POLYMER MATERIALS IN THE FOOD INDUSTRY

POLIMERNI MATERIJALI U PREHRAMBENOJ INDUSTRIJI

KATANA, Branko & BURIC, Mladen

Abstract: *Owing to the continuous development of the food industry, machines with increased production efficiency are constantly being designed, whereby strict hygiene standards have to be respected. During the process of designing machines for the food industry, there is an ever increasing need for the use of new materials exhibiting very good mechanical and tribological properties, such as polymer materials. The subject of this paper is to examine the working life of a wheel assembly made of polyethylene terephthalate (PET) material and to compare it with other materials used for this application, such as polyamide 6 (PA 6) and polyamide 6C (PA 6C).*

Key words: *Tribology, wear, polyamide, polyethylene terephthalate*

Sažetak: *Neprestanim razvojem prehrambene industrije kontinuirano se razvijaju strojevi sve veće proizvodne efikasnosti pri strogim higijenskim standardima. Tijekom procesa konstruiranja strojeva za prehrambenu industriju pojavljuje se sve veća potreba za korištenjem novih materijal sa vrlo dobrim mehaničko tribološkim svojstvima kao što su polimerni materijali. Predmet ovog rada je ispitivanje radnog vijeka sklopa kotača od polietilen tereftalat (PET) materijala u odnosu na često korištene materijale za tu primjenu kao što su poliamid 6 (PA 6), poliamid 6C (PA 6C).*

Ključne riječi: *Tribologija, trošenje, poliamid, polietilen tereftalat*

Author's data: Branko, **Katana,** PhD Student, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, branko.katana2@gmail.com; Mladen, **Buric**, PhD Student, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, mladen.buric@yahoo.com

1. Introduction

New machines used in the food industry have been developed with the aim to improve production efficiency with the least possible losses, abiding by the strict hygiene standards, and to increase the life cycle of machines with long service intervals, including the least possible production interruption caused by various failures that can result in major financial losses in the production process.

Polymer materials used in the food industry must be covered by adequate regulations in place such as EU Regulation No. 10/2011 and FDA (Food and Drug Administration) regulations to avoid contamination of the product or manufactured article that comes in contact with the polymer. Polymer materials in the food industry do not contain additives that can contaminate the product; hence they don't pose a threat to human health when consumed.

Stainless steels type AISI 304 and AISI 316 usually come in contact with polymer materials. Disadvantage of steel materials is the abrasive effect on polymer materials which leads to excessive polymer wear. This problem has been tackled and solved by the adding glass fibers to polymer material which consequently improves the tribological and mechanical properties of polymers. However, polymer with glass fibers can have an abrasive effect to stainless steel as it can be seen in Figure 1.

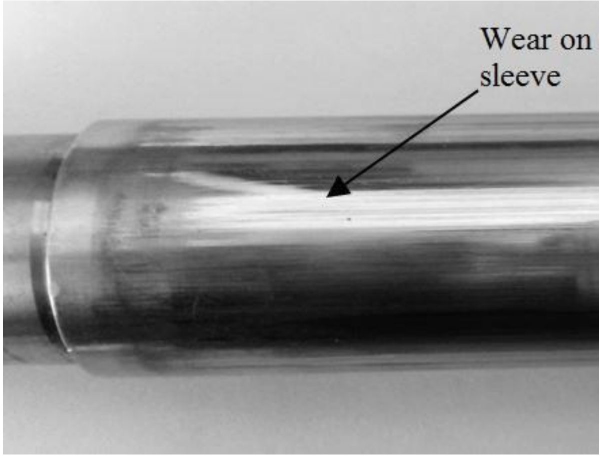

Figure1. Abrasive effect of the slide bearing made of PA6 + 25% GF to the sleeve made of AISI 316

To optimize the wear of the polymer - stainless steel system, whether it is a linear, circular or spiral movement, there is a need to improve the mechanical and tribological properties of polymer materials.

Another problem regarding the use of machines in the food industry is their frequent cleaning with hot water or steam containing various acids and alkalies. The most common methods of cleaning comprise CIP (Cleaning in Place) and SIP (Sterilisation in Place) which can cause damage to polymer materials in terms of swelling, cracking, dimensional changes etc.

The subject of this research paper is to analyse the typical polymer damage and measures for their prevention. Polyethylene terephthalate (PET) is a very good material exhibiting a variety of applications in the food industry due to its fine tribological properties, good thermal stability, small changes in mechanical properties and resistance to various chemicals. All this makes PET a very good choice for manufacturing slide bearings, wheels and other parts of machines used in the food industry.

2. Review of previous research papers

Polymer materials such as PET fall under a group of nonlinear elastic materials ie. load-unload displacement curves in the stress – strain diagram is not a polynomial of the first degree, which in other words means that the property of materials depends on the time and temperature; hence empirical relation stating that the allowable maximum load of the slide bearing equals one third of the maximum pressure loading cannot be applied [1] [2] [3] [4]. To obtain accurate values of the predicted service life of polymer bearing materials, it is necessary to carry out an experimental research in order to compare the results obtained by experimental measurement with the values obtained by calculation or FEM analysis [3] [5] [6] [7].

Polymer materials used for slide bearings should exhibit some of the following features [6] [8] [9] [10]:

1) Good sliding properties of materials, low friction and material wear
2) High chemical resistance
3) Good thermal and dimensional stability
4) Small changes in mechanical strength depending on the working temperature
5) Little absorption of the working medium or other medium that comes in contact with the slide bearing

Wear in polymer materials occurs due to the following reasons:

1) Given that the material is not compatible with the working fluid, a change occurs in the structure of the polymer material which consequently can lead to changes in mechanical properties
2) Polymer material can absorb the working fluid causing it to swell up which can cause bearing damage
3) As a result of contact between the sleeve and bearing, heat might develop in the area of contact which can lead to bearing damage
4) Inadequate surface roughness of the sleeve might lead to excessive wear of the polymer slide bearing

3. Theoretical principles and test results

In order to test if we can use a polymer material for a machine, it is necessary to calculate the pressure between the surface and the wheel i.e. inside the slide bearing. Equations (1) – (5) have been adapted to calculate the wheel contact pressure according to the Hertz theory of contact as can be seen in Figure 2 [1] [11] [12].

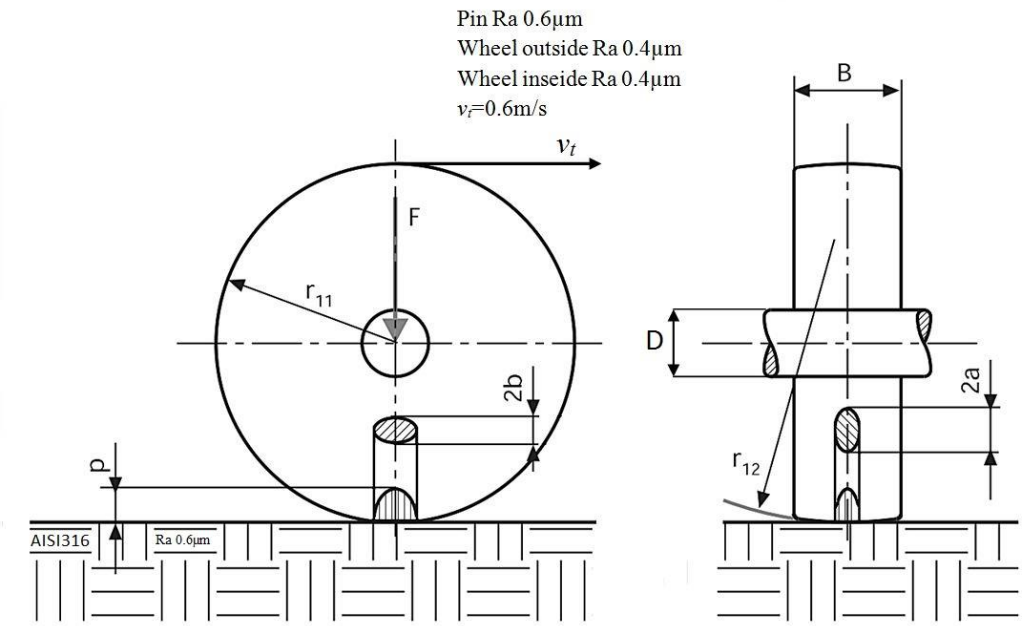

Figure 2. Pressure between the surface and wheel

$$a = S \cdot \sqrt[3]{3 \cdot F \cdot r_e \cdot \frac{1}{E_e}}\ , \tag{1}$$

$$b = I \cdot \sqrt[3]{3 \cdot F \cdot r_e \cdot \frac{1}{E_e}} \tag{2}$$

$$r_e = \frac{r_{11} \cdot r_{12}}{r_{11} + r_{12}} \tag{3}$$

$$\frac{1}{E_e} = \frac{1}{2}\left[\frac{1-\nu_1}{E_1} - \frac{1-\nu_2}{E_2}\right] \tag{4}$$

$$p = \frac{3 \cdot F}{2 \cdot \pi \cdot a \cdot b} \tag{5}$$

$$p_s = \frac{F}{B \cdot D} \tag{6}$$

In relation to the formula (1) and (2), correction factors are S = 1.486 and I=0.717 and equivalent wheel radius is r_e= 16.875mm, depending on the wheel radius r_{11}=22.5 mm and roundness of the wheel r_{12}=67.5 mm [11] [12]. Permissible pressure must be reduced by at least 15% of the p_{dop} allowable surface pressure for a given material. Calculation of the pressure between the surface made of AISI 316 (ν=0.25, E=193 MPa) and the wheel can be seen in Table 1.

Material	Poisson coefficient, ν	Elasticity modulus, E /MPa	Equivalent elasticity modulus, E_e /MPa	Contact half width a /mm	Contact half width b /mm	Hertzian surface pressure p/MPa	Allowable surface pressure p_{dop}/MPa
PET	0.37	3400	7730.96	1.4786	0.7124	67.99	79
PA 6	0.39	3300	7199.42	1.5126	0.7288	64.96	96
PA 6C	0.41	3200	7552.29	1.4886	0.7182	66.98	83

Table 1. Calculation of the Hertzian contact pressure between the surface made of AISI 316 and polymer wheel at a load of F_r=150 N for different types of materials

Contact slide pressure p_s between pin and wheel is calculated with formula (6), width B of wheel is 21 mm and pin diameter D is 11mm. The result of p_s is 0.64 MPa that is less than p_{dop} for all three polymer materials.

Testing of the dimension change of PET material was carried out in real operating conditions using the *Procomac* bottle rinsing machine. The results of the tests with polymer wheels can be seen in Figure 3. Tests were conducted on 10 wheels made from each type of polymer materials, which is in total 30 tested wheels.

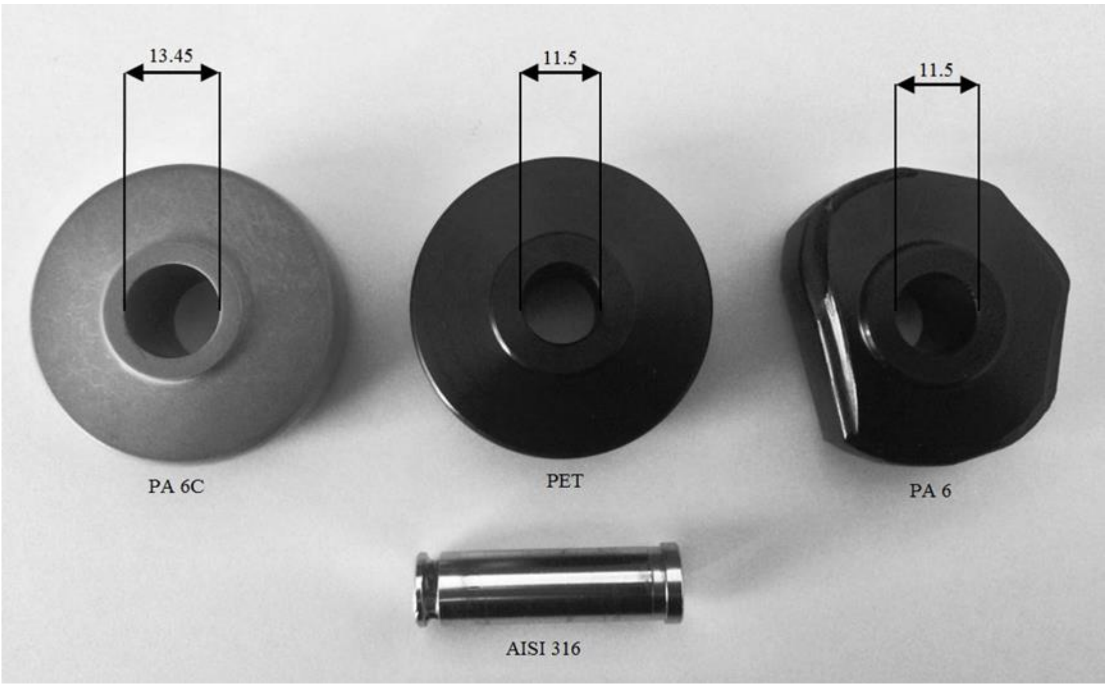

Figure3. Wear of polymer wheels on the inner and outer diameter, with the initial inner diameter 11.3 mm and outer diameter 45 mm

In the course of testing the wheels of machine, the following operating parameters were used:

- Peripheral speed at the wheel's outer diameter of 45mm is v_t = 0.6 m/s
- Lubrication by water, temperature from 15 ºC to 40 ºC
- Force exerted on the wheel F = 150N
- Pin used to securely attach the wheel is made of AISI 316
- Roughness of Pin is Ra 0.6 µm
- Roughness of the inside wheel is Ra 0.4 µm
- Roughness of the outside wheel is Ra 0.4 µm
- Testing circle is 200 hours
- Surface on which the outer edge of the wheel rests upon is a main strip made of AISI 316 with a roughness of Ra 0.6 µm

We can see that external dimensions of the wheel made of PA6C haven't changed; whereas the internal dimension with the pin inside changed from 11.5mm to 13.45mm and the inside roughness changed from Ra 0.4 µm to Ra 0.26 µm. Change of inside wheel diameter was caused by adhesive wear between polymer and pin made from AISI 316 [1].
Internal measure of the wheel made of PA6 is slightly modified, but due to the swelling of the material, the wheels are forced to brake on the pin which leads to excessive abrasive wear on the outer part of the wheel, while roughness from inside changed from Ra 0.4 µm to Ra 0.15 µm. Similar results were reported by Abdelbary [1].
As for the internal measure of the wheel made of PET, the measure of the wheel changed from 11.3mm to 11.5 mm which is negligible compared to the initial state the roughness from inside changed from Ra 0.4 µm to Ra 0.25 µm .
Dimensions of the pin made of AISI 316 remained unchanged i.e. 11.05 mm, as well as the roughness.

4. Conclusion

In this research three different polymer materials (PET, PA6 and PA6C) were tested. For this purpose 10 testing samples for each material in form of wheels were tested under real working conditions on *Procomac* bottle rinsing machine. On the basis of obtained test results, it can be concluded that polymer material PET, exhibited very good mechanical and tribological properties in comparison to other test materials PA6 and PA6C for the given operating conditions. The machine with wheels made of PET, indicated a significant shift in extending the service intervals from six to ten working months so that the bottle-filling station could operate smoothly in terms of production throughout the entire filling season. The cause of failure on PA6C was adhesive wear, while on PA6 it was abrasive wear. Limitation for PET polymer material compared to PA6 and PA6C is poor hydrolysis resistance on hot water above 70 ºC. However PET is more and more used as a structural material for construction.

5. References

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