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Study Of Mechanical Properties Of Al 5052- Al_2O_3- GraphiteHybrid Composite Fabricated Using Stir Casting Process

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Abstract- The composite materials are extensively used in automotive, aerospace and defence fields due to its high strength to weight ratio. The mechanical properties and machinability of composites not only depend on the volume of reinforcements, but also on the distribution of these reinforcements. Al 5052 alloy has high corrosion resistance; however, its hardness is lower which limits its applications. This project aims at fabricating a composite material using Al 5052 as matrix which has high hardness. Composite material with different proportions of Al_2O_3 and graphite were fabricated using stir casting process. Samples were prepared using Al 5052 reinforced with Aluminium oxide Al_2O_3 (2%, 4%) and Graphite (1%) by volume at various melting temperatures of 675°C, 700°C and reinforcement pre-heat temperatures as 250°C and 300°C. Experiments were conducted using Taguchi L_4 orthogonal design of experiments.The results show that the incorporation of Al_2O_3 increases the hardness of the material whereas graphite increases the wear resistance of the material.

Keywords:Distribution, Hardness, Reinforcement, Taguchi, Wear resistance

1. INTRODUCTION

Al_2O_3 content on microstructure reveal reasonable increase in hardness and decrease of ductility with increasing aluminium oxide content, [Bhaskar Chandra Kandpal., et.al]. The incorporation of particulate reinforcements like fly ash, rice-husk ash and mica reduces the density of composites, [Jaswinder Singh et al.,]. The presence of lubricating property reinforcements like graphite enhances surface finish due to reduction of friction and its presence improves machinability. [Anthony Xavior M et al.,]. Hardness and tensile strength of the composites increased with the addition of reinforcements like SiC, Al_2O_3, TiC. Composites reinforced with composite powders fabricated through stir casting showed lower porosity. [Yashpal et al.,]. hardness and tensile strength of composite is linearly increased with the increase in reinforcement addition. The AA6351/Al_2O_3/Gr hybrid composite containing 20% Al_2O_3 with 3% Gr has higher mechanical properties than the pure Al matrix alloy. [Mohanavel V et al.,]. The Aluminium matrix is strengthened when it is reinforced with hard ceramic particles like SiC, Al_2O_3, B4C, etc. resulting in enhanced wear resistance. Among the manufacturing processes, the conventional stir casting is an attractive processing method for producing AMCs as it is relatively inexpensive and offers a wide range of materials and processing conditions. Production of homogeneous AA6061/B4C composite could be achieved by using Stir Casting Technique. [B. Ravi et al.,]. The wear loss of particle reinforced Al specimens decreased due to presence of Al_2O_3- B_4C. The wear rate of Al_2O_3- B_4C 8% was approximately 10% lower than other weight percentages. [Hariprasad T et al.,]. The hardness and tensile strength increases with increase in CSA weight %. The wear rate decreases with increase in percentage of CSA in aluminium matrix. [Biswajit panda et al.,].

A. Problem statement

Aluminium-magnesium alloys and aluminium based metal matrix composites have found applications in the marine environment. Al 5052 alloy has high corrosion resistance; however, its hardness is lower which limits its applications. To overcome this problem, Aluminium oxide (Al_2O_3) and graphite are added as reinforcement particles to enhance the hardness and wear resistance

B.Objective

To study the mechanical properties of Al - Al_2O_3 - Graphite hybrid compositeproduced using stir casting process.

2. Methodology

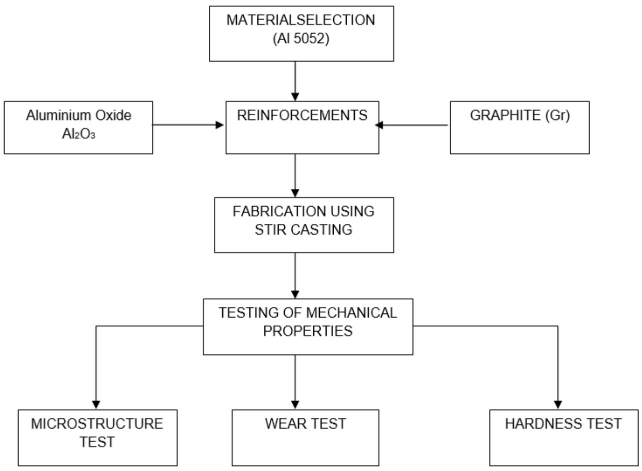

Figure 2.1 Methodology

3. Material Selection

Aluminium is selected as the metal matrix for the composite due to its abundance, low cost and already proven track record for the similar purpose. It is relatively soft, durable, light weight, ductile, malleable metal and has high corrosion resistance, excellent heat conductivity. The selected aluminium alloy Al 5052 bears excellent characteristics for marine applications. The composition is shown in the TABLE 3.1. It has major alloying elements Silicon, Copper which contributes for better strength, machinability and castability.The properties are listed in TABLE 3.2.

Table 3.1 Al 5052 chemical composition

Mg	Cr	Cu	Fe	Mn	Si	Zn	Others
2.2 to 2.8 %	0.15 to 0.35 %	0.1 % max	0.4 % max	0.1 % max	0.25 % max	0.1 % max	0.05 % max

Table 3.2 Al 5052 properties

Density	2.68 g/cm^3
Elastic Modulus	69.3 Gpa
Melting Point	607 °C
Specific Heat Capacity	880 J/Kg-K
Tensile Strength: Ultimate (UTS)	195 - 290 Mpa
Vickers Hardness	92 HV
Thermal Conductivity	138 W/Mk

Aluminium oxide is taken as the reinforcement phase due to the fact that Al_2O_3it has good wettability with Al, high hardness, and high temperature stability. Aluminium oxideAl_2O_3 in its various levels of purity is used more often than any other ceramic material. The properties of Aluminium oxide are listed in TABLE 3.3.

Table 3.3 Aluminium oxide properties

Density	3.75 to 3.95 g/cm³
Melting point	3160 °C
Mechanical strength	300 - 630 MPa
Thermal conductivity	20 to 30 W/mK

Graphite is well known as a solid lubricant and its presence in aluminium alloy matrices makes the alloy, self-lubricating. Graphite being a solid lubricant can improve the machinability of the composites. Furthermore, graphite possesses excellent thermal and electrical conductivity thereby, can improve the conducting capability of aluminium composites. The propertie s of graphite are listed in TABLE 3.4.

Table 3.4 Graphite properties

Density	2.266 g/cm³
Modulus of Elasticity	8-15 GPa
Thermal conductivity	25-470 W/Mk
Melting point	4300 K
Crystal structure	Hexagonal

4. Experimental work

A. Fabrication of composites

The experimental arrangement of stir casting fundamentallycontains an electric furnace and a mechanical stirrer. The capacity of electric furnace is 2kg. The extremeworking temperature of the furnace is 1000°C. The current rating of furnace is single phase 230V AC, 50Hz. The stir casting machine set up at GCT, Coimbatore is shown in Fig 4.1.

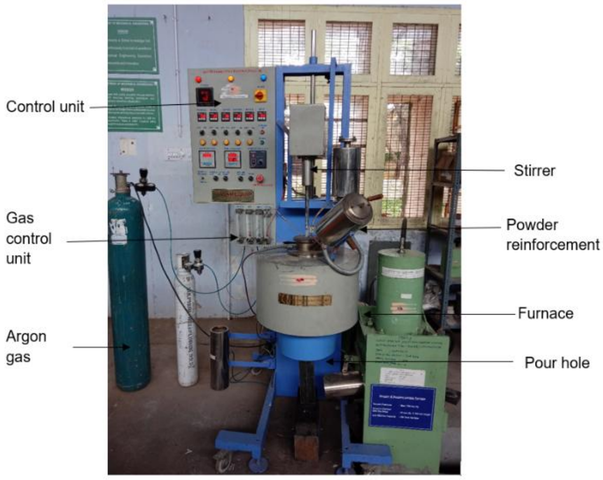

Figure 4.1 Stir casting setup

B. Experimental plan

The matrix material is aluminium alloy Al 5052. Samples are to be prepared using Al 5052 reinforced with Aluminium oxide Al_2O_3 (2%, 4%) and Graphite (1%) by volume at various melting temperatures of 675°C, 700°C and reinforcement pre-heat temperatures as 250°C and 300°C. Experiments were conducted using Taguchi L_4 orthogonal design of experiments is shown in TABLE 4.1 and Fig. 4.2 gives the various constituents levels of composite elements.

Table 4.2 Mass of matrix and reinforcement required for each sample

Experiment number	Sample No.	Melting temperature	Reinforcement pre-heat temperature	Reinforcement %	
				Al_2O_3	Gr
1.	1.	700	250	4	1
2.	2.	700	300	2	1
3.	3.	675	250	2	1
4.	4.	675	300	4	1

C. Material requirement

Diameter of die (D) = 302 mm

Length of die (L) = 240 mm

volume (V) = $\frac{\pi}{4} \times D \times L$

= $\frac{\pi}{4} \times 302 \times 240$

(V) =169644.24 mm^3

Material Required

Mass = Density × volume [Density of AA5052= 2.68g/cm^3]

=$2.68 \times 10^{-3} \times$ 169644.24

m = 454 g

Table 4.3 Mass calculation of Al 5052, Al_2O_3 and Graphite

Sample No.	Al 5052 (gm)	Al_2O_3 (gm)	Graphite (gm)
1	431.3	18.1	4.5
2	440.3	9	4.5
3	440.3	9	4.5
4	431.3	18	4.5

Figure 4.2 Reinforcement preheater

Figure 4.3 Casted samples

D. Testing of samples

The samples were casted as per the experimental plan to prepare specimens for various testing and investigating the properties of these hybrid composite samples.

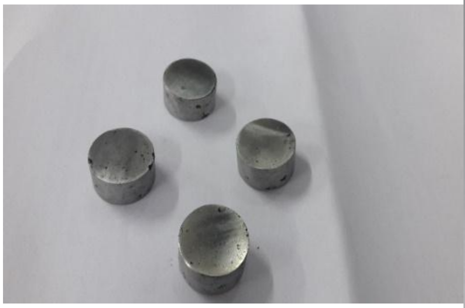

Figure 4.4 Hardness test samples

Figure 4.5 Microstructure test samples

Figure 4.6 Wear test samples

5. Results and discussion

A. Microstructure

Fig. 5.1 shows the micrograph of the samples. The micrograph clearly reveals the absence of dendritic morphology in all the composites under investigation.

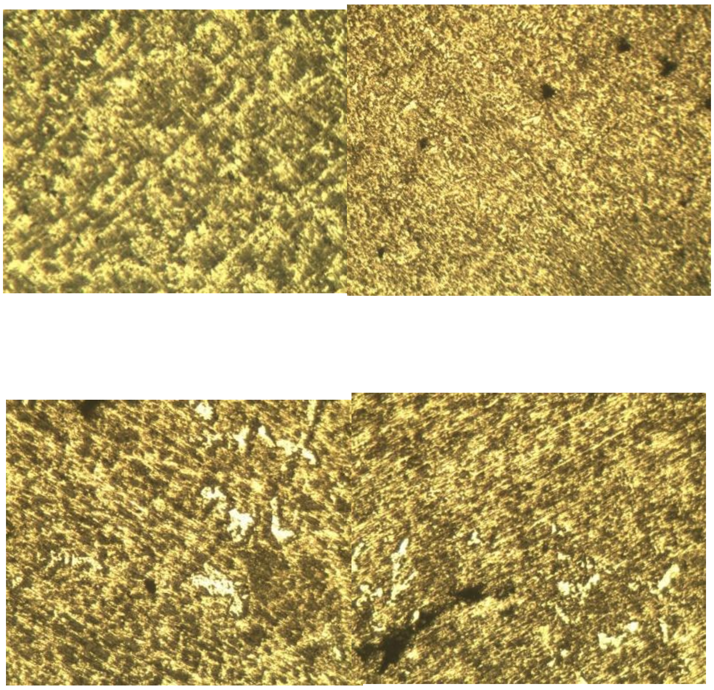

Figure 5.1 Microstructures of composite material (Samples 1,2,3,4)

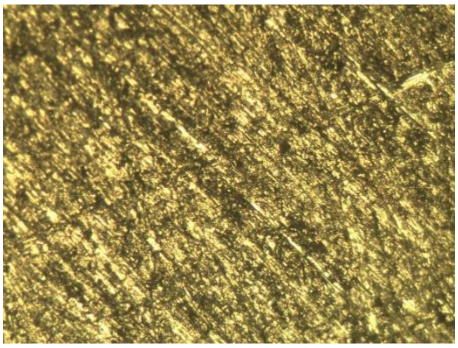

Figure 5.2 Microstructure of base alloy

Fig. 5.2 shows the microstructure of base alloy without adding any reinforcements. The dendritic structure can be modified during casting which is influenced by many factors such as dendritic fragmentation, restriction of dendritic growth by the particles, and thermal conductivity mismatch between the particles and melt.

Overall analysis of structure indicates that the reinforced particles are uniformly distributed in the alloy matrix. The good bonding between particles and alloy matrix is also revealed in the microstructural analysis.

Porosity is minimum and not observed in the optical examination, although clustering is seen at some places in the composite.

B.Hardness test

Micro hardness test at various locations was carried out to know the effect of reinforced particulates on the alloy matrix as given in Table 5.1. Vickers hardness measurement has been carried out on the embedded reinforcement particles as well as in the locality of particles and matrix.

Table 5.1 Vickers hardness values

Sample No.	Trial 1	Trial 2	Average
Base alloy	70	69	70
1	82	86	84
2	79	77	78
3	75	76	76
4	88	89	89

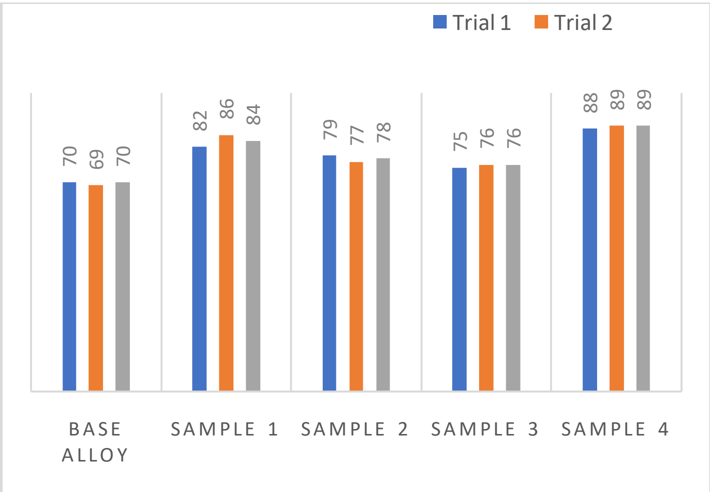

Figure 5.3 Hardness comparisons

Hardness test results compared in Fig. 5.3 indicate that the variation of hardness in the locations due to the uncertainty of reinforcement particles presence at the indentation location. The sample 4 with combination of 4% Aluminium oxide and 1% graphite with remaining Al 5052 is having higher hardness and base alloy has the lower hardness because of the absence of the reinforcement particulates.

C. Wear test

In the wear test the pin was pressed against the counterpart rotating against EN32 steel disc with hardness 65HRC. After running through a fixed sliding distance at specific time, the specimen was removed, cleaned and weighed to determine the weight loss due to wear. The difference in weight measured before and after the test gives the wear of the specimen. The volume losses were determined using the weight loss method.

Table 5.2 Weight loss for 2 kg load

Samples	Load (kg)	Speed (rpm)	Time (min)	Initial weight (gm)	Final weight (gm)	Change in weight (gm)
Base alloy	2	500	5	6.151	6.132	0.019
1	2	500	5	6.115	6.103	0.012
2	2	500	5	6.847	6.838	0.009
3	2	500	5	6.956	6.948	0.008
4	2	500	5	6.232	6.227	0.005

Figure 5.4 Time vs wear rate

From the Fig. 5.4 and TABLE 5.2 it is seen that the addition of particulate reinforcements such as Aluminium oxide and graphite into the Al 5052 matrix results in lesser wear rate. The hybrid composite exhibited superior wear resistance when compared with the base aluminium alloy Al 5052.

It can be seen that the sample 4 showed lesser wear rate when compared to other samples.

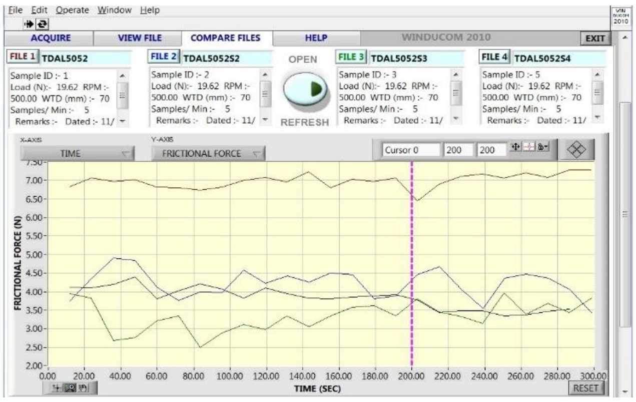

Figure 5.5 Time vs Frictional force

From the Fig. 5.5 it can be seen that the frictional force generated was greater for the base alloy when compared to composites for the same load, speed and time.

D. Wear morphology

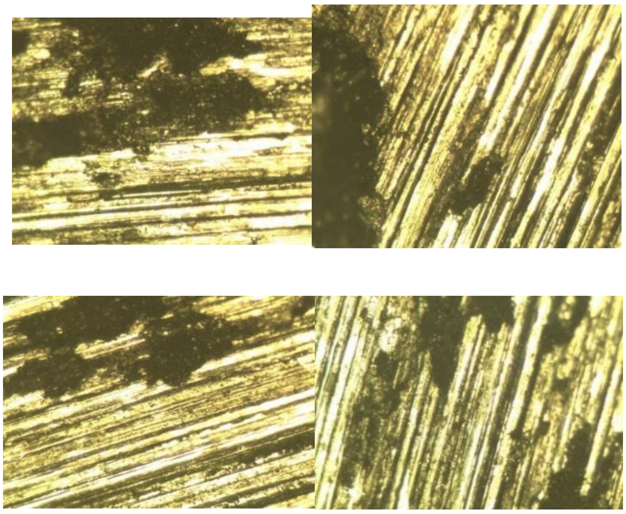

Figure 5.6 Microstructure of cast samples after wear test (Sample 1,2,3,4)

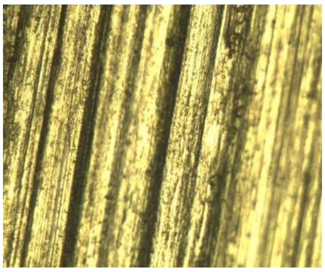

Figure 5.7 Microstructure of base alloy after wear test

Fig. 5.6 shows the presence of reinforcement particles over the weared surface which acts as a resistant to material's wear. Fig. 5.7 shows the surface of the base alloy after wear test is completed.

6.Conclusion

The hybrid composite samples of Al 5052 as matrix, Al_2O_3 and Graphite particulates as reinforcements were fabricated using stir casting process.The mechanical properties such as hardness, wear and microstructure were investigated from the fabricated samples. The microstructure analysis shows fairly even distribution of particles and some agglomerations of Al_2O_3 and Graphite.Composite having 4% Al_2O_3 and 1% Gr and 95% Al 5052 combination fabricated at melting temperature 675°C and reinforcement pre-heat temperature 300°C has higher hardness(89 HV) and superior wear resistance compared to other combinations. The maximum wear for base alloy is 72 microns whereas for the above composite,the maximum wear rate is 23 microns. This hybrid composite can be explored for use in applications where higher wear resistance is required.This project is focused in increasing the hardness and wear resistance of the aluminium alloys. The following may be adopted in future to explore further possibilities to improve the above properties.

1 The process parameters like stirring speed, stirring time, die pre-heat temperature, can be varied.
2 The percentage of reinforcements can be varied.
3 The same process parameters and percentage of reinforcements can be carried out using squeeze casting or vacuum casting method.

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