EVALUATION OF WEAR BEHAVIOR OF A NONMETALLIC SPUR GEAR

Jagannath Sardar, Dibakar Bandopadhya∗

Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati-781039, Assam, India, j.sardar@iitg.ac.in

*Corresponding author’s e-mail: dibakarb@iitg.ernet.in, Phone No.: +91 361 2582653, Fax: +91 361 2582699

Abstract

A thermoplastic composite material designed and developed for fabrication of nonmetallic composite spur gear. The composite is fabricated using Portland pozzolanic cement (PPC) as filler material into the polypropylene matrix followed by Injection molding technique. However, geometrical structure of the developed product depends on the parameter like loading-unloading condition and temperature fluctuation that severely influence the material performance and shorten the product life. In the present work, the composite spur gear material tested to evaluate its friction and wear characteristics in adhesive and abrasive wear modes. Weight loss due to wear of the composite gear is evaluated through direct measurement under a specific load and running condition. It is observed that the adhesive wear rate significantly reduced when the cement filler loading increases. This is because shear strength and surface energy of the composite material changes while toughness and hardness of the material improves due to strengthening by cement fillers.

Keywords: Composite, spur gear, coefficient of friction, wear

1 Introduction

Over the past decade, polymeric composite gears attract high attention due to their specific characteristics such as less weight to power consumption, low cost, durable, ease of processing and fabrication etc. over metallic gear.

Researchers have proposed and developed non-metallic gear as an alternative to metallic gear because of their superior advantages on wear and fatigue characteristics (Duzcukoglu et al., 2009, Hoskins et al., 2011, Kirupasankar et al., 2012). Mendi et al., 2006, demonstrated that due to reinforcement, and residual compression stress in the tooth profile is more effectual in increasing the fatigue strength. Mao (2007) has also discussed the detail fabrication of polymeric composite gears using various materials such as glass and carbon fiber reinforced Nylon 66 and Acetal. Research emphasized on the effect of various parameters on the performance of the composite gear such as fiber length, gear tooth fillet radius, topography, fatigue and failure, tooth deflection, friction and wear etc. Few researchers determined the polymeric composite gear wear with respect to metallic gear by either bending strength or surface durability (Chauhan et al., 2010).

Wright and Kukureka, (2001) have also exhibited similar works. Their work mostly encompasses the performance of the fibre-reinforced polyamide-66 composite gear, detailing on the wear performance. However, the work remains untouched on influence of filler percentages as well as filler aspect ratio on the tensile properties. These parameters significantly influence the mechanical properties of the composite materials for gear fabrication and its performance.

Further, these composite materials not only weight effective but also possess exceptional characteristics of corrosion and fatigue resistant characteristics. However, significant contribution can be achieved by designing composite materials which proves superior cost-effectiveness compared to conventional metals (Deo et al., 2001, Breeds et al., 1993). A number of literatures have been reviewed, however, very few literatures have shown the direct evaluation of wear characteristics of polymeric composite gear. Further, past researches indicate that, none of the procedures highlighted well with the experimental results.

The main objective of the present work is to design and develop a composite material spur gear using very inexpensive polypropylene and cement materials that substitute the need of metallic gear in industrial applications of specific purpose. The composite materials not only reduce the weight but also possess excellent characteristics of corrosion and fatigue resistant. Further, on selecting large series production of these gears, large cost saving seem also feasible. Thus, a technology demonstration is carried out successfully employing injection-molding technique for fabrication.
of complex shaped damage tolerant composite material gear for light to medium duty device application. However, three different weight (5, 10, 15) % of fillers are chosen apart from pure polypropylene to fabricate the gear.

Fabricated composite material undergoes several experiment to evaluate wear properties under Tribometer, wear & friction monitor (TR- 201, DUCOM) following both adhesive and abrasive friction wear mode with different loading conditions.

The composite spur gear is subjected to wear test to evaluate its performance during running conditions. Direct gear wear characteristics have been evaluated by weight reduction process after a certain run of a gear pair under 13.5 N and 8.5 N load. Few rotational speeds have been selected for this experiment and the final weight loss has been measured by Analytical Balance. It is observed that out of three variations, 10 wt% PPC composite gear material exhibit optimal wear properties compared to other percentage selected.

2 Investigation on wear behavior of composite gear materials

Initially, graded homopolymer, H110MA is used with grafted polypropylene (OPTIM-P-425) for improvement of fair bonding between the polymer and cement particles. PPC cement solution is prepared using distilled water with water to cement is taken 3:1 proportion. The solution is then stirred up for 45 min in an ultrasonic chamber and then piled up with the polypropylene matrix in a steel bowl for 30 min. Subsequently, cement solution and the polypropylene granules are cooked at 100°C until the cement particles are fully coated on the surface of the polypropylene granules. Details of the fabrication procedure can be found in the literature (Sardar and Bandopadhya, 2014). The processed materials are then dried at room temperature for 72 h in order to remove the entrapped moisture in the materials. The composite gear is then fabricated using injection molding process (TEXAIR, JTS 40). Chosen composite gear materials include; pure polypropylene, 5%, 10% and 15% cement reinforced polypropylene composite materials are considered for the friction and wear evaluation. Two different procedures have been adopted to evaluate and study the wear behavior of the composite gear materials:

(a) Adhesive friction wear and
(b) Abrasive friction wear.

2.1 Experimental evaluation of wear

Tribometer, wear & friction monitor – TR- 201, DUCOM is shown in the Figure 1 (pin-on-disc type) is used to investigate the adhesive and abrasive friction wear performance for the gear materials. The counter body of the instrument is a disc made of stainless steel (AISI 316 L stainless steel, hardened to 55 HRc). The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. Testing is carried out as per ASTM G99 standard. The experimental setup is shown in the Figure 1.

2.2 Adhesive wear

The friction force is measured with the force transducer fixed on the loading lever arm. Both the friction & wear testing are conducted at a constant load of 2 kgf (19.6 N) and 3 kgf (29.4 N) with a constant sliding velocity of 0.5 m/s at room temperature. Wear tests are conducted up to a sliding distance of 1000 m. The material loss from the composite surface is measured using a precision electronic balance with an accuracy of ± 0.01 mg. The specific wear rate (m3/Nm) is then expressed on ‘volume loss’ basis as given in the eqn. (1) (Bahadur and Polineni, 1996):

\[ K_w = \frac{\Delta m}{S \rho g F_n} \times 1000 \]  

(1)

Where, \( K_w \) is the specific wear rate (mm3/Nm), \( \Delta m \) is the mass loss (g) within the test duration, \( \rho_g \) is the density of the composite (g/cm3), \( F_n \) is applied normal load (N), \( S \) is the sliding distance (m). The variation of coefficient of friction (\( \mu \)) of the pure polypropylene and its composites with sliding distance is shown in Figure 2 (a) and (b). Similar effect can be observed in case of abrasive wear as shown in the Figure 3 (a) and (b).
distance. The coefficient of friction is in the range 0.2 - 0.3 in all the cases matching with the results of earlier researchers (Ferreira et al., 2001). Thus, it is anticipated that transfer film on the counter material plays a significant role in influencing wear mechanism (Myshkin et al., 2005). After the formation of transfer film on the counter face material, coefficient of friction reached steady state. As the sliding distance increases, the real area of contact increases as close as to apparent area of contact due to the asperities deformation. When two surfaces approach each other, initially their opposing asperities with maximum height come into contact. As the time increases, new pairs of asperities with lesser height make contact forming individual spots (Sugimoto et al., 2007).

![Figure 2 Coefficient of friction evaluated for an applied load (a) 19.6 and (b) 29.4 N](image)

2.3 Abrasive friction wear

Silica carbide abrasive emery paper of 320 grit size is used for this test. The emery paper is firmly attached on the stainless steel (AISI 316 L stainless steel) disc to alter from adhesive to abrasive counter surface condition. The abrasive wear tests are conducted under 9.8 and 19.6 N normal loads at 0.5m/s sliding velocity. The laboratory condition remains to be normal room temperature and 60% relative humidity for the experiment. The experiment is conducted up to a sliding distance of 1000 m. The volumetric wear rate is quantified by mass loss as stated in the eqn. (1).

![Figure 3 Coefficient of friction on abrasive mode under applied load (a) 9.8 N and (b) 19.6](image)

2.4 Influence of loading conditions on specific wear rate

In order to understand the influence of normal load and sliding velocity, coefficient of friction and specific wear rate is plotted against two different applied normal loads during wear test. The coefficient of friction, of all the gear materials for adhesive and abrasive wear properties, decreased with increase in normal load (Figure 4 and Figure 5). This behavior is due to the low sliding resistance offered by the specimen asperities at higher normal load. In spite of decrease in friction coefficient, specific wear rate of all the test gear materials increased with increase of normal load as shown in the Figure 4 and Figure 5. Further, it is observed that under same loading conditions, PPC reinforced composite gear materials exhibit less specific wear rate than unreinforced polypropylene, comparable to abrasive wear as well. The same trend has also demonstrated in the Figure 5. It is observed that 10%
cement filled composite material exhibits less specific wear rate than pure polypropylene.

![Figure 4 Variation of specific wear rate with applied normal load in adhesive wear](image1)

However, one can observed from the Figure 5 that 15% cement filled composite exhibits little more specific wear rate compared to 10% cement filled composite gear material. It is anticipated that due to the removal of PPC particles at running condition as loading % of PPC is higher when emery paper is used.

![Figure 5 Variation of specific wear rate with applied normal load in abrasive wear](image2)

However, this is not observed for adhesive wear as shown in the Figure 4, it is observed that the specific wear volume decreases with increase of loading of filler materials in polypropylene. Further, specific wear rate is increased when the applied normal load increases.

3 Evaluation of gear wear: direct from the tooth profile

For evaluation and measurement of wear due to friction in dynamic condition, a setup is developed equipped with an Infrared assisted camera, IR-TCM 384. The gear pair meshing in dynamic condition is shown in the Figure 6. The composite spur gears are subjected to the dynamic test and wear loss is evaluated by weight loss measurement. In dynamic condition, the gear pair runs at high speed, results in high friction between the gear pair at the contact tooth point, leads to wear of the material. These wear characteristics further aided by temperature arising, as a result, the gear performance starts to fall, which results in shorting of the gear life. This pros and cons are more applicable to the metallic gears. To remediate this problem, polymeric composite gears come in core interest to replace the metallic gears. The photographs of intact tooth profile and tooth profile after test have been given in the Figure 7.

![Figure 6 Gear pair meshing at dynamic condition](image3)

![Photograph of intact tooth profile](image4)

![Photograph of tooth profile after test](image5)
3.1 Results and discussions

From both intact edge profile and edge profile after test, are taken into account, and the weight loss due to wear and wear volume have been calculated for all the samples for two variable loading conditions i.e. 13.5 N and 8.5 N. The graphical expressions for both the cases are highlighted in the Figures 8-9 and Figures 10-11 respectively. Weight loss due to wear and wear volume of pure polypropylene gear is showing the highest value at elevated rpm. At 2500 rpm, both the parameters, weight loss due to wear and wear volume are highest in comparison with other running speeds. The reason is that the engaged tooth pair comes in contact more frequently when the running speed is 2500 rpm as compared to other variable speeds. Due to repeated contact, more friction takes place between the common tooth pair with less time as compared to other speeds. One can notice that, the 10% and 15% cement filled composite gear is giving relatively same results when running speeds are 1200, 1800 and 2500 rpm. However, when the running speed is 600 rpm, 15% cement filled composite gear gives lowest weight loss due to its significant higher stiffness and shear modulus compared to other materials. The weight loss i.e. volumetric wear of 10% cement filled composite gear is significantly less as compared to pure polypropylene and 5% and nearly equal to the 15% cement filled composite gear. This is because of comparatively lower coefficient of friction of 10% and 15% cement filled composite as compared to the other materials reported in this work.
4 Conclusions

The fabricated thermoplastic composite material and its gears have undergone several experiments to evaluate the performance and properties for industrial applications. It is observed that the 10% cement filled composite material gives optimum wear and fatigue performance because of its high stiffness ratio compared to pure polypropylene and 5% cement filled composite material though inferior to 15% cement filled composite materials.

The weight loss due to wear and wear volume have been calculated directly by weighing after running the gears at elevated speed under variable loading conditions. It is found that 10 wt% composite spur gear shows less weight loss due to wear friction during running. Thus, 10% cement filled composite material gear is better suitable to fabricate the non-metallic spur gear for industrial application.

References


