EXPERIMENTAL INVESTIGATION OF FRACTURE CHARACTERISTICS OF Al-Mg/Gr-SiCp COMPOSITE SPUR GEAR FOR LIGHT DUTY APPLICATIONS

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May 5, 2020

Abstract

Al-Mg/ (Gr+SiCp) composite material test specimens and gears using the liquid based stir casting process. The three particle sizes (10µm, 35µm and 65µm) and two weight fractions (5 and 10) of silicon carbide particle were reinforced in to the Al6061 and 2.8 wt. % of magnesium matrix metal alloy. Graphite was also added before the stirring to increase the wear resistance of the material during turning and hobbing of gear blanks. The fracture toughness was evaluated using Charpy impact test (ASTM E23 standards). The Charpy impact test was carried out for understanding the influence of SiC reinforcement with Al/Mg alloy. The results shows that reinforced aluminium matrix composite material having highest fracture toughness with lower contribution of ceramics SiC and increased in particle size than other composition.

INTRODUCTION

GLIGORIJEVIĆ (1976), have declared that selection of material and selection of process are playing vital role to design industrial products. It is very difficult to select the suitable material for different products out of wide range of material availability. Selection of materials should require some considerations/ factors like engineering design, mechanical properties, machinability, formability, cost effective, availability, market trends, recycling should meet the functional requirements, etc. ELECTRA – a computer model is the suitable one for selecting gear materials considering many factors and functional requirements, performance indices. Selection of Gear material requires use of six indices: surface fatigue limit index, bending fatigue limit index, surface fatigue lifetime index, bending fatigue lifetime index, wear resistance of tooth flank index and machinability index.

Jameel Habeeb Ghazi (2013), produced the aluminium silicon carbide particulate MMC containing the 7, 14, 21 wt. % of SiC_p(100-150 µm). He found the addition of Mg provided good wettability and improved uniform distribution of SiC_p. The result obtained showed increase in hardness, yield strength and ultimate strength by increasing wt. % of SiC_p. The addition of SiC showed a tendency to decrease the impact energy. Habibur Rahman & Mamun Al Rashed (2014), studied the characteristics of aluminum matrix composites reinforced by silicon carbide particle (below 74µm and above 53µm) through stir casting. The hardness, wear resistance and tensile strength of reinforced material were found to be higher than the unreinforced one. The microstructure studies revealed the presence of some non-uniform distribution and clustering of SiC_p.

YU Xiao dong et al. (2007), have investigated the effects of the influence of particle size on the mechanical properties of the Al 5210-SiC composite and the particle sizes used were 10, 28, 40 and 63 µm. The bending strength and the fracture toughness of the composite materials were found using a MTS test machine and three specimens were tested. The authors concluded that particle size increased, followed by a decrease in the bending strength because of defects encountered in larger particles. Fracture toughness was found to be directly proportional to the particle size. The main failure mechanism changed from the interface deboning to crack of ceramic particle, when the ceramic particle size changes from 10 to 63 µm. Tamer Ozben et al. (2008), made analysis of the density, toughness, hardness and tensile stress properties of 5, 10, 15 wt. % of SiCp reinforced with AlSi7Mg2 through the casting route. They found the addition of Mg in aluminium MMC causing an increase in wettability between matrix and SiC and providing a high bonding strength. The effect of SiCp reinforcement ratio on machining and the effects of operating parameters such as cutting speed, feed rate and cutting depth on wear of tools and surface roughness were investigated. The results showed the surface roughness as greatly affected by the addition of SiC. Cheng-hong Peng et al. (2011), analysed the tooth fracture of the 30CrNiMo8 steel gear used in steel plant rolling mill decelerator. The same gear was designed for a 25 year life. The gear tooth fracture was analysed by a chemical test, microstructure analysis, hardness and impact analysis. The studies explained that the uneven distribution of MnS, low content of Cr than the requirements and presence of coarse grain in 30CrNiMo8 steel gear. They stated that the quenching temperature reached more than the requirements, leading to reduce the toughness and increase the notch sensitivity. From fractography tests, they understood that this tooth fracture belonged to fatigue brittle multi source fracture and also found that some standardized heat treatment is required to prevent tooth fracture.

Experimental Work

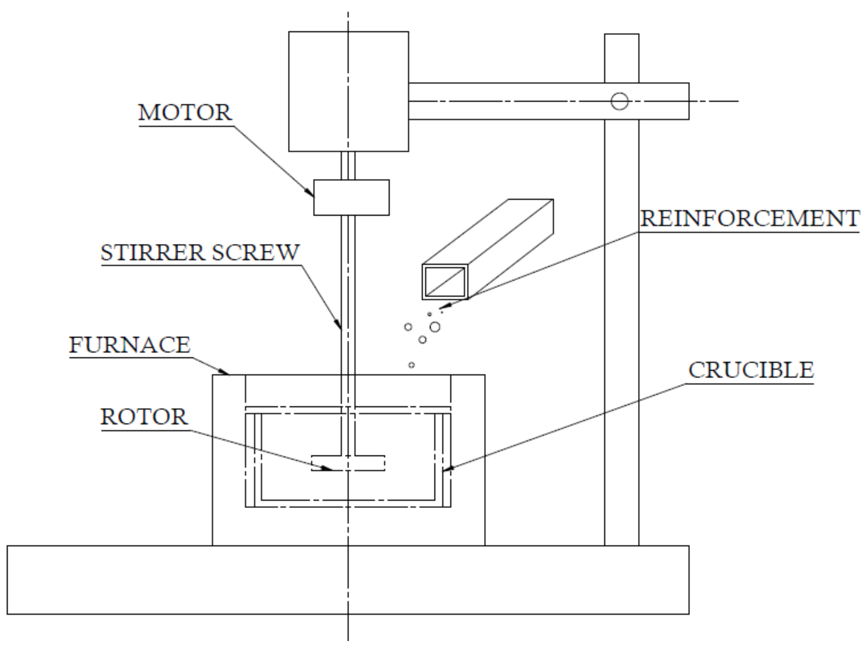

Figure 1 Stir Casting Setup

The stir casting setup consisted of an electrical induction furnace and a stirrer. In the liquid state stir casting process, the preparation of tools is an important step. The spoons and stirrer used for the operation were coated with wool fur coat in order to avoid the aluminium melt from getting stickled to the stirrer. After coating, the coated stirrer and spoons were placed inside the furnace and a temperature of 100@ C was maintained for one hour. This was repeated for two hours at 300@C. Then, the stirrer and the spoons were allowed till the room temperature is reached. The crucible was placed in the furnace with aluminium billet and furnace temperature was set to 741@C. The size of the crucible was chosen as maximum of 2 kg to suit the furnace.

SiC powder was preheated to 400@C by a preheater, having an operating range of 40@C to 700@C and the same was maintained at 400@C for an hour. Then the weighed magnesium billet was wrapped in aluminium foil and was added to the completely melted aluminium. When magnesium is added directly to aluminium melt, it is inflammable and may catch fire due to huge temperature difference. Magnesium was used for improving wettability between the aluminium melt and SiC. After this process, preheated SiC_p was taken out from the preheater. The stirrer was fixed and the stirrer speed was set at 700 rpm. After vortex formation, preheated SiC powder was added to the melt slowly, ensuring that SiC power did not stick on the crucible walls. After complete addition of SiC, the stirrer was rotated for ten minutes to enable uniform mixing of SiC_p with aluminium melt. Then, crucible was taken out from the furnace using tongs. The melt was poured into the top gate of the already prepared sand mould cavity.

The stir cast gear blank in this investigation had a dimension of 120 mm outer diameter and thickness of 25 mm. The gear blank was then turned to dimensions of 110 mm outer diameter, 20 mm thickness and 30 mm internal diameter using an inserted tool. A discontinuous chip was formed during turning. The turning process revealed the very poor machinability of the material. It also showed chatter markings at various places. Then the gear was hobbed at a feed of 0.8 mm/rotation, speed 113 rpm and depth of cut of 0.5 mm. The gear teeth had some material defects at one face. The hard face ceramic particles developed the localised strengthen area leading to poor machinability of MMC. Some blow holes were observed because of improper solidification between liquid and ceramics. Agglomerates were formed as a result of improper stirring. Stress concentration occurred in that area and there was a greater chance of material failure during machining. Then, graphite was added in material composition as an extra component to improve machining capability material before stirring because it has lower density than aluminium alloy. Graphite is the well-known solid lubricant, which facilitates machining and reduces the tooth wear. The compositions of the material used for making two pieces in each material composition are given in Table 1. The specification of the gear made is as follows

- Pitch circle diameter = 106 mm
- Number of teeth = 53
- Module = 2 mm
- Profile = Involute
- Pressure angle = 20@

Figure 2 Machined Gear Blank and Al-Mg-Gr - SiC_pSpur Gear

A few changes were made in the casting process also. The crucible size was changed from size 4 (2 kg) to size 3 (1.5 kg) to ensure the efficient heating. The stirring time was increased from ten minutes to twenty minutes in order to reduce clustering of hard particles. At the same time, the furnace area was protected from the atmospheric contact to prevent higher oxidation during stirring. The machined gear blank and MMC gear are shown in Figure.2 Based on the observations, the remaining casting methods were modified and various material composition of spur was prepared as given in Table 1.

Table 1 Material Composition for Al+Mg/(Gr+SiC_p) MMC

Material	**Density kg/m^3**	**Weight kg**	**Weight kg**	**We**
		Al-2.8 wt. % of Mg	**Al-2.8 wt. %of Mg/ (2.5 wt. %of Gr + SiC_p) 5 wt. % of SiC**	**Al- 10**
Billets of Al 6061	2700	1.552	1.438	1.36
Magnesium	1783	0.0448	0.0414	0.03
Graphite	2230	-	0.040	0.04
SiC_p	3200	-	0.080	0.16
Total Weight	Total Weight	1.6	1.6	1.6

TESTING

Mechanical testing was carried out using the developed material to verify the mechanical properties such as hardness, brittleness, plasticity, elasticity, toughness, wear resistance and strength. The design data parameters were determined using testing methods and also used in conceptual design of the machine elements. Testing was done to ensure quality control, alloy and new material development processes and provides the failure analysis data of the engineering components. Two types of testing methods were used, namely, the destructive type and the non-destructive type. The manufactured MMC gear and specimens were subjected to one of the destructive type mechanical testing to find the toughness. This gear testing results were used for obtaining design data, failure analysis and effectiveness of new material alloy development. The testing principles and results are explained in the following sections.

Charpy Impact Test

The capacity of the material to continue the operation without any sudden premature damage and full functional failure is related to the fracture toughness of material, which is used in gear mesh power transmission. In general, the design concept has never permitted the gear material with high brittleness or high strain rate sensitive. This has been verified through fracture toughness measurement. The impact test method (either Charpy test or Izod test) can be used for measuring the toughness and notch sensitivity of the engineering materials. Notch sensitivity refers to the tendency of some normal ductile materials to behave like brittle materials in the presence of notches. In an impact test, a notch is cut to a standard test piece gripped like three point bending in anvil, which is stuck by a single blow in an impact testing machine. Then, the energy absorbed in breaking the specimen can be measured using the scale provided on the impact testing machine. The test specimen is machined according to ASTM E23 standards with full size of 10 mm X 10 mm X 55 mm from the cylindrical stir casting Al-Mg-Gr/SiC MMC material as shown in Figure 3. The V notch angle was cut by the hacksaw blade. The V notch angle was 4545^{o} and the depth of the V notch was 2 mm.

Figure 3 End Milling of MMC Specimen	**Figure 4 Charpy Impact Test**

Testing Procedure

The specimen was gripped horizontally in the anvil like three point bending as shown in Figure 4. The pendulum hammer was raised to a known standard height depending on the type of specimen to be tested. Initially the energy stored in the pendulum was set as 300J. The loose pointer attached to the pendulum was set to read zero on the scale. The pendulum was then released by the trigger. The pendulum breaks the specimen and continues to swing due to residual energy, carrying forward the loose pointer along with it. When the loose pointer comes to rest it gives a direct reading of the fracture toughness in Joules and has been tabulated in Table 2.

Table 2 Impact Energy

Sl.No.	Material Composition of MMC spur gear	Impact Energy (J)
1	Al 6061-2.8 wt. % Mg	3
2	Al 6061-2.8 wt. % Mg- 2.5 wt. % Gr – 5 wt.% 10 µm SiC	9
3	Al 6061-2.8 wt. % Mg- 2.5 wt. % Gr – 10 wt.% 10 µm SiC	8
4	Al 6061-2.8 wt. % Mg- 2.5 wt. % Gr – 5 wt.% 35 µm SiC	7
5	Al 6061-2.8 wt. % Mg- 2.5 wt. % Gr – 10 wt.% 35 µm SiC	8.5
6	Al 6061-2.8 wt. % Mg- 2.5 wt. % Gr – 5 wt.% 65 µm SiC	12
7	Al 6061-2.8 wt. % Mg- 2.5 wt. % Gr – 10 wt.% 65 µm SiC	10

Effect of Addition of SiC_p on Fracture Toughness of Spur Gear

The very important design considerations in gear materials are high surface hardness and high toughness nearer to the root area of the gear. The toughness values measured in terms of impact energy are plotted in Figure 5. When the SiC_p wt. % was increased from 5 to 10, the impact energy decresed due to high brittleness. Theoretically higher wt.% of SiC has a tendency to increase hardness and decrease toughness. The results showed the association of the toughness with changes in the particle size of SiC. Increase in grain size directed the increase in the space between the particles, to enable elastic deformation of the aluminium matrix with a longer duration instead of a brittle fracture. The contribution of ceramic particle for elastic deformation was very small. At the same time, there was increase in the fraction of ceramic cracking during the fracture. This pheonamenan had a smaller likelihood for contribution and reduced toughness to some extent. At the result, the couple effect of the two was achieved to enhance the fracture toughness of AMC materials.

[CHART]

Figure 5 Influence of wt.% and grain size of SiC_p on Impact energy

CONCLUSION

This investigation explains the experimental procedure applied for the production of Al-Mg/ (Gr+SiC_p) composite material test specimens and gears using the liquid based stir casting process. The three particle sizes (10µm, 35µm and 65µm) and two weight fractions (5 and 10) of silicon carbide particle were reinforced in to the Al6061 and 2.8 wt. % of magnesium matrix metal alloy. Graphite was also added before the stirring to increase the wear resistance of the material during turning and hobbing of gear blanks. The Charpy impact test was carried out for understanding the influence of SiC reinforcement with Al/Mg alloy. Initially, some material wear was observed in AMC spur gear without any addition of graphite. Then, graphite (2.5 wt. %) was added to improve the machinability and reduce the tooth wear during hobbing. Graphite content same wt. % (2.5) was added in all AMC spur gears to enable explanation of the effectiveness of SiC reinforcement with respect to toughness properties as follows.

The highest fracture toughness of 12 J was measured in 5 wt. % and 65 µm SiC AMCs. This was about 300% higher than base Al 6061+ Mg alloy.

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