

# Wear resistance of polypropylene-SiC composite

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**Abstract.** In this work, the wear resistance of thermoplastic composites with a high amount of ceramic is evaluated. Composites made of polypropylene (PP) and silicon carbide (SiC) powder at 50 wt% were used with the final objective of manufacturing ablative materials. This is the first part of a project studying the wear resistance and the mechanical properties of those composites, to be used in applications like habitat industry. In theory, the exposure to high temperature of ablative materials involves the elimination of thermal energy by the sacrifice of surface polymer. In our case, PP will act as a heat sink, up to the reaction temperature (melting or sublimation), where endothermic chemical decomposition into charred material and gaseous products occurs. As the surface is eroded, it is formed a SiC like-foam with improved insulation performance. Composites were produced by extrusion and hot compression. The wear characterization was performed by pin-on-disk test. Wear test was carried out under standard ASTM G99. The parameters were 120 rpm speed, 15 N load, a alumina ball with 6 mm as pin and 1000 m sliding distance. The tracks were also observed by opto-digital microscope.

## 1. Introduction

When talking about ablative materials, it is thought in aerospace applications; for example, they are very important in missions re-entering the atmosphere. They are also used in internal areas of the nozzle as protective system to high temperature and thermal erosion [1]. According to Laub and Venkatapathy [2] when the ablative material is pyrolyzed, decomposition gases are blown in the boundary layer surrounding the capsule; then a part of the heat-flux coming from the high temperature shock layer is blocked. According to Galileo heritage, the convection heat-flux can be reduced mostly and blocked by the strong blowing. Convective blockage during earth re-entry has been discussed by Reynier [3]. There is many research about ablative materials, mainly focused on the study and simulation of heat flows, all of them based in ablation models [4,5], at surface temperatures ranging from 1700 to 2400 K.

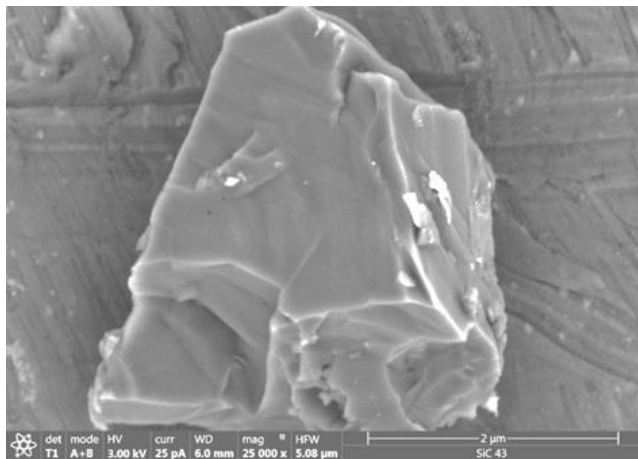
However, an ablative material could be used in many different applications. Applications with high heat-loads and heat fluxes, like for example a fire, could imply the use of an ablative material. In this study, ablative material is planned as a construction material, for its application on floors or walls of garages, parking or public places. The work is included in a SUDOE project named “KrEaTive”, which is raised to habitat industry, being this material one of the proposed to be used. For this reason, the ablative material also has to be wear and impact resistant. In this first part of the project, the wear tests carried out on the manufactured materials with thermoplastics resin and silicon carbide to 50 wt% are presented. The selection of the thermoplastic resin was made according to patent WO 2001062841



A3 [6], where thermoplastic composite materials were patented as ablative materials. It has been found that combining thermoplastic materials, reinforcing additives, a mineral, and optionally a foaming agent, produces an ablative material with good mechanical properties. With thermosetting resins, like polyester, and ceramic powder Portocarrero [7] manufactured the thermal zone of low orbit rocket nozzle.

## 2. Experimental Procedure

When carrying out this work, composites of polypropylene (PP) and silicon carbide (SiC) to 50 wt% were manufactured. PP was provided in the form of pellets with a diameter of 3 mm by Repsol (Madrid, Spain). SiC had a size of 43  $\mu\text{m}$ , with a polygonal shape as it can see in figure 1, and it was provided by Carburos Navarro (Cuenca, Spain). Solid composites were melted, blending the polymer and silicon carbide particles in a Haake Rheomix 252P, MA, USA, at 190  $^{\circ}\text{C}$ , 50 rpm speed, for 6 min. With the feedstock obtained, precursors of 3 mm thickness were processed by hot plate press at 190  $^{\circ}\text{C}$  and 5.5 MPa during 20 min.



**Figure 1.** Silicon carbide of 43  $\mu\text{m}$

Three different compositions were studied: (1) PP without SiC (using it as reference); (2) PP with SiC 50 wt%; (3) PP with SiC 50 wt% and glass fibre (GF) 1 wt%. GFs used were short fibres, 6 mm long, from Feroca (Madrid, Spain).

Dry wear tests were carried out at room temperature using a pin-on-disk tribometer (Microtest, Madrid, Spain). In this test, a stationary specimen (pin) with a defined normal force is pressed against the surface of another specimen placed on the rotary disk. Normal force, temperature, wear rate, frictional coefficient, number of turns, speed and other parameters are, firstly, registered and then real time displayed. The normal force is applied over the pin or ball by means of a set of dead weights between 0 N and 60 N (in this case 15 N was applied). This way of application allows a stable force during the test. A 6 mm diameter alumina ball was used for the pin. The test conditions were 120 rpm speed, relative humidity below 30% and a friction radius of 8 mm. The sliding distance was 1000 m. These parameters have been previously optimized for other composite materials by Abenojar [8,9].

Wear was evaluated using Archard's equation (Eq. 1). To calculate the wear and the friction coefficient, ASTM G99-05 standard was used. Measurements of the wear track radius ( $R$ ) and the wear track width ( $d$ ) were performed using a profiler and volume loss was calculated according to Eq. 2, where  $r$  is the pin end radius. In these tests, no significant pin wear is assumed and the wear debris was not removed from track. The mass loss was also taken into account for the calculation of volume loss, being the densities of samples measured using Archimedes' principle.

$$W = \frac{\text{Volume loss}}{\text{Load} \times \text{Sliding distance}} \quad (1)$$

$$Volume\ loss = 2\pi R \left[ r^2 \sin^{-1} \left( \frac{d}{2r} \right) - \left( \frac{d}{4} \right) (4r^2 - d^2)^{\frac{1}{2}} \right] \quad (2)$$

After wear test, optical microscopy and profilometer measurements were performed on the track by Olympus microscopy Dsx500 (Tokyo, Japan). Three tracks were made for each material.

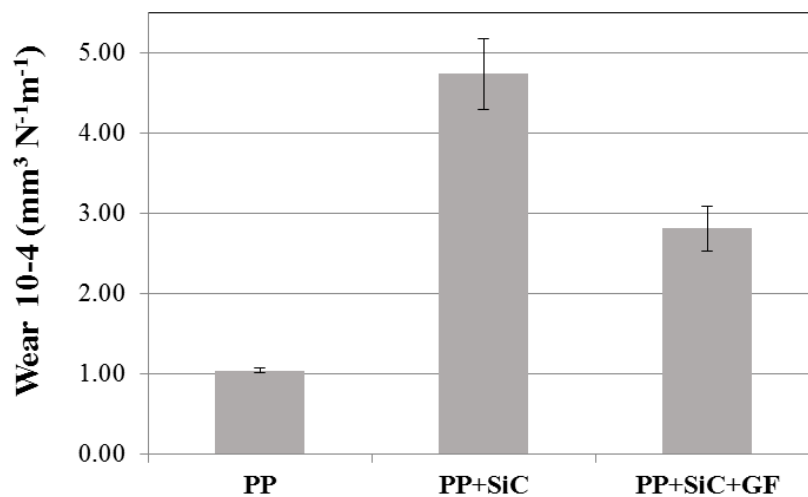
### 3. Results

The first wear results were calculated using mass loss and density. The densities measured by Archimedes' principle show that composite densities are lower than theoretical densities. The PP+SiC composites and PP+SiC+GF composites show relative densities of 90% and 92% respectively. So there is a 10 and 8% the porosity inside composite materials respectively. In table 1, it is shown the wear for the three studied materials; although the composite materials have higher porosity than plain PP, when 1% of GF is added, wear decreases a 16% and when it is not added wear increases a 50%.

**Table 1.** Wear of the three materials calculated by mass loss.

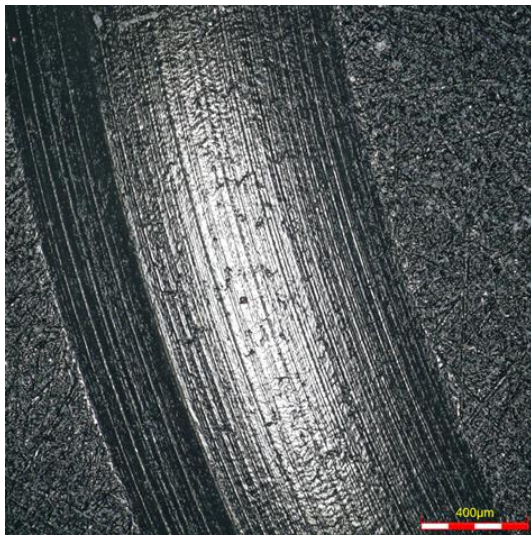
	Mass Loss (g)	Density (g/cm <sup>3</sup> )	Volume Loss (mm <sup>3</sup> )	Wear (mm <sup>3</sup> N <sup>-1</sup> m <sup>-1</sup> )
<b>PP</b>	0.003	0.92	3.51	2.34E-04 ± 5.24E-05
<b>PP+SiC</b>	0.007	1.29	5.28	3.52E-04 ± 4.79E-05
<b>PP+SiC+GF</b>	0.004	1.28	2.95	1.97E-04 ± 1.20E-05

If wear is calculated by volume loss (equation 2), the results are enough different from that of mass loss (figure 2). The depth and width of the tracks were measured with the profilometer at three points. In total, nine measurements were carried out for each material. In this case, both composites have a higher wear than PP, although composite with SiC and GF shows lower wear than PP+SiC. This can be explained when the tracks were studied together with the wear mechanisms.



**Figure 2.** Wear measured by volume loss for the three materials.

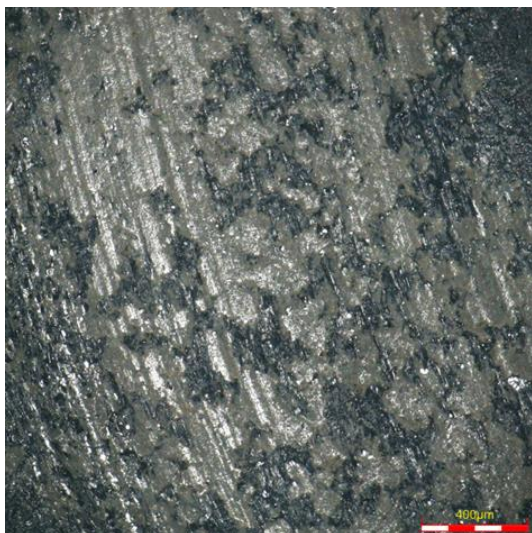
The figures 3 and 4 show the wear tracks in 2D. Figure 3 corresponds to the PP track. An abrasive wear (lines on track) following an adhesive wear (higher lines) are found. PP is deformed by the alumina pin, the track is uniform and it is slightly recovered after test. For this reason the wear is smaller in figure 2 when compared to values in table 1.



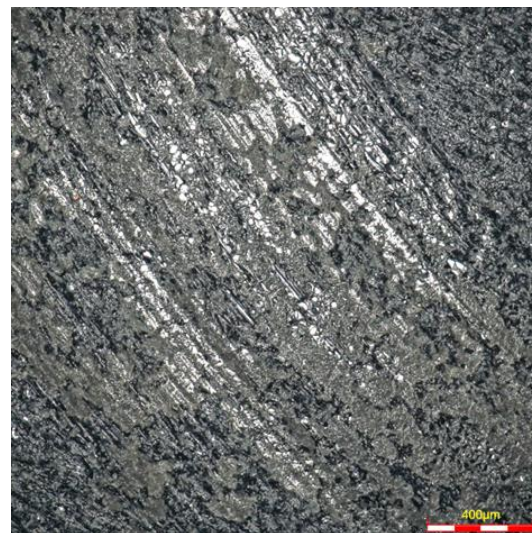
**Figure 3.** Polypropylene wear track in 2D

Something similar takes place on the composites. In all cases (figures 4a and 4b), there are abrasive and adhesive wears. For this reason, the mass loss is lower than volume loss (table 1 and figure 2). The porosity also has influence on mass loss, as it is filled with the wear debris and mass loss is lower. According to the porosity, the PP + SiC composite would have shown less wear. This may be offset by the third body present in the track, which increases wear and track width also increases. The track width values found for PP, PP + SiC and PP + SiC + GF were  $1308 \pm 18 \mu\text{m}$ ,  $2157 \pm 134 \mu\text{m}$  and  $1816 \pm 83 \mu\text{m}$  respectively. Depth also changes, although these changes are smaller, measuring a depth of  $80 \pm 14 \mu\text{m}$  for PP + SiC and  $75 \pm 19 \mu\text{m}$  for PP + SiC + GF.

In consequence, if volume loss is calculated from track width, bigger wear will be found because the tracks are wider. But if wear is calculated from mass loss, the wear measured is smaller due to adhesive wear.



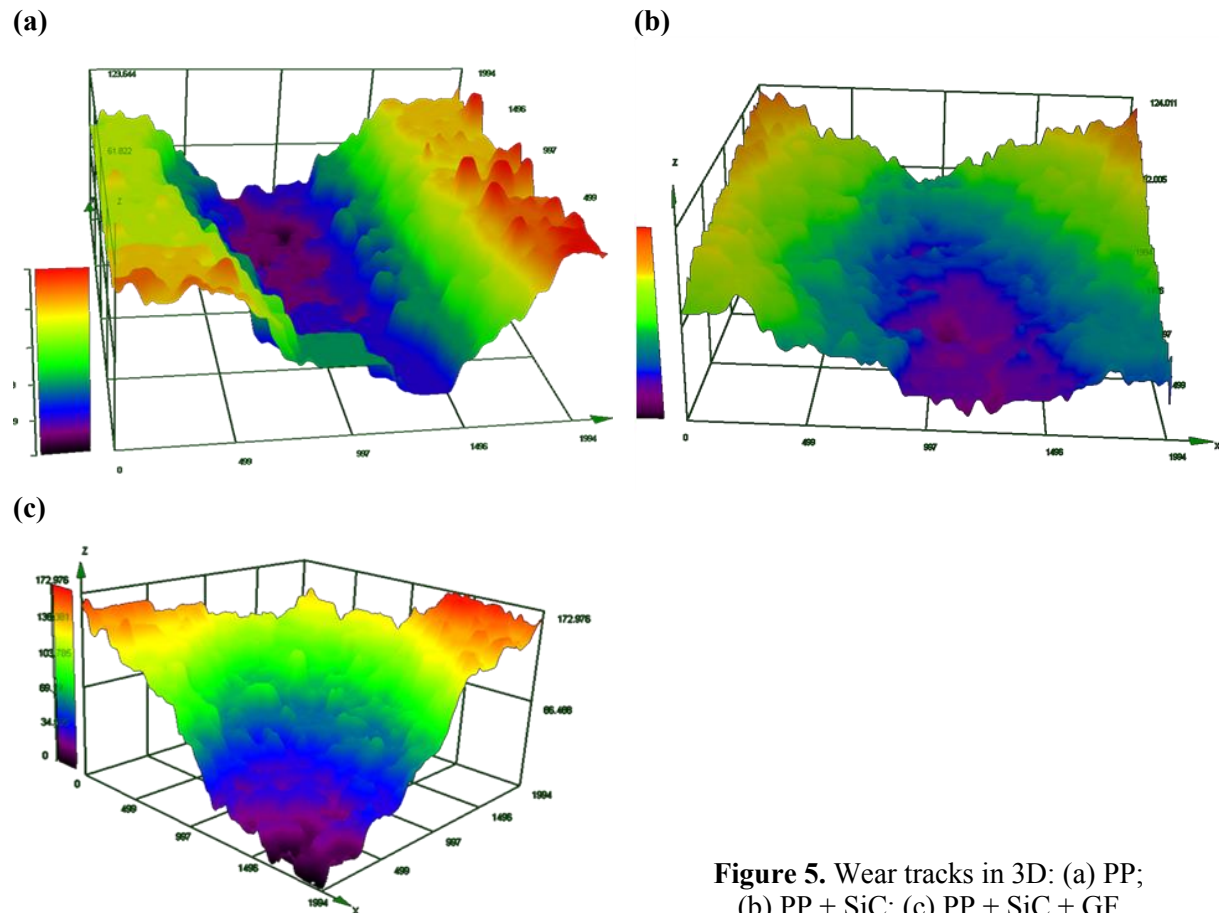
**(a)**



**(b)**

**Figure 4.** Wear tracks in 2D: (a) PP + SiC; (b) PP + SiC + GF.





**Figure 5.** Wear tracks in 3D: (a) PP; (b) PP + SiC; (c) PP + SiC + GF

The figure 5 shows wear track in 3D. With these plots, the differences among materials can be clearly seen. Although defining the accumulation zones at the edge of the tracks is complicated, it can be appreciated that PP + SiC + GF track is enough different to the other tracks. Its width in the surface is similar, but it is much narrower in the deepest zone. For this reason, the wear is smaller. According to these plots, wear should be lower, as it was observed in the wear calculated by mass loss.

The effect of GF in the composite is not understood yet, but it seems that it produces higher interaction between matrix and ceramic filler. This way, better properties are expected when the GFs are added.

Due to the presence of SiC particles, the friction coefficient (figure 6) increases from 0.45 (in PP) to 0.52 (in the composite); this increment is short if it is compared to the amount of added ceramic. Difference between composites is not found. This effect informs about the join of the matrix with the particles, if SiC particles were not joined to PP, the friction coefficient would be higher.

#### 4. Conclusions

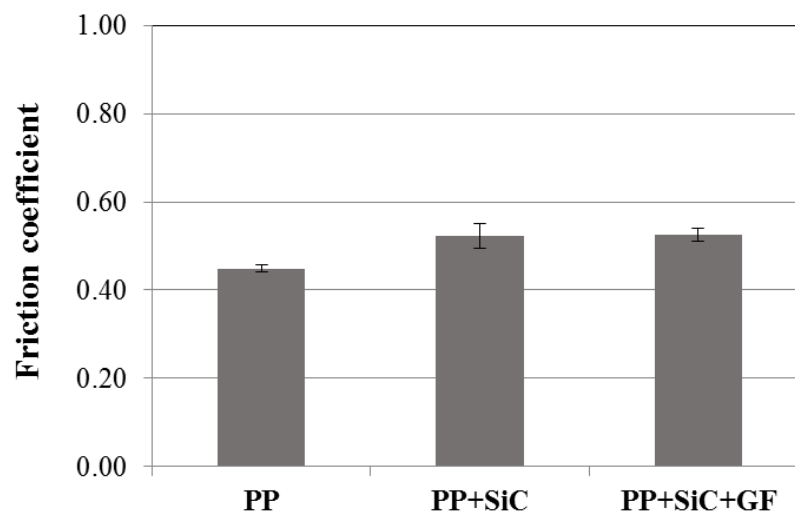
Wear resistance changes with the method used to calculate it, as there are factors which have influence on the outcome.

Two types of wear mechanism are found in these materials: abrasive and adhesive wear.

The adhesive wear is more significant in PP than in composites, where the porosity helps to decrease mass loss by accumulation of debris powder.

Addition of 1% GF to the composite improves wear resistance.

According with wear tests, the mass loss method seems a more correct way of calculation than track width to calculate volume loss.



**Figure 6.** Friction coefficient for the studied three materials.

## 5. References

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