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Wear Analysis of PEEK Composites

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Abstract

The wear behavior of PolyEtherEtherKeytone (PEEK) retainers in Air Force gyroscopes has been excessive in “life studies.” Due to the properties of the PEEK, a replacement of the material is not an option, but a composite may be permissible. This preliminary literature search is to find composite PEEK materials for further investigation.

Several studies have been conducted on blends of PEEK with PolyTetraFluruoroEthylene (PTFE), carbon fiber, and glass fiber. These studies have found that the optimum mixes to be: 1) a PTFE mix of 10-20% (by volume)[2], 2) a 20% (volume)[2] and a anti-parallel orientation[4] of carbon fibers, and 3) a 5-10% (weight) of glass fibers (SiC).

Now that these composites have been found, they need to be tested against each other on the same machine in the same environmental conditions for comparison. The machine to be used is the Umax Tribometer (located at Draper Labs), and the environmental conditions will consist of the static life test temperature of the gyroscopes of 57.2^{o}C, and in the lubrication of Krytox.

1. Introduction

Organic polymeric materials are being used more and more because of their ease of fabrication, low density, and resistance to corrosion. Many thermoplastic polymers exhibit self-lubricating behaviors, chemical resistance' and have a low friction coefficient[3]. Newer thermoplastic materials and composites also can withstand high temperatures (250^{o}C). PEEK has been in the scope of the Air Force for these reasons.

PEEK is a fiber reinforced polymer. Due to its light weight and strength, it is used in many applications, from rockets to automobiles. Because of the increased use of the material, many industries want to make PEEK less wear resistant to increase the life of their parts. Proposed studies have thought to reinforce the PEEK with carbon and glass fibers and PTFE. The problem that we are facing is the wear of PEEK retainers in gyroscopes. The retainers hold the ball bearings in place and are submersed in the lubricant Krytox. In life tests, the retainers are showing wear caused by the bearings. This wear causes debris which can impede the rotation of the gyroscope. We are looking to decrease the wear of PEEK, but keep the strength and environmental resistant properties intact.

The Air Force currently uses PEEK retainers in the gyroscopes of their missiles. The lubricant coating the ball bearings and retainer is Krytox. It has been seen that excessive wear and break down of the retainer occur while the gyroscope is in long term storage (Figure 1). Gyroscopes in storage are kept at 57.2^{o}C, and are rotated at 30 rpm.

Wear analysis can be conducted in several ways. Most of the methods require a hard known to wear against a softer unknown (in some instances, two of the same materials are used, but this can lead to "fusing," or sintering, and extra friction can be caused. Plus, both surfaces have to be measured for wear instead of just one surface). In the more popular cases, a known softer sample is measured for wear, as the harder sample won't wear. The wear can be measures in depth of wear, leading to units of (length/(force*distance traveled)), but the more common units are (volume/(force*distance)). As long as the samples are known, and/or the piece causing the deformation is known, then the depth of the wear scar can be used because the volume will be a ratio of the depth. Very precise equipment is needed for this.

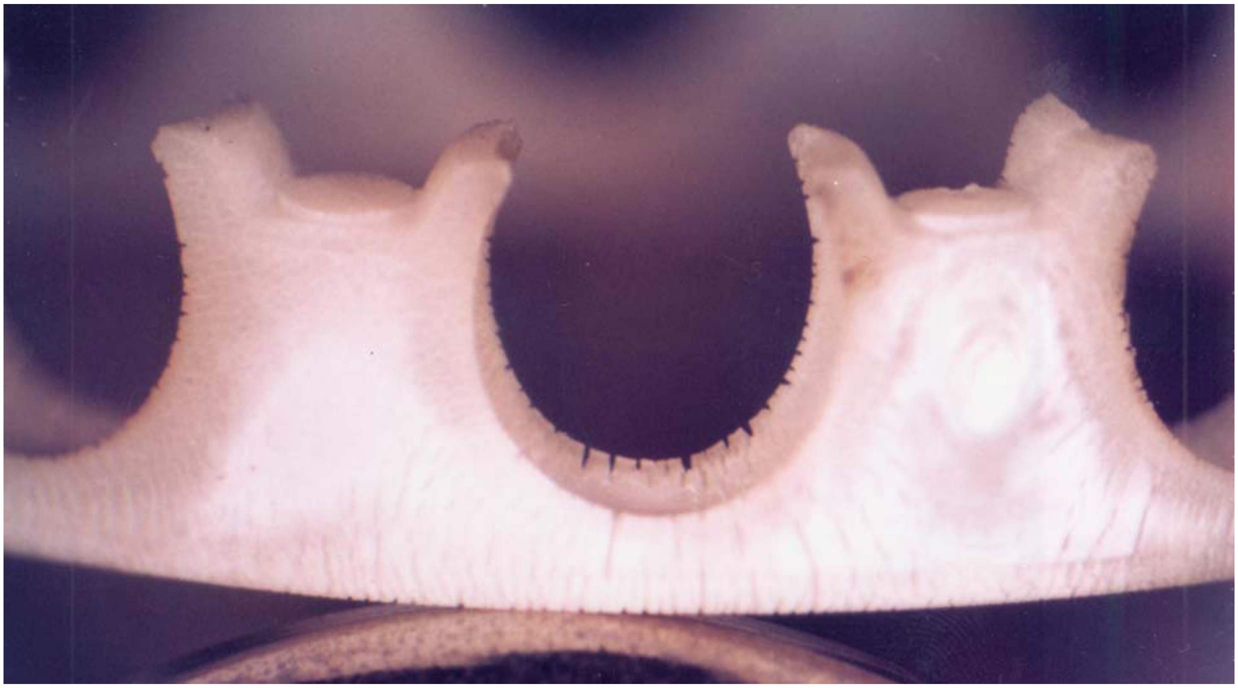

Figure 1: PEEK retainer after 10 years of storage.

This report is to see what studies on PEEK composites have proposed on their results, and then to expound upon that. The study proposed after this report will use a hard steel ball bearing on a PEEK composite disk, where the environmental conditions and the distance the ball is from the center of rotation will be the same. This will allow us to use a mounted microscope, with a digital x, y, and z axis to gage the depth removed, and the volume will be a ratio compared to the diameter of the ball bearing used.

2. Data

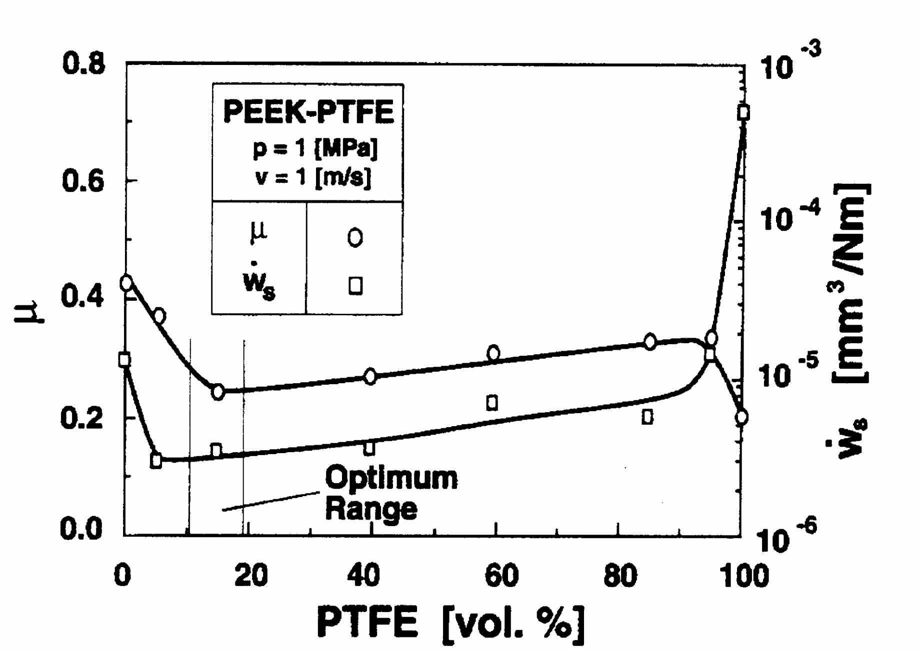

Figure 2[2]: Wear rate and friction coefficient of PTFE and PEEK compositions.

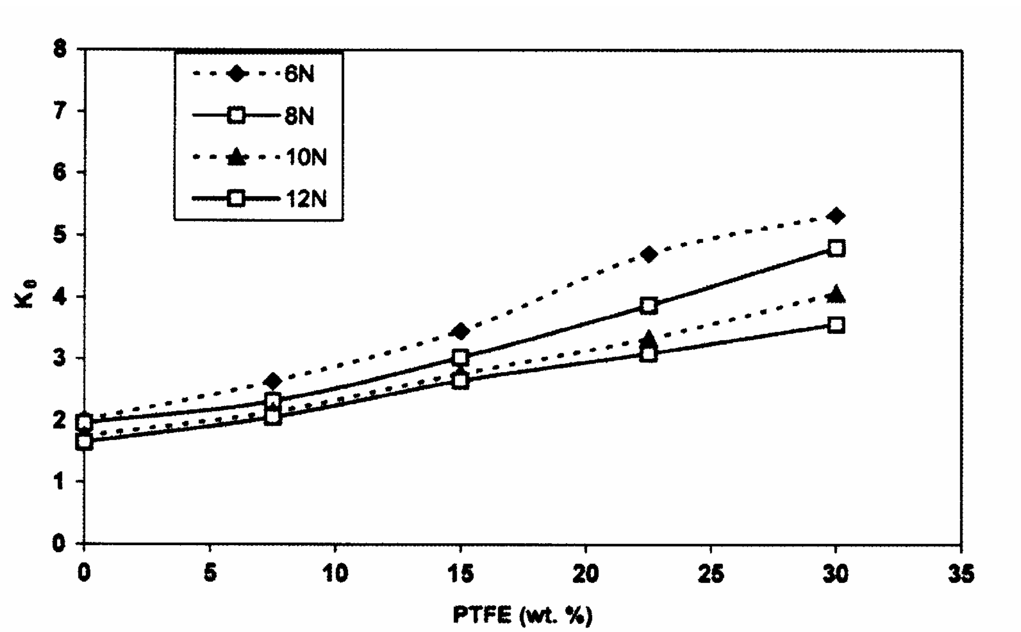

Figure 3[1]: Specific wear rate, Ko (10^{-10} m^3/Nm) in an abrasive wear mode as a function of PTFE content.

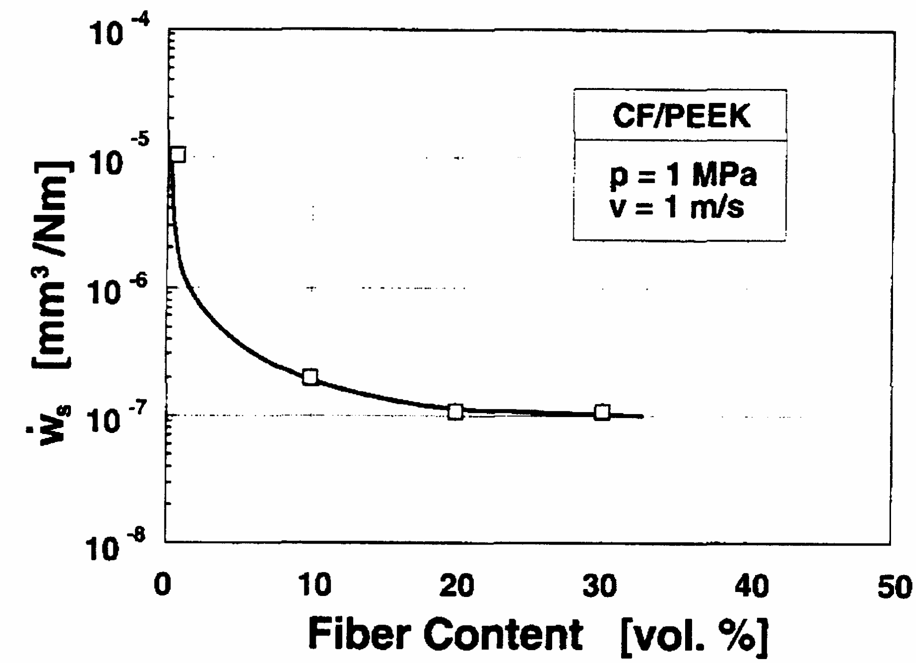

Figure 4[2]: Wear rate Vs carbon fiber content at room temperature.

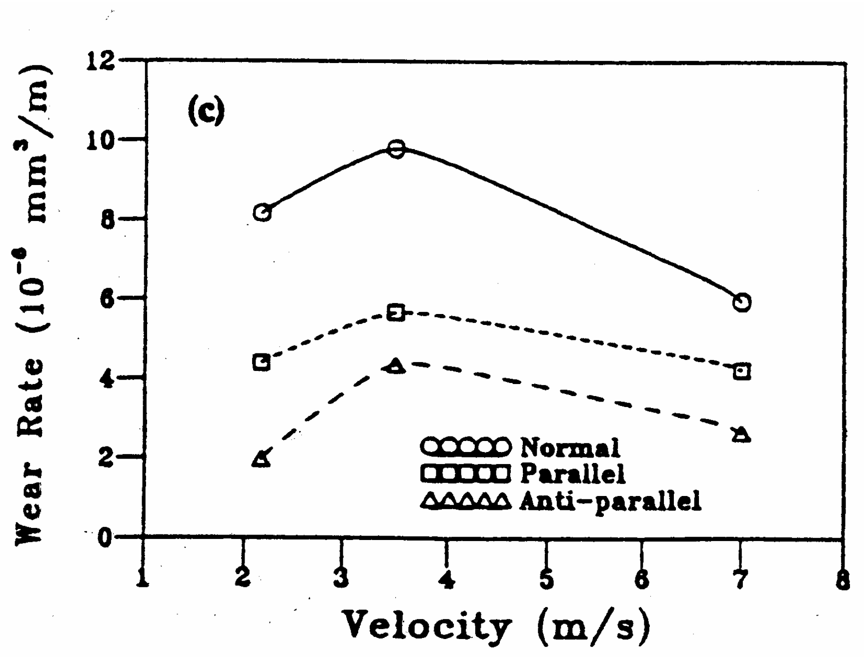

Figure 5[4]: Wear rate for carbon fiber reinforced PEEK compared with orientation of the fiber.

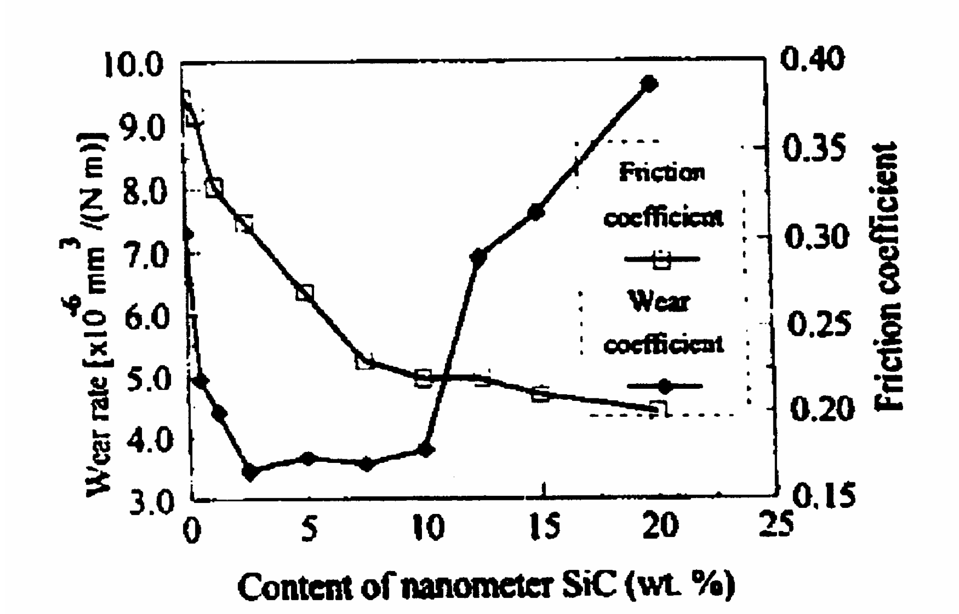

Figure 6[5]: Wear rate and friction coefficient of silicon fiber content in PEEK.

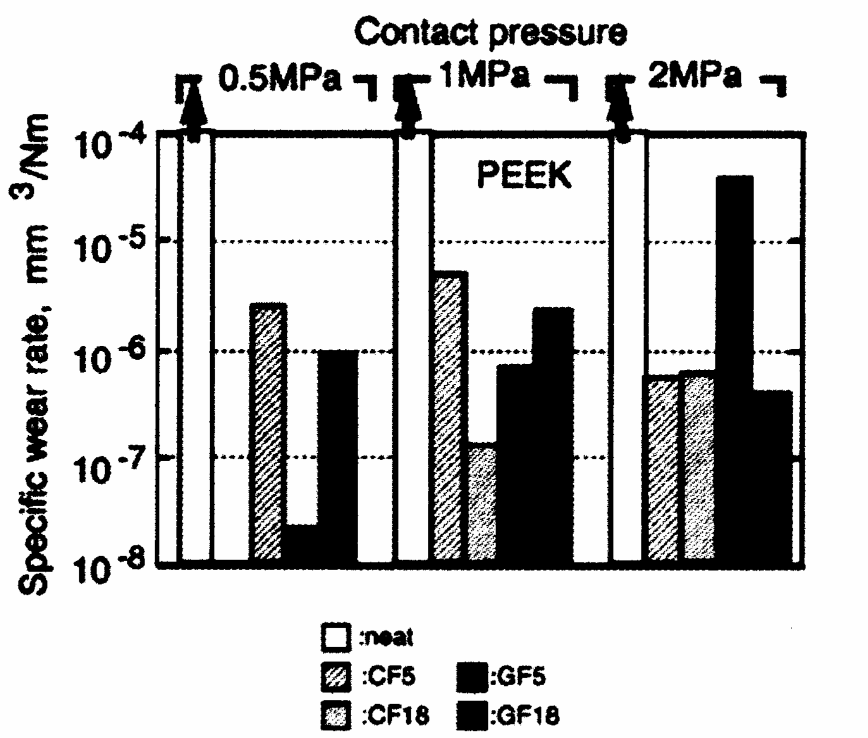

Figure 7[6]: Comparison of carbon and glass fiber filled PEEK at different loadings and at different compositions.

3. Discussion

By changing the percentage of PTFE in PEEK (Fig. 2), Lu[2] found an optimum range that had a low friction coefficient and a low wear scar. He also found that the addition of carbon fibers decreased the friction and wear rate, but that these were asymptotic after ~ 30% fiber content by volume. Also noted in the conclusion, “more than 20 vol.% carbon fiber can cause stick-slip behaviour.”

Bijwe[1] showed in Figure 3 that by adding a percentage of PTFE to the PEEK composite that the wear rate decreased with greater amounts of PTFE. Analysis done by Tripathy[4] showed that the carbon fiber orientation had an effect on the wear rates. Most notably, fibers running normal to the applied force wore faster than samples with fibers running anti-parallel.

Figure 5, done by Tripathy[1], showed that the carbon fiber orientation had an effect on the wear rates. Most notably, fibers running normal to the applied force wore faster than samples with fibers running anti-parallel.

Adding glass fiber (SiC) to PEEK as a filler was examined by Xue[5] to try and make the PEEK more wear resistant. Nanometer sized SiC was used to make up the blends. After experimentation, it was found that a 10% fraction of SiC produced the best results (Fig. 6) between wear rates and friction coefficients.

Yamamoto[6] found that the wear rate decreased with the addition of both glass and carbon fibers as compared to the neat PEEK (Fig.7). He also found mixed results by increasing the pressure, where the wear rate of the carbon fiber 18% and glass fiber 5% increased as the pressure increased, the carbon fiber 5% increased to a maximum before decreasing, and the glass fiber 18% did the opposite.

4. Conclusion

All of the studies conducted agree that adding either carbon or glass fiber or PTFE to PEEK will reduce the wear rate. However, all of the studies were conducted on different machines in different conditions. Lu's and Xue's study was a steel rotating ring on a composite pin. Bijwe had a similar set-up, but instead of rotating the steel disk, he oscillated the composite piece across the steel. Tripathy's test also used the composite as the pin, but used a sapphire disk instead of a steel one so that infrared heat sensors could be used to see the temperature of the specimen (sapphire is transparent to IR). And Yamamoto used a rotating chromium-molybdenum steel ring on a small sheet of the specimen.

All of these tests point in the direction that a composite PEEK will have a reduced wear rate, but the next question is which one? A comprehensive study of the best of results of the above studies will now need to be conducted on the same machine and under the same environmental parameters to compare the wear tracks against each of the composites.

References

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