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MECHANICAL CHARACTERIZATION OF AL6061-TUNGESTEN CARBIDE COMPOSITES USING POWDER METALLURGY TECHNIQUE

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Abstract— **There is a huge demand for Aluminium matrix based composites (AMC) as they offer high specific strength and wear resistance as compared to pure Aluminium. In this study the Mechanical Characterization of tungsten carbide (WC) particulate reinforcement in the Aluminium (Al) matrix was investigated. The Al composite was prepared by P/M process with tungsten carbide particulate of 2, 4%, 6%, 8%, 10% and 12% on weight fraction basis. Compaction was carried out in Hydraulic machine. The components were sintered at 540^{O}C for 120 minutes in a muffle furnace. Mechanical properties like hardness, compression strength and tensile strength of Al6061-WC composite alloy was increased with increase in WC particles compared to Al6061 alloy.**

Keywords— **Al composites, Metal matrix composites, Tungsten carbide, Hardness, Compression test, Tensile test, Powder Metallurgy**

I. INTRODUCTION

Aluminium alloys are the most widely used nonferrous materials in engineering applications owing to their attractive properties such as high strength to weight ratio, good ductility, excellent corrosion resistance, availability and low cost [3]. There is a huge demand for Aluminium matrix based composites (AMC) as they offer high specific strength and wear resistance as compared to pure Aluminium[4]. MMCs have become a very attractive method for various industrial applications. The interest in Tungsten Carbide (WC) as reinforcements for aluminum (Al) has been growing considerably [5].

Powder metallurgy is the process of blending fine powdered materials, pressing them into a desired shape or form (compacting), and then heating the compressed material in a controlled atmosphere to bond the material (sintering) [1].

The powder metallurgy process generally consists of four basic steps: powder manufacture, powder blending, compacting and sintering. Compacting is generally performed at room temperature and the elevated-temperature process of sintering is usually conducted at atmospheric pressure [2].

A.R.K. Swamy et al, the reinforcing particulates in the MMCs vary from 0% to 4% by weight. The 'vortex method' of production was employed to fabricate the composites. The results of this study revealed that as the Tungsten carbide particle content was increased, there were significant increases in the ultimate tensile strength, hardness and Young's modulus, accompanied by a reduction in its ductility.

Rajesh Purohit, et al studied Sintering of Al-SiCp composite parts is more energy efficient than for most other PM materials due to the relatively low sintering temperatures. During isostatic compaction of powders, the quality of final product depends upon the quality of initial manual compact.

Z. Zulkoffli, et al investigated SiC reinforcement fabricated by using a pre-alloyed AZ61 powder compressed without binder agent under compaction pressure of 200MPa for 20 minutes at different temperature intervals of 200°C, 250°C, 300°C and 350°C.

II. EXPERIMENTAL DETAILS

Materials

Chemical Composition of Al6061 Alloy by Weight Percentage

Si	Cu	Fe	Mn	Mg	Zn	Pb	Ti	Sn	Al
0.64	0.23	0.22	0.03	0.85	0.22	0.10	0.01	0.01	Bal

Tungsten carbide (WC) is a chemical compound containing equal parts of tungsten and carbon atoms. In its most basic form, tungsten carbide is a fine gray powder, but it can be pressed and formed into shapes through a process called sintering.

Specimen Preparation

Powder metallurgy is a metal working process for forming precision metal components from metal powders. The metal powder is first pressed into product shape at room temperature. This is followed by heating (sintering) that causes the powder particles to fuse together without melting. It is a highly energy-efficient and cost-effective process for the production of near-net shape products having a wide range of alloy compositions. The PM process has a high degree of flexibility and allows tailoring of physical characteristics of a product to suit specific property and performance requirements.

Planetary Ball Mill

Al6061 alloy powder blended with abrasive grade WC particles of average size 37μm to form a mechanical mixture of Al and WC powder. With the extent incorporation of tungsten carbide which is limited to 12% by weight. Tungsten carbide 0-12% of particulate was dispersed in base matrix in step of 2% by weight. Blending of powders are carried out in ball planetary mill, it comprises of four cylindrical containers of chrome steel within which 2 balls made up of chrome steel of sizes 20 mm. To achieve a homogenous distribution of the reinforcement in the mixture the blending machine continues rotations for 2hours at 20 Hz of speed 252rpm.

Fig 1. Planetary ball mill

Compaction

The compaction experiments were executed to make cylindrical compacts. Cylindrical die and punch having 20 mm diameter made of D-2 steel was used to make cylindrical compacts.

Fig2.Compaction of powder and green compact

Powder compaction is the process of compacting metal powder in a die through the application of high pressures. Typically the tools are held in the vertical orientation with the punch tool forming the bottom of the cavity. The powder is then compacted into a shape and then ejected from the die cavity. The model is generally called “green compact.” As is comes out of the die, the compact has the size and shape of the finished product.

Sintering

Sintering is a heat treatment applied to a powder compact in order to impart strength and integrity. The temperature used for sintering is below the melting point of the major constituent of the Powder Metallurgy material. After compaction, neighboring powder particles are held together by cold welds, which give the compact sufficient “green strength” to be handled. At sintering temperature, diffusion processes cause necks to form and grow at these contact points. Specimens are heated at 540ºC for 2hrs in a muffle furnace.

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Fig3. Muffle furnace and Sintering of specimens

III. TESTING OF COMPOSITES

To examine the mechanical behavior of the composites the hardness, compression tensile, SEM tests were carried out. The specimens were prepared as per ASTM standards.

1. Brinell Hardness Test

Brinell hardness test is widely used for testing hardness of metals and nonmetals of low to medium hardness.

Sl. No.	Material	Diameter of indenter in mm (D)	Load in kgf (P)	Dwell Time (s)	Diameter of indentation d (mm)	BHN
1	Al6061	10	500	15	3.82	41
2	Al6061+2%WC	10	500	15	3.76	43
3	Al6061+4%WC	10	500	15	3.67	45
4	Al6061+6%WC	10	500	15	3.82	42
5	Al6061+8%WC	10	500	15	3.7	44
6	Al6061+10%WC	10	500	15	3.5	50
7	Al6061+12%WC	10	500	15	3.4	53

Table1. BHN of MMC's

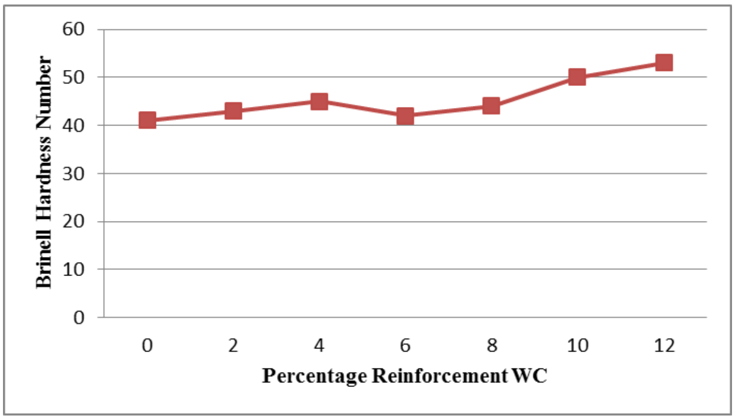

Fig4. BHN v/s Percentage Reinforcement WC

The results revealed a significant increase in hardness of 29% in MMCs when compared with base alloy.

2. Compression Test

Compression tests are used to determine the material behavior under a load. The maximum stress a material can sustain over a period under a load is determined.

Sl. No.	Sample	Max Load (KN)	Compressive Strength (MPa)	Elastic Modulus (Gpa)
1	Al6061	56.22	452.34	46.22
2	Al6061+2%WC	60.58	478.25	48.58
3	Al6061+4%WC	85.6	675.77	71.6
4	Al6061+6%WC	87.4	679.98	72.2
5	Al6061+8%WC	86.3	681.3	71.3
6	Al6061+10%WC	83.7	690.77	69.3
7	Al6061+12%WC	88	694.72	73.2

Table2. Compressive Strength of MMC's

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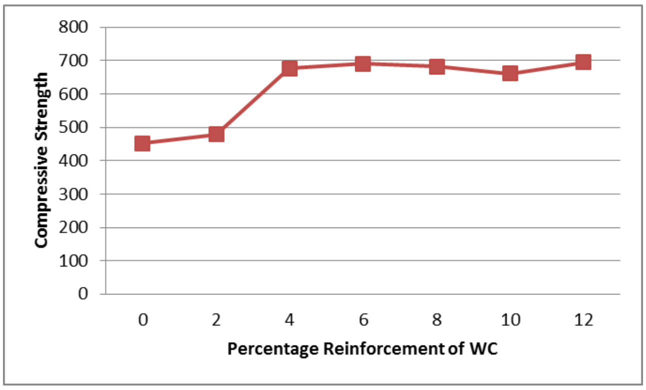

Fig5. Compressive Strength v/s Percentage Reinforcement WC

MMC's exhibited a significant increase in Compressive strength of 53% in MMCs when compared with base alloy.

3. Tensile Test

Tensile tests help determine the effectiveness and behaviour of a material when a stretching force acts on it. These tests are done under optimum temperature and pressure conditions and determine the maximum strength or load that the material can withstand.

Sl. No.	Sample	Max Load(N)	Ultimate tensile strength(N/mm2)
1	Al6061	753	25.1
2	Al6061+2% WC	1055	35.16
3	Al6061+4% WC	2322	77.4
4	Al6061+6% WC	2465	82.16
5	Al6061+8% WC	2422	80.733
6	Al6061+10% WC	3409	83.833
7	Al6061+12% WC	2515	113.633

Table3. Ultimate tensile strength of MMC's

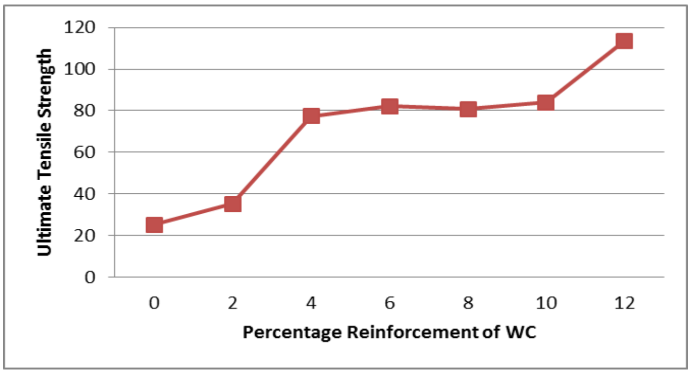

Fig6. Ultimate tensile strength v/s Percentage Reinforcement WC

Tensile test results indicated a significant increase in Ultimate Tensile strength of 77% in MMCs when compared with base alloy.

4. Wear Test

Wear test is carried out to find the wear characteristics of the composites developed by powder metallurgy route and to understand the wear mechanism. The aim of the experimental plan is to find the significant factors and combination of factors influencing the wear process to achieve the minimum wear rate with pin on disc apparatus. Preliminary wear test, by varying composition 0%-12%WC in which considering variables, via, Load (N), Speed (rpm) and sliding distance (m), Loss of weight of test samples indicates wear resistance, as materials of higher abrasion resistance will have a lower volume loss. Thus as a higher wear resistant (or lower wear rate) specimen composition of material to be carried out.

Specimen	LOAD (KG)	SPEED (RPM)	SLIDING DISTANCE In Meters	Wear Rate mm3/N-m
Al6061	2	600	2000	0.000229846
	3	800	3000	0.000166
	4	1000	4000	0.000138865
Al6061+2%WC	2	600	2000	0.00017535
	3	800	3000	0.000134219
	4	1000	4000	0.000114465
Al6061+4%WC	2	600	2000	0.000129183
	3	800	3000	0.000120048
	4	1000	4000	9.68869E-05
Al6061+6%WC	2	600	2000	0.000128758
	3	800	3000	0.00011005
	4	1000	4000	8.66641E-05
Al6061+8%WC	2	600	2000	0.00012054
	3	800	3000	8.48246E-05
	4	1000	4000	7.53376E-05
Al6061+10%WC	2	600	2000	0.000102676
	3	800	3000	7.75775E-05

	4	1000	4000	6.16056E-05
Al6061+12%WC	2	600	2000	**9.03695E-05**
	3	800	3000	**5.35523E-05**
	4	1000	4000	**4.26745E-05**

Table4 Preliminary wear test results

Wear rate of Al6061 with 12%WC having higher wear resistance, thus considering this the experiments were developed based on and orthogonal array L9, with the aim of relating the influence sliding speed (rpm), load (N) and track diameter (mm) for the wear test. Taguchi recommends analyzing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

Specimen Al6061+12%WC

LOAD (N)	**SPEED (RPM)**	**SLIDING DISTANCE**	**WEAR RATE**	**WEAR RESISTANCE**
		In Meters	mm3/N-m	N-m/mm3
10	200	1000	0.000236407	4230.00
10	400	1500	0.000183872	5438.57
10	600	2000	0.000177305	5640.00
15	200	1500	0.000210139	4758.75
15	400	2000	0.000170738	5856.92
15	600	1000	0.000183872	5438.57
20	200	2000	0.000226556	4413.91
20	400	1000	0.000157604	6345.00
20	600	1500	0.000131337	7614.00

Table5 Wear rate of Al6061+12%WC analyzed at various levels

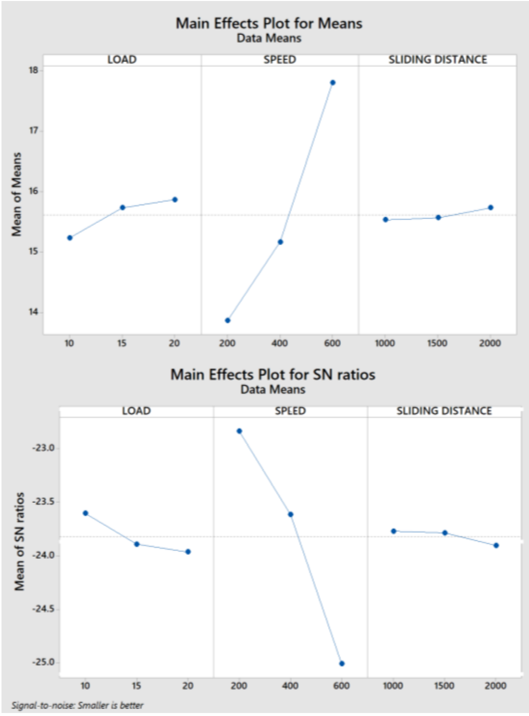

Fig.7 Main effect plots

ANOVA is used for analysing the experimental results and investigate the influence of wear parameters such as sliding speed, sliding distance and applied load on specific wear rate and Frictional force.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
LOAD	2	1702494	19.63 %	1702494	851247	1.73	0.366
SPEED	2	5227690	60.27 %	5227690	2613845	5.33	0.158
SLIDING DISTANCE	2	761589	8.78%	761589	380795	0.78	0.563
Error	2	981551		11.32 %	981551	490776	
Total	8	8673324	100.00 %				

Table6 ANOVA experimental results

It can be observed that for Al6061+12%WC the major contributing factor was speed (60.27%) followed by load (19.63%) and finally sliding distance (8.78%) influencing the wear rate of the Al6061-12%WC composite.

5. Scanning Electron Microscopy

The scanning electron microscope instrument (SEM) is utilized for the perception of the example surfaces. At the point when the specimen is illuminated with the fine electron beam (electron test), optional electrons are produced from the specimen surface.

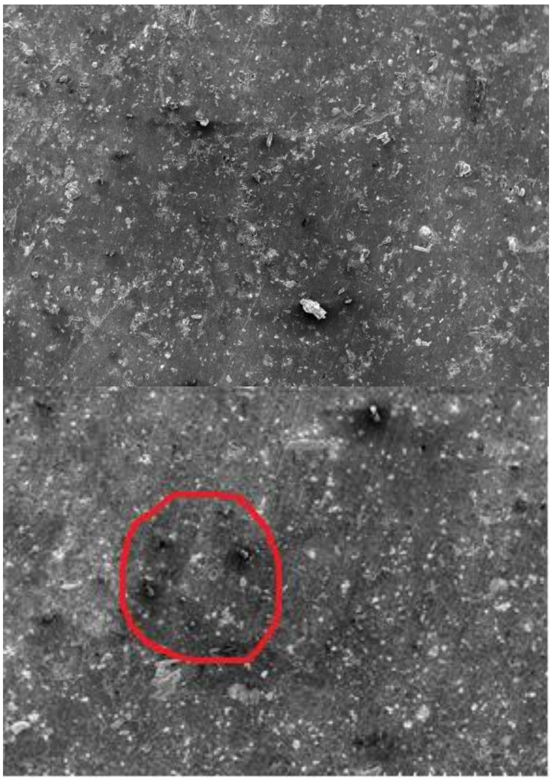

Fig7. SEM of Al6061+WC Composite

The images obtained through scanning electron microscope revels the uniform distribution of WC particles in Al6061 matrix.

IV. CONCLUSION

1. From the powder metallurgy technique Al6061base alloy, Al6061-WC composites were prepared successfully, SEM images revels the uniform distribution of WC particles in Al6061 matrix
2. The properties of the Al6061-WC composites are significantly improved by varying the amount of WC.
3. It was found that increasing the WC content within the matrix material, resulted in significant improvement in mechanical properties like hardness, tensile strength, and compressive strength.
4. Highest values of mechanical properties like hardness, tensile strength and compressive strength were found at 12wt% WC.
5. Highest wear rate was found at 12wt% WC, Taguchi and ANOVA experiment revels that the major contributing factor was speed influencing the wear rate of the composite.

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