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ANALYSIS OF ABRASIVE WEAR OF SELECTED AIRCRAFT MATERIALS IN VARIOUS ABRASION CONDITIONS

Aneta Krzyżak, Mateusz Mucha
Daniel Pindych, Damian Racinowski

Polish Air Force Academy, Aeronautics Faculty
Dywizjonu 303 Street 35, 08-521 Deblin, Poland
tel.: +48 261 518185, 48 261 517429, +48 261 517423
fax: +48 261 517493, +48 261 517417
e-mail: a.krzyzak@wsosp.pl, m.mucha@wsosp.pl
d.pindych2798@wsosp.edu.pl, d.racinowski3171@wsosp.edu.pl

Abstract

The use of composite materials is continuously increasing in modern transport. This process is especially noticeable in aviation. The mass percentage of epoxy resin composites in contemporary aircraft constructions is usually higher than 50%, and these materials must meet increasingly demanding requirements. In these circumstances, in addition to mass and strength, it is necessary to predict other properties of the material, such as abrasion resistance. The article presents the analysis of the process of abrasion of carbon fibre reinforced polymers reinforced with various fillers. Straight carbon fibre mats were used for the tests. In addition, powders of pumice, alumina, silicon carbide, and glass microspheres at various concentrations in relation to the matrix were used as fillers. In order to investigate the influence of external factors on the abrasion process, each group of samples was subjected to abrasion under different external conditions: in an insulated environment, in the presence of water and loose abrasives: brown fused alumina (BFA) and white fused alumina (WFA). The measurements were carried out using a precision balance and an electron microscope. The results allow concluding on which kind of filler and in what concentration contributes to improvement of the abrasion resistance of the composite material the most. In addition, it was found that the conditions in which abrasion occurs have a very large impact on the course of this process.

Keywords: *composite materials, tribology, carbon fibre reinforced polymer (CFRP), aerospace materials*

1. Introduction

The use of polymer composites in the transport industry is growing due to good mechanical properties and low density compared to traditional materials. Modern jet airliners such as Boeing 787 and Airbus A380 are often cited as an example of the fact that the mass percentage of composites in aircraft constructions continues to grow. In aviation, the most commonly used are composites based on epoxy resin. The use of composites is not limited to the fuselage, wing spar, rudder and engine cowlings. The range of machine parts that can be made of a composite instead of the alloy is systematically expanding. This process is accompanied by the study of the properties of composite materials, including tribological behaviour.

Nanotechnology is currently developing rapidly, which is why tribological tests are carried out with respect to nanocomposites. An example is the reduction of inner friction of the tyre with the addition of carbon black, soot, silica and organosilica to the rubber mixtures. A significant improvement is noted only when additives are added at the nanoscale [14]. Elements that are particularly exposed to abrasive wear are coatings. Research shows that with the reduction of the grain size to the nano scale, the tungsten carbide/cobalt composite improves its performance in both sliding and abrasive wear [17].

The use of particle reinforcement in appropriate proportions leads to improved tribological properties of the epoxy composite. So far, the influence of various fillers on the tribological behaviour has been published, including graphite [5, 12], graphene [11], multi-walled carbon nanotubes (MWCNTs) [2] and molybdenum disulphide (MoS2), boron carbide (B4C), and fly ash (FA) [8]. In these works, the particles contributed to the reduction of wear rate.

For some elements, it is advisable to minimize frictional wear while in the same time obtaining a high coefficient of friction. This situation applies to composites for aerospace braking applications. It has been proven that silicon (Si) nanoadditives contribute to reducing wear and maintaining a high and stable friction level in the range of 0.4-0.7 [16].

For environmental reasons, natural fibre reinforced polymer composites are being investigated more and more. This also applies to tribological tests that show that grewia optiva fibres and nettle fibres contribute to reduction in friction coefficient in a polylactide (PLA) based composite [4]. Other studies deal with the subject of the impact of fibre orientation with respect to the sliding direction on tribological behaviour. Normal oriented jute, kanaf and sisal fibres exhibit the greatest tribological properties [15].

Due to the widening use of composite elements, the range of conditions under which abrasion may occur is increased. For example, in the case of thermoplastic polymers, the effect of elevated temperature should be taken into account [13]. The necessity of mechanical processing of fibre-reinforced polymers involves the use of cutting tools and therefore friction models are being developed [6].

Environmental conditions are significant factor affecting the course of abrasive wear. Research shows that wear rates for inert gas argon environment are higher than for air [1] and abrasive wear for dry medium is greater in comparison to oil-lubricated sliding [3]. For ecological reasons, to test the possibility of replacing traditional lubricants with water, the polyphenylene sulphide (PPS) composites were tested in water lubricated sliding conditions [7]. It has been proven that a diamond-like carbon (DLC)/epoxy composite dual coating can be used as a machine component under extreme conditions, which means both working in dry and lubricated conditions [10].

2. Description of the experimental work

The aim of the article is to evaluate the abrasion process of carbon-fibre reinforced epoxy hybrids enriched with various fillers. To achieve these goal two sets of abrasive tests were carried out:

- first – study of the impact of the particle reinforcement on abrasive wear of the epoxy composite,
- second – study of the abrasive wear in various environmental conditions.

In order to examine the impact of the particle reinforcement on tribological behaviour of epoxy resin composites the following fillers were selected: pumice (6.0-6.5 Mohs hardness, mesh 280), glass microspheres (6.0-7.0 Mohs, mesh 140), white fused alumina (9.0 Mohs, mesh 280) and silicon carbide (9.2 Mohs, mesh 220). Samples were prepared in a volume ratio of powder to matrix 1 : 1 and 1 : 2. Thanks to this, 5 samples were prepared for each of the following mass fractions of the filler: pumice 58 wt% and 40 wt%, microballoons 64 wt% and 48 wt%, WFA 57 wt% and 39 wt%, SiC 54 wt% and 35 wt%.

In order to investigate the influence of external conditions on tribological behaviour, a carbon-fibre reinforced epoxy composite was subjected to abrasion test in an insulated environment with no additives, in the presence of water and loose abrasives: brown fused alumina (BFA) and white fused alumina (WFA). 5 samples were tested in each of four environments.

Samples were prepared by mixing CES R70 epoxy resin based on bisphenol A/F with CES H71 hardener in 100 : 54 weight ratio [9]. The rate of temperature increase as a function of time may vary depending on the volume of the composition. Fig. 1 shows the dependence of temperature on the time of a 200 g mixture of resin and hardener, which is a typical volume used to make small composite parts. Gelling and hardening points of the mixture are marked on the graph.

For the needs of first study, the reinforced resin was cast into moulds prepared for the abrasion test in the tribometer. During the preparation of samples for the second test, 5 layers of carbon fibre reinforcement were wetted out with resin mixed with hardener. Next, the pressure of 5 tons obtained in the hydraulic press during the 10-hour period was used.

Tribological test was carried out using the Taber Linear Abraser model 5750. The first abrasion test was carried out under the following conditions:

– the length of the friction path during one cycle – 63.5 mm,
– total load – 850 g,
– diameter of abrasive stone – 11.7 mm,
– maximum number of cycles for one sample – 800,
– measurement of material loss and visual condition after 200, 400 and 800 cycles.

In order to create an appropriate environment during the second test, loose abrasives or water were fed into the contact area. In addition, the test was carried out under the following conditions:

– the length of the friction path during one cycle – 88.9 mm,
– total load – 1850 g,
– diameter of abrasive stone – 6.5 mm,
– maximum number of cycles for one sample – 700,
– measurement of material loss and visual condition after 100, 200, 300, 500 and 700 cycles.

Abrasive wear was determined as the weight loss measured using an analytical balance. Scanning electron microscope (SEM) analysis was performed by means of the Tabletop Microscope TM3030Plus.

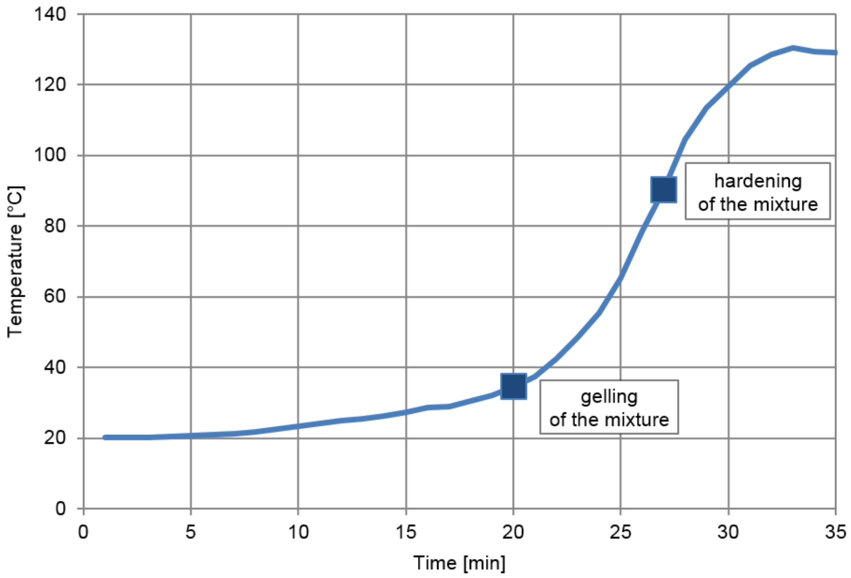

Fig. 1. The dependence of temperature on the time of a 200 g mixture of CES R70 resin and CES H71 hardener

3. Results

Figure 2 shows the average results for samples with a volume ratio of powder to matrix of 1 : 2. The lowest abrasive wear was recorded for a composite reinforced with glass microspheres. This is due to the fact that the microspheres were the largest particle size. This shows the importance of the size of the gain particles. The addition of WFA and SiC allowed for much better results than the addition of pumice. Considering that the particle size of the three fillers was similar, these results owe to the hardness of the reinforcement.

Higher values of mass concentration of fillers resulted in increased wear. Fig. 3 shows the effect of mass concentration of WFA on material loss. As can be seen, with the increase in the mass percentage of the filler, the tribological properties of the composite deteriorated. This indicates that there is a drop in wear resistance above a certain limit value of the filler.

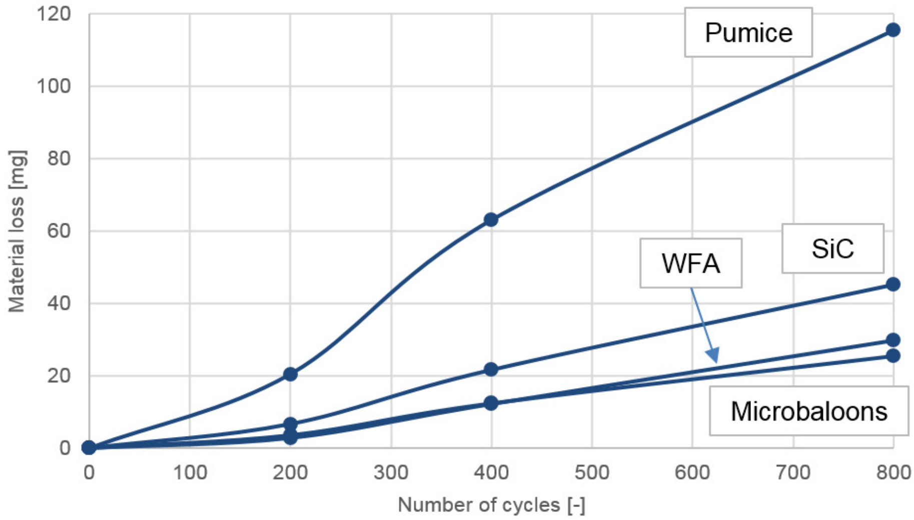

Fig. 2. The average material loss of samples containing pumice, microballoons, WFA and SiC with a volume ratio of powder to matrix of 1 : 2

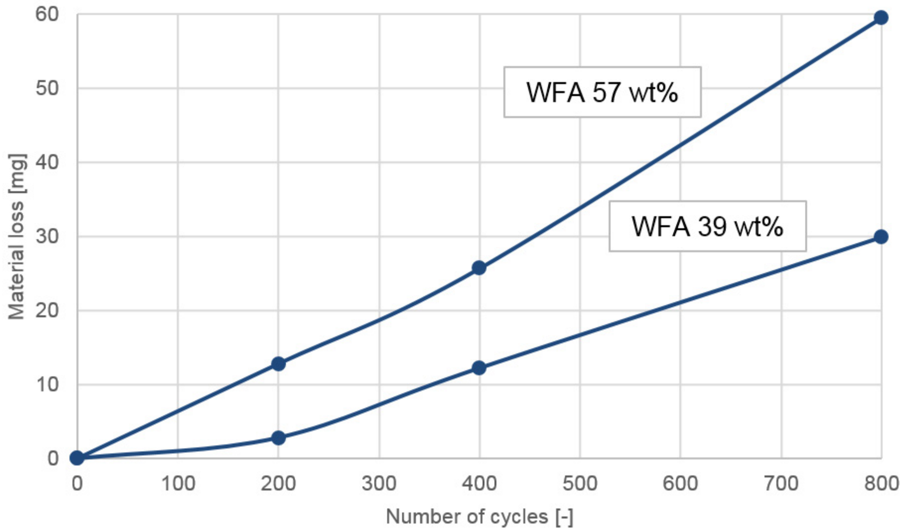

Fig. 3. The average material loss of samples containing WFA with a volume ratio of powder to matrix of 1 : 2 (39 wt%) and 1 : 1 (57 wt%)

Figure 4 presents the results of measurements in four different environments. Due to the destruction of samples, abrasion test in the presence of water and BFA was completed before the assumed number of working cycles. WFA gives very large values of standard deviation, almost 10% of the average sample mass, which indicates that it is impossible to predict the next results based on the trend.

Pictures of a sample abraded in the presence of water, which was destroyed after 550 cycles are presented in Fig. 5. In the first SEM image the limit of destruction can be observed, the shape of which results from the direction of abrasion. Grooves can be clearly observed in the second SEM micrograph showing the process of wear.

4. Conclusions

Composites based on epoxy resin are increasingly used in the automotive and aerospace industries. For this reason, there is a growing interest in the tribological properties of CFRP. In this article, results of research on the tribological behaviour of composites were presented. The conclusions drawn are as follows:

1) The size of the filler grains has a large impact on the reduction of abrasive wear. Along with a two-fold increase in grain size, more than three-fold reduction in material loss was noted.
2) The mass percentage of filler has a significant impact on abrasive wear. An increase in the percentage above the limit value causes a decrease in the abrasion resistance of the composite.
3) The hardness of the seeds also significantly contributes to the improvement of the tribological properties of the composite. Materials with a hardness above 9 mohs are suitable for fillers.
4) The conditions under which abrasion takes place have a huge impact on the course of the wear. The presence of water and loose abrasives accelerates the wear for several times.

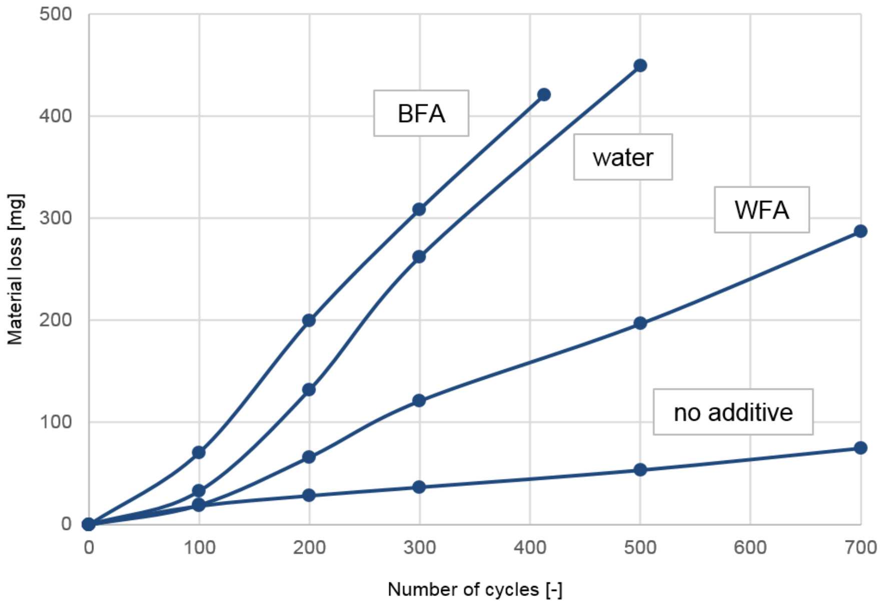

Fig. 4. The average weight loss for the abrasion test in the presence of water, WFA, BFA and with no additive

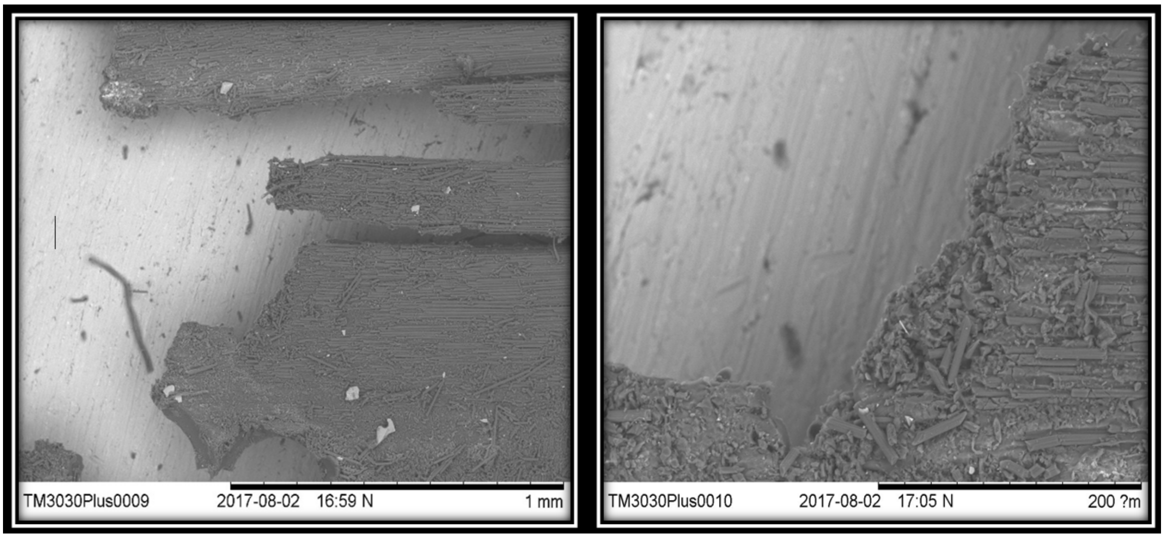

Fig. 5. SEM image of a carbon fibre reinforced composite, which has been destroyed after 550 friction cycles in the presence of water – instrument magnifications of 100 and 400

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