Wear 324-325 (2015) 118–121

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Abrasive wear of selected plastics in solvent/corundum suspensions

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ARTICLE INFO

Article history:
Received 16 September 2014
Received in revised form
12 December 2014
Accepted 13 December 2014
Available online 19 December 2014

Keywords:
Two-body abrasion
Polymers
Other materials
Wear testing

ABSTRACT

A screening program to investigate the stability of plastics against wet abrasion was conducted. Plastic discs were spun in solvent/corundum suspensions at high speed and their wear was determined. Nine different plastics were investigated in water/corundum suspensions, and the three most stable were chosen for further studies in other liquids. Five common solvents were used to prepare corundum suspensions in which ultra-high molecular weight polyethylene, polyurethane 90Shore A and polyamide 6 discs were spun and abraded. Here we show that abrasion is solvent dependent. The abrasive power of the corundum/solvent mixture decreases as follows: methyl ethyl ketone > ethyl acetate > butyl acetate > water > isopropanol > ethanol, on average for the three plastics. The suspensions with solvents containing carbonyl groups display higher abrasive power than the ones with hydroxyl groups. For polyurethane the above ranking could be linked to swelling. For this polymer, a correlation exists between the degree of swelling and the abrasion in the respective solvent. The polymer with the best abrasion resistance in the suspensions tested is ultra-high molecular weight polyethylene.

1. Introduction

It would often be cost effective to replace metals with plastics in, for example, chemical reactors. Moreover, wear debris from metals can introduce undesired contamination. In order to replace the metal, plastics have to possess high chemical stability and they must also be durable against wear under aggressive conditions. However, it was stated that some tests suggest that under certain conditions, some plastics and elastomers can have particle abrasion resistance comparable with that of hard steels [1]. We set up a program to investigate abrasive wear of selected polymers in solvent/corundum suspensions with the aim of finding the most stable polymer. Although abrasive wear of plastics is well studied under dry conditions [1–4] and in water or sea water [5–7] we did not find a study which explores abrasive stability of plastics in common, organic solvents. As our test is different from those described in the literature, and our choice of plastics is unique, it is difficult to draw direct comparisons between our findings and those from previous studies. The choice of plastics is limited by their solubility. Styrene based polymers such as acrylonitrile–butadiene–styrene (ABS) or styrene–butadiene (SB) will dissolve in ketones or esters and are therefore inappropriate. Other plastics will swell when in contact with a qualified solvent such as, for example, polyurethanes. Nevertheless, we included polyurethanes in our program, because they tend to display high abrasive stabilities [1]. We chose corundum as an abrasive medium, due to its hardness and chemical inertness. Corundum is used in emery paper and sandblasting and has a high abrasive power which allows us to perform relatively short but tough tests. The wear is caused by a fast rotational motion of a plastic disc in the corundum suspension. This is a typical case for a two-body abrasion [8]. The solvents we use are of low toxicity and quite common. They can be arranged in two categories, according to their chemical structure. Three solvents contain a carbonyl group and form the first group, such as methyl ethyl ketone, ethyl acetate and butyl acetate. The second group consists of three solvents containing a hydroxyl group; these are water, ethanol and isopropanol. Our program aims to first investigate a range of plastics in water/corundum suspensions and then to select the three most stable and test them in the five solvent/corundum suspensions.

2. Materials and methods

Plastic sheets of 2 mm thickness were purchased from Angst+Pfister AG, Zurich, Switzerland. From these sheets circular discs of 40 mm diameter were punched. Additionally, four circular holes of 7 mm diameter were punched symmetrically into the disc to increase wear. A hole of 5 mm diameter was punched at the center of the disc in order to attach the disc via a screw to the shaft

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http://dx.doi.org/10.1016/j.wear.2014.12.020
0043-1648/

of an electromotor. The volume of such a disk is 2166 mm^3. For each test a fresh, unused disc was employed. The plastics used, together with their abbreviations, were as follows: polyurethane 90Shore A (PUR), ultra-high molecular weight polyethylene (UHMWPE), polyamide 6 (PA6), polyamide 12 (PA12), polyether ether ketone (PEEK), high density polyethylene containing 2% soot (HDPE), polytetrafluoroethylene (PTFE), polyoxymethylene (POM), and polypropylene (PP).

The solvents were of purum quality, and are listed here together with their abbreviations: methyl ethyl ketone (MEK), ethyl acetate (EtAc), n-butyl acetate (BuAc), isopropanol (Isoprop.), and ethanol (EtOH).

The suspensions were prepared from 100 g corundum and 50 ml of solvent in an electrically grounded metal beaker, and externally cooled with ice during the whole experiment to prevent solvent evaporation and to provide reproducible conditions. Despite the ice cooling, the temperature in the suspension rose to $5 \pm \pm 1.4$ °C after one hour of abrasion, independent of the solvent employed.

The corundum used was "Edelkorund Alodur SWPL P100" from iepco, Höri, Switzerland and of 99.65% purity. Particle size distribution is as follows: > 300 μm, 0%; > 212 μm, 0.5%/ > 180 μm, 16.5%/ > 150 μm, 67.6%/ > 125 μm, 95.6%/ < 125 μm, 4.4%. In a typical, standardized experiment the electromotor spun the plastic disc in the suspension with 6000 cycles per minute for 3 h.

The plastic discs were weighed before the experiment. After the abrasion, the cleaned discs were dried in a vacuum oven at 3 mbar and 80 °C for about 20 h, cooled, and weighed again. Wear volume was calculated using weight loss and density of the plastic.

Each solvent (water)/corundum–plastic combination was investigated three times, except for the polyamide 6 – solvent pairings which were repeated only twice.

3. Results and discussion

Fig. 1 shows the wear volume of the nine plastics in water/corundum suspensions after three hours of abrasion. The bars indicate the standard deviation from three independent experiments.

In the section below we will discuss the behavior of the individual polymers in our test.

Three of the plastics investigated are polyolefines (UHMWPE, HDPE and PP) and despite their chemical relatedness, they behave very differently. UHMWPE is one of the most abrasion resistant plastic and, on the other hand, PP is the least abrasion resistant plastic in our experiment and HDPE is in between the two. This result was unexpected.

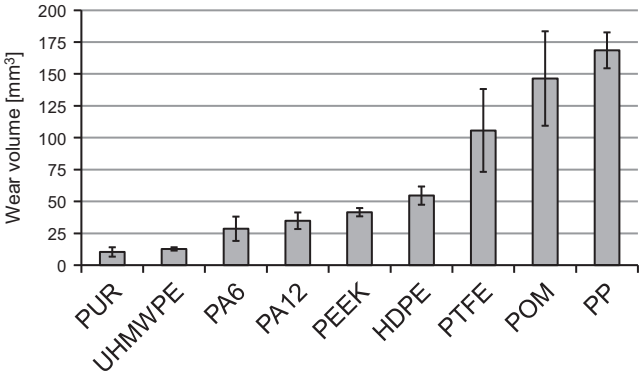

Fig. 1. Abrasive wear of nine plastics in water/corundum suspensions. For abbreviations see Section 2.

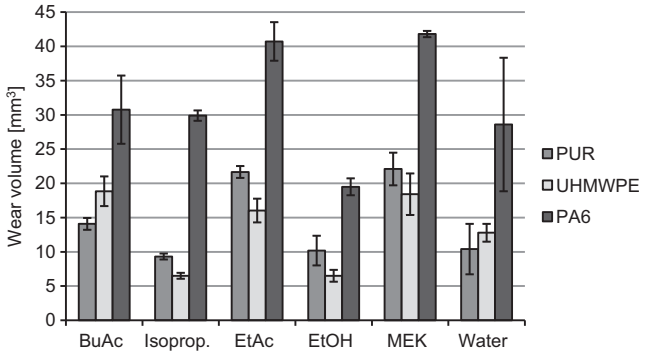

Fig. 2. Abrasive wear of three plastics in six different corundum suspensions. For abbreviations see Section 2.

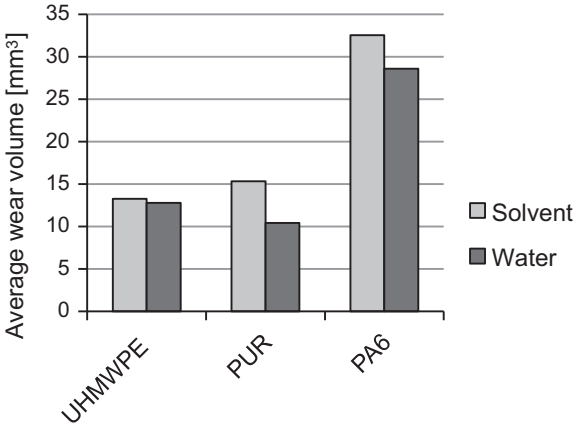

Fig. 3. The average wear from five solvent/corundum suspensions for three plastics. Abrasive wear for water/corundum suspensions is also shown.

PUR and UHMWPE are the two most abrasive resistant plastics in water/corundum suspensions; this fact qualifies them for further studies in solvent/corundum suspensions.

PA6 and PA12 achieve a comparable wear volume which is understandable given their chemical similarity. PA6 is the third most abrasion resistant plastic and therefore selected for studies in organic solvents.

We included PTFE in our program because it has a very good chemical stability, although it performs rather poorly in terms of abrasion resistance.

PEEK is a semi-crystalline thermoplastic with excellent mechanical and chemical resistance properties that are retained at high temperatures. However, it does not display a high abrasive stability in our test.

POM was chosen because of its reported high resistance against wear [9], but in our test it performed rather poorly.

The three plastics showing the least abrasion were subjected to tests in five solvent/corundum suspensions and the results are displayed in Fig. 2. The water/corundum results from Fig. 1 are also shown. For PUR and UHMWPE each test was repeated three times, and the corresponding standard deviations are displayed in Fig. 2. As the standard deviations are reasonably small, the tests with PA6 were repeated only twice. Generally, as in the water experiments, PA6 shows much higher volume losses than PUR or UHMWPE, whereas the latter are comparable in this respect. Isopropanol- and ethanol/corundum suspensions are very similar in their abrasive power for UHMWPE and PUR. Methyl ethyl ketone- and ethyl acetate/corundum suspensions are also similar in their abrasive behavior with regard to UHMWPE and PUR.