Experimental Evaluation of Mechanical, Wear and Corrosion properties of AA5083/Graphite Metal Matrix Composite Prepared using Compocasting Process

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***Abstract:** In most of the engineering applications such as aviation, defence, marine and automotive requires components with light weight and along with favorable mechanical properties; this demand perhaps satisfied by metal matrix composites (MMCs) of aluminium by virtue of its distinguished achievement. Also MMCs suffer from insufficient process stability, in-adequate economic efficiency and reliability. In the present research work an experiment was developed to synthesize metal matrix composite adopting Aluminium Alloy (AA) 5083 as matrix material reinforced with graphite particulates (6 wt %, 8 wt % & 10 wt %) using two stage in-situ stir casting process. Experiments were implemented to analyze mechanical and tribological properties like ultimate tensile strength, microhardness, wear characteristics and corrosion properties. From the above investigations, it is revealed that microhardness increases with decrease in tensile strength with upsurge in more wt % of reinforcement. Due to the very high self-lubricating property of graphite significant reduction in wear can be observed with deepen in wt % of graphite. Also corrosion rate decreases with more amount of graphite particulate when compared with base matrix material.*

***Keywords**: AA5083, Graphite, Metal Matrix Composite, Stir casting*

I. INTRODUCTION

In today's modern technological world, material science plays a major role in developing various new mechanical components, which has special mechanical and material characteristics for different environmental conditions. Conventional materials are durable and denser hence abundant in weight, hence exploration has been shifted from alloys to composite [1].

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It is very well established that aluminium metal matrix composite are exemplify as the materials that are typically fortified by strong ceramic particles for instance nitrides, carbides or oxides in to the matrix [2].

In MMCs, hard ceramic reinforcements are infused in to soft metal matrix [3] to achieve combination of enhanced elevated working temperatures, excellent resistance to corrosion, light weight, better strength, better hardness, good thermal and electrical conductivity [4]. Composite materials are usually used for buildings, structural application namely boat hulls, bridges, panels in swimming pools, race car bodies, bathtubs, imitation granite, storage tanks [5]. Norul Amierah Binti Nor Zamani et.al [6] investigated the mechanical and tribological behaviour of aluminium-graphite (Al-Gr) composite fabricated using powder metallurgy process. In order to evaluate the tribological behaviour, 3 – 7 wt % of graphite was chosen to determine its potential self-lubricating property under dry sliding condition. The graphite particles in the composite form a thin layer amidst the contact surface and act as a lubricant, which diminishes metal to metal influence. K.Sekar [7] developed Aluminium alloy (AA) 2014 reinforced with B_4C & Gr hybrid composites with disparate wt% of reinforcement particulates using conventional stir casting process. Microstructural analysis reveals uniform distribution of reinforcement with sufficient bonding strength among the reinforcement and matrix particulates after preheating. Mechanical properties for instance tensile strength, hardness and impact strength were analysed. The results reveal that, by adding B4C & Gr reinforcement particles an oxide layer was advanced in composite materials on the surface, the density of the composite and stress relieves of the composites increased, so that hardness of the developed composite material increases gradually with escalation in wt % of ceramic particles. V.Mohanavel [8] et.al pinpointed on the development of Aluminium Alloy (AA) 6351 matrix reinforced with 0 – 12 wt % in stages of 4 wt % of graphite particulates by adopting stir casting method. V.N.Gaitonde et.al [9] evaluated the aftermath of the corrosion and wear properties of Al5083 bolstered with 3 & 6 wt % of Al2O3 and graphite developed by stir casting method. The experimental results reveal that the developed composite material curtail the corrosion and wear rates after increasing the wt % of ceramic reinforcement particulate.

In this present research work, an effort is made to synthesize Aluminium Alloy (AA) 5083 as a base matrix material reinforced with Graphite (Gr) ceramic particulates by exploiting traditional stir casting procedure. Different weight percentage of reinforcement was used and the manufactured composite material was experimented with divergent mechanical and tribological tests. The main motive of this research is to establish a peculiar aluminium metal matrix composite material that could serve for military and defence equipment's that are subjected to extreme environmental condition. Mechanical properties like microhardness, tensile strength were scrutinized. The proposed composite material was subjected to corrosion and tribological studies and evaluated.

II. EXPERIMENTAL PROCEDURE

A. Selection of materials

Aluminium Alloy (AA) 5083 was chosen as the base matrix material with magnesium as the primary alloying element [10] as demonstrated in Table 1. The mechanical and physical characteristics of AA5083 matrix material is delineated in Table 2. Alloys in this series avail excellent welding characteristics and high resistance to corrosion in marine atmosphere [11]. AA5083 aluminum alloy has highest strength of the non-heat treatable alloy, one of the major drawback of the AA5083 that it is not reusable and cannot be used above 650°C temperature [12].

Table- I: Chemical composition (wt%) of 5083 aluminium alloy

Element	Mn	Fe	Cu	Mg	Si	Zn	Cr	Ti	Al
Min	0.4	0.4	0.1	4	0.4	0.25	0.05	0.15	Bal
Max	1.0			4.9			0.25		

Graphite (Gr) is one of the candidate reinforcement material that has been used widely to develop self-lubricating composites. Graphite achieves a good consolidation of stiffness, strength, density and toughness when combined with aluminium alloy [13]. Graphite is an allotropic form of carbon. Depending upon the carbon adjustment, variation in tendency and structure can be observed. It exhibit both metal and non-metal properties [14]. Graphite affords lubrication fallout and dwindle the friction and wear in the course of sliding. But a larger content of Gr can manage more advanced wear rate by virtue of the devaluation in fracture strength of AMCs [15]. Graphite also improves the dimensional stability.

Table- II: Physical and Mechanical Properties of AA5083 aluminium alloy [16]

S.No	Properties	Units	Values
1	Density	g/cm^3	2.80
2	Melting Point	°C	635
3	UTS	MPa	317
4	YS	MPa	229
5	Shear Strength	MPa	190
6	% Elongation	-	16
7	Poisson's Ratio	-	0.33
8	Crystal Structure	-	FCC

B. Fabrication Process

Owing to its cost effectiveness and simplicity, Conventional stir casting method was preferred to develop the aluminium MMCs. The AA5083 alloy ingots as exposed in the Figure 1 were blended inside the crucible with its melting temperature inside the stir casting furnace as demonstrated in the Figure 2. Graphite of 99.5% purity with particle size less than 20µm was preheated before mixing with aluminium melt. Legitimate stirring is obligatory to accomplish orderly distribution of reinforcement in the matrix material. The melt is stirred with the guidance of mechanical stirrer in order to develop a vortex. Meanwhile, Graphite particulates with 6, 8 & 10 wt% were preheated and fed in to the aluminium melt at constant feed rate.

Fig. 1.Pure AA5083 ingots.

The various process parameters used to contrive the aluminium metal matrix composite material is displayed in Table 3. After continuous stirring of the molten mixture, it was discharged in to the preheated permanent mould at room temperature, which is previously adopted for required dimensions for accomplishing specimens. After cooling, the samples were taken out from the mould and the required specimens were cut using Wire Cut EDM machine for further testing and analysis.

Fig. 2.Setup for stir casting process

Table- III: Testing specification of stir casting

S.No	Process parameters	Value
1	Stirring time	5 mins
2	Stirring speed	200 rpm
3	Melting temperature	650°C
4	Crucible size	4 (Bell crucible)
5	Furnace	Electric muffle furnace
6	Preheating temperature	550°C
7	Maximum temperature of furnace	706°C

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C. Mechanical Characteristics of Composites

The mechanical properties specifically microhardness of the cast specimens and Ultimate Tensile Strength (UTS) were explored. Tensile test was implemented out to assess the mechanical behaviour of developed AA5083/Gr aluminium metal matrix composite material. Figure 3 shows the tensile specimen in consonance with ASTM E8M04 standard. Tensile strength was regulated by employing digitalized universal testing machine alongside maximum load about 50 kN.

The microhardness was retrieved using Vickers microhardness tester according to ASTM E92 standard specimen as shown in Figure 4. Each sample is polished using emery papers before micro-hardness test is conducted. 5N load was enforced at the same time as the indentation for every test with an interminable dwell time of 5 seconds. At 10 disparate spots the microhardness of the advanced composite material was resolved to furnish repeatability of the secured results.

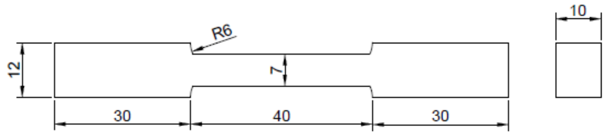

Fig. 3.Standard tensile specimen

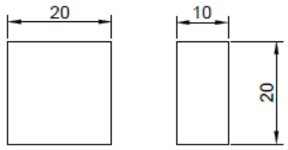

Fig. 4.Standard hardness specimen

D. Corrosion Nature of Composites

Corrosion study of immersion type was diagnosed according to ASTM G31 – 72 at ambient temperature with standard specimen as shown in Figure 5. In order to initiate the test, an alkaline solution of pH slightly above seawater is prepared with a conductivity equivalent to sea water. In order to prepare such a solution the first requirement is to obtain distilled water having a pH of 7 and low conductivity. Before drenching in NaCl solution, the Al5083/Gr composite specimens were cleansed by deionized water and flushed using methanol and dehydrated. Every sample was initially weighed since drenching in the concoction of Sodium Chloride (NaCl) and a solution of distilled water. Subsequently 3 hours specimens were cloistered, suppressed assiduously and composite material was counterbalanced. Weight loss of prepared composite material was deliberated adopting a weighing machine. The weight obtained was transformed in to corrosion rate (mm/year). From the loss in mass, the rate of corrosion interpreted adopting ensuing relation.

Fig. 5.Standard corrosion test specimen

E. Wear Behaviour of Composites

A computer unified pin on disc machine (DUCOM – TR 20-LE) as shown in the Figure 6 was employed for the investigation of wear rate at room temperature. The machine consists of a fixed arm with pulley at one end and a stationary pin at other end. Before each attempt, the specimens were gleamed using recognizable SiC emery sheets to persuade homogeneous surface roughness (Ra value of 0.03 µm). In line with typical ASTM G99 30 mm height & 8 mm diameter wear samples were flourished over wire EDM method and the surface was gleamed metallographically. Every analysis was bolstered 3 times & a balance data was depicted. Experiment was conducted at loading condition of 5 & 10 N at a sliding distance of 2000 m, 2 m/s and track diameter of 100 mm.

Fig. 6.Pin on Disc Machine (DUCOM – TR 20-LE)

III. RESULT AND DISCUSSION

A. Tensile Strength

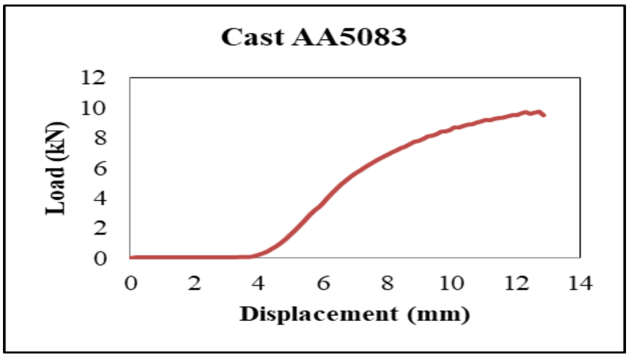

Fig. 7.Load vs displacement plots for Cast AA5083

Tensile tests were conducted to estimate the yield strength, ultimate tensile strength and various properties. The empirical testing authorized the stress-strain curves for pure AA5083 and AA5083 augmented 6, 8 and 10 wt% Gr particulates. It is observed that the yield strength decreases with upturn in wt% of reinforcement in the composite material. It is not necessary that the graph between percentages of reinforcement versus yield strength should have to be a linear one. Figure 7 & 8 depends on the elastic nature of the composite under consideration, and the stress at which the material begins to deform plastically.

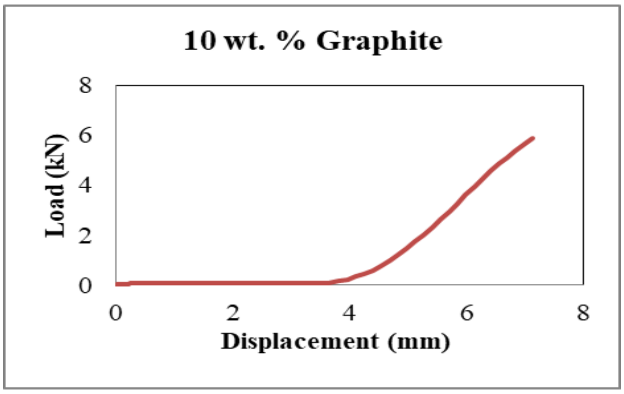

Fig. 8.Load vs displacement plots for AA5083 with 10 wt% graphite

B. Microhardness

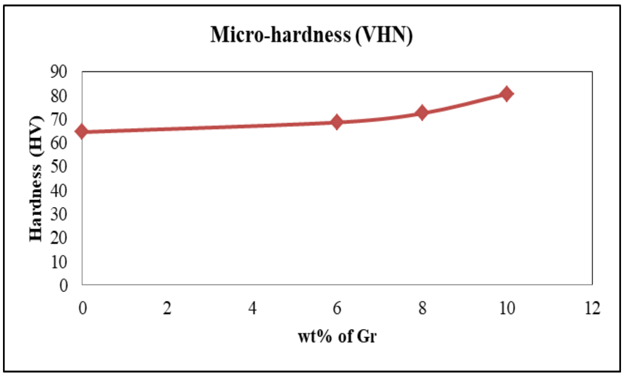

Fig. 9.Hardness of AA5083/Gr with respect to wt% of reinforcement

From Table 4, it can be analysed that the hardness increases marginally with raise in weight percentage of graphite. This steady increase in hardness can partially prove the dispersion of Graphite and magnesium in AA5083 metal matrix. The superior value of hardness of composites illustrates that the continuation of ceramic particulates in the matrix. The presence of graphite reinforcement starts to the increase in deprive to plastic deformation of the matrix during the hardness test. From Figure 9, the appreciable hardness difference between samples can be studied.

Table.4 Microhardness with varying wt% of graphite

S.No	wt% of Graphite	Microhardness (VHN)
1	0	64.5
2	6	68.6
3	8	72.4
4	10	80.62

C. Wear characteristics

Tribological observations were implemented to under-stand the wear behaviour of AA5083/Gr composite employing a pin-on-disk wear tester. Wear experiments were supervised adopting a 'pin-on-disc wear tester' for 6, 8 & 10 wt% Gr. The experimental wear data's achieved from verifying 16 specimens is delineated in Table 5.

Table- V: Experimental wear results

S.No	Time (sec)	Wear of AA5083	Wear in µm when Gr is 6 wt%	Wear in µm when Gr is 8 wt%	Wear in µm when Gr is 10 wt%
1	0.98	0	0	0	0
2	50.96	24.89	21.34	18.47	14.97
3	100.95	25.81	22.18	16.85	15.49
4	150.945	26.96	24.61	17.95	16.18
5	200.933	28.23	26.88	18.38	16.61
6	250.921	29.47	28.53	19.24	17.88
7	300.916	30.28	29.31	20.64	18.53
8	350.906	31.90	30.12	21.49	19.31
9	400.897	33.06	31.14	23.36	20.12
10	450.886	35.14	33.89	25.14	21.14
11	500.878	36.71	35.18	30.89	25.89
12	550.864	38.35	37.81	33.18	27.18
13	600.855	39.89	38.96	35.81	30.81
14	650.844	41.27	40.23	38.96	33.96
15	700.834	44.92	42.47	41.23	37.23
16	750.823	49.81	46.28	44.47	39.47
17	800.813	53.13	51.90	48.28	43.28
18	850.803	57.72	55.06	51.87	46.90
19	900.792	63.56	58.14	53.11	48.06
20	950.782	66.25	61.71	56.46	50.14
21	1000.772	68.92	64.35	58.18	51.02

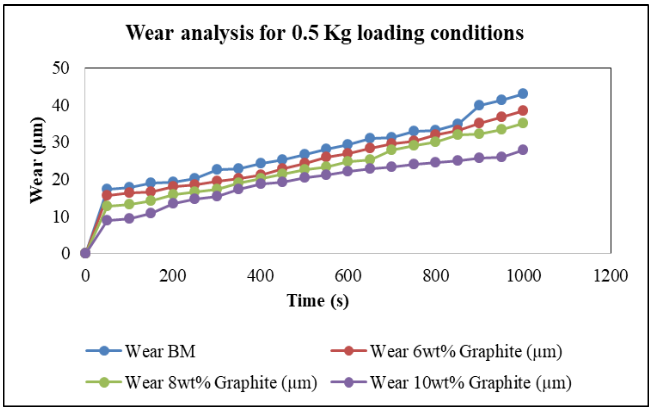

Fig. 10. Wear with respect to time (0.5 Kg loading condition)

The Figure 10 represents wear of the samples with respect to time. From the Figure 10, it can be analysed that the sample with higher Graphite content has lesser wear rate that all other samples with lesser percentages of Graphite. The wear rate for the samples with 6 & 8 wt% graphite has very low difference in wear comparing with 10 wt% of graphite at 1000 seconds. The test reveals that the sample with 10 wt. % Graphite has a wear of 27.92 µm which is significantly lower than the base metal sample with 42.92 µm. The samples with 6 and 8 weight percentage of Graphite also show substantial reduction in wear compared to the base metal alloy.

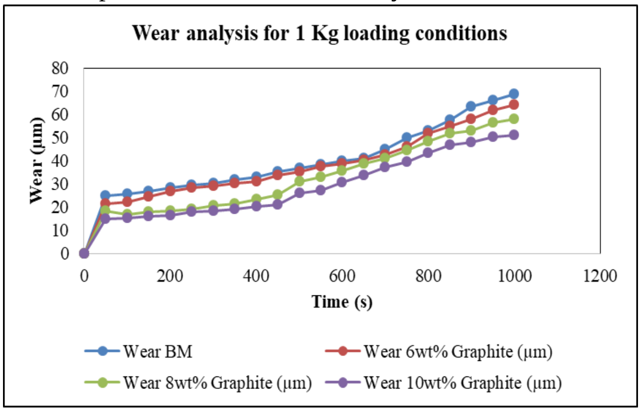

Fig. 11. Wear with respect to time (1 Kg loading condition)

The Figure 11 represents wear test performed on the sample pins for a load of 1 Kg. From the Figure 10, it can be observed that greater wear takes place under greater loading conditions. Unlike the wear data's of the samples at 0.5 Kg load taken at a particular time instance, the wear rate for samples at 1 Kg load is substantial greater. It is evident that the sample with 10 wt. % Graphite has experienced greater wear of 51.02 µm than that observed from the wear of the same sample at 0.5 Kg loading i.e. 27.92 µm, and the difference in wear between the 10 wt. % Graphite sample and the base metal sample i.e. (68.92 µm and 51.02 µm) appears to be higher when compared to difference in the same under 0.5 Kg loading condition i.e (42.92 µm and 27.94 µm) at an instance of 1000 seconds. This can be attributed to the accumulation of graphite particles at the interfaces. It can also be understood that the difference in wear of sample with 6 wt. % Graphite sample and 8 wt. % Graphite sample is greater than the difference in wear for same samples at 0.5 Kg loading condition.

D. Corrosion Test

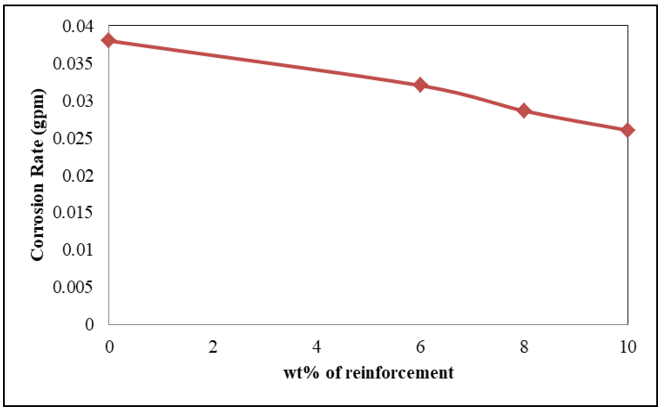

Fig. 12. Corrosion Rate (gpm) vs wt% of Graphite (Gr)

Corrosion rate is naturally low for larger proportion of Graphite. Greater Graphite percentage in aluminium composite promotes the corrosion defiance of the AA5083 alloy. From the Table 6, it can be recognized that for a composite for 6 wt% of Graphite, the corroded mass per year is 0.384 gpm which is undoubtedly smaller amount of material detached by salt water corrosion upon contrast to the base matrix. It can be terminated that larger percentages of Graphite assisted in AA5083 can outlaw corrosion in a way improved than typical AA5083 alloy. The Figure 12 displays greater corrosion on juxtaposition with natural AA5083 on the specimen with 6 wt. % Graphite therefore, on the specimen with 10 wt. % Gr is marginally smaller than the sample with 8 wt. % Gr. It was further examined that corrosion over 12 months is essentially smaller for the strengthened composites at the prevailing rate of corrosion rate for individual specimen.

Table- VI: Corrosion rate per month and Mass corroded per year

% of reinforcements	Mass before immersion (g)	Mass upon retrieval (g)	Corrosion rate per month (gpm)	Mass corroded per year (gpy)
0	8.2233	8.1853	0.038	0.456
6	12.0520	12.0195	0.032	0.384
8	10.7353	10.7067	0.0286	0.3432
10	8.5840	8.5584	0.026	0.312

IV. CONCLUSIONS

1) In this work, AA5083 alloy was successfully reinforced with varying weight percentage reinforcement of graphite and magnesium by in-situ stir casting process.
2) From the micro hardness test it was recognized that the surface hardness of the material surge with upturn in reinforcement, a trend which could be associated to the increase in presence of magnesium which increases the surface hardness of the composite and improves the wettability of graphite in the matrix.
3) The wear test conclusions further prove that wear resistance of the samples further escalates unquestionably as the percentage of reinforcement increases. This is due to the evolution of a thin Graphite layer which brings about self-lubricity to the material. This thin Graphite layer formation was realised at the interfaces.
4) The corrosion test was performed at standard ambient conditions after an initial surface cleaning and it was espied that the corrosion rate decreases significantly with increase in Graphite addition, on comparison with pure AA5083 which developed a rugged surface and significant discoloration.
5) From the tensile testing outcomes, it was discovered that the tensile strength of the material reduces with increment in reinforcements by a factor of approximately 14% for every 2% addition of Graphite and the material seemed to fail in a more ductile manner with increase in reinforcements which may be attributed to the decrease in the base material.

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