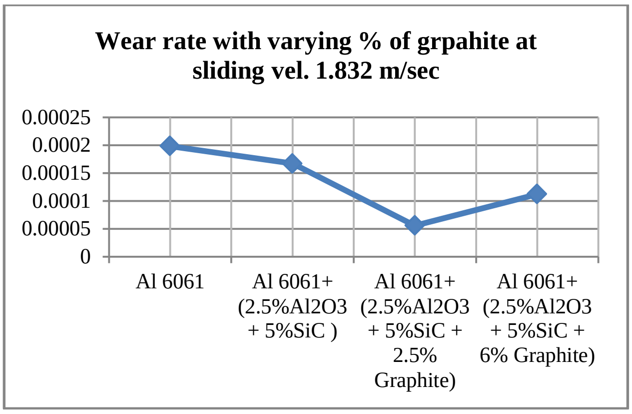

Fig. 13 wear rate with varying % of graphite at sliding vel. 1.832 m/sec

Wear rate is plotted along vertical axis. Matrix alloy Al6061 has wear rate varying from 0.00020 to 0.00025mm3/Nm. Wear rate of PAMC decreases with increase in the percentage of graphite reinforcement up to 2.5%. Wear rate of PAMC having reinforcement graphite more than 2.5% wear rate increases.

As SiC percentage goes on increasing i.e. up to 3% wear rate goes on decreasing. As Sic is hard in nature wear rate of composite decreases same wear of contacting surface i.e. steel plate will increases. With further increases of SiC wear rate of AMC will increases

4.2 Testing the mechanical properties

Tensile tests have been conducted on universal tensile machine as per ASTM E8 standards. These tests are conducted to determine the ultimate tensile strength, ductility and stiffness of the PAMC.. Table 5.4 shows effect of increasing percentage of graphite on the strength, stiffness and ductility of the PAMC. The below graph shows stress strain variation of one of PAMC results. Stress (N/mm^2) is plot along Y axis while strain is plot along X axis.

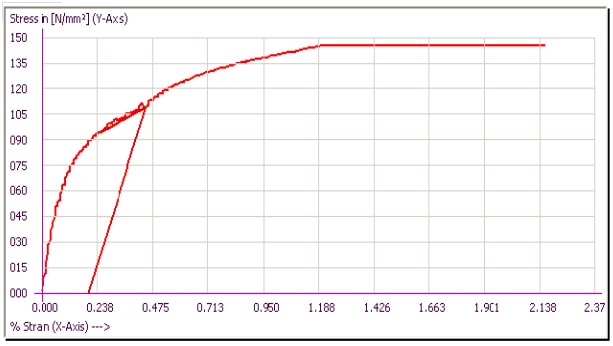

Fig. 14 Stress strain graph

Table.5 UTS and Ductility (% Elongation) of PAMC

Composition	UTS (MPa)	Ductility (% Elongation)
Al 6061	121	8.12
Al 6061+ (1%Al_2O_3+ 3%SiC)	131.71	6.12
Al 6061+ (1%Al_2O_3 + 3%SiC + 4% Graphite)	142.92	2.97
Al 6061+ (2.5% Al_2O_3 + 5%SiC + 4% Graphite)	151.77	8.74
Al 6061+ (4% Al_2O_3 + 7%SiC + 4% Graphite)	103.17	0.28
Al 6061+ (2.5% Al_2O_3 + 5%SiC)	97.78	5.68
Al 6061+ (2.5% Al_2O_3 + 5%SiC + 2.5% Graphite)	88.4	15.39
Al 6061+ (2.5% Al_2O_3 + 5%SiC + 6% Graphite)	118.04	5.02
Al 6061+ (4%Al_2O_3 + 7SiC)	121	5.03
Al 6061+ (4% Al_2O_3 + 7SiC + 2.5% Graphite)	144.97	3.84
Al 6061+ (4% Al_2O_3 + 7SiC + 6% Graphite)	114.89	3.41

4.2.1 Effect of varying % of SiC & Al_2O_3 reinforcement on Tensile Strength

The graph as shown in Figure 15 & 16 represents variation of the ultimate tensile strength (UTS) of the PAMC with change in percentage by weight of the SiC & Al_2O_3 in as cast conditions. Percentage of SiC & Al_2O_3 reinforcement is plotted on horizontal axis. UTS of the PAMC are plotted on the vertical axis. Matrix material Al6061 has UTS of 121 N/mm2. It is expected that the reinforcement in the alloy will result in improvement in the UTS of the composite. Tensile strength of Al_2O_3 and SiC are higher as compare to that of Aluminium. As reinforcement % of SiC & Al_2O_3 goes on increasing they positively contribute improvement in tensile strength

As expected the UTS of composite increases upto addition of 5% SiC & 2.5% Al_2O_3 and then it start decreasing. Maximum tensile strength of the PAMC occurring at Al 6061+(2.5%Al_2O_3 + 5%SiC + 4% Graphite) reinforcement is 151.77 N/mm2. This increases is due to the presence of Al_2O_3 Particles which act to refine the grain size of aluminium casting composites by nucleating fine grains size during the solidification process in cast conditions (Jokhio, et al, 2001)..

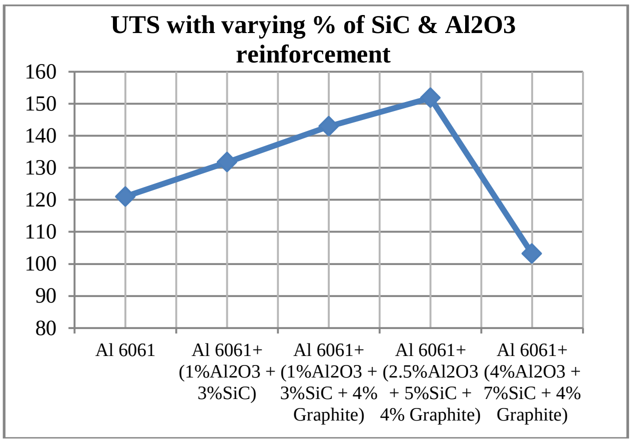

Fig. 15 UTS with varying % of SiC & Al_2O_3 reinforcement

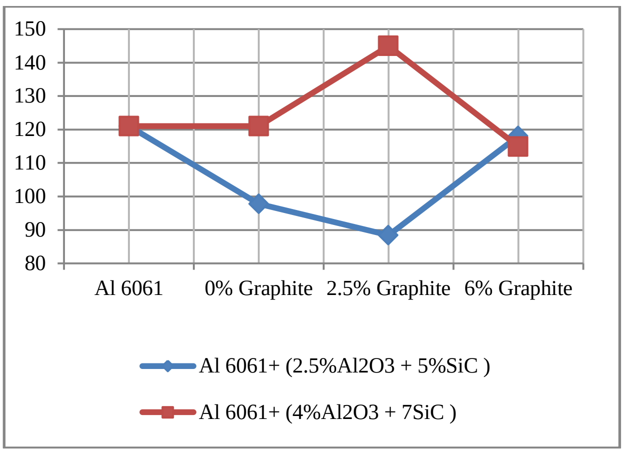

Fig. 16 UTS with varying % of SiC, Al_2O_3 & Graphite reinforcement

The decrease in tensile strength & ductility with increase the volume fraction of Al_2O_3 above 2.5 % is due to increase in porosity in stir casting aluminium matrix. Literature reveals that high Al_2O_3 particles in matrix requires the higher melting, alloying treatments temperature and longer holding time is also required for homogenizing the alloy chemistry.

4.2.2 Effect of Increasing Concentration of Graphite on Ductility

The graph as shown in Figure 17 represents variation of the ductility i.e., percentage elongation of the PAMC with change in percentage of the graphite reinforcement in as cast conditions. Percentage of graphite reinforcement is plotted on horizontal axis. Percentage elongations of the PAMC samples are plotted on the vertical axis.

Percentage elongation of the matrix material Al6061 in as cast conditions is 8.12%. The graph reveals that the ductility goes on decreasing with increasing concentration of the SiC & Al_2O_3 reinforcement. PAMC having Al 6061+ (4%Al_2O_3 + 7%SiC + 4% Graphite) reinforcement shows 0.28% of elongation which is lowest among all.

Alumina particles reinforced in the matrix alloy helps to increase the ductility of the composite while reinforcement of the SiC and graphite has reverse effect. As the percentage of the alumina was low as compare to that of the SiC and graphite, the effect of alumina on ductility of the composite was compromised by SiC and graphite.

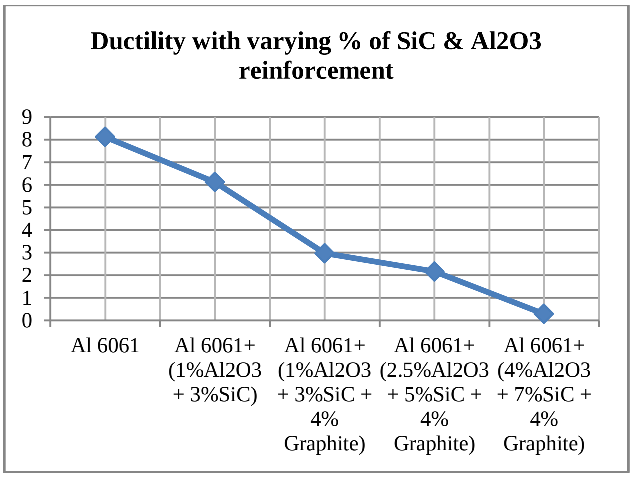

Fig. 17 Ductility with varying % of SiC & Al_2O_3 reinforcement

4.3 Effect of increasing percentage of graphite on hardness of PAMC

Table 6 shows the hardness value of the PAMC. Figure 18 shows the variation of the hardness with change in percentage of SiC & Al_2O_3 reinforcement. Percentage of SiC & Al_2O_3 reinforcement is plotted on horizontal axis. Hardness is plotted along vertical axis. Hardness value for matrix alloy Al6061 in as cast condition is 49.23 HRB.

Table.6 Effect of % reinforcement on hardness

Composition	Hardness (HRB)
Al 6061	49.23
Al 6061+ (1%Al_2O_3 + 3%SiC)	56.47
Al 6061+ (1%Al_2O_3 + 3%SiC + 4% Graphite)	69.21
Al 6061+ (2.5%Al_2O_3 + 5%SiC + 4% Graphite)	82.1
Al 6061+ (4%Al_2O_3 + 7%SiC + 4% Graphite)	92.5
Al 6061+ (2.5%Al_2O_3 + 5%SiC)	93.67
Al 6061+ (2.5%Al_2O_3 + 5%SiC + 2.5% Graphite)	69.95
Al 6061+ (2.5%Al_2O_3 + 5%SiC + 6% Graphite)	74.9
Al 6061+ (4%Al_2O_3 + 7%SiC)	101
Al 6061+ (4%Al_2O_3 +7%SiC + 2.5% Graphite)	91.85
Al 6061+ (4%Al_2O_3 + 7%SiC + 6% Graphite)	81.63

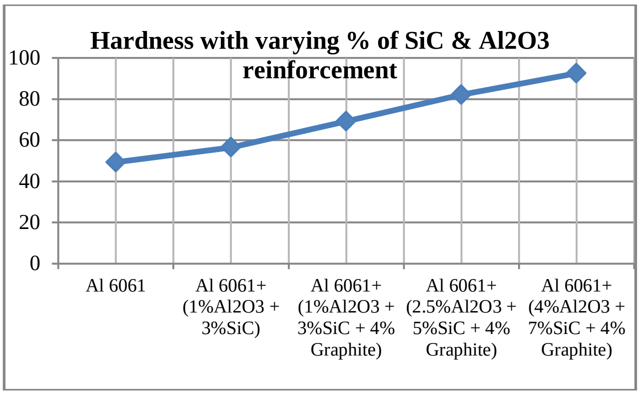

Fig. 18 Hardness with varying % of SiC & Al_2O_3 reinforcement

Hardness of PAMC Al 6061+ (4% Al_2O_3 + 7%SiC) reinforcement is 94.8 HRB highest among other reinforcement. Increase in the hardness of the PAMC results in the reduction in wear rate. Hardness of PAMC with goes on increasing with percentage SiC. This is due to aluminium is a soft material and the reinforced particle especially ceramics material being hard, contributes positively to the hardness of the composites.

From figure 18 we can conclude as percentage of graphite goes on increasing hardness of material goes on decreasing. Along that we can conclude that higher percentage of SiC higher is hardness value.

Conclusion

In present study the aim is to development of Aluminium matrix composite material by using stir casting method and characterization for its mechanical, metallurgical and tribological properties.

1) With present stir casting apparatus, we have successfully processed the total reinforcement up to 18% by weight.
2) PAMC samples are lighter than the parent matrix material of Al6061 due to the low density of graphite and porosity generated during casting.
3) Graphite acts as a dry surface lubricant, which results in reduction of the coefficient of friction between pin made of PAMC and disc made of steel up to 11%.

The lowest value found for coefficient of friction is 0.316425 for Al 6061+ (2.5% Al_2O_3 + 5%SiC + 6% Graphite) reinforcement.

4) Addition of SiC results in reduction of wear rate. The lowest value found for wear rate is 0.00000764 mm^3/Nm for Al 6061+ (1%Al_2O_3 + 3%SiC + 4% Graphite).
5) PAMC components show brittle fracture in tension test as a result of its cast condition.
6) Addition of SiC and Al_2O_3 gives good improvement in UTS. For Al 6061+ (2.5%Al_2O_3 + 5%SiC + 4% Graphite) we get maximum tensile strength i.e.154.16 N/mm2 .We get 28 % of increase in tensile strength..
7) As percentage of reinforcement goes on increasing ductility of the PAMC goes on decreasing.
8) With increase in percentage of SiC hardness of PMAC goes on increasing. It is due to hard ceramic nature of SiC. For Al 6061+ (4%Al_2O_3 + 7%SiC) we get 94.8 HRB i.e. almost 90% improvement.

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