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Analyses of abrasive wear behaviour in Pin-on-Plate Tribo-System for several materials

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Abstract. To improve the performance of the Agricultural machinery, several composite materials were suggested as replacements of critical fast-wearing steel parts. Three possible replacements were selected (PA6E, PA6G, and PA66GF30) and examined by a pin-on-plate system with sliding abrasive cloths. The results were compared according to the pin-on-plate system with a combined property (H/E) of these materials. Then to see how the friction affected these specimens, 3D microscopic photos of the worn surfaces were taken. As results, an inverse relationship between the wear rate and H/E property for these materials, an increasing of H/E factor leads to a decrease in the wear rate. While for the 3D microscopic PA6G was the most outstanding worn surface.

1. Introduction

Nowadays, abrasive wear of engineering and agricultural machine components caused by the abrasive particles is a major industrial problem. Therefore, a full understanding of the effects of all system variables on the abrasive wear rates is necessary to undertake appropriate steps in the design of the machinery and the choice of materials to reduce/control wear [6].

La Mantia et al. mentioned that the recycling of composite is a complicated process and very limited, for example, when we have two different components in the composite, it will be hard to separate and recycle them, and often they use the incineration which considered as an unsatisfactory way [4].

Lee et al. introduced a simple model of composite materials abrasive wear. This model is based on the mechanics and mechanisms associated with sliding wear in soft matrix composites, which contain solid reinforcement particles. The model supposes that any removed part of the reinforcement as wear debris participate to the wear resistance of the matrix material [5].

Walczak et al. presented an analysis of the tribological properties of a ball on a disc as sliding elements in agricultural machinery. They conducted dry friction tests for polymer-metal pairs to obtaining the corrosion rate and friction coefficient of the samples used. Three pairs of Iglidur samples were used [10].

Patnaik et al. reviewed the solid particle erosion behaviour of fibre and particulate filled polymer composites. This review focused on polymer matrix composites and showed the problem related to the processes and modes during erosion. During the experimental studies, several aspects have been

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affirmed. Moreover, they discussed the use of the statistical techniques to analyse that erosion behaviour [8].

Ando et al. selected cast polyamide 6 material for semi-finished structural materials because it has excellent mechanical and chemical properties and easy for composite production, and they selected magnesium catalytic cast polyamide 6 natural polymer matrix as basic grade to have some new composites according to the need of the agricultural and they decided to develop a new composite version of it to improve tribology grade having abrasion resistance, antistatic composite version and improve fire-resistant version [1].

Kalacska studied improving the tribology properties by adding several materials like graphite, silicon dioxide, polytetrafluoroethylene, polyethylene, lead, oils, calcium silicate, waxes and silicone [3].

By using a scanning electrochemical microscopy (SECM) high-resolution three-dimensional images were generated by measuring the variation in the tip current due to perturbations in the diffusion layer [2].

A study of Surface Roughness of Thin Silicon Films Deposited on SiO_2 was done by using an Atomic Force Microscope. Several Silicon Films were used like amorphous silicon and Low-pressure, chemically-vapour-deposited silicon films on silicon dioxide [7].

Also, the Atomic Force Microscope and Profilometer were used to calculate the Surface Roughness in Ceramics specimens where the surfaced had different Finishing Techniques. Three ceramic materials were used: Vitadur Alpha, IPS Empress 2 and AllCeram. Five surfaces finished systems were used. The stylus profilometer and an atomic force microscope (AFM) are the two used roughness measuring instruments [9].

2. Materials and Methods

At that point, as per the above brief survey for some written literature, two types of composite materials which are (PA6G, PA6E, and PA66GF30) materials were recommended to supplant these steel parts.

Table 1 shows the main properties of the used materials.

Table 1. The main properties of the PA6G, PA66GF30 and PA6E

Properties	Method	PA6G	PA66GF30	PA6E
Density [g/cm3]	DIN EN ISO 1183	1.15	1.34	1.14
Yield stress [MPa]	DIN EN ISO 527-2	80	91	78
Modulus of elasticity [MPa]	DIN EN ISO 527-2	3500	5500	3300
Elongation at break [%]	DIN EN ISO 527-2	130	13	130
Flexural strength [MPa]	DIN EN ISO 178	109	135	100
Impact strength, Charpy [kJ/m2]	DIN EN ISO 179-1eU	No break	87	No break
Tensile strength [MPa]	DIN EN ISO 527-2	83	91	79
Compressive strength [MPa]	EN ISO 604 1% / 2%	19/ 36	25/ 46	24/ 41
Notched impact strength, Charpy [kJ/m2]	DIN EN ISO 179-1eA	4		7
Ball indentation hardness [MPa]	ISO 2039-1	170	216	155
Shore D hardness [-]	DIN EN ISO 868	83	86	75

To test these materials, a pin-on-plate test with a sliding abrasive cloth. Pin-on-plate test made by using the following device:

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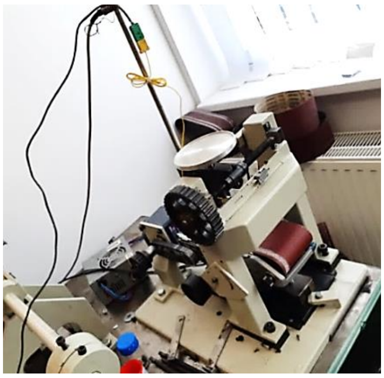


Figure 1. Pin-on-plate wear device

This device can give us a nonstop wear interface and furthermore a possibility to control several parameters:

1. Opportunity to control the speed of the interface wear;
2. Possibility to use several wear interfaces;
3. Opportunity to add a load over the specimens:
    - Two types of wear interfaces were used (P60 and P150);
    - Two speeds are used which are (20%=0.032 m/s and 40%=0.056 m/s);
    - Moreover, we used three loads (9.81 N, 29.43 N and 49.05 N).

Wear of different structural plastic materials was analysed by measuring relevant features during abrasion tests (time, force, abrasion rate). Experimental equipment has been utilised to trace the wear of plastic materials under the same conditions. Abrasion rate has been recorded, together with pressure (force) applied to the sample. Length (duration) of the experiments have been standardised by taking identical experimental runtime. Simple apparatus assembled (figure 2) and sensors were connected to a computer data collecting interface. The interface was converting the sensor signals into digital values and provided the data to a computer that was recording the values.

Figure 2. The Specimen holder and the connected sensor

Several strain gages are connected to a PC by an estimation device (Spider 8) to take these parameters as results. The interface was converting the sensor signals into digital values and provided the data to a computer that was recording the values.

Figure 3. Spider 8, a strain gage measurement device

The used specimens have an exact dimension with 8mm diameter and 20 mm length. We tested each sample for 10 minutes; some samples did not bear this time due to its specifications, enormous load, and substantial sliding speed. These cases, we can see it amid the results.

After testing these samples, we took them to do the 3D microscopic check to calculate some parameters and to get a 3D profile of the worn surfaces. To do this process, we used (Taylor Hobson CCI HD) device. The Measurement type is Non-contact 3D optical profilometry.

Figure 4. Taylor Hobson CCI HD device

This device has several features like:

- Reduced inaccuracy and noise compared to 2D;
- High resolution, precise results;
- Data extraction from whole 3D surface.

Moreover, during the measurement, the used settings are:

- 50X lens;
- Scanning speed: x1, 4m mode, filter 2, rough surface.

3. Result

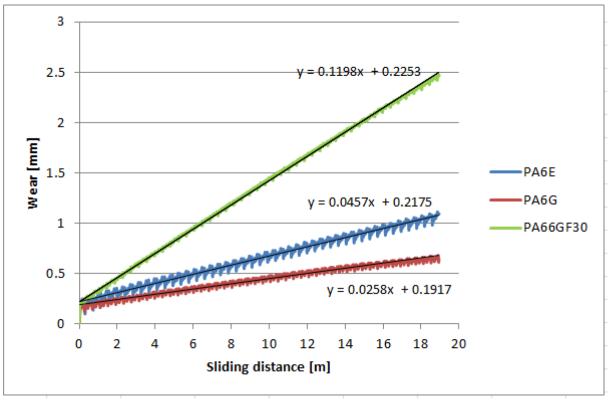


Figure 5. The relation between the wear and sliding distance for several polymers types (0.031m/s, 9.81N)

Figure 5 demonstrates a comparison between the wear and sliding distance for several polymers types; the load is 9.81N, the sliding speed is 0.0315m/s, and the wear interface is P60.

We can compare the different types of polymers by using the slope value of the wear lines.

Table 2. Wear line equation and the slope value of the different polymers types

Type	Wear line equation	Slope value
PA66GF30	y=0.1198·x+0.2253	0.1198
PA6E	y=0.0457·x+0.2175	0.0457
PA6G	y=0.0258·x+0.1917	0.0258

From figure 5 and table 2, we can see that PA66GF30 was subjected to the highest wear rate and had the maximum slope value, while PA6G had the lowest wear rate and had the minimum slope value. Moreover, in other words, we can state that the high slope value implies high wear occurred in the specimen.

Moreover, to study the effect of the speed we compared these three specimens with a new three specimens were the speed was 0.056 m/s with the same load (9.81N) and same wear interface P60.

From figure 5 and figure 6, we can see that by increasing the sliding speed that will lead to increase the wear values.

Figure 6 shows the result of this comparison.

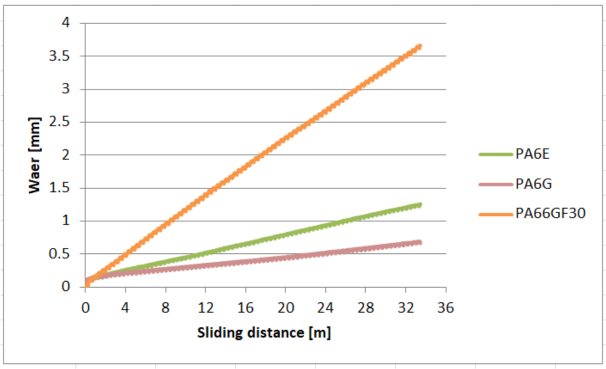


Figure 6. The relation between the wear and sliding distance for several polymers types (0.056m/s, 9.81N)

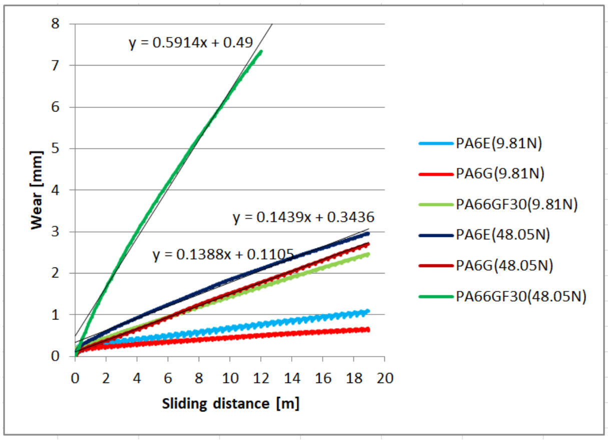


Figure 7. The relation between the wear and sliding distance for several polymers types

While to study the effect of changing the load, we compared these three specimens with a new three specimens were the speed was 0.031 m/s with same wear interface P60 and the load was (48.05N). Figure 7 shows the result of this comparison.

The wear line equations for the new three specimens are shown in the following table:

Table 3. Wear line equation and the slope value of the different polymers types

Type	Wear line equation	Slope value
PA66GF30	y=0.5914·x+0.4900	0.5914
PA6E	y=0.1439·x+0.3436	0.1439
PA6G	y=0.1338·x+0.1105	0.1138

By using figure 5 and 7 with table 2 and 3, we can see that by adding a higher load will lead to increase the values of the slope values of the wear lines, and of course, an increase in the wear values.

The obtained results were compared with two main properties of these materials, which are Modulus of elasticity (E) [MPa] and Shore D hardness, and were used as a ratio of (H/E). However, we had to convert the value of the hardness to [MPa] as a unit firstly by using the following equation:

$$\text{Hardness}\left[\text{MPa}\right] = \text{EXP}\left(\left(\text{Shore D} + 50\right) \cdot 0.0235 - 0.6403\right) \quad (1)$$

According to a table 1, we have the Shore D hardness values as the following:

Properties	Method	PA6G	PA66GF30	PA6E
Shore D hardness [-]	DIN EN ISO 868	83	86	75

And by using the previous equation, we got the hardness values in MPa as the following:

Table 4. Hardness values in MPa for the used materials

Properties	PA6G	PA66GF30	PA6E
Hardness [MPa]	12.003	12.88	9.946

Then we calculated the ratio (H/E) and got:

Table 5. H/E ratio for the used materials

Properties	PA6G	PA66GF30	PA6E
$\frac{\boldsymbol{H}}{\boldsymbol{E}}$	$\frac{12.003}{3500} = 0.0034$	$\frac{12.88}{5500} = 0.0023$	$\frac{9.946}{3300} = 0.00301$

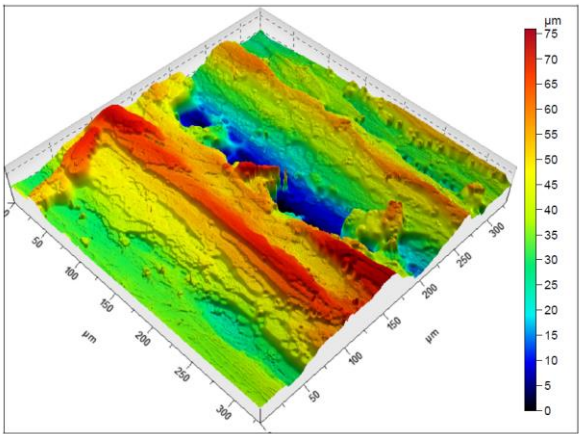
As an order of these numbers, we can see that PA6G had the highest value as (0.0034), then PA6E as (0.00301), then PA66GF30 as (0.0023).

By comparing this order with figure (5) and table (2), where:

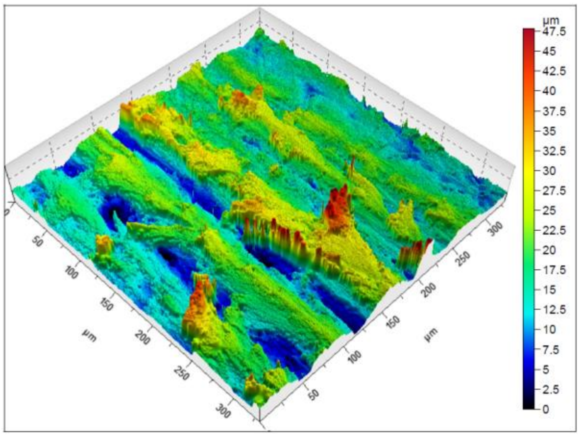
- PA6G had the lowest wear rate and had the highest (H/E) value;
- PA6E had the mid wear rate and had the mid (H/E) value;
- PA66GF30 had the highest wear rate and had the lowest (H/E) value.

We can see that there is an inverse relationship between H/E and the wear rate.

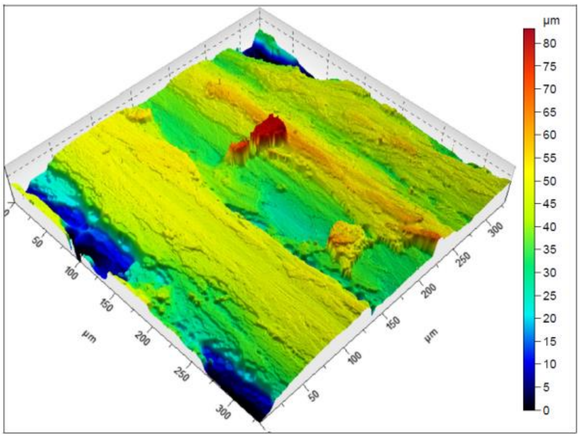
Then these samples were tested by the 3D microscopic to have a further idea about the worn surfaces after the pin-on-plate process, and the results were as the following figure:



PA6E



PA66GF30



PA6G

And as results for these photos, we got the following table:

Table 6. The Height Parameters of the worn surfaces according to ISO 25178

	PA6E	**PA6G**	**PA66GF30**
S_q (µm)	15.03766	12.46001	6.67540
S_{sk}	-0.33826	-1.15040	0.54640
S_{ku}	2.91990	5.04750	3.77496
S_p (µm)	34.30528	41.84994	29.88581
S_v (µm)	41.67346	41.30695	17.96119
S_z (µm)	75.97874	83.15689	47.84700
S_a (µm)	12.17908	9.32774	5.21821

From the previous table we can recognise that:

- The height distribution is skewed below the mean plane for PA66GF30 since S_{sk} value is bigger than zero, while for PA6E and PA6G the height distribution is skewed above the mean plane since S_{sk} is less than zero;
- The sharpness of the roughness profile of the PA6G is the most spiked then PA66GF30 since S_{ku} values are bigger than 3, while PA6E have a normal distribution since the value is almost 3;

- PA6G had the highest peak within the defined area as 41.84994µm, while PA66GF30 had the lowest as 29.88581µm;
- PA6E and also had the largest pit height as 41.67349µm. Also, PA33GF30 had the lowest one as 17.96119µm;
- The Maximum height where for PA6G as 93.15689µm, which is the sum of largest peak height value and the largest pit depth value, but the minimum height was for PA66GF30 as 47.84700µm;
- PA6E had the highest arithmetic mean of the absolute value of the height from the mean plane of the surface as 12.17908µm, while PA66GF30 had the lowest as 5.21821µm.

As a result of the previous points, we can see that the PA6G was the most outstanding worn surface, and that is obviously also according to the surface photo.

4. Conclusions

In this work, several kinds of Polyamide polymers were used to study their wear performance with various changing parameters such as the speed of friction and the applied loads. As a result, PA6G was the best choice of these used polymers because it had the lowest wear rate.

Also, we got that by increasing the load and increasing the speed, the wear values increased. By comparing the wear rate result with the combined properties (H/E) ratio, we found that there is an inverse relation between (H/E) ratio and the wear rate for these tested polymers.

While for the 3D microscopic photos, we had a further understanding of the worn surfaces. The PA6G was the most outstanding worn surface compared to other materials according to the surface photos, where the sharpness of the roughness profile was the most spiked, with the highest peak and largest pit height.

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