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Thickness effect on particle erosion resistance of thermoplastic polyurethane coating on steel substrate

Na Zhang [a,b,1], Fan Yang [a,1,2], Lei Li [a], Changyu Shen [b], Jose Castro [c], L. James Lee [a,*]

[a] *Department of Chemical and Biomolecular Engineering, The Ohio State University, OH 43202, USA*
[b] *Department of Materials Science and Engineering, Zhengzhou University, Zhengzhou 450052, China*
[c] *Department of Integrative Systems Engineering, The Ohio State University, OH 43202, USA*

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ABSTRACT

The thickness effect of thermoplastic polyurethane (TPU) coating on solid particle erosion has been characterized. It was found that thickness affected the particle erosion resistance of TPU coating on a steel substrate. For our experiment, the results of the erosion tests show that the best thickness is around 0.75 mm; the thermal effect during the experiment had a significant influence on erosion resistance. The morphology of erodent surfaces before and after sand erosion was examined by scanning electron microscopy (SEM). Finite element (FE) simulation was used to provide some insights into the reasons for the effect of thickness on particle erosion.

1. Introduction

Solid particle erosion caused by the repeated impact of small solid particles on a solid surface is a typical wear mode, involving progressive loss of materials. It is an important issue in many industries such as marine, mining and wind energy in which parts such as turbine blades are often exposed to aggressive erosive environments. Tilly [1] reviewed the different mechanisms of erosion, which were categorized into brittle and ductile behaviors. Bitter [2,3], Arnold and Hutchings [4,5] stated that ductile materials showed peak erosion rate around 30° impinging angle because the cutting mechanism is dominant in erosion. Particle erosion may result in the need for material replacement and a consequent decrease of productivity [6]. Therefore much effort has been made to mitigate erosion, among which protection of the target surface through coating is a widely used approach [7,8]. Some authors used hard ceramic materials for this purpose and achieved distinct enhancement of erosion resistance [8]. A more popular choice is using ductile elastomers [7,9–12].

Thermoplastic polyurethanes (TPU) which possess high corrosion resistance and high adhesion ability [13,14] are often used as coating materials in the mineral, aeronautical and mechanical industries to protect metallic components [15–17]. However, TPU shows poor heat resistance, which undermines its application potential. In general, the temperature that TPU performs well in erosion-resistance ranges from several degrees above its glass transition temperature (T_g) (−50–25 °C) to tens of degrees below the melting temperature (around 120 °C). Marei and Izvozchikov [18] carried out a series of erosion experiments on polymers, and concluded that the difference between the test temperature and T_g was important, with a larger difference between the testing temperature and T_g corresponding to lower erosion rate. There are many factors that influence the erosive wear. Meng and Ludema [19] summarize 33 independent parameters after reviewing 22 erosion models found in the literature. Zhang et al. [20] investigated the correlation degree of erosive wear rate with various characteristic properties using an artificial neural network approach. Some attempts [4,21–24] have been made to correlate solid particle erosion resistance of polymers to some more fundamental properties such as modulus and toughness of the target materials. However there is a lack of systematic study for the effect of coating thickness on the erosion resistance.

The objective of the present work was to investigate the effect of TPU coating thickness on the resistance to solid particle

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[*] Corresponding author. Tel.: +1 614 292 2408; fax: +1 614 292 3769.
E-mail addresses: zhangna163163@163.com (N. Zhang), yangyangyang99@gmail.com (F. Yang), li.668@osu.edu (L. Li), shency@zzu.edu.cn (C. Shen), castro.38@osu.edu (J. Castro), lee.31@osu.edu (L.J. Lee).

[1] N. Zhang and F. Yang have contributed equally to this work.

[2] Present address: Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, ON, Canada M5S 3G8.

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erosion, and explore the thermal effect on erosion rate. The effect of thickness on particle erosion as well as the details of the tests and simulations will be stated in Section 2. Analysis of the thermal effect will be given in Section 3, with the aim of providing a qualitative explanation for the experimental observation. The surface morphology was further investigated in Section 4. Conclusions will be given in Section 5.

2. Effect of thickness on the erosion rate

2.1. Materials and apparatus for particle erosion testing

The thermoplastic polyurethanes studied were 3M#8545 polyurethane protective tape, supplied by 3M Co. In the present study, seven samples with different thicknesses were prepared. Silica sand, which were green particles with sharp edged blocky shape of about 150 μm size and 2600 Knoop hardness were selected as the erodent. A scanning electron micrograph of the silica sand is shown in Fig. 1.

Square TPU samples of size 30 mm × 30 mm for the erosion tests were used. The conditions under which the erosion tests were carried out are listed in Table 1. The same procedure was employed for each erosion test. Before testing, the polyurethane samples were burnished to remove pollutants from the surface of the samples. After each test, specimens were rinsed in tap water, degreased with acetone, dried in a jet of cold air and weighed with a precision balance (Explore, ep214C). The mass loss was the difference in the sample mass before and after the erosion test (with an accuracy of 0.1 mg). The specific mass loss i.e. the mass loss per unit mass of erodent was used to evaluate the erosion resistance. The smaller the specific loss, the better the erosion resistance of the materials was. Each data point was obtained from the average value of five measurements.

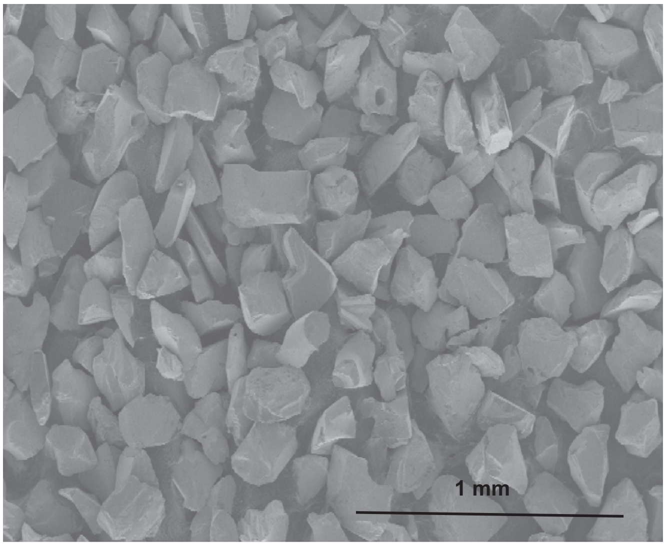

Fig. 1. Scanning electron micrograph of silica sand used.

Table 1
Erosion test conditions.

Impingement angle (°)	30
Impingement area (mm^2)	600
Impingement time (min)	3
Erodent feed rate (g/min)	453.4
Test temperature (°C)	20
Nozzle to sample distance (mm)	25.4
Nozzle diameter (mm)	8
Air pressure (MPa)	0.47

To characterize the morphology of the eroded surfaces and to understand the mechanism of material removal, erodent surfaces before and after sand erosion were observed using a scanning electron microscope (SEM, Hitachi s-4300 Tokyo, Japan). The samples were gold sputtered in order to reduce charging on the surface.

The experiments were carried out in a sand-blasting chamber equipped with a boron carbide jet nozzle with an internal diameter of 8 mm. The film was tightly attached to a smooth steel surface. All the tests were conducted at an impact angle of 30°, close to the conditions of impact likely to occur in practice [6].

2.2. Observation of thickness effect on erosion resistance

A very interesting phenomenon was observed that the mass loss first decreases as the TPU thickness increases, then increases with further increase of TPU thickness. A thickness with minimum erosion exists for the particle erosion resistance of the investigated TPU and the conditions tested, as shown in Fig. 2.

2.3. Finite element simulation

To understand the mechanisms underlying the observed experimental results, finite element (FE) simulations were carried out on the particle erosion at the TPU films with different thicknesses.

The simulations were carried out using the generalized FE software ABAQUS/EXPLICIT version 6.9. One collision event with periodically distributed particles was simulated. Utilizing the symmetry and periodicity, only one-half of the particle-target periodic configuration was needed for calculation, which formed the computational representative volume element (RVE). Based on the conditions used in the experiments, the diameter of the spherical eroding particle was chosen as 0.2 mm, and the distance between the centers of two adjacent particles was 0.4 mm. Thus the lateral dimensions L_x, and L_y in Fig. 3a were respectively 0.4 mm and 0.2 mm, and the thickness L_z can be changed to investigate the thickness effect. Symmetric boundary conditions were applied on the nodes of the two end faces along y axis of the film, and on the cross-section faces of the erodent particles. While

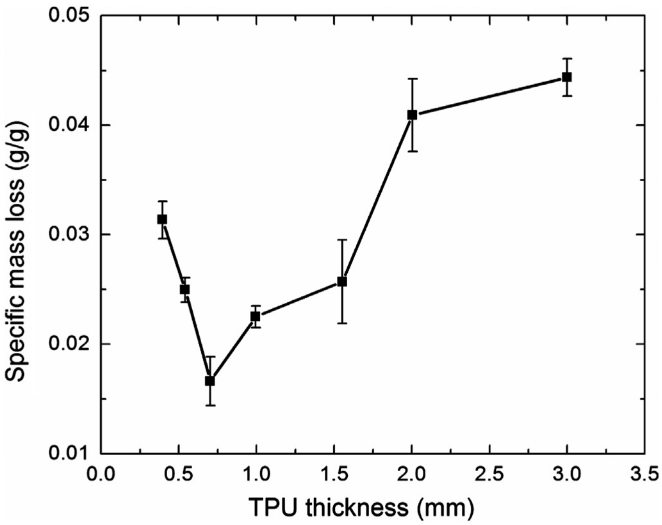

Fig. 2. Specific mass loss of TPU coating with different thicknesses at an impingement angle of 30° after 3 min of erosion.