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The Effect of Impact Angle of the Particle on Solid Particle Wear Properties of Basalt Base Glass-Ceramics

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In this study, the effect of impact angle of the particles on solid particle erosive wear properties of basalt base glass-ceramics used for industrial applications was investigated. Commercial basalt glass-ceramic materials size of $20 \times 20 \times 3$ cm was sectioned to the size of $5 \times 5 \times 1.2$ cm. The experimental procedure was performed by using erosive wear test device with nozzle diameter of 0.78 cm. Na feldspar size of 300 μm was used as erosive media. The samples were fixed 2 cm distance from the nozzle, Na feldspar particles were sprayed by using 1.5, 3, 4 bar pressure for 20 s. The tests were repeated with $30° + 45° + 60° + 75° + 90°$ impact angles. The erosive wear rates were measured and the effect of particle impact angle on wear properties was determined.

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1. Introduction

Basalt is a type of hard and the dense volcanic igneous rock that contributes to the major part of the earth. It exhibits a wide variety of rocks, which may generally have gray, brown, or dark color. Basalt contains olivine, clino-pyroxene (salite), plagioclase, and opaque metal oxides as major constituents. Plageocene and pyroxene constitute to about 80% of basaltic rocks [1].

Basalt glass-ceramics are produced by melting and casting processes at 1400–1500 °C, crystallized by controlled heating process. It has been used in many industrial applications as glass-ceramic material via its high strength, high thermal, and chemical resistance [2, 3], for instance: pipe, plate and elbow-shaped pneumatic and hydraulic systems, cyclone separators, chain conveyors, silos, mixers, tanks and pulp machines. It is important, especially in solid particle or slurry transportation systems in iron-steel, ceramic, cement and fuel industries [4, 5]. Because of this, erosion wear behaviors are significant for basalt based glass-ceramic materials. In the current study, commercial basalt based glass-ceramic plates were used to investigate erosive wear behaviors of these by using some parameters such as impact angles, pressure, particle impact velocity and particle size. Erosive wear is defined as a damage which is obtained from particles having different size, constant impact effect and geometrical shape on solid surface in gas or liquid fluid media. Material losses have occurred via hard and moving particles that impact on material surface [6].

In the current study, commercial basalt based glass-ceramic materials were subjected to erosive wear test, and their wear resistance and behaviors were investigated.

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2. Experimental studies

In this study, the erosive wear properties of commercial basalt based glass-ceramic materials obtained from Matas mining and trading company were investigated. $200 \times 200 \times 30$ mm sized basalt plates seen in Fig. 1 were cut, and then the samples were shaped as $50 \times 50 \times 12$ mm. Erodent Na feldspar particles having particle size of 300 μm were used for erosion tests. Erodent Na feldspar particles were performed by using three different pressures 1.5, 3, and 4 bar for 20 s. The tests were repeated with $30° + 45° + 60° + 75° + 90°$ impact angles. The chemical analysis of erodent Na feldspar and basalt and the physical properties of commercial basalt glass-ceramics were given in Table I and Table II, respectively.

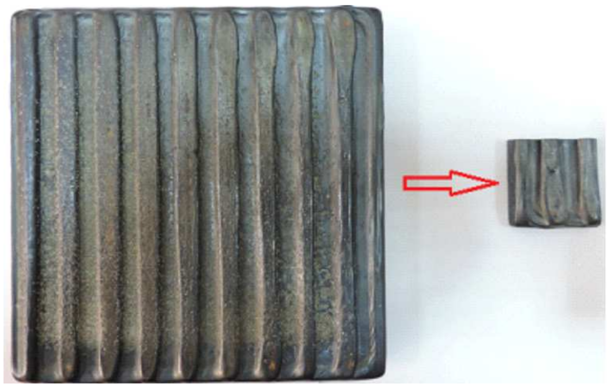

Fig. 1. Commercial basalt plate used in the study.

During the wear tests, the samples were fixed in holder and distance between the sample and the nozzle was 2 cm. After the wear tests, the worn samples weights were measured to determine material loss. These values were divided to mass flows, thus, wear rates were calculated. Some parameters of the wear test can be seen in Table III.

TABLE I

The chemical analysis of erodent Na feldspar and basalt [wt%].

	Na feldspar	Basalt
Na_2O	10.5 ± 0.50	1.50–3.50
K_2O	0.30 ± 0.10	0.50–2.00
Fe_2O_3	0.02 ± 0.01	11.00–15.00
TiO_2	0.04 ± 0.01	1.00–3.50
SiO_2	69.00 ± 1.00	43.00–47.5
Al_2O_3	18.50 ± 1.00	11.00–13.50
CaO	1.00 ± 0.30	10.00–12.50
MgO	0.20 ± 0.10	9.50–12.50
P_2O_5	–	0.50–1.50
l.o.i.	0.30 ± 0.20	–
dampness	8.00	–

TABLE II

The physical properties of commercial basalt glass-ceramics.

Parameter	Value
commercial basalt plate used in the study [g/cm^3]	2.90–3.00
porosity [%]	0–3.00
hardness [MOHS]	8.00
compressive strength [N/mm^2]	300.00–450.00
flexural strength [N/mm^2]	45.00
coefficient of expansion (0–100 °C) [1/K]	8×10^-6
thermal conductivity [W/(mK)]	1.10–1.16
operating temperature [°C]	350.00
resistance of abrasion [cm^3/50cm^2]	5.00
specific heat [kJ/(kgK)]	0.80
specific induction capacity [MHz]	7.00

3. Results and discussion

Figure 2 indicates wear rate results depending on erodent powder pressure, the results show that lowest wear rates are detected in the sample tested at 30°. When the impact angle is low, the erosion on the glass-ceramic surface is crack developing and brittleness fracture, probably. Since the impact angle is low, whole kinetic energy of the erosive media cannot transfer to the surface of glass-ceramic completely, erodent particles sliding on the surface and non-effective damage is detected, so that the erosion rate is lower than others. When the impact angle reached to 90°, the wear rate increased, clearly. The highest wear rates were determined for the sample tested at 45°. When the impact angle is 90°, kinetic energy of the particles transfers to the surface and strong damage is effective. When the impact angles were performed at 45°+60°+75°, scraping effect began, probably. It is possible that scraping at 45°+60°+75°causes more material loss from the material surface according to the frontal impact at 90°. On the other hand, increase in pressure caused increase in wear damage. The literature has reported that higher erosive wear damages occur at low impact angles for ductile materials according to test performed at high impact angle, while, for brittle materials, maximum erosive wear rates have been observed at high impact angle [7]. In the current study, erosion trend is in accordance with erosion behavior of brittle material, the erosion wear result at 30° is lowest than others. But, it changed by increase in impact angle, the angle was 45°, maximum abrasion effect was observed. Curkovic et al. reported that the erosion at impact angles between 0 and 30° is defined as abrasive erosion. If the impact angle is between 60° and 90°, the erosion is regarded as impact erosion. The formation and intersection of cracks via particle impacts cause grain ejection from the surface for brittle materials [8].

TABLE III

Some parameters of the erosion test.

Particle injection pressure [bar]	Mass flow [kg/s]	Abrasive mass [g]
1.5	7.25	145
3	12.75	255
4	14	280

The basalt plates tested in the study have been produced by melting and casting processes. Because of this, the residual glass structure remains in the body. It is possible that these glass structures affect the wear mechanism of the basaltic surfaces. Wellman et al. presented that the erosive wear rates exhibited sudden increase between 45° and 60° impact angles in ceramics. Similar trend was observed in the current study, the highest erosive wear rates were determined at 45°. Wang et al. have presented similar behavior for ceramic materials, there is a sudden increase at 45° [9]. When the impact angle increases, the erosion rates differ from the general phenomenon between impact angle and erosive wear rate. From 45° impact angle, decreases in the erosive wear rates with increase in impact angle show that scraping effect is stronger than direct particle impact in the current study. Yang et al. have reported similar behavior for the ceramic base bricks, increase in erosive resistance with increase in impact angle has been explained as higher wear resistance [10].

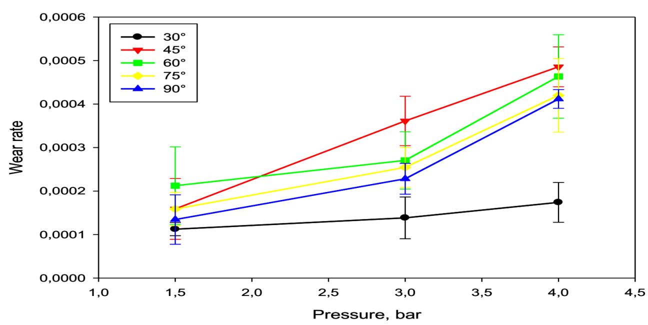

Fig. 2. Erosive wear rates of the samples for Na feldspar.

The mass flow rate versus pressure curves (Fig. 3) shows flow rate of the erodent powder Na feldspar. As seen, the more pressure means the more flow rate. It is natural result for erosive wear systems; increase in pressure causes increase in mass flow rate of erosive media. It is normal behavior for erosion tests, because increase in pressure means increase in particle velocity, thus, harsh wear circumstances occur. Celotto et al. reported that the same trend were observed for hard ceramics [11]. High particle velocity means high kinetic energy for particles, because of this, general tendency in terms of impact velocity indicates that high impact velocity causes high erosive rates.

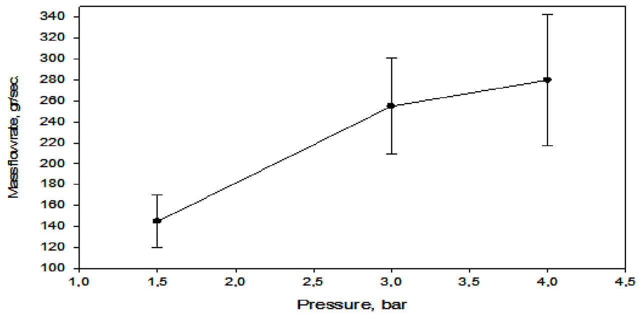

Fig. 3. The mass flow rates versus pressure.

4. Conclusion

In this study, erosive wear resistance of commercial basalt glass-ceramic against Na-feldspar erosive media was investigated. The results showed that the wear rates were strongly related to impact angles. When impact angles were changed, wear and damage mechanisms changed, possibly. In low impact angle such as 30°, the erosive particles cannot cause harsh wear effects, since their kinetic energies could not be transferred to the glass-ceramic, completely. When impact angle increase, more energy can pass on the surface, thus more material loss occurs. In medium impact angles such as 45°+60°+75°, stronger wear effects such as scraping activated, probably. Because of this, higher wear rates were determined in these conditions.

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