Structural and mechanical study of concrete made from cementitious materials of low environmental impact

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Abstract. This work shows the results obtained by replacing Type I Portland®, by cementitious geopolymers materials, derived from minerals, in concrete mixtures. Synthesis of both geopolymers through alkaline activation of two aluminosilicates: Bentonite and Pumice with sodium silicate (Na₂SiO₃). XRD, SEM and XRDE are used to structural study of new geopolymers. Concrete mixtures with replacement of Portland have 10% and 30% of geopolymer. Finally, concrete mortars formed were mechanically analysed according to ICONTEC 220 at 7, 14, 28, 41, 90 and 120 days of cure. Results shows that compressive strength of concrete from Bentonite and Pumice are almost the same for the standard concrete at 28 days of cure. At 90 days of cure, compression resistance of concrete from Pumice at 10% is even higher than those that standard concrete shows.

1. Introduction
Because of the socioeconomic development and the population increase, demand of Portland Cement (PC) as construction material has increased. Its manufacturing process is one of the most polluting practices, since 6 to 7% of the CO₂ emissions of the planet correspond to the cement industry. This industry together with research groups seek solutions for the conservation and protection of non-renewable resources through the development of new raw materials that improve the production processes and quality of cement achieving sustainability [1-3]. Alumini and silica oxides are geopolymerized for partial cementitious replacement reducing greenhouse gases producing in PC clinkerization. This study presents the results of the synthesis of IP from the alkaline activation of two clays: bentonite and pumice, to obtain a new material with properties similar to those of PC. X-ray diffraction (XRD), Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Microscopy (EDS) and Mechanical Resistance (MR) according to the ICONTEC 220 standard are employ to characterization of IP.

2. Experimental
Geopolymerization of pumice (PP) from Sabaneta, Antioquia, Colombia and bentonite (BT) (Quimicos Campota®) was carried out at 80±5°C for 31 hours in metallic containers with sodium silicate (Na₂SiO₃) (Aldrich®). Dried product reached at 4.77 nm of particle size according to ASTM C 94/C 94 M-09) [5]. XRD (Bruker D8 ADVANCE, DaVinci geometry, CuKα1 radiation), SEM (FEI Quanta 650 FEG SEM, magnification=2000-5000X, WD=9.2-10.0mm, HV=5-20kV), EDS (HV:
20.5kV, Tilt: 0.00, Take-Off: 35.88, Amplitude: 14.4.) are used to structural analysis. It was performed mechanical strength for PP, BT and IP.

3. Result and discussion

3.1. Geopolymerization reaction
Dissolution, hydrolysis and polycondensation of raw materials it happens because of the sodium silicate media to obtain polymeric matrix for each aluminosilicate source (PP and BT) [7].

3.2. Structural analysis

3.2.1. X-Ray diffraction. Structural study by XRD shows for BT: albite, gypsum, calcite, anortoclase, kaolinite, montmorillonite and quartz; for the IP from BT and because of the alkaline activation, new phases (orthoclase at 28°, muscovite at 16°, 27° and 39°) appear instead of gypsum and anortoclase. On the same way, for PP there are present: quartz, illite, albite, anorthite and iron oxide. In IP from PP there are not presents anorthite, illite and iron oxide while muscovite (28°) and cristobalite (22°, 37° and 60°) appears; this cristobalite gives a greater crystallinity degree to IP [3,5].

It is remarkable that PP has a porous structure and it is composed of vitreous particles of various forms, mainly elongated and angular, and shows amorphous structure, which undergoes a structural rearrangement of tetrahedra of Si and Al inducing in the system a certain degree of crystallinity. This fact is proof in the appearance of new mineralogical phases and in the increase in the intensity of the initially existing phases [2,7-9], as in the case of quartz and albite with peaks at 27°, 28° and 36° 2θ respectively.

3.2.2. Analysis by scanning electron microscope. The SEM micrographs of the raw materials and the synthesized PIs are presented in Figure 1, where in a and c (starting materials) homogeneous morphology and a similar particle size are observed. In turn, in b and d (IP of PP and IP of BT, respectively), the observed conformation is different, not homogeneous, exhibiting remains of unpolymerized raw materials. Presumably, the above is due to albite does not react by a low concentration of activating solution and it does not geopolymerized all the raw material. Thus, reaction medium should have a higher Na2SiO3 concentration [8]. Thus, various morphologies can exist in the geopolymeric paste as unreacted particles, “semi-reacted” particles attacked by the activating solution and the reaction products, as evidenced by the respective micrographs [11].

Finally, the particle size is clearly smaller for the synthesized IP than for the BT and PP clays, due to the compaction of the materials in the cement mixture, which presents a better molecular organization, which generates the crystallinity in each IP formed.
3.2.3. Analysis by X-ray energy dispersive spectroscopy. Based on the results obtained in the EDS analysis (Figure 2), it is possible to determine that the geopolymers are mainly constituted by Na-Si-Al and some traces of Ca and K as is the case of PI of PP. These traces come from the impurities of the raw materials, being able to be present in a dispersed and random way in the microstructure, because they are not dissolved in the geopolymer matrix. [5,9]

The results showed that the Si, Al and Na contents of the IP differ from the initial values of the aluminosilicate sources (BT and PP), as a consequence of alkaline activation with Na$_2$SiO$_3$, finding that the IP of BT presents more content of Si and for IP of PP greater content of Al.

![Figure 1. SEM micrographs of (a) PP, (b) IP of PP, (c) BT and (d) IP of BT.](image)

![Figure 2. EDS of (a) BT, (b) IP of BT, (c) PP and (d) IP of PP.](image)
3.3. Mechanical analysis

The compressive strength in MPa was determined according to the ICONTEC 220 standard at curing ages of 7, 14, 28, 41, 90 and 120 days, for each of the 10 and 30% substituted mortars in the PC for each IP (BT and PP). Results obtained appear in Figure 3, where it is evident that in the case of IP of 10% and 30% BT, the best values of mechanical resistance correspond to 28 days of curing in comparison with the other IP substitutions and the PC, where higher exposure time shows higher mechanical performance. Likewise, there is a significant difference in the values of MR for substitutions of 10% compared to those of 30% of each IP in the PC, where the lower percentage of substitution in the PC, generated greater mechanical resistance [6].

On the other hand, the results of MR are almost linear until the 28 days of curing for all the mortars where they reach their longest hydration time and by increasing the curing time this increases but steadily. This is because in concrete, hydration reactions occur at high speed, generating hydrated calcium silicates that contribute to increase the mechanical resistance and decrease the porosity of the same. However, it is noteworthy that at 90 days of curing the concrete resistance derived from IP of PP exceeds that of CP [4,10,12].

![Resistance to Compression](image)

**Figure 3.** Compressive strength of (a) IP de BT al 30 and 10% and PC; (b) IP of PP al 30 and 10% and CP

4. Conclusions

The Physicochemical and mechanical properties of the synthesized IP depend directly on the mechanism of the geopolymerization reaction, in which the concentration of the raw material, concentration and type of the activating solution and temperature are parameters that allow the formation of the silicate monomer for subsequent condensation and formation of the polymer matrix.

Results of XRD, SEM and EDS, allow verifying that geopolymerization reaction occurs in the reaction medium, through an alkaline activation. The above implies a structural rearrangement in the aluminosilicates (BT and PP), due to formation of the Si-O-Al bond in each IP synthesized with the improvement in the degree of crystallinity.

Not all the raw material polymerized. More concentrate activating solution (Na$_2$SiO$_3$) would be all aluminosilicates reacts.

From MR test, it is evident that the mortars that presented the best mechanical performances of the synthesized IP are the 10% PP, which implies that it is as possible cementing agent.

Acknowledgements

The authors express their gratitude to the School of Chemistry, X-ray diffraction Laboratory and Microscopy Laboratory of the Universidad Industrial de Santander and the “Universidad Pontificia Bolivariana, seccional Bucaramanga”, for the financial support of the project 016-0615-9560.
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