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Evaluation of the Mechanical Behavior of Mortars Obtained By Geopolymerization of Calcined Clay and Demolition Mortar

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Abstract –Geopolymeric mortars were prepared from a mixture of calcined clay powders (from demolition bricks), demolition mortar and a 12 molar alkaline hardening solution of sodium hydroxide. The geopolymeric mortars were compared physically, microstructurally and mechanically with their Portland cement counterparts. The results revealed similar densities between both types of mortars (geopolymeric and ordinary Portland cement). The microstructure was also similar in both mortars, two phases can be clearly identified, the continuous binder phase and the phase of individual fine sand particles dispersed within the continuous cement phase. Regarding the mechanical data, it could be verified that the mixture with 80 Vol.% of fine sand, 10 Vol.% of calcined clay and 10 Vol.% of demolition mortar was the one that showed the best mechanical results, with an average mechanical resistance of 34.5 MPa. However, the highest average mechanical strength value for geopolymeric mortars is below the average mechanical strength value of ordinary Portland cement mortar (50 MPa).

Keywords: mechanical behavior, mortars, geopolymerization, calcined clay, demolition mortar, Portland cement

1. Introduction

Geopolymers are a class of inorganic synthetic materials obtained at room temperature by a chemical process called geopolymerization, which consists of the solubilisation of amorphous phases of aluminosilicates present in industrial solid waste, calcined clays, natural minerals, among others, by the action of a alkaline activator in aqueous solution [1,2]. Geopolymers have received extensive interest of the scientific community in recent years, mainly due to the variety of applications in which they can be used, this derived from their excellent fire resistance, low density, low cost, easy manufacturing, excellent chemical/thermal stability and eco-friendly synthesis [3,4].

For some years these materials have been considered revolutionary for their potential use as an alternative material to ordinary Portland cement [5,6]. Several research papers have reported that geopolymeric concretes can reach up to 70% of maximum compressive strength within the first 4 hours of curing at an appropriate temperature [7], unlike Portland cement concretes, which require up to 28 days to reach maximum mechanical resistance. On the other hand, geopolymeric concrete shows very little shrinkage due to drying, it was noticed that after one year it presents between 5 to 7 times less shrinkage than Portland cement concrete [8,9]. On the other hand, several works have shown the negative influence of sulfates on Portland cement concrete, which drastically reduces its mechanical resistance to compression, this reduction is explained by the reaction of sulfates with the calcium present in Portland cement, which leads to the formation of gypsum and ettringite [10], which are phases that require a greater volume and therefore their formation generates internal stresses in the Portland cement concrete, which then lead to nucleation and propagation of cracks. On the other hand, geopolymeric concrete does not present similar problems because its properties depend on other types of reactions (in the absence of calcium) [11,12].

Geopolymeric concretes exhibit good mechanical response to high temperatures compared to their Portland cement concrete counterparts; in this regard, Kong et al. [12] studied the mechanical behavior of Portland cement and geopolymer pastes after being subjected to high temperatures, noticing that while at 800 °C the geopolymer paste improves its resistance to compression, Portland cement paste at 400 °C lost all its residual resistance, this loss of resistance of the Portland cement paste was attributed to the decomposition of $Ca(OH)_2$ at approximately 400 °C. One of the most important materials in the composition of conventional concretes is Portland cement, which is basically a mixture of gypsum and clinker, the latter is obtained by calcining limestone and clay at temperatures from 1350 ºC to 1450 °C. Obtaining the Clinker is accompanied by large CO_2 emissions. In this regard, it has been determined that a cement kiln produces approximately 0.8 tons of CO_2 for every ton of Portland cement [13].

2. Materials and Methods

2.2. Sample Preparation

Adequate amounts of binder and fine sand were ground in an alumina mortar and then sieved separately on an ASTM # 140 sieve (106 μm), then based on 20 g. of powder mixes and with the matrices of mixes of table 1 were prepared. In the case of geopolymeric mortars (GM) samples, binding powders and 10 ml of Na(OH) solution were mixed for 5 minutes, then the corresponding mass of fine sand (FS) was added and mixed for another 5 minutes, the GM paste obtained was compacted for 5 minutes at 60 MPa in a 20 mm diameter hardened steel cylinder mold. In the case Portland cement mortars (M-PC) samples, the PC powder was mixed for 5 minutes with 10 ml of drinking water, the following preparation steps were similar to those followed for GM samples preparation. The cylindrical specimens of GM and M-PC obtained were placed in hermetic bags for 7 days and then dried in an oven at 60 ºC for 24 hours.

Table 1. Matrix of mixtures for the preparation of geopolymeric (GM) and conventional mortars of Portland cement (M-PC)

sample	fine sand (FS) (Vol.%)	BINDER		
		calcined clay (CC) (Vol.%)	demolition mortar (DM) (Vol.%)	Portland cement (PC) (Vol.%)
M-20CC0DM	80	20	0	0
M-15CC5DM	80	15	5	0
M-10CC10DM	80	10	10	0
M-5CC15DM	80	5	15	0
M-0CC20DM	80	0	20	0
M-20PC	80	0	0	20

2.3. Physical, Structural, Microstructural and Mechanical Characterization

All prepared mortars were physically, microstructurally and mechanically characterized. The physical characterization consisted in the determination of the real density by the pycnometry technique, for this research a calibrated glass pycnometer and distilled water were used. The microstructural characterization was carried out on polished surfaces of the manufactured mortars. The preparation of the samples for microscopy began with a fine roughing of the surfaces using SiC abrasive paper of # 600, # 800 and # 1200 grit, then surfaces were polished using diamond paste (6, 3 and 1 micron) and lubricating liquid. The polished surfaces were cleaned with plenty of distilled water and were air dried, no grain development technique was used. Microstructural observations were made in an AMSCOPE brand light microscope (50X - 500X), model ME320B-PZ (USA).

The mechanical tests consisted of uniaxial compression tests at a constant compression speed of 0.05 mm / min, in an air atmosphere and were carried out in a universal testing machine, MICROTEST brand, model EM1 / 50 / FR, (Spain). Samples for compression tests consisted of 10x5x5 mm^3 parallelepipeds and were obtained from cylindrical samples of set mortars. From the mechanical tests, force and displacement data were obtained, which were later converted into stress vs. deformation

3. Results and Discussion

3.1. Physical and Microstructural Characterization

The average real density for all the materials studied was 1.8 g/cm^3. Fig. 1 shows light microscopy micrographs of the six types of mortars studied, two well differentiated phases could be identified, on the one hand, a continuous phase in dark gray contrast that corresponds to the interconnected binder phase (Portland cement or mixture of calcined clay and demolition mortar) and, on the other hand, individual polygonal particles are seen dispersed within the continuous phase, which corresponds to the fine sand particles (light gray phase).

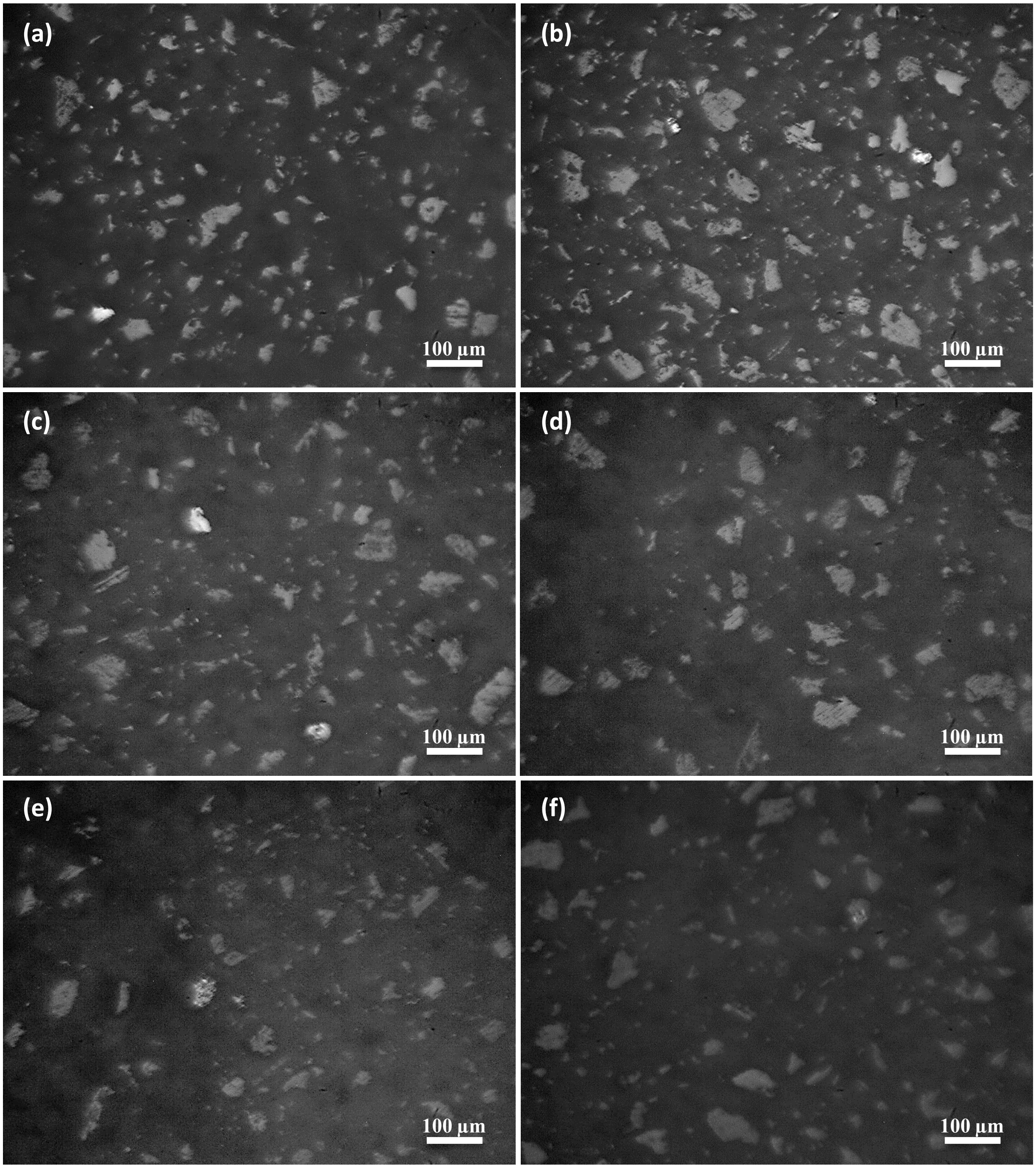

Fig. 1: Light microscopy micrographs of geopolymeric (a-e) and conventional Portland cement mortars (f)

3.2. Mechanical Characterization

Fig. 2 presents stress vs. strain for all the mortars studied, from these curves it could be noticed that the geopolymeric mortar M-10CC10DM in fig. 2 (c) with 80 Vol.% of fine sand, 10 Vol.% of calcined clay and 10 Vol.% of demolition mortar was the one that showed the best mechanical results, among all geopolymeric mortars, however, the data from maximum strengths for Portland cement mortars were higher than all the values found for geopolymeric mortars.

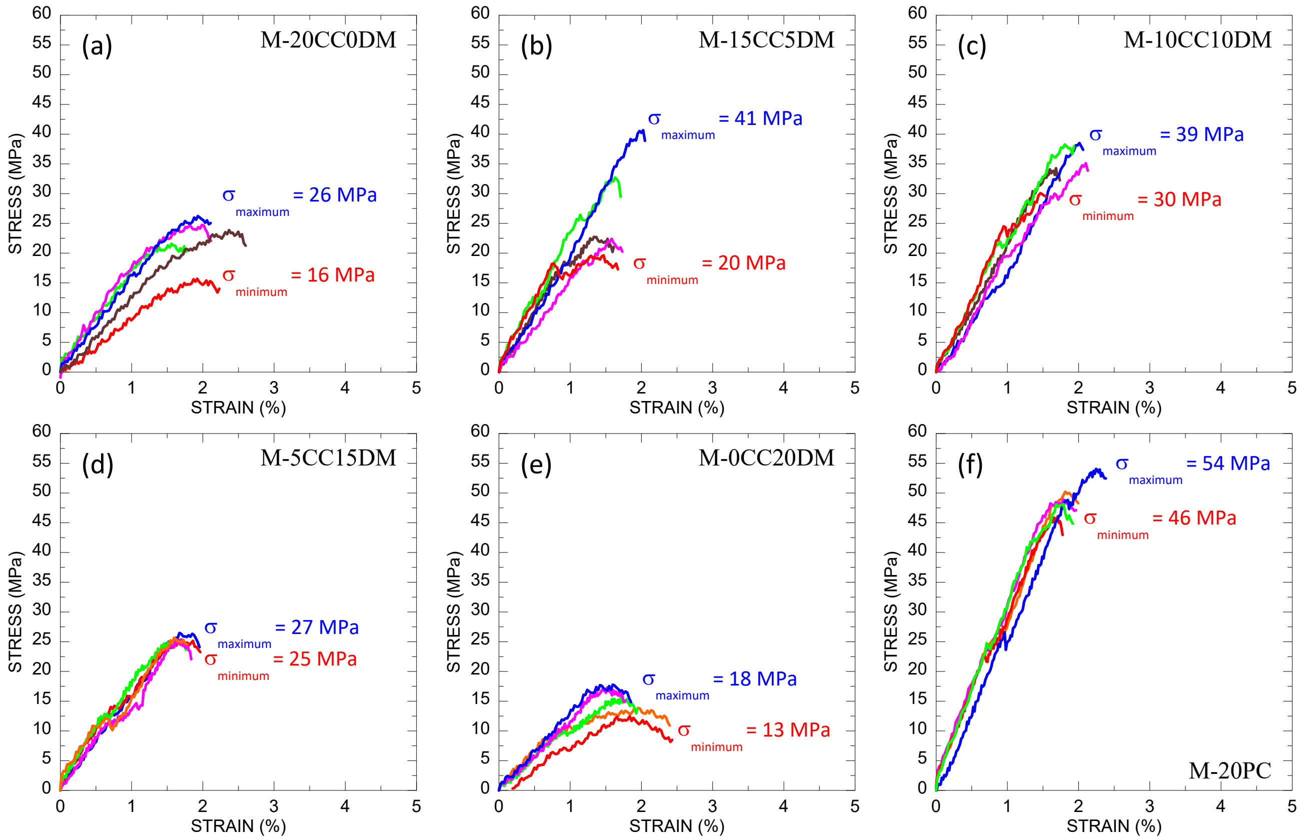

Fig.2: Stress vs. strain curves for the six types of mortars studied

4. Conclusions

Geopolymeric mortars derived from calcined clay powders and demolition mortar, and conventional Portland cement mortars were prepared and compared regarding their physical, microstructural and mechanical characteristics.

The real density of geopolymeric and conventional Portland cement mortars was similar and around 1.8 g / cm3, on average.

The microstructure of geopolymeric and conventional Portland cement mortars was also similar, finding for both cases a continuous and interconnected binder phase of Portland cement or a mixture of calcined clay powders and geopolymerized demolition mortar and, on the other hand, polygonal particles were found individual dispersed within the continuous phase, which corresponds to the fine sand particles.

The geopolymeric mortar with 80 Vol.% of fine sand, 10 Vol.% of calcined clay and 10 Vol.% of demolition mortar was the one that showed the best mechanical results, among all the geopolymeric mortars studied.

The maximum mechanical resistance for Portland cement mortars were higher than all the values found for geopolymeric mortars.

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