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# Erosive wear on ceramic materials obtained from solid residuals and volcanic ashes

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ABSTRACT

In this study, the performance of ceramic materials that were subjected to solid particle erosion was analyzed. This research was performed to characterize the materials in relation to the wear process. The materials could be used in the construction of devices and machine components that are commonly exposed to environments where volatile, abrasive particles typically cause a high rate of wear. The types of composites used in this study could have useful applications in mechanical components, automotive coatings, etc. These materials are usually obtained from solid residuals and volcanic ashes, in which clay and epoxy resin were used as binders.

The erosion testing was performed in accordance with the ASTM G76-95 standard. The samples had a rectangular shape, and their dimensions were $50 \times 25\ mm^2$ and 10 mm in thickness. The abrasive particles used were angular silicon carbide (SiC) with a particle size of 420–450 μm. The tests were performed using three different incident angles (30°, 45° and 90°) with a particle velocity of $24 \pm 2$ m/s. The abrasive flow rate was 70 g/min. The particle velocity and the abrasive flow rate were low in all the tests to reduce the interaction between the incident particles and the rebounding particles in the system. Additionally, the total time of each test was 10 min, and the specimens were removed every 2 min to determine the amount of mass lost. The test specimens were located a distance of 7 mm from the shot blast. The surface of the specimens was examined with a scanning electron microscope (SEM), which characterized the erosive wear damage.

The results indicated that all of the ceramic materials reached their maximum erosion rate at an incident angle of 90°. The erosion rate was significantly decreased when the angle of incidence was 30°. Additionally, the ceramics that consisted of volcanic ashes and sand mixed with epoxy resin gave a better erosion resistance compared with the materials that were combined with clay. It was assumed that the combination that was mixed with epoxy resin produced a more compact structure in the specimens, which resulted in a less severe attack of the particles that were acting on the surface of the material. The sand and the volcanic ashes that were mixed with clay, which had the poorest performance in the tests, exhibited similar behavior.

It was also observed that the damaged area was extended in all of the cases that used an incident angle of 45°, whereas the depth of the wear scars was higher when an incident angle of 90° (normal incidence) was used. The wear scars were characterized by an elliptical shape at 30° and 45°, which is a characteristic feature when the specimens are impacted at low-impact angles ($\alpha \leq 45°$), whereas a circular shape was observed at 90°.



## 1. Introduction

Recently, Osawa et al. [1] developed a noble metallic powder by mixing a pure powder from a noble metal such as gold, platinum, palladium and silver with a powder alloy solution that contained an organic binder. This mixture formed a ceramic composite that was called broken clay [1].

Masahiro et al. [2] also discovered a calcium silicate that was formed during the reaction when an acid gel of silica was compressed. This gel was obtained from a mixture of clay material and calcium composites.

The ceramic composites that were commonly used in the manufacture of components and materials were reinforced with fibers [3–5] and wood was also reinforced with nylon fibers [6]. Despite some failures between the matrix and the reinforcement

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of these materials, the application of ceramic composites with a particle-reinforced resin has increased since 2006 because they exhibit high mechanical and thermal resistances. Some examples of the resulting products are reinforced polyethylene with particles molded rotationally, epoxy resin reinforced with particles to contain thermal effects and composites that contain no toxic waste particles [7–11].

Studies on the erosion of ceramic materials have been performed by various researchers, such as Srinivasan and Scattergood [12], who conducted tests on alumina samples ($H_v$=10.8–15.7 GPa) by using two different erodents: Norton E17 $Al_2O_3$ ($H_v$=18–20 GPa) and SiC particles ($H_v$=24–25 GPa), to support the significant role of the erodent particle hardness relative to the target hardness on crack morphologies and erosion resistance.

From the results, it was observed that the alumina samples being attacked by E17 alumina abrasive were damaged to a lesser degree. In some cases, the samples exhibited only scouring marks due to fragmentation of the particles upon contact, which caused some fragments to slide on the surface and form the scoured region. No evidence of a classical lateral crack impact or punching as a result of the plastic deformation was observed. On the other hand, the alumina samples were severely damaged by the SiC particles. The samples exhibited radial cracks around the impact-contact zone in addition to lateral cracks on the surface. However, no evidence of fragmentation was noted. Additionally, the erosion rates of the samples when SiC was used were greater than the erosion rates obtained when using Norton E17 $Al_2O_3$. This confirmed that the use of a softer erodent reduces the severity of erosion.

In addition to these studies, Wheeler and Wood [13] performed erosion experiments on other brittle materials such as diamond coatings. The materials were subjected to particle impacts at angles other than 90° to study the damage features and to identify the damage mechanism. Examination of the eroded surfaces revealed circumferential cracks and pin-holes at all the angles that were used in the tests (30°, 45°, 60° and 90°). These diamond coatings exhibited the maximum erosion damage at higher impact angles ($\alpha > 45°$), and a reduction in the damage was observed when the impact angle was close to 20°. The wear scars were characterized by elliptical shape at low impact angles ($\alpha \leq 45°$), whereas an approximate circular shape was observed at higher impact angles ($\alpha > 45°$).

Telling and Field [14] performed a study on the degradation of three nominally brittle materials (diamond, sapphire and zinc sulfide) when they were impacted with small, fast-moving particles of quartz. In this study, the zinc sulfide material exhibited a central deformation and conical, radial and lateral cracking (top left) where a large portion of the material was removed. The other two materials exhibited similar damage characteristics: of partial cones and lateral cracks, but they were damaged to a lesser extent. Again, it was observed that each of the three materials exhibited their maximum erosion rate at higher impact angles (near or at 90°).

In this study, the performance of new ceramic materials was assessed. The aim of the experimentation was essentially to rank these materials with respect to their erosion resistance. An erosion test rig based on ASTM G76 was used to conduct the tests. As previously mentioned, these materials can have various useful applications such as coatings used to protect mechanical components, including engine pistons and steam generators. Generally, these types of coatings are exposed to severe atmospheric conditions and are prone to being damaged by the continuous impact of abrasive particles and solid objects such as stones. These severe conditions can lead to the degradation of the surfaces in a similar manner to that observed in solid particle erosion and abrasive wear, where pitting, irregular lines and grooves on the surface are the primary characteristics [15–18]. In this particular study, angular particles of silicon carbide (SiC) were used to accelerate the wear process and to study the behavior of these materials, they were subjected to highly erosive conditions.

Tests were conducted on epoxy-based materials and ceramics that were obtained by using the following procedure: wastes from gold and silver mines that were located in Pachuca and Zimapán (State of Hidalgo, Mexico) were collected to obtain the raw material (representative of silicates), which was then combined with a small amount of toxic and organic materials. The waste contaminated with cyanide was then treated with sodium hypochlorite in four thermostatic columns [19]. Subsequently, the wastes contained in the columns were mixed with surfactants and reducers to eliminate or decrease the concentration of heavy metals containing pH values of 2, 5, 7 and 10. The solid was then separated from the liquid by a filtration process. Prior to this stage, the samples were analyzed for chemical composition in both cases.

The waste was also dried and sieved to determine the grain size [20]. The test samples were then manufactured. In one process, each type of the solid waste was mixed with polyester resin and epoxy separately at room temperature to produce the polymer matrix composite. To produce the ceramic matrix composites, the materials obtained were separately mixed with clay and volcanic ashes [21].

## 2. Experimental details

### 2.1. Specimens

The materials that were employed in the tests were four ceramic materials: sand and clay, sand and epoxy resin, clay and volcanic ashes, and volcanic ashes and epoxy resin. The micrographs of the ceramic materials before testing are presented in Fig. 1. The chemical composition was obtained by using dispersive energy spectrometers (EDS and EDA sapphire) model XL30, as

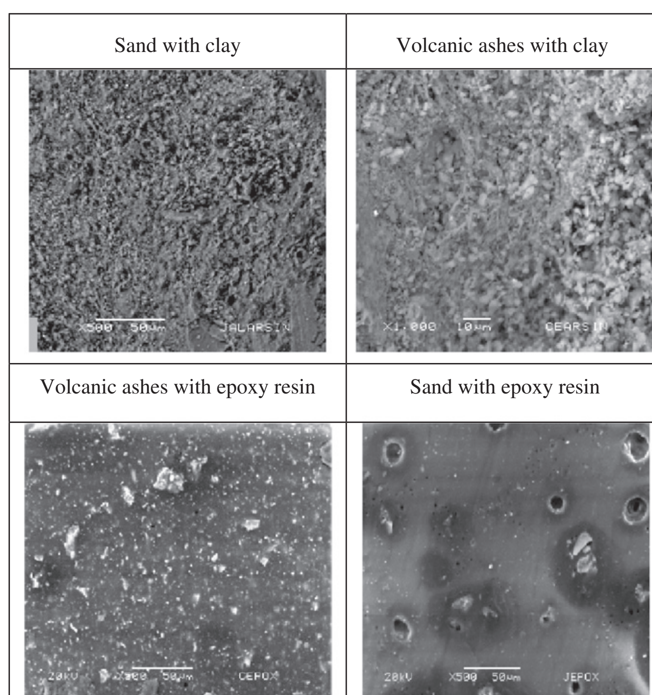


**Fig. 1.** Micrographs of the ceramic materials before tests.