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Slurry erosion resistance of polyethylene under conditions relevant for mineral processing

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ABSTRACT

The use of polyethylene (PE) liners for protection against wear has become of interest in applications dealing with abrasive slurries, for example in the minerals processing industry. The present study aims at studying the influence of various operating conditions on the erosive wear by slurry of low-density polyethylene and high-density polyethylene samples, manufactured by either rotational molding or extrusion. In particular, this work presents for the first time a systematic study on slurry erosion at temperatures from 35 to 65 °C, since minerals processing operations may reach temperatures above ambient. The experiments were conducted in a slurry-pot equipment using quartz suspended in water as erodent. The wear of PE was also investigated as a function of impact angle. The indicator to describe wear was weight loss of PE samples after the experiment. Finally, the erosion of PE in experiments lasting up to 72 h with and without addition of fresh erodent was analyzed. It was determined that high temperatures invariably resulted in lower resistance to wear, but its influence on wear is only observed at impact angles lower than 90°. Furthermore, it was found that the manufacturing method of PE has a stronger influence on its erosive wear compared to its density.

1. Introduction

Polyethylene (PE) is a plastic material commonly used as a protective layer to shield mechanical components of machinery against wear that has recently gained interest in the field of minerals processing. PE is considered to offer an excellent resistance to erosive wear while also being lightweight, easily processed, and resistant to corrosion. These properties make PE an interesting material to protect equipment in direct contact with abrasive slurry, for example when handling suspended mineral particles. PE is often classified by its density and branching, e.g., ultra-high-molecular-weight polyethylene (UHMWPE), high-density polyethylene (HDPE), low-density polyethylene (LDPE) and high-density cross-linked polyethylene (HDXLPE). It is well established that the mechanical properties of polyethylene depend significantly on its density and branching [1].

Erosion studies of plastics and plastic composites can be found in the literature for at least PE [2–4], polyether ether ketone (PEEK) [4–6], polyethylenimine (PEI) [4,7–10], polyimide (PI) [11], polypropylene (PP) [2,12], polyphenylene sulfide PPS [4,13,14], polystyrene (PS) [2], and polyurethane (PU) [15,16]. Wang et al. [17] and Walley and Field [18] for example, showed that the maximum damage for PE in erosion experiments occurred at impact angles around 30°. Noticeable here is that both of those experiments were conducted utilizing high (10–100 m/s) impact velocities. Yabuki et al. [3] studied the anti-slurry erosion properties of PE (i.e., erosion resistance) in order to evaluate its usability for sewerage pipe use. They experimented the impact velocity dependence of the maximum erosion angle for PE and concluded that the maximum erosion angle shifted towards higher angles while the impact velocity decreased. At similar impact velocities as earlier studies [17,18], they also reported the maximum erosion angle at 30°. This is typical behavior for ductile materials which are worn the most by cutting wear at low impact angles, whereas the main source of wear in hard and brittle materials is deformation wear caused by particles hitting at high impact angles [19,20].

Studies about the effect of the solid particle characteristics on erosion have also been conducted by several authors e.g. [21–24]. Desale et al. [21] concluded that the maximum erosion angle was a function of the properties of the target material and not dependent of the erodent. However, the total amount of erosion was influenced by erodent properties such as particle size and hardness, but also shape and density. These studies also indicated that the effect of erodent properties is more dominant at low impact angles and that the dominant material removal mechanism is a function of erodent shape and density. According to Desale et al. [22] erosion wear of ductile materials due to

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normal impact is strongly dependent on velocity and particle size but only weakly dependent on solid concentration. Nguyen et al. [23] studied the erosion of stainless steel with sand particles and suggested that the erosion rate increased with particle size, until it reached a maximum value with particle size of 150 µm. In the presence of larger particles however, the erosion rate gradually decreased while the particle size increased. Sparks and Hutchings [24] studied the effect of erodent recycling in solid particle erosion tests. They reported the significance of particle angularity on erosion by observing that recycled particles caused less damage than unused particles with sharp edges, even if the size distribution was similar.

Friedrich [2] studied the erosion resistance dependence on temperature for various polymeric materials, including PE, by conducting erosion experiments in an air-blast rig using steel balls as erodent. He carried out experiments at room temperature and at –35 °C and reported that a decrease in temperature led to lower erosion resistance, which was more pronounced in polymers which undergo a ductile-brittle transition within the studied temperature range. Friedrich [2] also suggested that instead of using hardness as the indicator for the erosion resistance of polymers one could utilize a “brittleness index” which is hardness of the material divided by its fracture energy. Various polymers that were included in his study showed high correlation between their erosion resistance properties and the brittleness index. It is worth noting that, in minerals processing applications, the slurry temperature may elevate up to 50 or 60 °C, which requires materials to sustain its wear resistance properties at this temperature level. Nonetheless, studies about the erosion resistance of PE at temperatures higher than room temperature have not been reported, to the best of our knowledge.

In the present study, the erosion resistance of three different kinds of PEs is discussed. These PEs include rotational molded LDPE (RM-LDPE), rotational molded HDPE (RM-HDPE), and extruded HDPE (E-HDPE). The densities of these species were determined using the Archimedes principle and had values of 0.92 g/cm^3, 0.94 g/cm^3 and 0.96 g/cm^3 for RM-LDPE, RM-HDPE and E-HDPE, respectively. Therefore, the influence of the manufacturing method and density on the erosion resistance are studied. Slurry erosion experiments of the three PE plastics were conducted in a slurry-pot equipment at elevated temperatures and at different particle impact angles. To the best of the author's knowledge, this work presents for the first time slurry erosion studies for PE at temperatures above ambient in the range between 35 °C and 65 °C. The effect of the impact angle was studied at various angles between 15° and 90° at two different temperatures to also study the possibility of a combined effect of temperature change and change in impact angle. A possible correlation between hardness and erosion resistance is discussed and also the effect of erodent particle shape is briefly discussed. Additionally, the effect of particle angularity to erosion damage was studied.

2. Experimental

2.1. Erodent

The erodent utilized in this study was quartz sand (Sibelco Nordic) with a nominal particle size of 100–600 µm. The quartz particles were suspended in water from the nearby Kokemäenjoki river bed to produce a slurry with solid content of 30 wt%. Fig. 1. presents a scanning electron microscope (SEM) image of the erodent particles taken with JEOL JSM-6490 LV scanning electron microscope. Table 1. shows size distribution of the erodent particles obtained experimentally by sieving.

2.2. Equipment

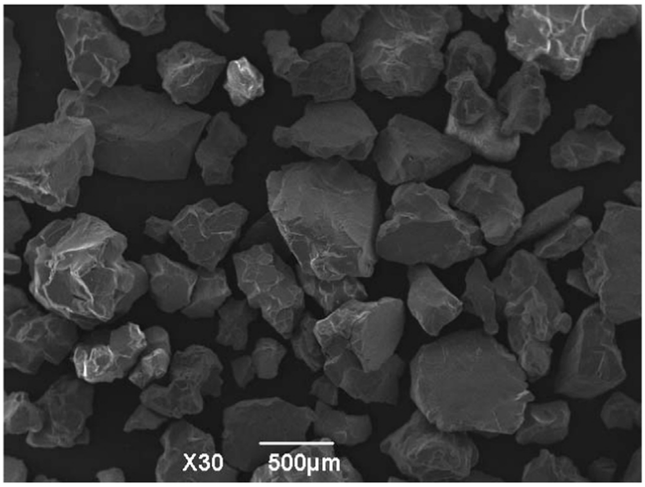

Fig. 1. SEM image of the quartz particles utilized for erosion experiments.

Table 1
Sieve analysis of the quartz particles.

Sieve size (µm)	Retained on sieve (%)	D50 (µm)	D80 (µm)
600	0.6	280	400
425	12.8		
300	30.0		
212	23.4		
150	19.8		
106	7.9		
75	3.0		
−75	2.6		

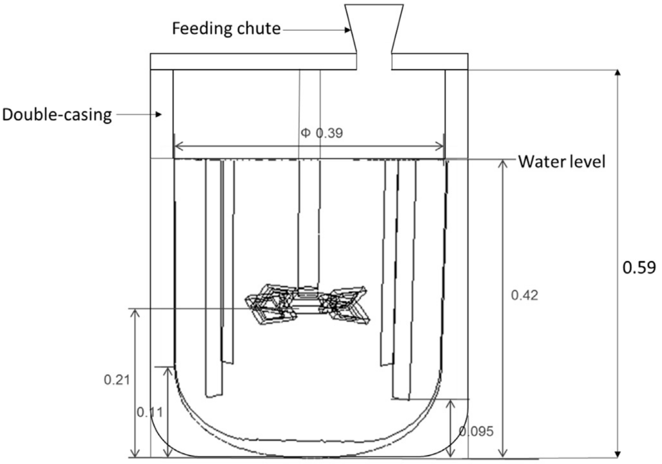

Fig. 2. Schematic of the reactor and the impeller inside it (dimensions in m).

A slurry-pot erosion tester was employed to conduct the erosion experiments. A schematic of the vessel and the sample holding impeller is shown in Fig. 2. Two similar stirred vessels were utilized to run parallel experiments at once. Each vessel counted with four baffles as shown in Fig. 2. Four blades were attached to a pitch-blade impeller and the PE samples were attached to the pressure side of the blades, one sample for each blade. The impeller was attached to a shaft which was ran in rotational motion by an electric motor. The temperature was controlled by feeding either steam or cold water in between the double-casing of the vessel. The test setup was able to keep the temperature very close to the desired set point. With the aid of an automated process control system, the temperature fluctuations were within ± 1.5 °C throughout the experiments.

The rotational speed of the impeller was 520 rpm during the experiments, which means that the outermost side of the PE sample was moving with a velocity of 5.0 m/s while its innermost side had a velocity of 3.2 m/s.