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Comparison of wear behavior of ABS and ABS composite parts fabricated via fused deposition modelling

M. N. Sudin [1, 2, *], F. R. Ramli [1, 2], M. R. Alkahari [1, 2], M. A. Abdullah [1, 2]

[1]*Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia*
[2]*Center for Advanced Research on Energy (CARe), Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia*

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ABSTRACT

Since, the material wear is an important phenomenon influencing the functionality of a part, this research was carried with the aims to study the friction and wear behaviour of parts made of ABS composite material by FDM. This study also compare the friction and wear behaviour of ABS composite with the existing acrylonitrile butadiene styrene (ABS) filament of the FDM machine. The experiment was carried out on the pin-on-disk apparatus according to ASTM G99-04 standard under dry sliding condition that were carried out at room temperature. The load was varied (5, 10, 15 and 20 N) at speed of 286 RPM for the run time of 3 and 5 minutes. The results shown that the applied load and run time significantly affect the wear rate, friction force and friction coefficient of the test samples. Based on the experiment, carbon fiber reinforced ABS specimens showed better wear resistance and durability comparing to pure ABS specimens. This research could be useful to develop a better wear resistance component for various fields of applications.

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1. Introduction

Tribology is the science of bodies in relative motion that involves friction, wear and lubrication (Gustafsson, 2013). Friction and wear are reactions of a tribology system that are represented by coefficients of friction and wear, respectively. In reality it is hard to predict the friction and wear between bodies from material parameters and geometry, since, most of materials may change their characteristics under friction and wear. Theoretically, the coefficient of friction is proportional to the normal load. Though, this criteria is just satisfied for some polymers under specific conditions, thus it is difficult to generalize the results since it differs from polymer to polymer. In general, the result might be that friction is constant or decrease/increase by the normal load. The wear of polymers is a complex process which is related to the formation of the transfer film. The wear is quantitatively measured in terms of the mass, or volume, loss from a sliding or eroding contact. Wear types for polymers are mainly adhesion, abrasion and fatigue. The adhesive wear of polymers relates to the formation, shearing and rupture of the adhesive junction in the contact spots. When a material slides against a polymer a transfer film is developed due to rupture of polymer and adheres to the opposite counter face and in turn influences on friction and wear (Sinha and Briscoe, 2009). This happens for most of the polymers except the highly cross linked and some glassy polymers (Briscoe, 1983). Abrasive wear is defined as wear by displacement of material through relative motion between the surfaces. This wear occurs from hard asperities from one of the material or can also derive from hard particle embedded in one of the materials. Fatigue wear arise from repeated cyclic stresses in the material. The crack propagation starts at the point with highest tangential stress or tensile strain. The fatigue wear only involves the region close to the surface.

In recent years, research have focused on developing surface-modified engineering polymers and nano-composites because of new technology that enhances the tribological behavior by changing the molecular or matrix structure to change the surface or bulk properties (Brostow et al., 2010; Khan et al., 2009). Plastics are often reinforced with fillers, additives, binders, and very recently researchers have shed light on adopting electroplating as a technique for enhancing the

* Corresponding Author.
Email Address: nizamsudin@utem.edu.my (M. N. Sudin)
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strength of materials. The present of reinforcement material have a positive effect on friction but particularly for the combination of reinforced polymers and steel. Reinforcement increases the strength of the material which in turn reduces wear dramatically. The best reinforcement material is carbon fiber with lubricating properties, but also glass fiber has similar characteristics of the wear rate (Kukureka et al., 1999). Polymer materials when reinforced with high modulus fibers yield higher strength, higher stiffness, better toughness, and good dimensional stability. Fiber reinforcements are effective in reducing wear in adhesive situations in addition to increasing the strength and stiffness. The adhesive conditions are generally encountered in automotive and aerospace applications. In such applications, the types of reinforcement material used are important from the point of improved performance under different tribo situations. Suresha et al. (2006) compared the tribological properties of carbon-epoxy (C-E) composite with that of glass-epoxy (G-E) composites based on a pin-on-disc experimental set up. C-E composites show lower friction and lower slide wear loss compared to G-E composites irrespective of the load or speed employed.

Fused deposition modelling (FDM) is one of the proficient technologies among all rapid prototyping (RP) processes due to its capability to build durable end-use parts with reasonable mechanical strength. FDM process has the ability to develop 3D complex geometry accurately with less time and material waste without any tooling requirement and human interface. However, mechanical wear unfavourably affects the durability and lifespan of the FDM build part when used as an end-use part. Garg and Singh (2015) studied the friction and wear behaviour of parts made of newly developed Nylon6-Fe composite material by FDM. The comparison of the friction and wear characteristics of the Nylon6-Fe composite with the existing acrylonitrile butadiene styrene (ABS) filament of the FDM machine was also carried out. This experiment was carried out on the pin on disk setup by varying the load (5, 10, 15 and 20 N) and speed (200 and 300 r/min). They concluded that the newly developed composite has higher wear resistant than pure ABS material. A comparison of the tribological properties of Nylon6-Al-Al_2O_3 and ABS parts fabricated using the fused deposition modelling (FDM) method under dry sliding conditions at room temperature, the sliding wear behavior of FDM-built parts with three different proportions of Al and Al_2O_3 was investigated. Loads of 5, 10, 15 and 20 were applied at a sliding velocity of 1.36 m/s for durations of 5 and 10 minutes. The results show that all FDM-built Nylon6-Al-Al_2O_3 components have better wear resistance as compared to their FDM-built ABS counterparts. Further, the influences of filler materials on various wear mechanisms such as adhesion, abrasion, etc. were identified. It was also observed that the composite materials prepared with different proportions are more wear resistant, having less friction coefficients and friction force than the commercially used ABS material for FDM components (Boparai et al., 2015).

FDM process parameters significantly determine the mechanical strength, wear resistance and surface roughness of build parts. Resistance to wear is an important consideration for enhancing the service life of functional parts. Since wear is an important phenomenon affecting functionality of a part, effect of six FDM build parameters viz. contour number, layer thickness, raster width, part orientation, raster angle and air gap on sliding wear of the specimen was experimentally investigated (Mishra et al., 2017). Using analysis of variance (ANOVA), effect of each process parameter on wear of the build specimen was analysed. From the scanning electron microscope (SEM) images, wear surfaces and internal structures of the specimens were evaluated. In separate studies, Equbal et al. (2010) and Sood et al. (2012) focused their investigation on understanding the effect of five important parameters such as layer thickness, part build orientation, raster angle, raster width, and air gap on the sliding wear of test specimen. Microphotographs were used to explain the mechanism of wear. Complex dependency of wear on FDM process parameters were found from these two studies.

Polymers, in general offer low frictional resistance to sliding and hence many polymers are used in dry sliding conditions. The widespread use of polymers as the end products has led to an intense research on the basic friction and wear mechanisms of polymers (Jia et al., 2007; Franklin, 2001; Dearn et al., 2013). One of the most industrially useful polymers that FDM processes is acrylonitrile butadiene styrene (ABS). Given the fact that ABS parts made by FDM can have widespread use under several critical relative sliding conditions, tribological study of FDM parts is very important. Thus this study aims to investigate wear behavior of carbon fiber reinforced ABS composite material and compared its performance with existing ABS that was prepared using FDM machine.

2. Material and method

2.1. Materials and specimens preparation

The ABS and composite ABS filament materials used to produce test specimens were 3DXTECH™ ABS and Carbonx™ Carbon Fiber ABS 3D Printing Filament, produced by 3DXTECH, USA. Computer aided three dimensional interactive application (CATIA) was used to generate 3D model of test sample. 3D print models were saved and distributed in a stereolitoghraphy (STL) file format. 3D printer slicer software (FlashPrint) was used to convert an STL file into G-code, the language that can be understood by FDM machine. Since the research is only aims at investigating the wear behaviour FDM part subjected to variable loads, thus the FDM process parameters was set constant for the fabrication of all specimens which was 0.25 mm layer thickness and 0° part built orientation and 90% infill density.

2.2. Wear testing

The specimens for sliding wear test with 10 mm diameter and 30 mm length were prepared on FDM system in high-density mode (90% infill density). The wear test was performed on pin-on-disk based on ASTM G 99 standard under dry sliding conditions at room temperature. To avoid less wear of polymers and polymers composites when sliding against steel disc due to the formation of thin protective film, the silicon carbide (SiC) paper (600 grit size) was placed on the steel disc (EN-32; Hardness 65 HRC). To ensure the specimen has proper constant with counter face all specimens were polished using SiC paper. The wear tests were performed at sliding speed of 286 rpm (0.63 m/s) for the contact load of 5, 10, 15 and 20 N with run time 3 and 5 min at room temperature (23 ± 5 °C and 50 ± 10% relative humidity). The wear testing equipment was equipped with data acquisition system. The specimen was weighed before and after wear test and the difference between them is the measure of sliding wear loss. The weight loss of specimen material was measured by single pan election weighing machine with an accuracy of 0.001g. Temperature measuring probe was used to determine the specimen temperature during the test. After sliding through a fixed time interval, the specimen was removed; cleaned with acetone, dried and weighted to measure the material loss because of wear. The wear rate (K, mm^3/Nm) was calculated according to the following equation:

$$K = \frac{\Delta m}{LP\rho}$$

where, Δm was the weight loss (g), L the sliding distance (m), P the applied load (N) and ρ was the density of polymers (g/cm^3). The density was measured as per ASTM D792 standard, which was primarily based on Archimedes principle. For minimizing data scattering, three replicate sliding tests were carried out in this work, the wear coefficient and wear rate were average values of three replicate test results.

3. Results and discussion

3.1. Wear of materials

Wear is the progressive damage, involving material loss, which occurs on the surface of a component as result of its motion relative to the adjacent working parts (Kato et al., 1999). Polymer materials when reinforced with high modulus fibers yield higher strength; higher stiffness, better toughness, and good dimensional stability thus improve wear resistance of polymer. The result in Fig. 1 and Fig. 2 show that the pins based on carbon fiber reinforced ABS composite material has smaller wear as compared to pure ABS specimen. The material loss or wear of both materials increase when the run time increases and load increases. It is obvious that, wear of material dependent on temperature, applied load and sliding distance (directly proportion to run time). In generally, the volume loss of polymer material is due to abrasion and adhesion and often it starts with abrasion (Naga Raju et al., 2011). Wear rate decrease of composite materials are due to higher load bearing capacity of harder material such as carbon as reinforcement material. In particular fiber reinforcements are effective in reducing wear in adhesive situations in addition to increasing the strength and stiffness. The wear tracks were obtained to study wear phenomena and extent of wear. When material slide against the emery paper, which was pasted on the rotating disk, material start delaminating form the pin and grooves were formed on the surface and the wear was majorly reduced due to presence of abrasive particle in composite material marked in dark black circles. These results are in line with the finding of other researchers (Xu et al., 2010; Zhang et al., 2011; Boparai et al., 2015; Kulkarni et al., 2016).

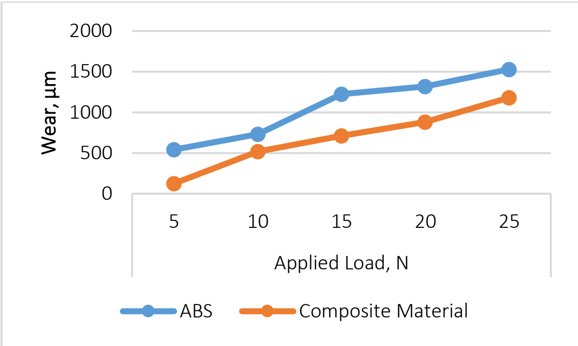

Fig. 1: Wear with applied load (3 min)

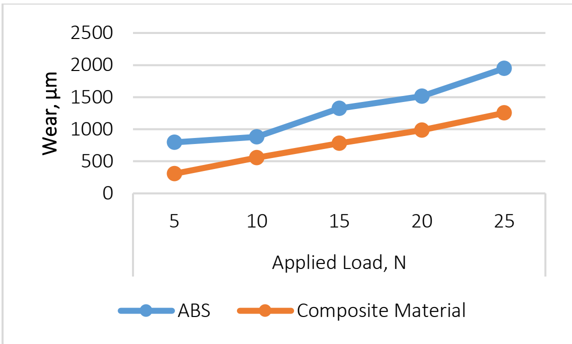

Fig. 2: Wear with applied load (5 min)

3.2. Fiction force

Friction force is the resistance offered by bodies under sliding condition. The results as in Fig. 3 and Fig. 4 show that, the composite material offer less friction force as compared to pure ABS and Friction force increase when applied force and run time increases for both materials. The effect of friction on the wear of engineering polymers is a complex and intricate consequence of the micro and macroscopic interactions of surfaces move against one another (Kalácska et al., 2012). The main tribological properties contributing to friction are adhesion and deformation. Adhesion refers to the shearing at local contact spots. Adhesive bonds exist in the contact region for polymers. Molecular bonds are created between contact surfaces in the same manner as within the polymers. The strength of the bond between the surfaces can be almost as strong as within the bulk polymer. Therefore under sliding condition elements of one polymer surface can be teared away from the opposite surface. The deformation component in tangential direction refers to the sliding over the asperities of the surfaces. The deformation can be compared with plowing, where tangential force must be great enough to pass over the asperities while surfaces might slide or shear depending on relative mechanical properties.

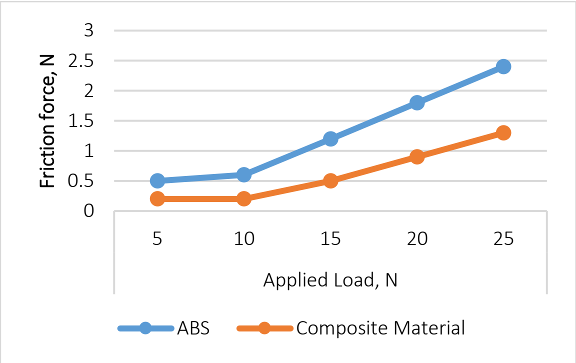

Fig. 3: Friction force with applied load (3 min)

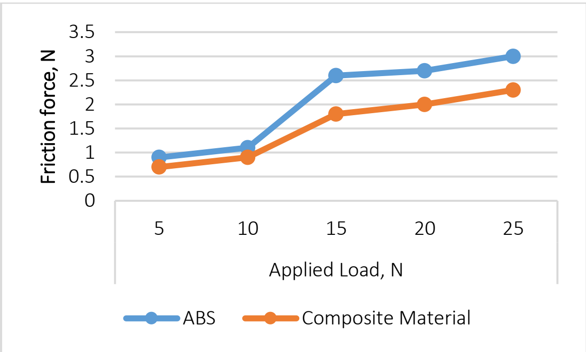

Fig. 4: Friction force versus applied load (5 min)

3.3. Friction coefficient

The friction coefficient is the ratio between the friction force and the applied load. The relationship between friction coefficient and run time/applied load under dry sliding condition is exhibited in Fig. 5 and Fig. 6. The results show that composite material has less coefficient of friction as compared to pure ABS material. This result with an agreement other finding (Garg and Singh, 2015; Xu et al., 2010; Singh Boparai et al., 2016; Srinivas et al., 2012). The coefficient of friction initially has a higher value because of high resistance faced by pin when sliding on fresh abrasive surface and it becomes steady as the test continues (Singh Boparai et al., 2016). This result indicates that the parts produced by FDM have asperities which get surfaced out, and after sometime, as the asperities are smoothened, the coefficient of friction decreases and becomes stable as much of material is worn out in the form of powder. The effect of applied load and run time on friction coefficient is varied since it decreases from 5 to 10 N load then constantly increase from 15 to 25 N load for 3 min run time. The clear pattern cannot be seen for run time of 5 min as the value of friction coefficient is fluctuated.

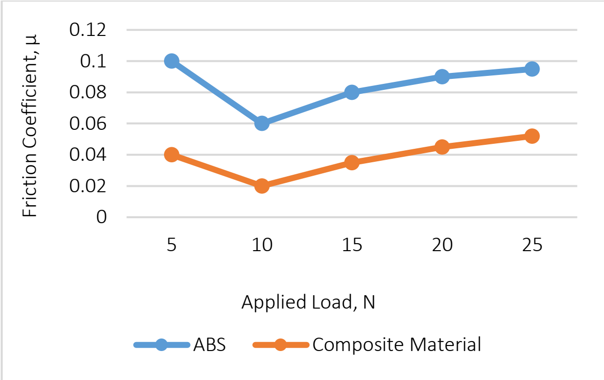

Fig. 5: Friction coefficient versus applied load (3 min)

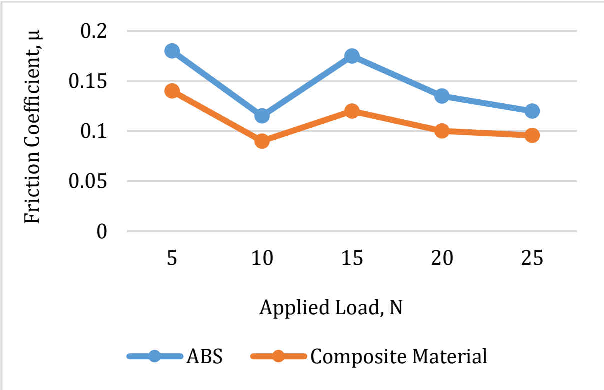

Fig. 6: Friction coefficient versus applied load (5 min)

3.4. Temperature change

Watanabe et al. (1968) stated that the maximum friction with increasing sliding speed for nylon–metal couple is attributed to temperature effects is caused by frictional heat. The results in Fig. 7 and Fig. 8 show that the pure ABS material produces higher temperature than ABS composite.

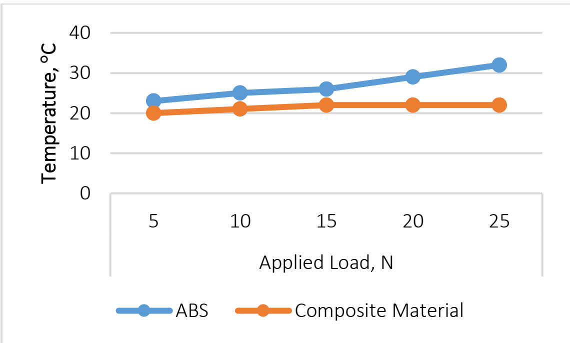

Fig. 7: Temperature change versus applied load (3 min)

This result is supported by the fact that the existence of reinforcement material act as load bearing thus reduces friction and subsequently temperature. The specimen temperature was observed increases but not significant with the increase of applied load and run time. In general, wear rate increases with temperature increase, with an agreement to the finding of Zhao et al. (2015). Hence it can be seen from the wear tracks (Figs. 9-12) and value obtained from the wear testing.

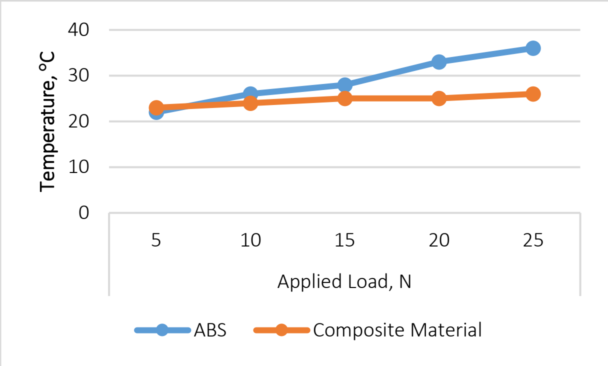

Fig. 8: Temperature change versus applied load (5 min)


5N load


10N load


15N load


20N load


25N load

Fig. 9: Wear track of ABS material (3 min run time)


5N load


10N load


15N load


20N load

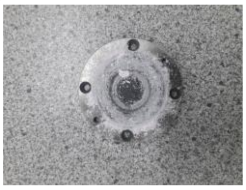
25N load

Fig. 10: Wear track of ABS material (5 min run time)


5N load


10N load


15N load


20N load


25N load

Fig. 11: Wear track of ABS composite material (3 min run time)


5N load


10N load


15N load


20N load


25N load

Fig. 12: Wear track of ABS composite material (5 min run time)

4. Conclusion

Carbon fibre reinforces ABS shows less wear as compared to pure ABS material for the tested specimens. Reinforcement material has increased the wear resistance of polymer material due to higher load bearing capacity of carbon fiber. The applied load and run time clearly influence the wear rate and frictional behaviour of material under dry sliding condition.

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