# TRIBOLOGICAL BEHAVIOR OF GEOPOLYMER MIXTURES INCLUDING FLY ASH AND VARIOUS INDUSTRIAL WASTE

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## ABSTRACT

The tribological behavior of fly ash based geopolymer mixtures incorporating different types of industrial waste has been investigated. Therefore, 5 different geopolymer mixtures were analyzed, with the intent to retrieve information about their Coefficient of Friction (COF) and degradation by weight loss, as a result of direct contact with a stainless steel pin. A result analysis revealed varying results across the different mixtures.

**Keywords:** Geopolymer, Fly Ash, Wastes, Coefficient of Friction, COF, Weight Loss, Degradation, Tribological

## TRIBOLOGY AND WEAR – INTRODUCTION AND MECHANISMS

Tribology is a multidisciplinary science that finds its base in mechanics, physics, chemistry, and materials science. The main goals of tribology are the determination of the coefficient of friction (COF) and the quantification of the wear as a result of interaction between two opposing surfaces which move, one relative to the other. In reality, the study of tribology can be reduced to a trinomial relation between COF, wear and lubrication, involving a selection of different areas of application, such as health, energetic resources, selection and development of new materials, means of transportation, and nature preservation. It is important to be aware of the several laws of COF: COF is directly proportional to load; COF is independent of the area of contact, COF is independent of speed (of the sliding material). There are also several types of wear, such as adhesion, abrasion, fatigue, tribochemical, and erosion wear. In the result analysis, one will tend to only mention wear by adhesion and abrasion, as these where the predominant mechanisms. It is also important to mention that the rate of wear is influenced by temperature, presence of superficial particles, and load, which explains the need to do the experiments under different loads. [1] [2] [3] [4]

## EXPERIMENTAL PROCEDURE

The experimental procedure included a cutting process of the samples from geopolymer samples of 160*40*40 millimeters. After this, the samples' surface was polished with a SiC sandpaper of 180 mesh, and cleaned with 2-propanol. Following this, the samples were placed in an oven at 80º for 72 hours, then being transferred to a desiccator for another 72 hours. This way, the weight of the samples could the controlled, and there would be no influence of porosity on the determination of the wear rate. The samples were made from 5 different mixtures: Mixture I - 19% fly ash (FA), 5% steelmaking ladle slag (SLS), 5% NaOH solution at 10 M, 12,5% Na2SiO3 solution at molar ratio = 2,2 and density of 43 ºBe, and 58,5% sand; Mixture II: 25% FA, 3% SLS, 4% NaOH, 13% Na2SiO3, and 55% sand; Mixture III: 15% FA, 12% stone cutting sludge (SCS), 18% matrix cleaning sodium aluminate solution (MCL), 1% ceramic wastes (CW), and 54% sand; Mixture IV: 14,4% FA, 9,6% SCS, 18,3% MCL, 2% CW, and 55,7% sand; and Mixture V: 24,5% FA, 5,1% SCS, 14,4% MCL, and 56% steel making slag.

The variables of the experiments were the duration of the test (1 hour), the radius of action of the pin on the samples (13 millimeters), the load (5 and 10 newton), and the angular speed (60 rpm). After the tests were run, the samples were analyzed, as well as the pin, so that its wear could also be determined. The final results would be percussed by the repetition of the initial procedure, to ensure that no influential parameters were at play upon the analysis. Before both initial and final weight evaluations of the pin, this component was submitted to an ultrasound cleaning operation, so that any type of particles could be removed, and only the weight of the pin was actually and accurately determined.

## RESULTS AND CONCLUSION

The initial wear data was converted into wear rate, where the weight variation was divided by the total sliding distance of the pin as seen in Eq. 1:

$$Wear\ Rate = \frac{\Delta m}{((26*2)*3600)} \text{ [g/mm]} \quad (1)$$

By the results shown in figure 1, one can conclude that all the samples gained weight and all the pins lost weight, possibly by incorporation of metallic particles of the pin onto the samples, and by influence of atmospheric conditions due to the high porosity of the samples. However, one can not establish a direct relation between the porosity and the increase in weight, possibly by influence of the mixtures' components and higher or lower ability to "trap" metallic particles. As such, we can not say that there was "wear" in the samples with a load of 5 newton.

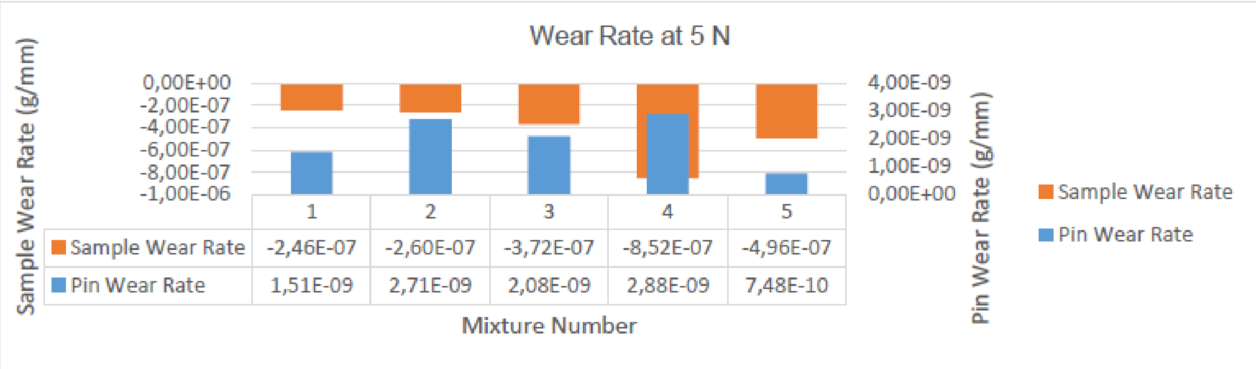


*Figure 1 - Wear Rate Analysis at 5 N*

With an increase in load, it can be concluded that a significant increase in wear rate can be verified in the samples, as shown in figure 2. As for the pins, a general increase in wear rate can also be noted. At the present load, is it possible to claim that the sample regarding mixture 1 presents the lowest wear rate, opposing the sample relating mixture 3, which reports the highest wear rate. This way, one proves the applied load is proportional to the wear rate.

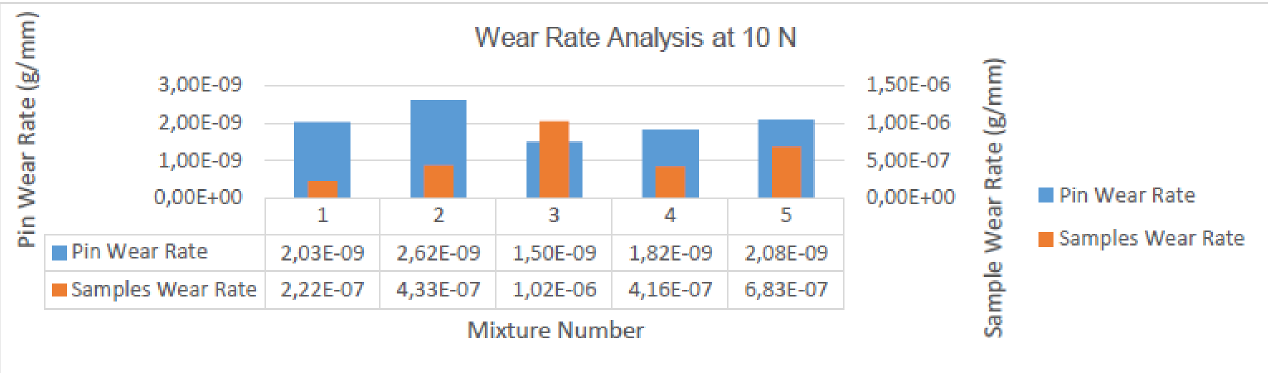


*Figure 2 - Wear Rate Analysis at 10 N*

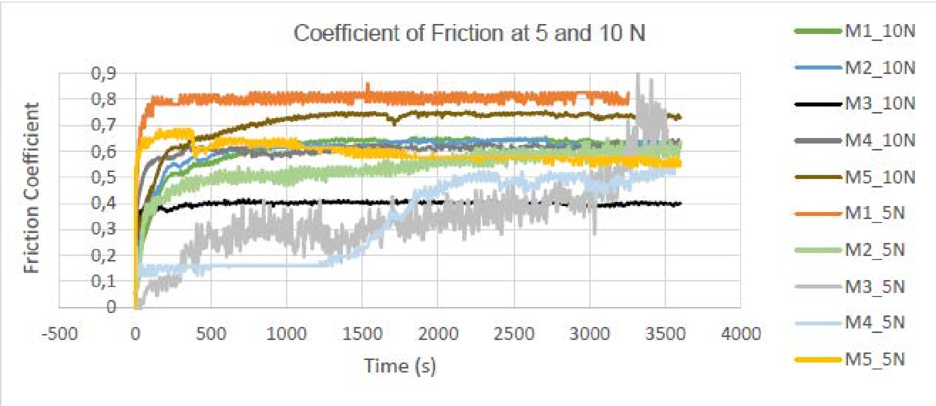


*Figure 3 – Coefficient of Friction at 5 and 10 N*

Through the analysis of figure 3, we can conclude that on the samples of mixtures 1, 2, and 3, a decrease of the Friction Coefficient was verified with the increase of the applied load, due to the formation of a solid lubricant, which had not been formed at 5 Newton. In these samples, a *stick-slip* effect was reported during the trials. As for mixtures 4 and 5, an increase of the COF was verified, due to the high surface roughness in the sample regarding mixture 4, and due to a decrease in the formation of a solid lubricant in the sample regarding mixture 5. Microstructural analysis on the various samples confirmed that there was a lodging of metallic material of the surface of said samples, as a result of the tests, which influenced the final weight of the samples.

By the pictures in figure 4, on the left an example of oxidation phenomena by adhesion of metallic particles to the geopolymeric surface, as well as abrasion, is represented. As for the image

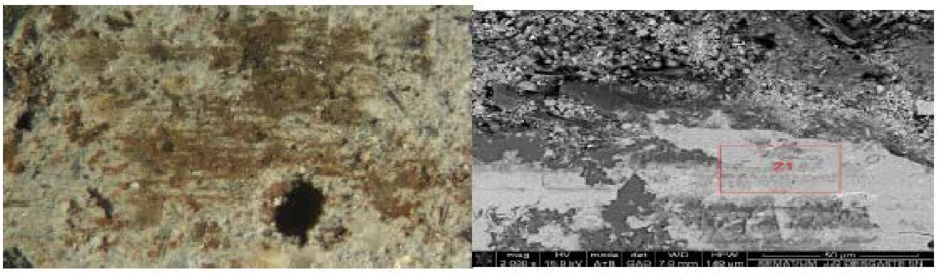

*Figure 4 - From left to right: Oxidation phenomena by adhesion of metallic particles and abrasion magnification x0,67; Adhesion phenomena as shown by SEM imaging; both regarding mixture 1.*

on the right, the upper part of the image relates to a non-degraded area, as the lower portion of the image relates to a degraded area, where one can confirm the presence of metallic particles in the surface of the samples. Through the analysis of microscopic photographs and SEM data, one can conclude that the main wear phenomena verified were adhesion and abrasion.

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