Investigation of Mechanical and Tribological Properties of Cu, Mg, Si, Zn Reinforced AA1100 Composite Fabricated By Stir Casting

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Abstract— In the present work, a low cost stir casting process is used for the fabrication of Aluminium (AA 1100) based Metal Matrix Composites (MMC's) adding Copper (Cu), Magnesium (Mg), Silicon (Si) and Zinc (Zn) as the reinforcements. The objective of this work is production of Aluminium Matrix Composite (AMC) with better mechanical and tribological properties and relatively low manufacturing cost. Different wt% of Cu, Mg, Si and Zn are added to Aluminium (1100) to make the AMC and its mechanical and tribological properties have been investigated such as tensile strength, hardness, etc. These reinforcements showed improvements in the mechanical as well as tribological properties. These improvements in the properties are compared with the pure Aluminium (1100). It was found that tensile strength and hardness of the fabricated samples increased, with a maximum increase of 44.4% in tensile strength and 26.2% in hardness compared to pure Al 1100 but the percentage elongation decreased in each sample.

Keywords—Mechanical properties, Tensile Strength, Hardness, AMC, Tribological, Cu, Mg, Si, ,Zn

INTRODUCTION

Composite materials play a very vital role in the field of engineering as well as advance manufacturing in response to unprecedented demands from technology due to quickly advancing activities in aerospace, aviation and automobile industries. These materials have low specific gravity that makes their properties particularly superior in strength and modulus to many traditional engineering materials such as metals [1]. These innovative materials open up unlimited possibilities for modern material science and development. The characteristics of MMCs can be changed, depending on the applications.

However, the technology of MMCs is in competition with other modern technologies like powder metallurgy. Favorable properties of composites materials are high tensile strength, lower density, high electrical and thermal conductivity, corrosion resistance, improved wear resistance, etc. The advantages of composite materials are only realized when there is a reasonable cost equal to performance relationship in the component production. The use of composite material is obligatory if a special property can be achieved by application of these materials**.**

Aluminium alloy reinforced the discontinuous ceramic reinforcements is rapidly replacing conventional materials in various automotive, aerospace and automobile industries [2]. Due to light weight and high strength applications metal matrix composites has found increasing usage in industries found that aluminum matrix had poor fluidity compared with a casting of a aluminum alloy [3]. Silicon is the main alloying element in Al-Si alloys; it imparts high fluidity and low shrinkage, which result in good castability and weldability. Due to their excellent cast ability and good compromise between mechanical properties and lightness aluminum silicon alloys are most important and widely used casting alloys to cast components with complex shapes. Furthermore the applications of aluminum alloys in the automotive sector could be one of the economically sustainable innovations[4]. Al-Zn-Mg alloys can be used for both castings and wrought products, but because of the poor castability, the bulk is in the form of wrought products. Zinc is a tolerated impurity in many alloys, often up to 1.5-2% Zn, because it has no substantial effect on room-temperature properties. Interfacial bonding is improved by adding Mg. Additionally, the mechanical properties of composites are remarkably improved with the Mg content increasing [5]. Aluminium-magnesium alloys are both lighter than other aluminium alloys and much less flammable than alloys that contain a very high percentage of magnesium [6]. Density is reduced by magnesium and increased by all the other elements. The total amount of Zn + Mg + Cu controls the properties and consequently the uses. When the total is above 9%, high strength is paramount and corrosion resistance, formability and weldability are subordinated to it. With a total of from 6 to 8%, strength is still high, but formability and weldability are much better. Below a total of 5-6% fabricability becomes paramount and stress corrosion susceptibility tends to disappear [7]. Copper additions have a rather limited effect, which is approximately the same as that caused by the addition of the same amount of zinc. Thus, a copper-bearing alloy can be expected to have properties similar to those of a copper-free alloy with zinc content equal to the zinc plus copper content. This additive effect of copper applies up to 2.5% copper. The strength generally increases and ductility decreases with increase content of Cu and Mg [8,9].

The principal reasons for the use of these materials are light weight, low density and load bearing applications on account of their enhanced mechanical properties. Unreinforced Al shows the lowest wear resistance, while composites with the highest hardness and second-phase volume content are the most wear resistant, especially at high load [10]. Hardness was usually thought of as a wear controlling property, i.e. the higher the hardness, the greater is the wear resistance of the material. However, it should be emphasized

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that it is the hardness of the contacting asperities and not the bulk hardness that will control the wear rate. The addition of hard second phase particles to the matrix improves both wear resistance and mechanical properties [11].

MATERIALS AND EXPERIMENTAL PROCEDURE

Raw Materials

The materials identified for the experiment are:

- Aluminium alloy 1100

Table 1: Composition of Aluminium alloy (AA 1100)

Constituent	Aluminium	Copper	Mangenese	Zinc
% Composition	99	0.05	0.94	0.1

- Cu particulates of particle size 500 mesh (50 µm).
- Si particulates of particle size 500 mesh (50 µm).
- Mg particulates of particle size 500 mesh (50 µm).
- Zn particulates of particle size 500 mesh (50 µm).

Material Preparation

Different wt% of reinforcement was taken for the three samples fabricated. These wt% of reinforcements for the samples fabricated are shown in the table. These reinforcing particulates were then mixed according to their wt% for different samples and are preheated in oven to remove the moisture content present in it.

Fabrication of Composite by Stir Casting Process

Composite specimens are casted using the stir casting method. A muffle furnace is used for stir casting fabrication of MMC (line diagram shown in fig. 1). Mechanical stirring is used in stir casting liquid state method of composites materials fabrication, in which preheated reinforcement is mixed with a molten aluminium metal.
Factors considered in preparing metal matrix composites by stir casting method are:

- Maintaining a uniform distributed reinforced material.
- Wet ability of the substance.
- Porosity of the composites
- Chemical reaction between the reinforcement material and the matrix alloy.

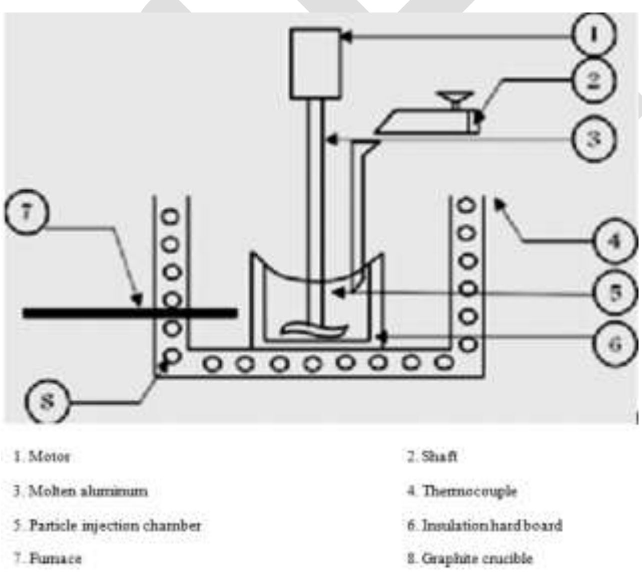

Figure 1: Schematic view of the Furnace [12]

Figure 2: Fabrication by stir Casting Process in a Muffle Furnace

Table 2: Different wt% of reinforcements used for the fabrication of AMC

Sample No.	Aluminium Alloy 1100 (By Wt.)	Cu Particlulates wt %	Mg Particlulates wt %	Si Particlulates wt%	Zn Particlulates wt %
1	1.8 Kg	1.5%	2 %	2.5%	0.5%
2	1.8 Kg	1.5%	4 %	5 %	1 %
3	1.8 Kg	3 %	2 %	2.5%	1 %

In the process, first, the Al matrix material is melted in a graphite crucible contained within a resistance-heated furnace and the liquid metal is heated to 910 ^{o}C and then Cu, Mg, Si & Zn particles are added into the molten Al material according to their volume fraction in nitrogen gas flow with a slow rate. The Cu, Mg, Si & Zn particles are stirred by a mixer at 750 rev/min. then again molten metal reheated in the stir casting furnace after completing the stirring process, the mixed material is cast into a metallic mould at 700-800^{o}c, and then quenched in water together with the mould. After that MMC is cooled in air. The fabricated MMC are shown in Figure 3.

Figure 3: Fabricated Samples of AMC.

Mechanical and Tribological Properties

The mechanical and tribological properties have been tested for the fabricated samples of the Aluminium Matrix Composite. The tests performed were tensile and elongation test, hardness test and wear test.

Tensile & Elongation Test Equipment: The testing machine used for tensile strength & elongation testing is the universal testing machine, UTE100 (Make: FIE, Capacity 100 kN, Resolution 0.01 kN).
Testing method used is IS 1608:2005. Temp. 25^{o}C and Rel. Humidity 40-60%. This test was performed at CITCO-IDFC Testing Laboratory, Chandigarh.

Hardness Testing Equipment: Vicker Hardness Tester (Make: FIE) is used for testing hardness of the fabricated composite samples. Testing method used is IS 1501:2002. Temp. 25^{o}C and Rel. Humidity 40-60%. This test was performed at CITCO-IDFC Testing Laboratory, Chandigarh.

Wear Testing Equipment: Sliding wear test was carried out using pin-on-disc apparatus. The disc is allowed to rotate at 1500 rpm. The pins which are held against the rotating disc are of 8 mm diameter and 30 mm length. The pressure on the specimen is applied by means of a precision dead weight pressure tester operated manually. In the experimentation, the specimens to be tested are taken in the form of a pin and are allowed to slide against a heat treated steel disc. The wear rate is calculated from weight loss measurements taken by weight balance machine (with accuracy 0.01 mg) before and after sliding. This test was performed at the Tribology Lab, MMEC, Mullana, Ambala.

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RESULTS & DISCUSSION

Tensile & Elongation Test

Dumbell shaped specimens made for the tensile and elongation testing are shown in the figure 4.

Figure 4: Tested specimen for tensile and elongation test

1- Sample 1, 2- Sample 2, 3- Sample 3

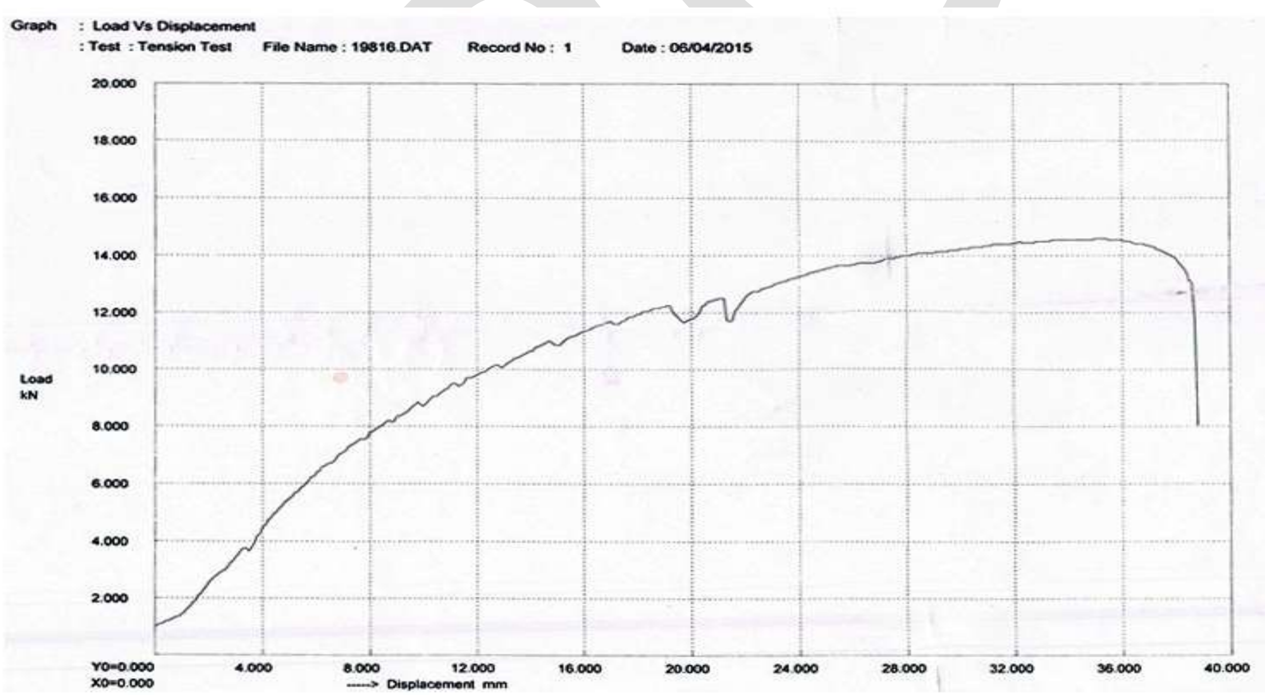

Figure 5: Stress v/s Displacement Graph for Sample 1

Figure 5 shows sample 1 which contain 1.5% Cu, 2% Mg, 2.5% Si & 0.5% Zn, can bear a maximum load of 14.70 kN and has a maximum displacement of about 38.5 mm.

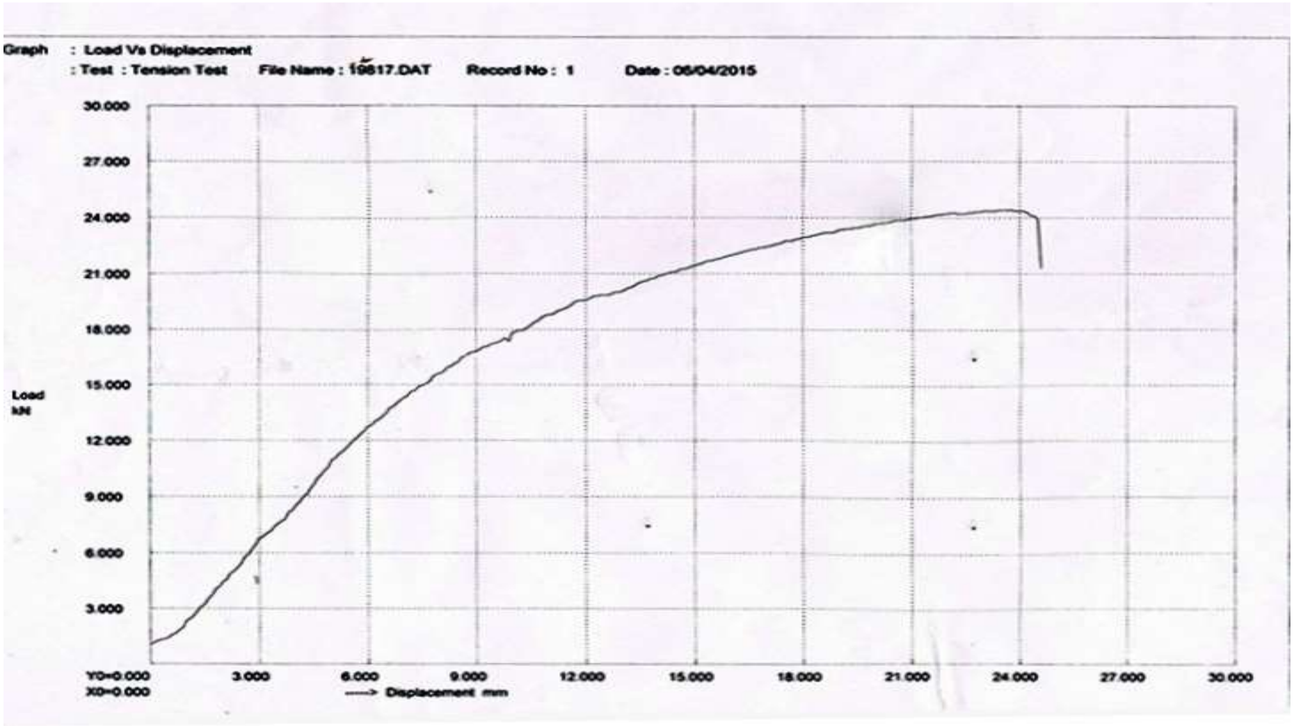

Figure 6: Stress v/s Displacement Graph for Sample 2

Figure 6 shows sample 2 which contain 1.5% Cu, 4% Mg, 5% Si & 1% Zn, can bear a maximum load of 21.30 kN and has a maximum displacement of about 24.5 mm.

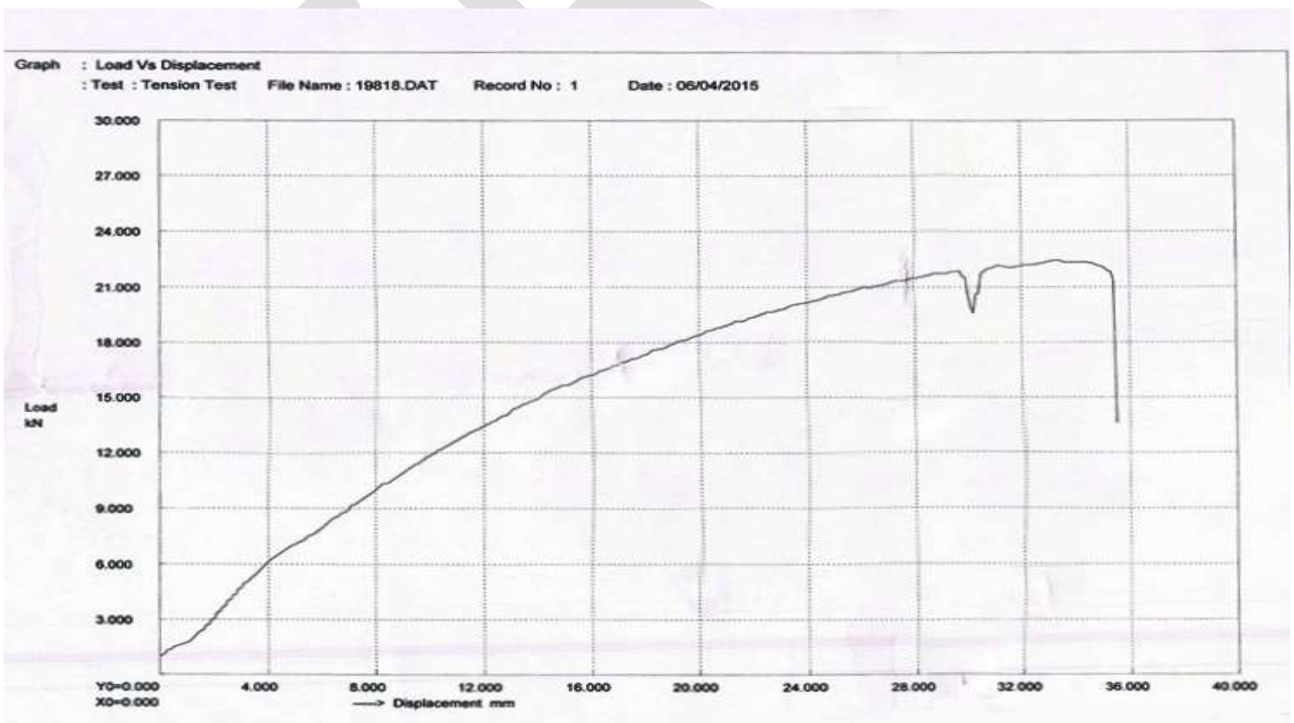

Figure 7: Stress v/s Displacement Graph for Sample 3

Figure 7 shows sample 3 which contain 3% Cu, 2% Mg, 2.5% Si & 1% Zn, can bear a maximum load of 22.50 kN and has a maximum displacement of about 35.5 mm.

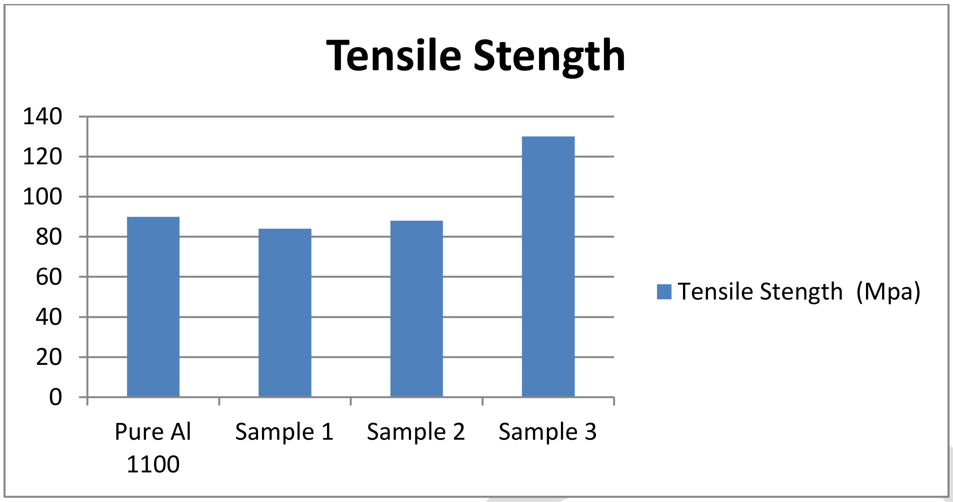

Figure 8: Tensile Strength Chart

The tensile strength for Aluminim Alloy 1100 is taken as 90 MPa [13]. The comparison of the fabricated samples with Pure Al 1100 is given in the Figure 8.

Table 3: Tensile & Elongation Test Results

Sample	Area (mm^2)	Tensile strength (MN/mm^2)	% Elongation
Sample 1	174.4	84	32.40
Sample 2	165.2	88	15.86
Sample 3	172.1	130	23.30

The results show that the maximum tensile strength is in sample 3 (130MPa) which is 44.4% more than the tensile strength of Pure Al 1100 which could be due to the increase in wt% of Cu and the additive effect of Cu & Zn which increases the tensile strength but decreases %elongation or ductility.

Hardness Test

The Vickers hardness for Pure Aluminium 1100 is taken as 35 HV [14]. The comparison hardness of Pure Al 1100 with fabricated samples is shown in Fig. 10. The maximum hardness is found in sample 2 (44.2 HV) which is 26.2% more than the hardness pure Al 1100 which could be due to the increase in wt% of Mg & Si from the other two samples.

Figure 9: Tested specimen of Hardness Test
1-Sample 1, 2- Sample 2, 3- Sample 3

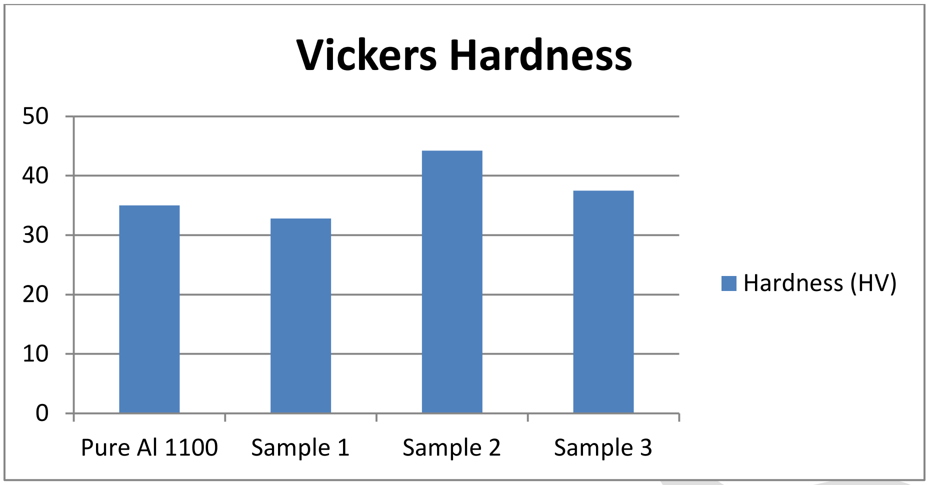

Figure 10: Hardness Chart

Table 4: Results of Vickers Hardness Test

Sample	HV (1)	HV (2)	HV (3)	HV (Average)
Sample 1	32	33.8	32.6	32.8
Sample 2	46.1	43.2	43.3	44.2
Sample 3	37.6	35.8	39.1	37.5

Wear Test

For analyzing the wear rate, 3 specimens were taken and held against the steel disc for 5 min time intervals. The weight loss during the wear process is measured by measuring the difference in the final and initial weight of the specimen thereby weighing the specimen before and after the wear test on the digital analytical weighing machine. The results of the wear test of the 3 fabricated samples are shown in Table 5.

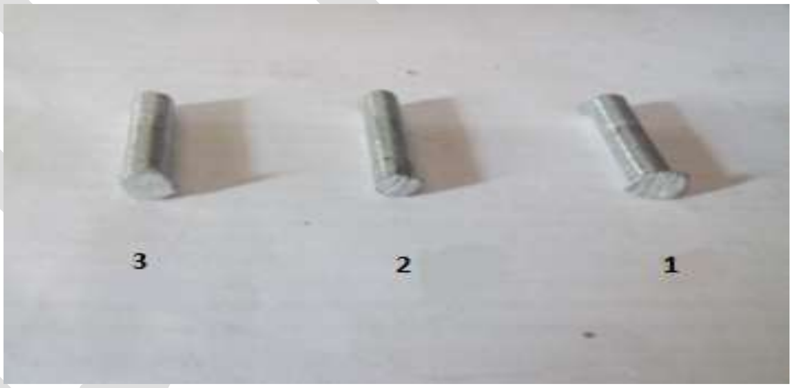

Figure 11: Tested specimen of Wear Test.

1-Sample 1, 2- Sample 2, 3- Sample 3

Table 5: Results of Wear Test.

Sample	Weight of the material before testing (g)	Weight of the material after testing (g)	Weight loss (g)
1	5.9980	5.9903	0.0077
2	5.0363	4.9565	0.0798
3	5.2003	-	-

The test on the third specimen failed in less than a minute because of the extreme amount of heat generation the specimen got stuck to the disc. The least amount of wear was found in the sample 1 with a weight loss of 0.0077g.

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CONCLUSION

In the present work, Cu, Mg, Si & Zn are being reinforced in Aluminium Alloy 1100 at different weight percentages. Mechanical and Tribological properties of the fabricated AMC's are being investigated. The improvements in the mechanical properties are compared with the properties of pure Al 1100 which gives several conclusions:

Tensile & Elongation Test:

The improvements tensile strength observed in sample 3 (3% Cu, 2% Mg, 2.5% Si & 1% Zn) which is 44.4% more than the tensile strength of Pure Al 1100. But the % Elongation has decreased as compared to pure Al 1100.

Hardness Test:

The improvement in hardness is found in sample 2 (1.5% Cu, 4% Mg, 5% Si & 1% Zn) which is 26.2% more than the hardness pure Al 1100.

Wear Test:

The lowest weight loss observed at applied load 3 kg, 1500 rpm sliding speed and 100 mm track diameter is 0.0077 grams in sample 1 (1.5% Cu, 2% Mg, 2.5% Si & 0.5% Zn).

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