Evaluation of Tribological and Mechanical properties of Aluminium 2024 reinforced with Tungsten carbide (WC) and Graphite

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Abstract— Aluminium alloy materials found to be the best alternative with its unique capacity of designing the materials to give required properties. Aluminium alloy Metal Matrix Composites (MMCs) are gaining wide spread acceptance for automobile such as engine cylinders and pistons, industrial, aerospace and it is also useful in defence applications like torpedoes, manufacture of missile bodies, because of their low density, high strength to weight ratio, high thermal conductivity and good structural rigidity. Poor wear resistance of the alloys is major limitation for their use. Which also exhibit poor tribological properties is the drawback of this material. Hence the desire in the engineering community to developed a new material with greater wear resistance and better tribological properties without much compromising on the strength to weight ratio which led to the development of metal matrix composites. The matrix aluminium 2024 alloy was melted in a furnace and stirred to form a vertex, Tungsten carbide (WC) particles and graphite particles were added as reinforcement material to the periphery of vertex and the composite melt was solidified in a permanent mould casting. And hardness test, Tensile test, Wear test and microstructure analysis are carried out.

Keywords: WC, Metal Matrix Composites (MMCs)

I. Introduction

Composite materials are gaining wide spread acceptance, due to their characteristic behavior and high strength to weight ratio. Of these aluminium metal matrix composites are finding increased applications, because of their improved mechanical (such as hardness, young's modulus, yield strength, and ultimate tensile strength due to the presence of micro-sized reinforcement particles into matrix material), physical and tribological properties and also the thermal conductivity of composite material are good. A metal matrix composite (MMCs) consists of a metallic alloy matrix (such as aluminium, magnesium, and titanium). Typically reinforced with a ceramic phase in the form of particles, platelets, whiskers, short fibers and continuously aligned fibers. Aluminium alloy reinforced with various particulate ceramics particles.

Fabrication of casting is done by stir casting processes among all the different processes, references [11] [12] [13].

Tungsten carbide is used as reinforcement material in aluminium alloy as matrix, references [4] [5] [6].

Aluminium alloy are used in vast number of applications mostly used in automobile filed (such as engine cylinders, drive shafts, pistons, and brake rotors), industrial applications, aerospace applications and it is also useful in defence applications like torpedoes, manufacture of missile bodies, because of their low density, high strength to weight ratio, high thermal conductivity, high elastic modulus, and good structural rigidity. Aluminium alloy reinforced with various particulate ceramics particles are universally known as aluminium matrix composites (AMCs).

A composite may be defined as a structural material system that consists of two or more combined constituent's material that are combined at a macroscopic level and are not soluble in each other. One constituent is called the *reinforcing phase* and the one in which it is embedded is called the *matrix*. The bulk material forms the continuous phase that is the matrix (e.g. metals, polymers, etc) while the other acts as the discontinuous phase that is the reinforcements (e.g. fibers, whiskers, particulates, etc). While the reinforcing material usually carries the major amount of load, the matrix enable the load transfer by holding them together.

Metal matrix composites (MMCs) are important class of material with non metallic reinforcement incorporated in metal matrices. Aluminium (Al) alloy matrices mainly 2024, 5052, 6061, and 7071 have been widely used as matrix materials

The present investigation has been focused on tungsten carbide (WC) particulate composite formation by utilization of low grade powdered graphite (Gr) by its dispersion into aluminium matrix by stir casting method. The objective is to form the reinforcing phase within the metallic matrix by reaction of graphite with aluminium in the metallic melt.

In this investigation aluminium 2024 (Al 2024) is the base material and reinforced with tungsten carbide (WC) and graphite (Gr) is used (Al 2024/WC-Graphite).

II. Materials and methods:

A. *Materials:*

In this investigation aluminium 2024 (Al2024) alloy is used as matrix material and it is purchased from Fenfe Metallurgical, Bangalore, Karnataka, India, in the form as shown in Figure (1). And particles of tungsten carbide (WC) and Graphite are also purchased from Ace rasayan Bangalore, Karnataka, India, and Graphite (Gr) was commercially available. The chemical composition of the matrix aluminium alloy is given in the Table (1).

Element	Weight%
Cu	4.1
Mg	1.6
Mn	0.4
Si	0.15
Fe	0.3
Cr	0.05
Zn	0.2
Ti	0.1
Al	Balance

Table 1: Chemical composition of Al2024

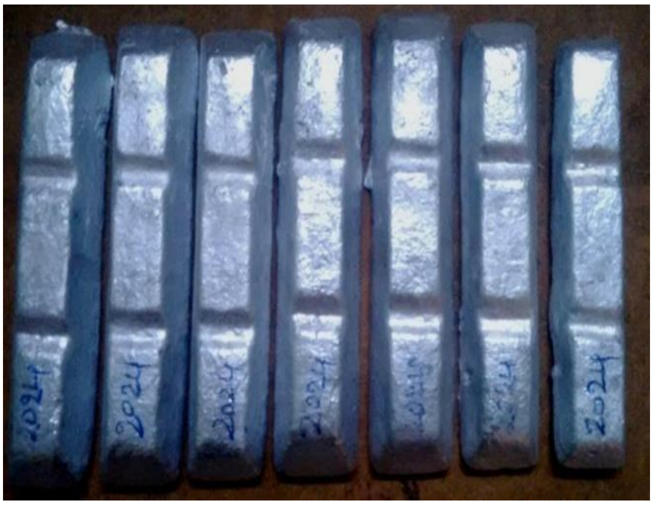

Fig. 1: 2024 Aluminium alloy

B. Experimental Work:

Appropriately estimated amount of Alminium alloy was fed into the furnace and was melted at 680 ^{0}C. At this high temperature appropriate amount of tungsten carbide (WC) and graphite (Gr) are added slowly to the molten metal. The tungsten carbide added to the molten metal was pre-heated to remove the moisture (if any) in it. Simultaneously, the molten metal was stirred slowly. The high temperature molten metal was poured into the pre-heated cast iron permanent moulds to get the required specimens. The same procedure was followed to get the different specimen with different percentage of reinforcement. The experimental setup is shown in Figure (2).

Fig. 2: Melting of Al2024 metal in furnace.

The following Table (2) shows the designation of reinforced with Tungsten carbide and Graphite. And naming of specimens. In below table H refers to T6 heat treatment.

Alloy designation	Percentage of tungsten carbide wt%	Percentage of graphite wt%
M1	As cast Al2024	As cast Al2024
M2	2	2
M3	4	2
M4	6	2
M1 H	As cast Al2024	As cast Al2024
M2 H	2	2
M3 H	4	2
M4 H	6	2

Table 2: Designation of reinforced with Tungsten carbide and Graphite.

C. Testing:

The fabricated specimens were proposed to test for mechanical properties like hardness test, tensile strength test and wear test. The Microstructure analyses were proposed to be done to know the dispersion of the reinforcement in the metal matrix.

1) Microstructure test:

The specimens who are used for microstructure test analysis are prepared in the form of cylindrical pieces of 15 mm thickness, and 25 mm diameter as shown in Figure (3). Specimens are examined using Nikon Microscope LV150 with Clemex Image Analyser.

Fig. 3: Microstructure test specimen.

2) Hardness Test:

The hardness tests were conducted as per ASTM E10 norms using Brinell hardness tester. Tests were performed at randomly selected points on the surface by maintaining sufficient spacing between indentations and distance from the edge of the specimen. Hardness test specimens are same as that of the microstructure specimen as shown in Figure (3).

3) Tensile testing:

A tensile test is carried out as per ASTM E8M-15a. The specimens used for tensile test are shown in Figure (4).

Fig. 4: Tensile test specimen

4) Wear Test:

Dry sliding wear tests were conducted as per (American Society for Testing and Materials) ASTM-G99 norms using Pin-on-Disc machine driven by a D.C motor with counter face disc of the machine having diameter of 190 mm and thickness 30 mm as shown in Figure (5). The specimens used for wear test is shown in Figure (6).

Fig. 5: Wear Testing Machine

Fig. 6: Wear test specimen.

III. RESULTS & DISCUSSIONS

A. *Microstructure:*

Microstructure structure of material plays an important role in the overall performance of composites. The microstructure of a material can strongly influenced physical properties such as strength, toughness, ductility, hardness, corrosion resistance, wear resistance. The microstructure of as cast and different composites are seen below

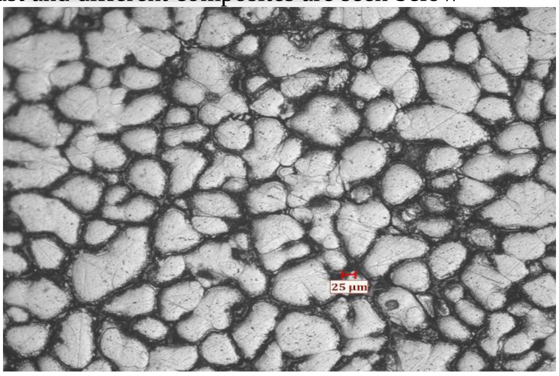

Fig. 7: Microstructure of M1 (as Cast)

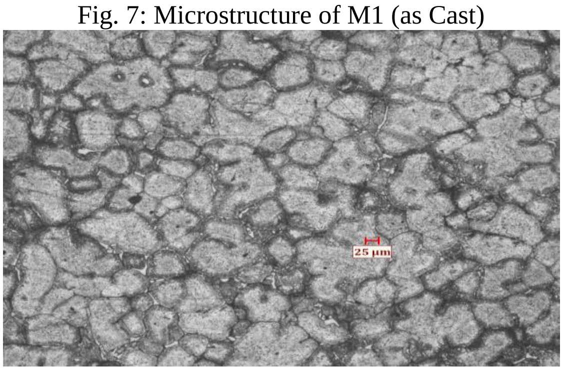

Fig. 8: Microstructure of M2

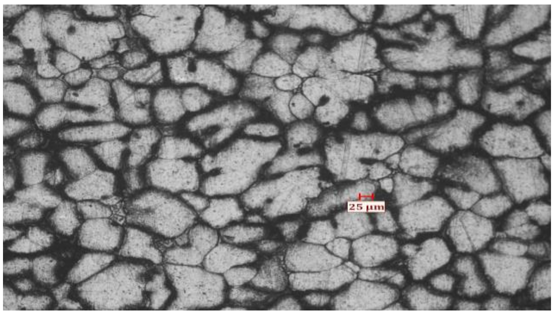

Fig. 9: Microstructure of M3

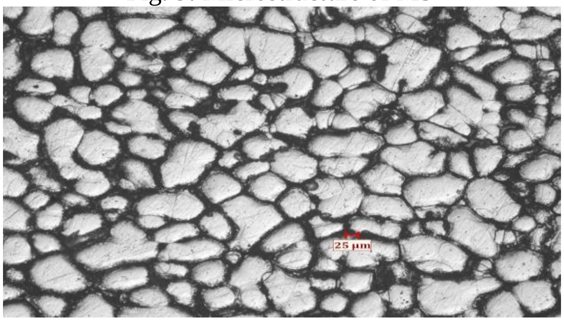

Fig. 10: Microstructure of M4

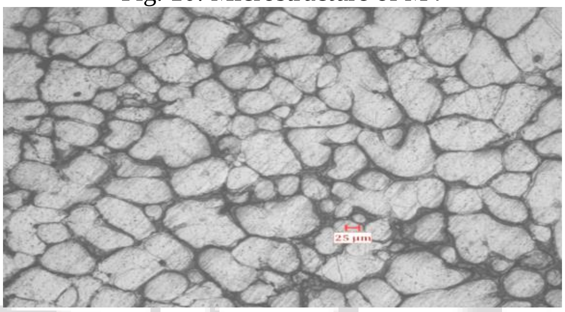

Fig. 11: Microstructure of M1H

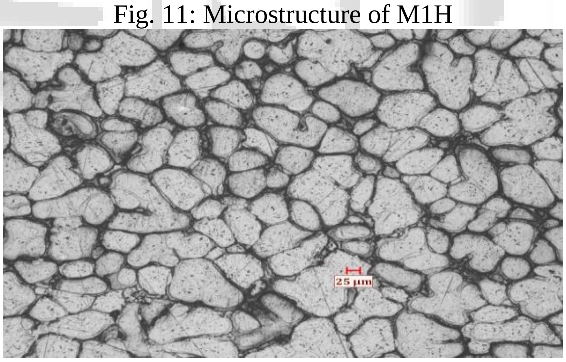

Fig. 12: Microstructure of M2H

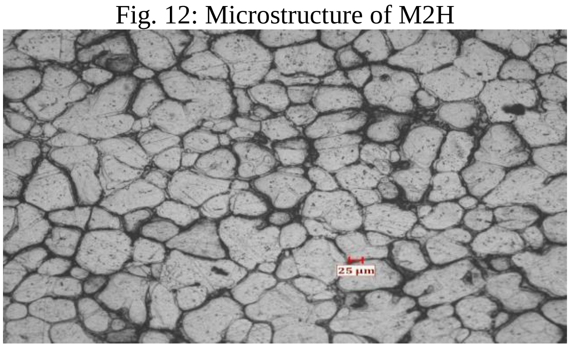

Fig. 13: Microstructure of M3H

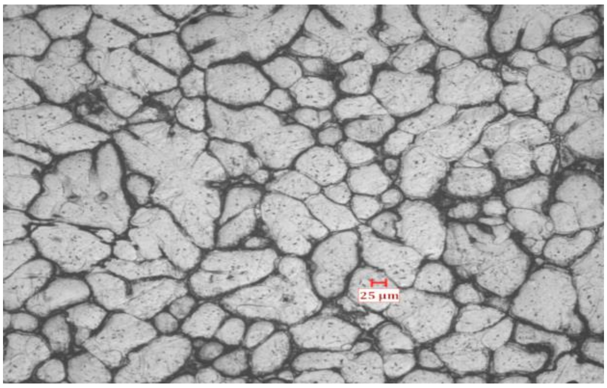

Fig. 14: Microstructure of M4H

B. Hardness:

Table (3) shows the value of hardness of untreated and heat treated Alloy and it's composite. In this table it is clear that the maximum hardness value is95.4 for the M3H i.e. with heat treated. Figure (15) shows the graph of hardness values of untreated and Heat Treated as cast Al2024 alloy and its composites.

Alloy/Composites	Hardness Untreated	Hardness Treated
Al2024 as cast	82.7	72.7
M2	86.4	84.6
M3	93.5	95.4
M4	89.5	91.4

Table 3: Hardness of untreated and heat treated alloy and its composites

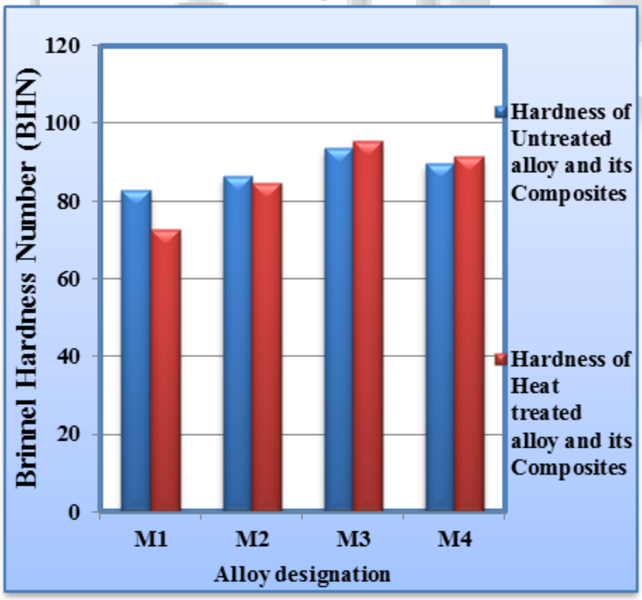

Fig. 15: Graph of BHN of untreated and Heat Treated alloy and its composites V/S Alloy Designation

C. Tensile Strength:

Table (4) shows the variation of tensile strength of the composites with the different weight fractions of tungsten carbide and Graphite particles. It can be noted that the tensile strength increased with an increase in the weight percentage of tungsten carbide and graphite. This is due to the reinforcement particles acts as barrier to dislocation movement in microstructure.

Alloy & Composites	Peak load (KN)	Tensile Strength (N/mm2)	% Elongation
M1	11.04	100.94	1.50
M2	12.20	110.79	0.42
M3	14.32	131.82	1.70
M4	12.32	113.02	0.24
M1H	12.28	111.90	0.16
M2H	11.68	113.09	0.28
M3H	15.56	137.65	0.24
M4H	14.68	130.11	0.40

Table 4: Tensile test result

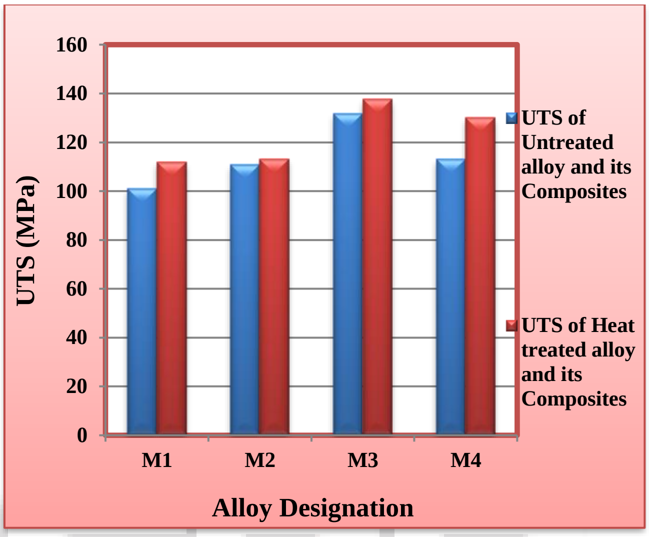

Fig. 16: Graph of UTS values of Untreated and Heat Treated alloy and its composites

D. Wear:

The below Table (5) shows the wear test results of untreated and heat treated Al2024 alloy and its composites in different sliding speed.

Alloy Designation	Wear rate (gm/m X 10^{-5}) Sliding distance (m)				
	300	600	900	1200	1500
M1	3.45	3.76	4.01	4.9	5.4
M2	2.81	2.93	3.4	4.1	5.01
M3	2.1	2.3	2.6	2.7	3.1
M4	2.9	3.4	3.8	4.3	4.9
M1H	2.91	3.4	3.82	4.5	4.8
M2H	2.3	2.61	2.9	3.89	4.7
M3H	1.9	2.00	2.1	2.3	2.65
M4H	2.4	3.21	3.7	4.1	4.6

Table 5: Wear test results of untreated and heat treatedAl2024 alloy and its composites

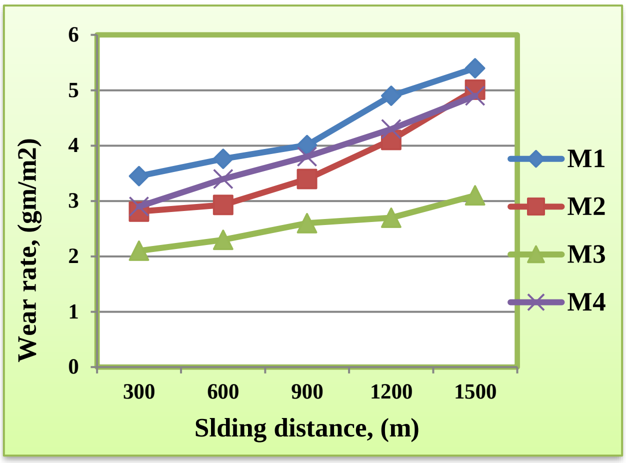

Fig. 17: Plot of wear rate versus sliding distance of untreated Al2024 alloy and its composites

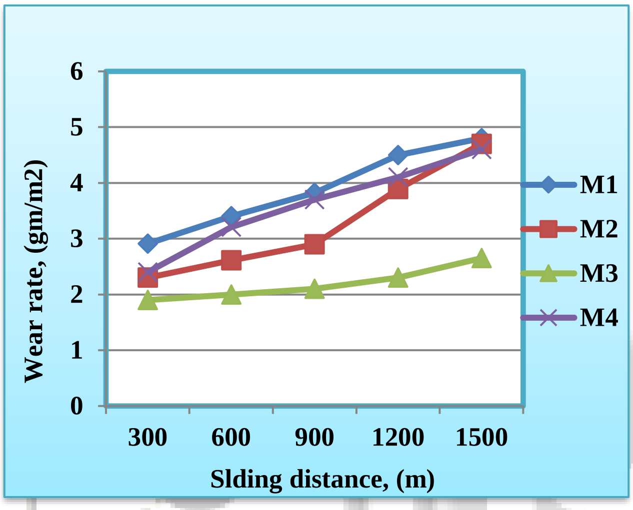

Fig. 18: Plot of wear rate versus sliding distance of heat treated Al2024 alloy and it composite

IV. CONCLUSION

In the present study, the analysis of as cast Al2024 alloy and its composites with and without heat treated were made to evaluate microstructure, mechanical and tribological properties. Based on the study the fallowing conclusions are made.

1) Microstructure indicate uniform distribution of ceramics in the matrix resulting in good bonding of the particulates and showed primary dendrite □□-Dendrite phase rich in aluminium. The composite with 2% Graphite and 4% Tungsten carbide has highest hardness, Ultimate tensile strength, and ductility and wear resistance.
2) Heat treatment resulted in the modification of needle shaped Tungsten particles to spherical shape, reduction in size and their uniform distribution in the matrix.
3) Inclusion of WC and Graphite particulate reinforcement content improves the mechanical properties of the composite material like tensile strength, hardness, and compression strength at the cost of ductility.

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