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Fabrication and investigation of hybrid composite metal matrix composite parameters on spur gears

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Abstract - **Nowadays gears are one of the most important parts in a mechanical power transmission system. This rotating element would be operated in different load and wide range of speed in its operating conditions. Gears are mostly failed when load is increased above certain limit. Gear materials are required adequate strength with weight reduction. Metal matrix composites possess improved properties including Mechanical properties such as high strength, high stiffness and reduction in weight could be improved by using metal matrix composites comparatively unreinforced alloy. Aluminum metal matrix composite (MMCs) materials are the appropriate material to meet such requirements. In this work, Aluminum, Titanium and Stainless steel hybrid metal matrix composites are prepared by stir casting method and studied mechanical properties. Experimental investigation is carried out on these composite gears. This composite would be improved tangential and compressive strength. The mechanical properties such as hardness and wear resistance are also determined. The result shows that reinforced stainless steel would give highest contribution in mechanical properties in its composites.**

Keywords — metal matrix composite, Al-Ti-SS, reinforcement, performance, spur gear

I. Introduction

The rapid growth of industries such as vehicle, shipbuilding and aircraft industries require extensive application of gear technology. Gears have a wide range of applications from light duty machinery to heavy duty machinery. This is one of the most critical components in a mechanical power transmission system and also to drive the most industrial rotating machinery. Hence it is required wide range of speed and torque in their applications. Gear teeth normally fail when increasing load above certain limit. In order to avoid such failures to increase the strength of gear. At the same time reducing its weight. Therefore it is required to explore alternate material instead of its metallic materials for gear manufacturing. Composite materials would provide adequate strength and also weight reduction. Nowadays manufacturing composite materials is an emerging field.

Aluminium alloys play a wide role in various engineering fields due to their weight proportion in fabrication and other mechanical properties like light weight, high stiffness, easy fabrication and high dimensional stability in molding and recyclability. Many reinforcements are used in metal matrix composite for imparting special mechanical and physical properties to enhance the matrix properties. This depends on the matrix material formation and their relative positions. Aluminum based metal matrix composite have high ductility and fracture toughness. Senthilvelan.S and Gnanamoorthy.R [1] prepared a composite material for making gears. Kwangjae Park et al [2] fabricated Aluminum (Al)-stainless steel 316L composites by the spark plasma sintering process. They examined the presence of these intermetallic compounds by using scanning electron microscopy and found formation of these intermetallic compounds as impotartant factor for high mechanical hardness.

While selecting a gear material other factors also be considered. They are the ability of the gear material to withstand high frictional temperature and less abrasive wear. Purohit et al [3] prepared Aluminium Silicon Carbide composite material and conducted experiment for tensile strength and maximum tensile strength has been obtained at 15% SiC ratio. The strength of the composite gears is modelled and analysed in finite element analysis concepts using Ansys software which required a number of assumptions and simplifications. Normally FEM analysis software was used for static structural analysis in order to determine the strength of the gear material at different composition under the different loading conditions [4]. Sharad. J.Chauhan [5] had an review on bending and contact stress analysis of helical gear.

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Paras Kumar et al [6] proved that fatigue life is less than the bending fatigue life for plastic gear [7]. They also pointed out that the failure of spur gear is associated with bending strength and contact surfaces [8]. Even through polymeric materials having less manufacturing cost and less weight compared with metal gears, it is having poor mechanical strength compared with metals. Vigithra.R [9] noticed that the toughness and hardness of the composite material by adding cement fillers. Pawar.P.B and Abhay A.Utpat [10] prepared aluminum silicon carbide composite material and noticed that the hardness and material toughness are enhanced by increasing silicon carbide content. While selecting a gears material considering another ability of the Gear material are withstand high frictional temperature and less abrasive wear [11,12]. Van-Ta Do et al [13] prepared composite material by using graphite fibers reinforcement with addition of bronze and copper powders for improving friction and wear properties. Singla et al [14] studied the properties of Al-SiC composite and they found that the wear rate decreases linearly with increasing SiC content. Al Qutub.M et al [15] studied wear behaviour of Al_2O_3 6061 composite under different sliding speeds and applied load using pin-on-disk. They found that higher load and higher concentration of Al_2O_3 particles lead to higher wear rates.

The main objective this work is to prepare Aluminum, Titanium and Stainless steel hybrid metal matrix composites by stir casting method and studied mechanical properties.

II. PREPARATION OF COMPOSITE MATERIAL

Stir casting method was selected to produce near net shape of metal matrix composite gears in a simple and cost effective manner. For this composite Aluminium-Grade7075 with particle size of 200µm, Titanium- Grade12 with particle size of 25µm and Stainless steel-Grade310 with particle size of 50µm materials are used. First the metal matrix composition is to be added and then the stirrer is switched on. The stirring speed to be maintained 550 rpm for uniform distribution of all metal matrix composite. These materials are added in powder form. Borax powder is added to metal matrix powder for attaining the wettability of the material. The composition is heated at 700° C temperature to melt the Aluminum alloy completely. This molten metal is then slightly cooled and maintained below its liquidus state. The molten solution is then checked for any large particles of Titanium and Stainless steel in Aluminium for fully mixed in the solution. Then the solution is slightly cooled below its liquidus to get viscous nature. After that the viscous nature of the material is poured into the pattern for obtaining required shape that is made in the mould. Then the solid material is taken off the mould and is machined for getting gears as shown in Fig.1. For preparing hybrid metal matrix composite by using stir casting process in the following weight basis percentage 90:6:4, 90:5:5, 85:10:5, 85:13:2 for Aluminium, Stainless steel and Titanium grade respectively have been taken.

Fig. 1 Photographic view of fabrication of composite gears

III. THEORETICAL CALCULATION OF SPUR GEAR

An attempt has been made to analytical calculations method for designing of gears. All parameters are taken from fabricated composite gear dimensions and its materials. Analytical calculations are derived for the spur gears to withstand tangential and radial load.

Radial load:

No of tooth =18

Module, m=4

Radial load, $F_r = \sigma_b . b . p_c . y$

Circular pitch, $p_c = 3.14\ x\ m = 3.14x4 = 12.566\ mm$

Face width, $b = 40\ mm$

Lewis form factor, $y = 0.175 - 0.841/z = 0.175 - 0.841/18 = 0.128\ mm$

Tensile stress, $\sigma_b = 350\ N/mm^2$ for alloy case hardened

$F_r = 350\ x\ 40\ x\ 12.566\ x\ 0.128 = \mathbf{22518.27\ N}$

Tangential load:

Tangential load,

$F_t = 22518.27/5 = \mathbf{4503.64\ N}$

IV. EXPERIMENTAL TESTING

Mechanical testing was carried out on the developed hybrid metal matrix composite material to study the mechanical properties such as tangential load, radial load, hardness and wear resistance.

A. *Testing of radial load*

For spur gears, the axial force acting on driven gear is equal to the radial force acting on drive gear. The radial and tangential load test conducted by hydraulic machine with capacity of 60 Ton as shown in Fig.2. The tested gear was placed in such a way that applying radial load with hydraulic force acted through the ram. This force was maintained constant load for a certain period of time then gradually increased. This process of incremental load

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increase continues until failure occurred and the applied load was taken for radial load. This method of test were conducted for all type of composite gears and the values are tabulated in the table 1.

Fig.2 Testing of radial load arrangement of gear

B. Testing of tangential load

Gear tooth bending test has been performed on the single tooth as shown in Fig.3. Tangential load is applied on the tangential direction of the gear tooth. The applied load is gradually increased on the specimen. At particular stage, the tooth failure was occurred and the beam strength of the specimen is noted. The noted value is tangential load of the specimen. Tests have been conducted on all four samples and tabulated the values in the table 1.

Fig.3 Testing of tangential load arrangement of gear

C. Testing of hardness

Hardness test were carried out on the metal matrix composite samples by using the standard Brinel hardness test machine. This hardness tests were carried out in order to investigate the influence of Ti and SS particulate weight fractions on the matrix hardness. The hardness test is obtained by applying a standard load to the surface of the gear material through a hardened steel ball of standard diameter. The Brinell hardness tester is shown in Fig.4. Five experiment readings were taken at five distinct places and the average value was taken as hardness value. The tested values are tabulated in the table 1.

Fig.4 Brinell hardness tester

D. Wear Test

The experiments were conducted at dry condition at room temperature on 6 mm diameter stainless steel ball pin-on-disc to obtain wear rate. Dry sliding wear test was performed with a load of 30 N at 200 rpm using a 60 mm track diameter. The parameters such as the load, sliding speed and sliding distance were same for all composite specimens. The wear rate of composite materials was listed in Table 1.

Table 1 Observation table for composite gears

Sample No.	Composition	Theoretical load in N		Experimental load in N		Average hardness in BHN	Wear rate g/m
		Radial	Tangential	Radial	Tangential		
A	90:5:5	22518.27	4503.64	20502.9	4218.3	86	0.00848
B	90:6:4			20699.1	4296.8	82	0.00794
C	85:10:5			21091.5	4316.4	89	0.00462
D	85:13:2			20797.2	4321.5	91	0.00438

V. RESULTS AND DISCUSSION

The gear parameters were determined using testing methods and also compared with analytical results. Theoretical values of radial load and tangential load were calculated only for specimen A. Experimental values of radial load and tangential load for this specimen are very close to each other shown in Table1. Experimental values are plotted the graphs as shown in Fig.6, Fig.6, Fig.7 and Fig.8.

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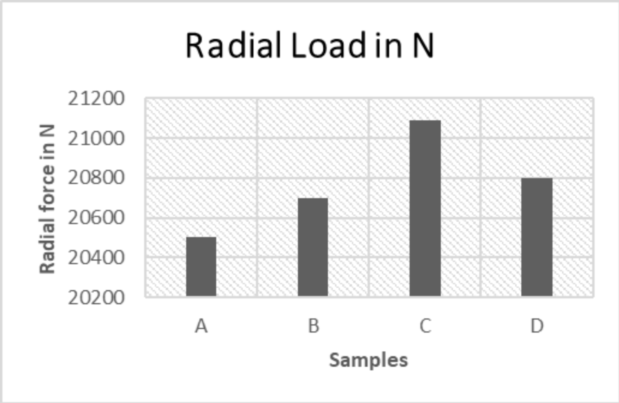

Fig.5 Radial loads of different specimens

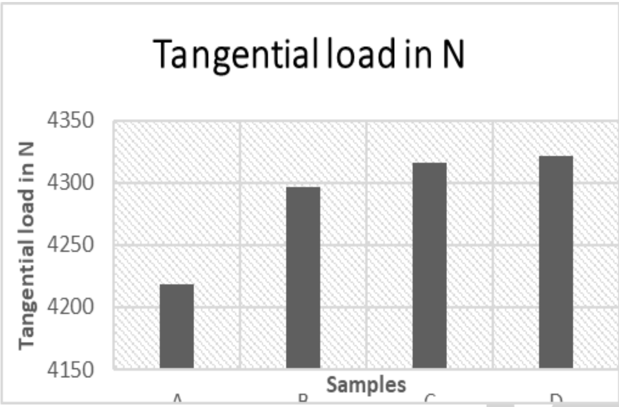

Fig.6 Tangential load of different specimens

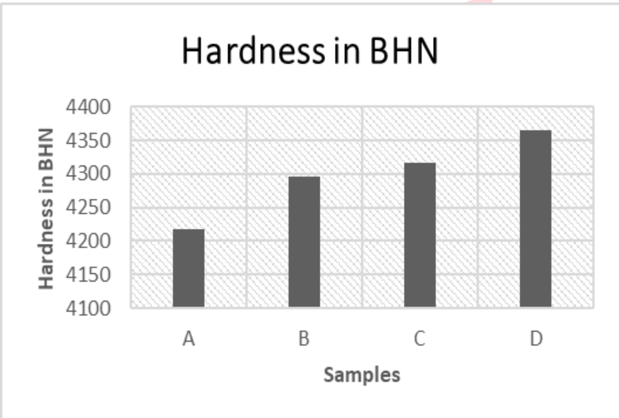

Fig.7 Hardness value of different specimens

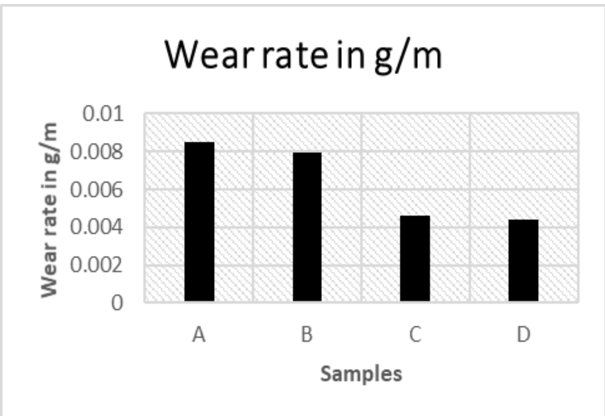

Fig.8 Wear rate value of different specimens

The results of the radial load on all specimens of hybrid metal matrix composite were compared with its weight fraction as shown in Fig.5. It is also observed that radial load is increased when increasing stainless steel composition. It shows that the Stainless steel is having more density and the particles spread uniformly around the circumference of the gear as well the better adhesive bonding between the constituent particles would extend of its fracture. The maximum strength on radial load is specimen C. Results showed that Stainless steel and Titanium content varies from 10% to 15% by weight as reinforcements percentage increases, composite became stronger.

Tangential load tests are conducted on composites of different combinations of reinforcement of materials. Fig.6 shows tangential loads and contribution of Titanium and Stainless Steel nano particles reinforcements for all the specimen gears. It is observed from the graph Fig.6 that tangential load is maximum for specimen D. For increasing percentage in the tangential load, Stainless steel would have double the amount compared to Titanium in the specimen C as shown in Fig.6.

The hardness is higher in specimen D when compared to other test gears as shown in Fig.7. When stainless steel and Titanium added to Aluminium would give higher mechanical strength than aluminum because of its higher density. From the chart as shown in Fig.7, the hardness of the all samples are increased while increasing the percentage of Titanium and Stainless Steel nano particles. But for samples B to C the hardness are the same because of not denser reinforcement particles.

Fig.8 shows the effect of weight fraction of composite particles on the wear behavior of composite materials. The wear rate of hybrid composite was significantly reduced by increasing in the weight fraction of Titanium and Stainless steel particles. The higher amount of wear rate was obtained from all specimens is A specimen and the lower amount of wear rate was obtained from all specimens is C specimen. Results showed that the decreased wear rate with increased weight fraction of Stainless steel content on composites. From the graph as shown in Fig.8 wear rate decreases while increasing the percentage of reinforcements of Titanium and Stainless Steel nano powder particles. From the graph as shown in Fig.8, 5% of Titanium and 10% of stainless steel and 2% of Titanium and 13% of stainless steel having the same wear resistance. It shows that stainless steel particles influence more on the properties of hybrid metal matrix composite.

VI. Conclusion

Hybrid metal matrix composite material spur gears were developed by stir casting process. The comparison of different weight fraction of hybrid metal matrix composite on spur gear is investigated. The experimental results were compared with analytical results are found closer. Based on the investigation, it is fount that stainless steel particles

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influence more on the properties of hybrid metal matrix composite. It is also observed that Stainless steel and Titanium content varies from 10% to 15% by weight as reinforcements percentage increases, composite became stronger.

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