FRACTURE BEHAVIOR IN GEOPOLYMER MIXTURES INCLUDING FLY ASH AND VARIOUS INDUSTRIAL WASTE

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ABSTRACT
The fracture resistance behavior of fly ash based geopolymer mixtures incorporating different types of industrial wastes has been investigated. Therefore, 4 different geopolymer mixtures were analyzed, with the intent to retrieve information about their Initial Flexural Stiffness (R_i), and Ultimate Load (P_u). A result analysis revealed that one type of mixture was considerably superior to the rest in terms of Initial Flexural Stiffness and Ultimate Load.

Keywords: Geopolymer, Fly Ash, Wastes, Fracture Resistance, Initial Flexural Stiffness

PURE PROPAGATION MODES – THEORETICAL GROUNDING

Geopolymers are inorganic materials, which form covalently bonded non-crystalline (amorphous) interconnections consisting of layers of alkaline activated alumino-silicates. Other factors, particularly at the level of geopolymerization, are the Si / Al ratio, the type and concentration of the alkaline solution, temperature, curing conditions, and additives, such as slags and fibers [1].
One intended to accomplish trials as a mean to verify the behavior of geopolymer materials to fracture. In Fracture Mechanics, there are 3 different basic ways in which a fissure can propagate, called mode I, mode II, and mode III, just as shown in Figure 1 [2]. These modes differentiate themselves for the nature of the strains applied to the pre-cracked structure. To the interest of the experiment, only mode one (I), or opening mode, will be explained, which represents a fracture mode that is induced by normal traction tensions that results in a symmetric separation of the fracture surfaces relatively to the x1x3 plane. It is also important to mention that these fracture modes may occur simultaneously which will result in a mix mode fracture loading [3].

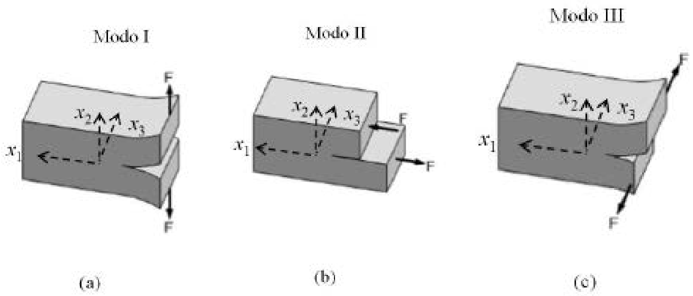

Figure 1 - Fracture Modes in Fracture Mechanics

EXPERIMENTAL PROCEDURE AND RESULTS

In this study four different compositions were employed:

- Mixture 1: 19 % Fly Ash, 5 % Steelmaking ladle slag, 5 % NaOH (10 M), 12.5 % silicate and 58.5 % sand
- Mixture 2: 25 % FA, 3 % LS, 4 % NaOH (10 M), 13 % silicate and 55 % sand
- Mixture 3: 15 % FA, 12 % Stone cutting sludge (SCS), 18 % alkaline solution, 1 % ceramic waste (CW), and 54 % sand;
- Mixture 4: 14.4 % FA, 9.6 % SCS, 4 % 18.3 % AS, 2 % CW and 55.7 % sand

Paralelipipedic specimens were cast in iron molds, with 160 x 40 x 40 [mm] size. Then, the cast samples were cured in an oven at 80 ºC, with no controlled humidity, for 24 hours.
From the different tests that enabled inducing the intended solicitation, the SEN-TPB (Single-Edge-Notched beam loaded in Three-Point-Bending [4]) was selected, using the previously mentioned specimen geometry. Only with the full separation of the specimen into two halves, managed through flexural stress in each sample, would it be possible to determine the total work of fracture. Therefore, it is conceivable to infer that through stable flexural resistance tests, one could obtain this fracture property. For this to be possible, a well laid out crack along the specimen must be achieved. The main goal of this crack would be to reach tension concentration and the instalment of traction tensions in the gap [5].

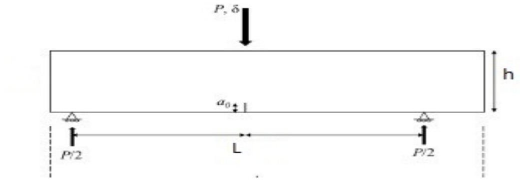

Figure 2 - Configuration of SEN-TPB Test (L=140; h=40; a_0=6 [mm])

For the current test, 4 samples per mixture were made, as shown in figure 3, 2 of which were tested at the 7th day after the mixture had been prepared. The remaining specimens were tested at the 28th day after the specimens had been concluded. Sharp metal plates (thickness equal to 0.6 [mm]) were placed in the molds, so that the samples could be obtained with a fine crack, as intended.
In regard to the fracture tests, the distance loading span was fixed to 140 millimeters. The inicial crack length, a_0, was produced along the height of the specimen (40 mm), in the mid span, with the inicial crack length fixed to 6 mm, i.e., 15% of the total height [4].

(a) (b) (c) (d)

Figure 3 - From left to right: (a) Cut sheet to form crack in the specimen; (b) Specimens in the oven; (c) Specimens after demolding; (d) Specimens after test.

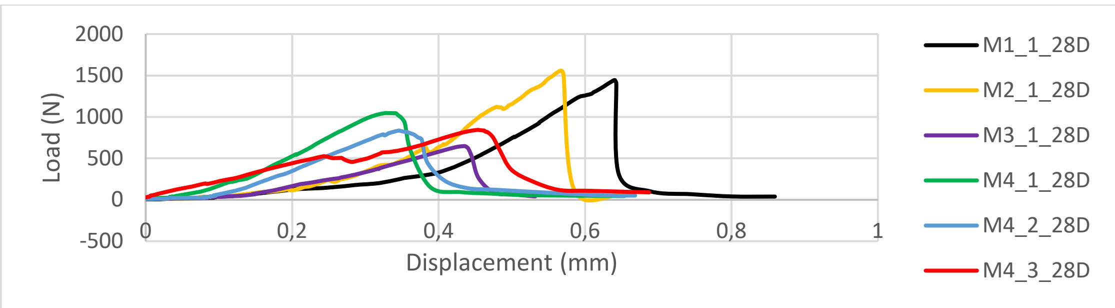

Figure 4 - Load-displacement curves obtained in the fracture tests – Results for Mixtures 1 to 4 at 28 Days

Figure 4 shows the load-displacement curves obtained in the fracture test. This data was obtained using a mechanical spindle-driven tension–compression machine (LLOYDS), with a load-cell of 50 kN, by applying the load at 0.3 mm/min. In Table 1, the test results can be examined.

Table 1- Fracture Results for Mixtures 1, 2, 3 and 4

Mixture Reference	**Rest (Days)**	**Initial Flexural Stiffness (R_i) [N/mm]**	**Ultimate Load (P_u) [N]**	**Mixture Reference**	**Rest (Days)**	**Initial Flexural Stiffness (R_i) [N/mm]**	**Ultimate Load (P_u) [N]**
M1_1	7	9010	1680	**M1_1**	28	4910	1440
M1_2	7	8970	2080	**M1_2**	28	SR (specimen broke upon pre-load)	SR
M2_1	7	4280	1530	**M2_1**	28	4560	1560
M2_2	7	4430	1780	**M2_2**	28	SR (specimen broke upon pre-load)	SR
M3_1	7	1750	450	**M3_1**	28	2050	650
M3_2	7	SR (specimen broke upon pre-load)	SR	**M3_2**	28	SR (specimen broke upon pre-load)	SR
M4_1	7	3100	710	**M4_1**	28	4200	1050
M4_2	7	2910	640	**M4_2**	28	3130	840
				M4_3	28	1930	840

CONCLUSIONS

By an analysis conducted on the test results, it is possible to conclude that:

- Mixture 1 (M1_1), particularly at the 7th day, attains the highest value for ultimate load, as well as the highest values for Initial Flexural Stiffness;

- Mixture 1 reveals a decrease in Ultimate Load from the 7th to the 28th day, while in Mixture 2 the results were inconclusive. As for Mixture 3 the P_u value increased. In Mixture 4 the results were inconclusive;

- Analyzing the initial flexural stiffness, in mixture 1 a decrease is revealed from the 7th to the 28th day. Regarding mixture 2, nothing can be concluded. Lastly, for mixtures 3 and 4 an increase was reported between days 7 and 28.

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