redin Revista Facultad de Ingeniería, Universidad de Antioquia, No. 79, pp. 163-173, 2016

Effect of the use nickeliferous laterite and pumice as additives in the performance and durability of the Portland cement

Efecto del uso de laterita niquelífera y piedra pomez como aditivos en el desempeño y la durabilidad del cemento Portland

María Carolina Rueda-Gualdrón[1], Karen Milena Vega-Nuñez[1], Carlos Alberto Ríos-Reyes[1*]

[1]Escuela de Geología, Universidad Industrial de Santander. Cra. 27 Calle 9. A. A. 678. Bucaramanga, Colombia.

ARTICLE INFO

Received April 22, 2015
Accepted February 02, 2016

KEYWORDS

Puzzolan, nickeliferous laterite, pumice, cement, mortars

Puzolana, laterita niquelífera, pumita, cemento, morteros

ABSTRACT: This work evaluated the pozzolanic behavior of the niqueliferous laterite of Cerromatoso (Córdoba) and the pumice of Cemex (Boyacá), based on the NTC standards for fine aggregates. The mortars were prepared with additions of 2.5%, 5% and 10% as substitutes of type I Portland cement, which tested to extreme environments (high temperatures and chemical attacks with H_2SO_4 y $MgSO_4$). Results demonstrates how these alternative materials increase or decrease their puzolanic degree, as well as the effect of these additives in the mortar mixtures with the time, demonstrating similar properties respect to mortars prepared with type I Portland cement. Therefore, the mortars have an acceptable answer under the tested conditions, although it is possible to improve their workability and durability, collaborating not only with of the energy saving in the production of type I Portland cement but also in the use of alternative additives that let to mitigate the environmental impact produced by the cement industry.

RESUMEN: En este trabajo se evalúa el comportamiento puzolánico de la laterita niquelífera de Cerromatoso (Córdoba) y la pumita de Cemex (Boyacá) en la preparación de morteros según normas NTC para agregados finos. Los morteros se prepararon con adiciones de 2,5%, 5% y 10% como sustitutos del cemento Portland tipo I, los cuales fueron sometidos a ensayos de resistencia mecánica antes y después de ser sometidos a ambientes extremos (altas temperaturas y ataques químicos como H_2SO_4 y $MgSO_4$). Los resultados demuestran cómo estos materiales alternativos incrementan o disminuyen su grado de puzolanidad, así como el efecto de estos aditivos al interior de las mezclas de mortero en el tiempo, demostrando propiedades similares con relación a los morteros preparados con cemento Portland tipo I. Por lo tanto, los morteros tienen una respuesta aceptable ante las condiciones evaluadas, aunque es posible mejorar su desempeño y durabilidad, colaborando no solo con el ahorro energético en la producción del cemento Portland tipo I sino también en el uso de aditivos alternativos que permitan mitigar el impacto ambiental provocado por la industria cementera.

1. Introduction

One of the main concerns in the construction industry is the more efficient use of waste materials as cement replacements to provide resource sustainability and environment quality [1], which contributes to reduce the problem of land-filling, environmental and health concern [2]. The recycling of waste materials into useful products to replace the natural resources which will mitigate the economic and environmental problem of waste disposal and also reduce the depletion of natural resources [2]. The ordinary Portland cement (OPC) is the more useful material in the construction industry due to its excellent mechanical properties and advantages in front of other materials, particularly with respect to its low cost and versatility. Annually, billons of tons of OPC are produced around the world [3], which expected to increase because of population growth and economic development. In the medium term, it is expected that concrete and mortar will remain the most economical materials for construction. However, the cement industry is one of the most polluting and therefore faces the challenge of reducing emissions of greenhouse gases. The environmental impact resulting from the use of cement is considerable as 1 kg of OPC by about 1 kg of CO_2 into the atmosphere, emitted by decarbonation of the raw material ($CaCO_3$) and energy use at various stages of processing [4]. Thus, the cement industry has been focusing on reducing the amount of clinker by substituting alternative materials using alternative fuels and improved

* Corresponding author: Carlos Alberto Ríos Reyes
e-mail: carios@uis.edu.co
ISSN 0120-6230
e-ISSN 2422-2844

DOI: 10.17533/udea.redin.n79a15

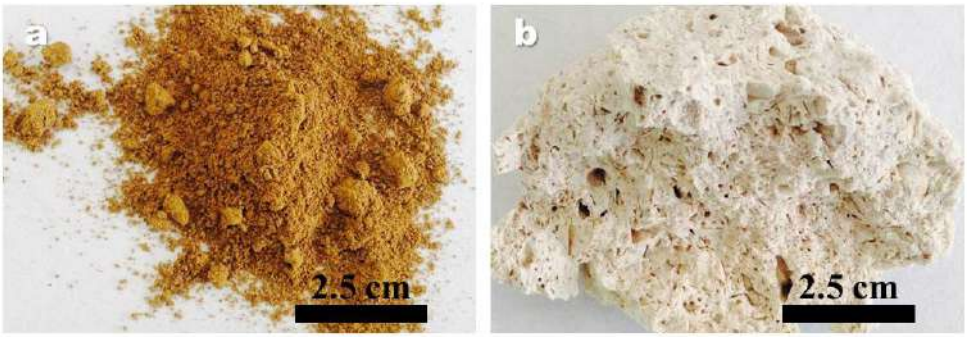


Figure 1 Natural puzzolans

energy efficiency. The use of alternative energy sources to produce cement faces many difficulties [5] and there is no alternative source to $CaCO_3$ in nature [4]. The incorporation of pozzolanic additions of waste materials in the cement manufacturing industry presents two principal interests: (1) ecological (reduction of pollution and environmental protection) and (2) economic (reduction of consumption of clinker and improvement of land conditions) [6]. The mechanical properties of cement mortars characterized by high compressive strength, low tensile strength and low ductility [7]. However, due to the increasing of aggressive agents in extreme environments, these mortars show a lack of performance and durability, which is manifested in the fact that its mechanical properties deteriorate over time, which has led to incorporation of different materials in the preparation of mortars. In recent years, various investigations have been developed focusing on the use of various other processes or products of natural materials, which include fly ash [8-12], silica fume [9, 13], blast furnace [9], refining aluminum [14], ceramic waste [15], gypsum waste [16], plastic waste [17], lime sludge [12], rice husk ash [2, 13, 18], crumb rubber [19], fluid catalytic cracking catalyst residue [20], expanded vermiculite [21], metakaolin [4, 22, 23], and pumice [24, 25]. In the present study analyzed the use of nickeliferous laterite and pumice, replacing the OPC of up to 10%, in order to analyze the behavior of mortars based on these additives. Laboratory tests conducted to determine the compressive strength of these materials in extreme conditions (H_2SO_4 and $MgSO_4$ attacks and high temperatures).

2. Experimental protocol

The experimental work was carried out in order to determine the suitability of nickeliferous laterite and pumice as natural puzzolans to manufacture mortars.

2.1. Materials

The Type I OPC of reference in this study manufactured by CEMEX Colombia and is certified by the NTC 121 [26] y 321 [27] standards for type I cements. The nickeliferous laterite and pumice samples were collected from the Cerromatoso deposit in Montelíbano (Córdoba) and CEMEX Colombia mine in Paipa (Boyacá), respectively (Figure 1). Figure 1(a) shows the nickel laterite formed after ultrabasic peridotite rocks, which contains garnierite (a name describing a small group of serpentine minerals containing nickel). Figure 1(b) shows the pumice created when super-heated, highly pressurized rock is violently ejected from a volcano, which consists of highly vesicular rough textured volcanic glass, which contains phenocrystals. These geological materials were sun-dried during three days to delete water without modifying their physical properties; then they subjected to rough crushing with a Retsch Jaw Crusher BB200 to ~ 2 mm and milling with a Retsch RM100 mortar grinder mill to obtain a particle size of 125 µm, which was used for the manufacture of mortars. An Ottawa sand from Illinois (USA), which is a siliceous sand internationally tested, was used in the sample preparation and mix compositions. The mortars were prepared using clean water, which should be free of oils, acids, alkalis, organic matter and other substances that can be dangerous for the mortar [28].

2.2. Characterization of raw materials

The raw materials were milled in an agate mortar and then mounted on a sample holder of polymethylmethacrylate (PMMA) by the technique of filling front. The X-ray powder diffraction (XRPD) patterns of the raw materials were recorded in a BRUKER D8 ADVANCE diffractometer operating in Da Vinci geometry and equipped with an X-ray tube (Cu-Kα1 radiation: λ = 1.5406 Å, 40 kV and 30 mA), a 1-dimensional LynxEye detector (with aperture angle of 2.93º), a divergent slit of 0.6 mm, two soller axials (primary and secondary) of 2.5º and a nickel filter. Data collection was carried out in the 2θ range of 12-80°, with a step size of 0.01526° (2θ) and counting time of 1 s/step. Phase identification was performed using the crystallographic database Powder Diffraction File (PDF-2) from the International Centre for Diffraction Data (ICDD) and the program Crystallographica Search-Match. Scanning electron microscopy (SEM) imaging and energy dispersive spectroscopy (EDS) were carried out by environmental scanning electron microscopy (FEI Quanta 650 FEG ESEM) to examine the mineral phases' textures and cross-cutting relationships in the nickeliferous laterite and pumice, under the following analytical conditions: magnification = 100x, working distance (WD) = 9.6-10.1 mm, high vaccum

(HV) = 20-30 kV, signal = atomic number contrast (Z CONT), back scatter electron detector (BSED). The sieving of granular materials carried out according to the standard INV E-123 [29] in a Ro-Tap sieve shaker (using 4, 8, 16, 50, 100 and 120 mesh series). The presence of organic matter in the sand determined by the methylene blue adsorption test according to the standard INV E-235 [30]. The specific gravity and water absorption of the additives were determined according to the standard INV E-222 [31].

2.3. Sample preparation and mix compositions

The quantities of materials obtained from the mix design were measured with the aid of a weighing balance, which is synthetized in Table 1. Mortars manufactured according to the standard NTC 220 [32]. Figure 2 illustrates the preparation of mortars. First, the molds were cleaned, dried and greased. The mix proportions were prepared based on the dry weights of the ingredients. The quantities of the dry materials obtained from the homogeneous mix design were measured in each case with the aid of weighing balance. Then, water added to each mix under agitation conditions to obtain a cementicious paste. Finally, the paste poured in molds up to 50% of their capacity, compacting the cementicious mixes. A new amount of paste poured in the molds up to 100% of their capacity, compacting the cementicious mixes and removing the excess of paste in the molds, which were then covered with plastic bags. After 24 hours the mortars were removed from the molds, and then they were labeled.

2.4. Technological tests

The determination of the compressive strength carried out according to the standard NTC 220 [32] as follows: The mortars cured after 7, 14 and 28 days in a humid chamber where they stay after triplicate testing to obtain an average value (Figure 3). The attack of mortars with H_2SO_4 and $MgSO_4$ performed to subject them to extreme conditions, simulating highly corrosive environments. First, the mortars cured during 28 days. They were exposed to H_2SO_4 solutions of pH = 1 during four weeks (2 tests for the same mix per week to determine an average), with a mortar of each mix evaluated after nine weeks. The attack with H_2SO_4 was evaluated by the loss of weight and compressive strength. They were exposed to $MgSO_4$ solutions of 50 g/L concentration during four weeks (2 tests for the same mix per week to determine an average), with a mortar of each mix evaluated after nine weeks. However, this interaction can produce negative effects on the mortars, such as expansion, cracking, loss of mass and disintegration. Two mortars of each mix cured during 28 days were subjected to high temperatures (300, 600 and 1000 °C) during two hours. The behavior of mortars under attacking with H_2SO_4 and $MgSO_4$, and high temperatures was evaluated by the loss of weight and compressive strength. The porosity of the mortars determined by saturation and flotation techniques. The mortars weighed and immersed in water during 24 hours; then, they removed and dried. The weight of mortars was determined before and after testing.

Table 1 Experimental design for the preparation of reference OPC-based mortars (OPCMs) and nickeliferous laterite- and pumice-based mortars (LATMs and PUMMs)

OPCMs									
OPC		A		H_2O		H_2O/OPC ratio	Additive		Total
1 part		2.75 parts				0.485			mortars
%	G	%	g	%	g		%	g	
23.6	83.3	65.0	229.2	11.4	40.3		0	0	
		OPCM							
		Curing at T_{env}							
								9	Compressive strength (7, 14, and 28 days)
								9	Attack with H_2SO_4 (4 weeks)
								9	Attack with $MgSO_4$ (4 weeks)
								9	Resistance at high temperatures
LATMs and PUMMs									
OPC		A		H_2O		H_2O/OPC ratio	Additive		Total
1 part		2.75 parts				0.485			mortars
%	g	%	g	%	g		%	g	
100	250	65.0	229.2	11.4	40.3		0	0	
97.5	243.7	65.0	229.2	11.4	40.3		2.5	6.3	
95	237.5	65.0	229.2	11.4	40.3		5	12.5	
90	225	65.0	229.2	11.4	40.3		10	25	
		LATM and PUMM							
		Curing at T_{env}							
								9	Compressive strength (7, 14, and 28 days)
								9	Attack with H_2SO_4 (4 weeks)
								9	Attack with $MgSO_4$ (4 weeks)
								9	Resistance at high temperatures

Figure 2 Procedure for manufacturing and test of mortars

Figure 3 Compression strength test. (a) Experimental set up, (b) mortar before testing, and (c) mortar after testing

3. Results and discussion

3.1. Characterization of the raw materials

Figure 4 illustrates the XRPD patterns of the additives used in the preparation of mortars. The XRPD pattern of the nickeliferous laterite reveals that the main crystalline phase is antigorite, which displays high intensity peaks, with forsterite, enstatite and clinochlore as minor phases, and traces of quartz, goethite, clinocrysotile, magnetite, wuestite and montmorillonite. On the other hand, the XRPD pattern of the pumice reveals that it is characterized by the occurrence of an amorphous aluminosilicate (see the broad hump at 2θ = 15–35° of low intensity). There are also high intensity peaks corresponding to quartz and low intensity peaks corresponding to traces of halloysite and anorthoclase.

The BSE images in Figure 5 shows the textural relationships observed in nickeliferous laterite and pumice. The SEM images of nickeliferous laterite (Figure 5(a)) indicated that it is mainly composed of many small and aggregated

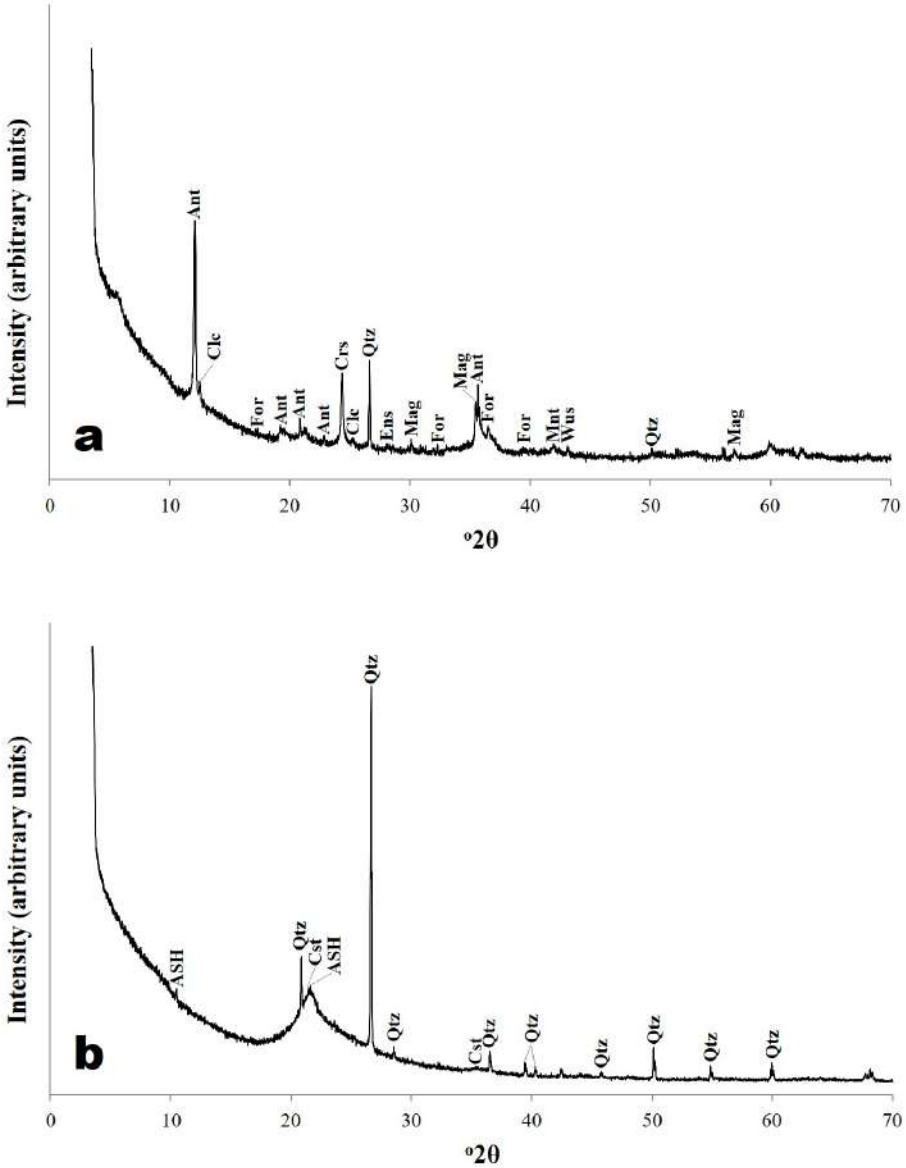
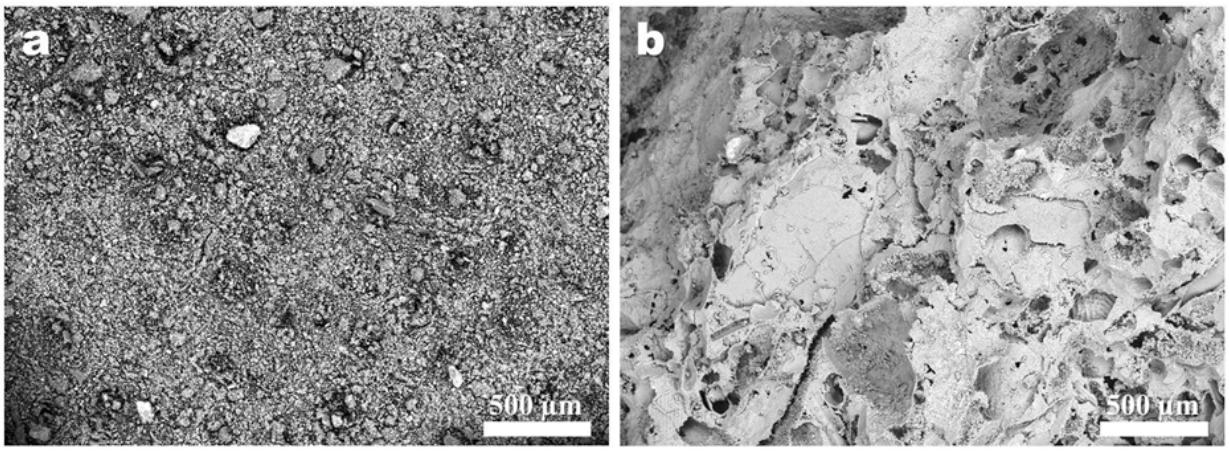


Figure 4 XRPD patterns of the nickeliferous laterite (a) and pumice (b) used as additives in the manufacturing of mortars

particles of blocky and flaky morphology. The SEM images of pumice (Figure 5(b)) indicated that its surface had a large porous surface with irregular or oval shaped and fibrous cavities (or pores), which generally did not intersect each other. In addition, it may be said that these pores are either in closed or in open forms. EDS allowed us to identify what those particular elements are and their relative proportions in the mineral phases that constitute these puzzolans. EDS of nickeliferous laterite indicates that it is mainly composed of 21.84 wt% SiO_2, 15.15 wt% MgO, 13.06 wt% Fe_2O_3, 12.33 wt% K_2O, 1.61 wt% Al_2O_3, 1.34 wt% NiO, with minor Cr_2O_3 (0.67 wt%), CaO (0.19 wt%). EDS of pumice indicates that it is mainly composed of 44.87 wt% SiO_2, 4.39 wt% P_2O_3, 1.13 wt% Al_2O_3, with minor Cr_2O_3 (0.67 wt%), TiO_2 (0.55 wt%), CaO (0.32 wt%). The appearance of carbon is attributed to the carbon coating on the sample before SEM analysis and the occurrence of calc-silicate mineral phases. EDS analyses are in agreement with literature data [33].

The specific gravity of the nickeliferous laterite is 1.76 g/mL and the maximum water absorption of fine aggregates is 2.16%. The pumice shows a specific gravity of 2.34 g/mL and a maximum water absorption of fine aggregates of 0.095%. The particle size distribution (the relative content of clay, sand and gravel) of the Ottawa sand (Figure 6) reveals that it is mainly composed of sand particles (98.20%), with 1.30% of fine particles and few gravel particles (0.50%), which indicates that this sand is within appropriate parameters. The test of organic impurities reveals that the results are appropriated taking in account that they were within the range established by the standard NTC 127 [34].



Nickeliferous laterite

Pumice

Figure 5 BSE images of the nickeliferous laterite and pumice

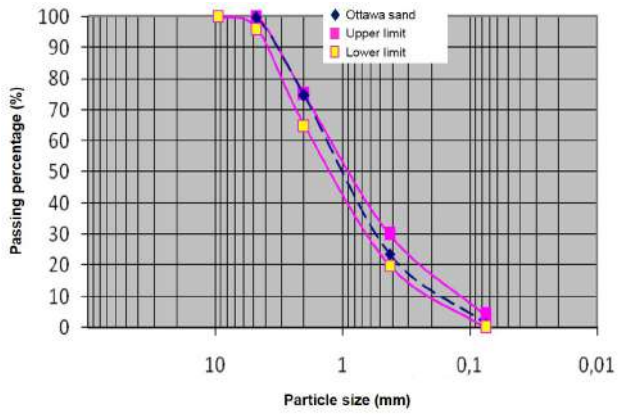


Figure 6 Particle size distribution of the Ottawa sand

3.2. Potential of reactivity of the raw materials in alkaline media

It is well known that the potential alkali-silica reaction of geological materials is mainly attributable to unwanted dissolution of mineral phases [35-38]. However, the key factor to determine the potential alkali-silica reaction seems to be the presence of microcrystalline quartz [36, 39]. We evaluate the pozzolanic reaction of nickeliferous laterite and pumice in cement based mortars to ascertain their applicability in mitigating Alkali Silica Reaction (ASR) and Calcium Silica Hydrate (CSH) or Calcium Hydroxide (CH) by-products, which are the result of combining water and Portland cement. Replacing Portland cement with natural pozzolans (geological materials) sets off a reaction within the hydrated paste that consumes trouble-making CH and converts it into additional CSH, reduces the alkali content of the paste and pH of the mortar pore solution [40]. Therefore, the amount of resulting damage in mortars due to alkali-silica reaction would depend on the availability of alkali and silica in the system. The main source of alkali in mortars is Portland cement. Nickeliferous laterite is an innocuous material, with silica content comparatively less than that in pumice. Therefore, the nickeliferous laterite does not produce a harmful reaction with alkali Portland cement and is expected to perform better than that in the pumice.

3.3. Compressive strength

The compressive strength of natural puzzolan-based mortars (LATMs and PUMMs) and reference mortars (OPCMs) was determined at 7, 14 and 28 days and the test results as a function of time are presented in Figure 7. In general, the LATMs and PUMMs showed a similar behavior, taking into account that as curing time increases, the compressive strength increases, with lower increase between 14 and 28 days of curing; however, the reference OPCMs showed a decrease between 14 and 28 days of curing. Using an additive dose of 6.3 g, the LATMs showed lower compressive strength values respect to those obtained for the PUMMs, with intermediate values for the OPCMs. Using an additive dose of 12.5 g, the LATMs and PUMMs showed higher compressive strength values than those for the OPCMs. LATMs and PUMMs showed similar values at 7 days of curing, with lightly higher values for the PUMMs and LATMs at 14 and 28 days of curing, respectively. A dose of 25 g reveals that the LATMs and PUMMs showed slightly lower compressive strength values than those for the OPCMs. In general, compressive strength increased between 7 and 14 days of curing. Between 14 and 28 days of curing the compressive strength of LATMs and PUMMs continue increasing, with the PUMMs and OPCMs showing the higher and lower values of compressive strength, respectively. In this study we report higher compressive strength of natural puzzolan-based mortars compared with the results obtained by a previous study [25], particularly at 14 days of curing.

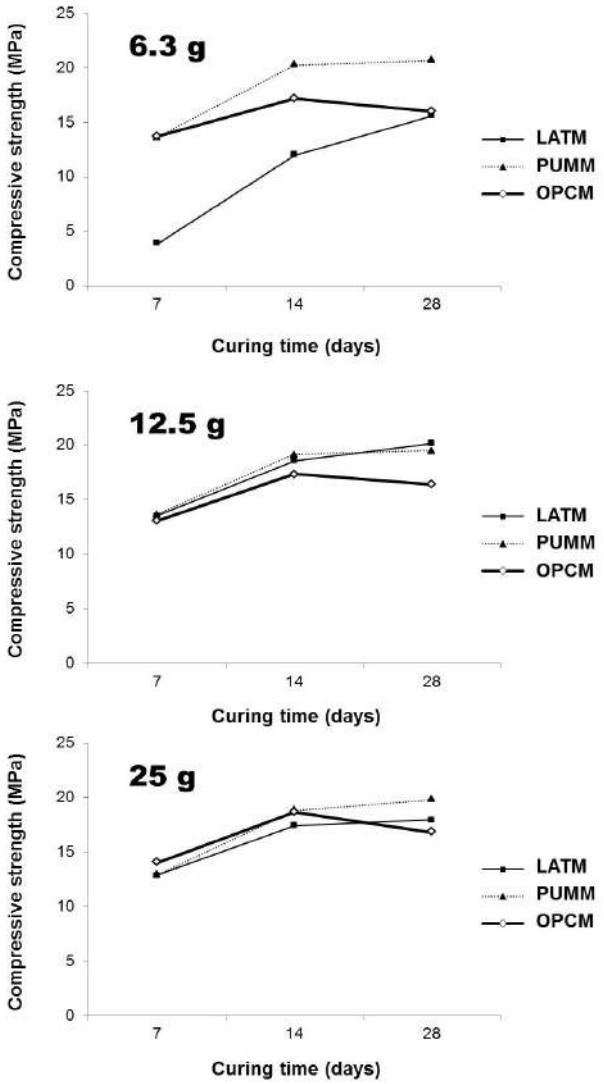


Figure 7 Compressive strength of mortars as a function of curing time

3.4. Compressive strength to high temperatures

Figure 8 illustrates the results obtained from the compressive strength to high temperatures. In general, the mortars showed a decrease in the compressive strength with increasing temperature between 300 and 1000 °C, except the OPCMs, which showed an abrupt increase at 1000 °C. [41] investigated the role of aggregate type on high temperature resistance of mortars, with pumice aggregate mortars not showing compressive strength loss up to 500 °C. However, this study demonstrates that nickeliferous laterite aggregate mortars can show a better performance at higher temperatures, although it depends on the dose of puzzolan incorporated in the alkaline paste. Using an additive dose of 6.3 g; at 300 °C, the compressive strength increased in 76% for LATMs and 23% for OPCMs, and decreased in 27% for PUMMs; at 1000 °C, the compressive strength decreased in 93% (LATMs), 91% (PUMMs), and 77% (OPCMs), with the LATMs and PUMMs showing lower compressive strength values than those obtained for the OPCMs. However, the LATMs showed the lowest compressive strength values. Using an additive dose of 12.5 g; at 300 °C, the compressive strength decreased in 23% (LATMs) and 50% (PUMMs), and increased in 22% for OPCMs; at 1000 °C, the compressive strength decreased in 88% (LATMs) and 92% (PUMMs), and 53% (OPCMs), with the LATMs and PUMMs showing lower compressive strength values than those obtained for OPCMs. However, the PUMMs showed the lowest compressive strength values. A dose of 25 g reveals that at 300 °C, the compressive strength decreased in 17% (LATMs) and 37% (PUMMs), and increased in 22% (OPCMs); at 1000 °C, the compressive strength decreased in 72% (LATMs) and 54% (PUMMs), and unusual increased in 138% for the OPCMs, with the LATMs and PUMMs showing lower compressive strength values compared with those obtained for the OPCMs. However, the PUMMs and LATMs showed the lowest compressive strength values at 300 °C and between 600 and 1000 °C, respectively. These results reveal that the mortars showed, with some exceptions, a progressive decrease of compressive strength to high temperatures.

The factors that influence the performance of mortars when exposed to high temperatures are directly related to the materials and environmental effects, such as the thermal processes (time, temperature, rate of heating and/or cooling) [42]. We are in agreement with a previous work [43], which establishes that the exposure of mortars to high temperature has a significant effect on the thickening of the pore structure, and, therefore, the compressive strength loss can be attributed to this instead of decomposition of CSH. However, CH decomposition, which is generated at temperatures between 430 and 600 °C, has an additional effect on the compressive strength loss below 600 °C [20].

3.5. Compressive strength to attack with H_2SO_4

Figure 9 illustrates the evolution of the compressive strength of mortars cured during 28 days, which immersed in a H_2SO_4 solution of pH = 1 during 2, 4 and 8 weeks. In general, the mortars showed an increase of compressive strength with weeks of attack of H_2SO_4, with some exceptions between 4 and 8 weeks. Using an additive dose of 6.3 g; after 2 weeks, the compressive strength decreased in 21% (LATMs), 41% (PUMMs), and 25% (OPCMs); after 8 weeks, the compressive strength decreased in 9, 27 and 7% for the LATMs, PUMMs and OPCMs, respectively, with the LATMs and PUMMs showing lower compressive strength values compared with those obtained for the OPCMs. However, the lowest compressive strength values obtained between 2 and 4 weeks for the OPCMs, and after 8 weeks for the LATMs. Using an additive dose of 12.5 g; after 2 weeks, the compressive strength decreased in 42% (LATMs), 44% (PUMMs), and 31% (OPCMs); after 8 weeks, the compressive strength decreased in 24, 28 and 27% for the LATMs, PUMMs and OPCMs, respectively, with the

LATMs showing the highest compressive strength values. Between 2 and 4 weeks, the PUMMs showed the lowest compressive strength values; after 8 weeks, the OPCMs showed lower compressive strength values compared to those obtained for the PUMMs. A dose of 25 g reveals that after 2 weeks, the compressive strength decreased in 24% (LATMs), 35% (PUMMs), and 26% (OPCMs); after 8 weeks the compressive strength decreased in 15, 30 and 21% for the LATMs, PUMMs and OPCMs, respectively, with the highest and lowest compressive strength values for the LATMs and OPCMs, respectively. These results reveal that the mortars showed, with some exceptions, a progressive increase to the attack with H_2SO_4.

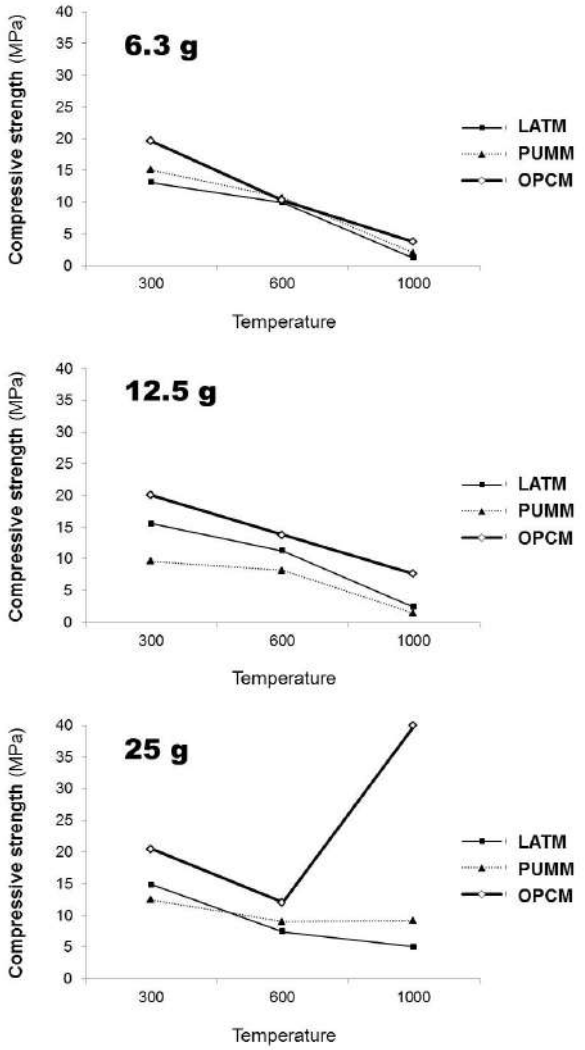


Figure 8 Compressive strength of mortars subjected to high temperatures

3.6. Compressive strength to attack with $MgSO_4$

Figure 10 illustrates the evolution of the compressive strength of mortars cured during 28 days, which immersed in a $MgSO_4$ solution of concentration 50 g/L and pH controlled during 2, 4 and 8 weeks. In general, the mortars showed an irregular behavior as demonstrated with the oscillations observed in the compressive strength values. Using anadditive dose of 6.3 g; after 2 weeks, the compressive strength increased in 8% (LATMs) and decreased in 23% (PUMMs) and 10% (OPCMs), although between 2 and 8 weeks, the compressive strength increased in 60 and 59% for the LATMs and OPCMs, respectively, whereas the PUMMs showed an increase of compressive strength between 2 and 4 weeks, which a decrease of 26% between 4 and 8 weeks. Using an additive dose of 12.5 g; after 2 weeks, the compressive strength decreased in 3% (PUMMs) and increased in 6% (LATMs) and 15% (OPCMs); after 4 weeks, the compressive strength decreased in 27% (LATMs) and increased in 20% (PUMMs) and 69% (OPCMOPCMs); after 8 weeks, the compressive strength decreased in 5% (PUMMs) and increased in 30% (LATMs) and 60% (OPCMs). However, the PUMMs and OPCMs showed a similar trend,

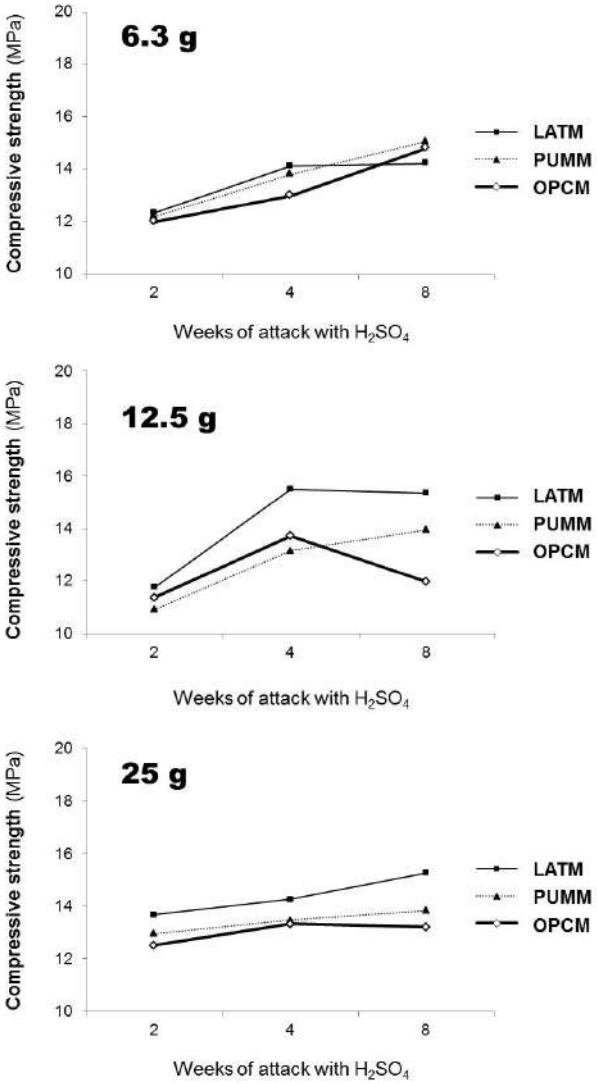


Figure 9 Compressive strength of mortars after attack with H_2SO_4

with an increase in the compressive strength between 2 and 4 weeks, which decreased between 4 and 8 weeks. On the other hand, the LATMs showed a reversal behavior compared to that observed for the PUMMs and OPCMs. A dose of 25 g reveals that after 2 weeks, the compressive strength decreased in 8% (LATMs) and 35% (PUMMs), and increased in 10% (OPCMs); after 4 weeks the compressive strength showed a slight increase for the LATMs and PUMMs and an abrupt increase in 101% for the OPCMs; after 8 weeks, the compressive strength increased in 42% (LATMs) and 32% (OPCMs), and decreased in 13 % for the PUMMs. Therefore, only the LATMs showed a progressive increase in the compressive strength during the 8 weeks of attack. These results show that mortars showed an irregular behavior after attacking with $MgSO_4$ as revealed by the oscillations observed in the compressive strength, which deviate from the general trend.

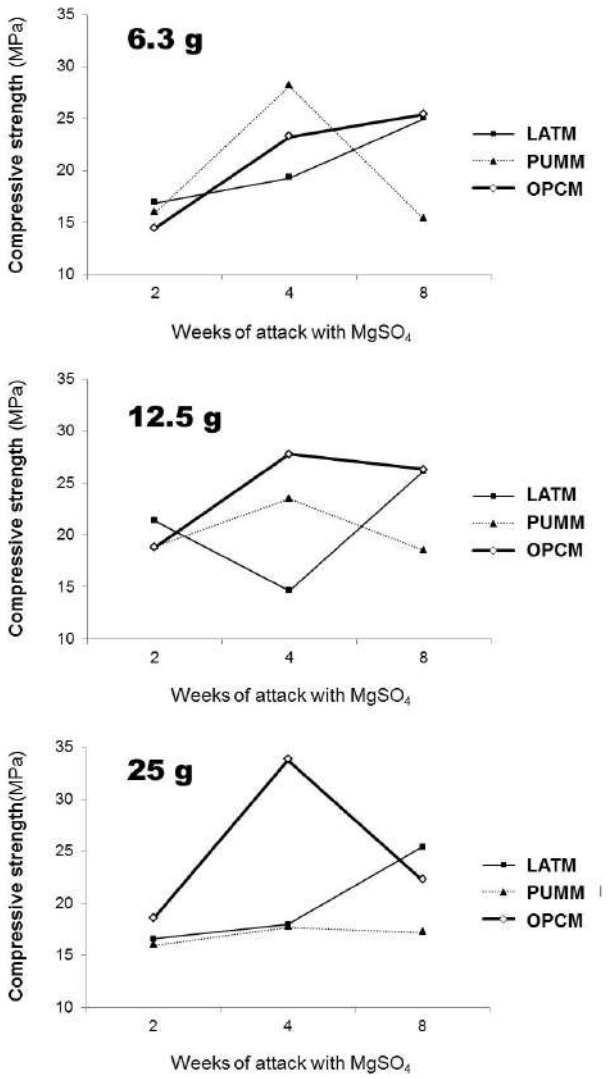


Figure 10 Compressive strength of mortars after attack with $MgSO_4$

4. Conclusions

Based on the present study, it is concluded that:

- The characterization of nickeliferous laterite and pumice used as natural puzzolans in the preparation of LATMs and PUMMs confirmed the presence of large amount of silica, Fe oxides and clays such as kaolinite and montmorillonite, which offer greater durability in mortars.
- Both nickeliferous laterite and pumice satisfy the specifications to be used as puzzolans, and, therefore, their use is advisable for making mortars.
- Due to the high compressive strength values obtained, the mortars can be classified as Type M mortars, exceeding the set value of 17.5 MPa.
- Mortars without any attack reveal that mixtures containing different proportions of natural puzzolans (nickeliferous laterite and pumice), with increasing setting time, increases the compressive strength.
- The damage of LATMs and PUMMs under attack with H_2SO_4 and H_2SO_4 was not as high due to the silica content of the natural puzzolans.
- Mortars subjected to 300 °C showed the best performance to high temperatures, with the reference mortars, showing the higher compressive strength values.
- The performance of LATMs and PUMMs exhibits an excellent behavior in highly corrosive environments, which makes the nickeliferous laterite and pumice very useful due to their role in the durability of mortars.
- The pozzolanic reaction of nickeliferous laterite and pumice in cement based mortars reveals that they have potential application in concrete industry.
- From these results different aspects could be developed to improve the application of nickeliferous laterite and pumice as natural puzzolans, such as the modification of several experimental parameters, such as grain size, dose, and binary mixes.

5. Acknowledments

This research forms part of the undergraduate thesis of M. Rueda and K. Vega. The authors acknowledge to Andina Ingeniería Ltda. for laboratory facilities. We are indebted to Universidad Industrial de Santander for providing research facilities. The authors also acknowledge to the anonymous referees for their critical and insightful reading of the manuscript and are most grateful to the above-named people and institutions for support.

6. References

1. S. Desai and S. Ujjaval, "Effective use of Industrial Waste in Cement Mortar", *International Journal of Earth Sciences and Engineering,* vol. 5, no. 6, pp. 1677-1682, 2012.
2. D. Agrawal, P. Hinge, U. Waghe and S. Raut, "Utilization of industrial waste in construction material - A review",

International Journal of Innovative Research in Science, Engineering and Technology, vol. 3, no. 1, pp. 8390-8397, 2014.
3. J. Coutinho, "The combined benefits of CPF and RHA in improving the durability of concrete structures", *Cement and Concrete Composites,* vol. 25, no. 1, pp. 51-59, 2003.
4. J. Escalante, A. Navarro and L. Gómez, "Caracterización de morteros de cemento portland substituido por metacaolín de baja pureza", *Revista ALCONPAT,* vol. 1, no. 2, pp. 156-169, 2011.
5. E. Gartner, "Industrially interesting Approaches to low CO_2 Cements", *Cement and Concrete Research,* vol. 34, no. 9, pp. 1489-1498, 2004.
6. A. Naceri and M. Hamina, "Effects of pozzolanic admixture (waste bricks) on mechanical response of mortar", *IJE Transactions B: Applications,* vol. 21, no. 1, pp. 1-8, 2008.
7. M. Sánchez and V. Sánchez, "Comportamiento a tracción de cementos reforzados con fibras de vidrio", *Informes de la Construcción,* vol. 43, no. 413, pp. 77-89, 1991.
8. A. Hauser, U. Eggenberger and T. Mumenthaler, "Fly ash from cellulose industry as secondary raw material in autoclaved aerated concrete", *Cement and Concrete Research,* vol. 29, no. 3, pp. 297-302, 1999.
9. R. Gutiérrez, S. Delvasto and R. Talero, *Permeability properties of cement mortars blended with Silica Fume, Fly Ash, and Blast Furnace Slag*, ASTM Standard STP 1399, 2000.
10. J. Swanepoel and C. Strydom, "Utilization of fly ash in a geopolymeric material", *Applied Geochemistry*, vol. 17, no. 8, pp. 1143-1148, 2002.
11. A. Fernández and A. Palomo, "Composition and microstructure of alkali activated fly ash binder: Effect of the activator", *Cement and Concrete Research*, vol. 35, no. 10, pp. 1984-1992, 2005.
12. V. Sahu and V. Gayathri, "The Use of Fly Ash and Lime Sludge as Partial Replacement of Cement in Mortar", *International Journal of Engineering and Technology Innovation,* vol. 4, no. 1, pp. 30-37, 2014.
13. N. Hasparyk, P. Monteiro and H. Carasek, "Effect of silica fume and rice husk ash on alkali-silica reaction", *Materials Journal,* vol. 97, no. 4, pp. 486-492, 2000.
14. F. Puertas, M. Varela and T. Vazquez, "Behaviour of cement mortars containing an industrial waste from aluminium refining: Stability in $Ca(OH)_2$ solutions", *Cement and Concrete Research,* vol. 29, no. 10, pp. 1673-1680, 1999.
15. F. Puertas *et al.,* "Ceramic wastes as raw materials in Portland cement clinker fabrication: characterization and alkaline activation", *Materiales de Construccion,* vol. 56, no. 281, pp. 73-84, 2006.
16. M. Singh and M. Garg, "Making of anhydrite cement from waste gypsum", *Cement and Concrete Research*, vol. 30, no. 4, pp. 571-577, 2000.
17. B. Safi, M. Saidi, D. Aboutaleb and M. Maallem, "The use of plastic waste as fine aggregate in the self-compacting mortars: Effect on physical and mechanical properties", *Construction and Building Materials,* vol. 43, pp. 436-442, 2013.
18. A. Givi, S. Rashid, F. Aziz and M. Salleh, "Contribution of rice husk ash to the properties of mortar and concrete: A Review", *Journal of American Science,* vol. 6, no. 3, pp. 157-165, 2010.
19. W. Aules, "Utilization of crumb rubber as partial replacement in sand for cement mortar", *European Journal of Scientific Research,* vol. 51, no. 2, pp. 203-210, 2011.
20. S. Izquierdo, R. Mejía and J. Torres, "Study of mortars added with fluid catalytic cracking catalyst residue (FCC) under the influence of high temperatures", *Ingeniería y Competitividad,* vol. 16, no. 2, pp. 297-308, 2014.
21. F. Koksal, O. Gencel, W. Brostow and H. Hagg, "Effect of high temperature on mechanical and physical properties of lightweight cement based refractory including expanded vermiculite", *Materials Research Innovations,* vol. 16, no. 1, pp. 7-13, 2012.
22. J. Torres, R. Mejía and C. Gutiérrez, "Desempeño de morteros adicionados con metacaolín frente a la acción de sulfatos", *Revista Ingeniería e Investigación,* vol. 28, no. 1, pp. 117-122, 2008.
23. R. Mejía, J. Torres, J. Silva and S. Delvasto, "Influencia de la adición de metacaolín a morteros y hormigones", *Boletín Geológico y Minero,* vol. 117, no. 4, pp. 715-722, 2006.
24. K. Hossain, "Properties of volcanic pumice based cement and lightweight concrete", *Cement and Concrete Research*, vol. 34, no. 2, pp. 283–291, 2004.
25. N. Degirmenci and A. Yilmaz, "Use of pumice fine aggregate as alternative to conventional sand in production of lightweight cement mortar", *Indian Journal of Engineering and Material Sciences,* vol. 18, no. 1, pp. 61-68, 2011.
26. Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC), *Ingeniería Civil y Arquitectura. Cemento Portland. Especificaciones físicas y mecánicas,* NTC 121, 1982.
27. Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC), *Ingeniería Civil y Arquitectura. Cemento Portland. Especificaciones químicas,* NTC 321, 1982.
28. Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC), *Concretos. Mortero premezclado para mapostería,* NTC 3356, 2000.
29. Instituto Nacional de Vías (INVIAS), *Análisis granulométrico de suelos por tamizado,* Norma INV E-123, 2007.
30. Instituto Nacional de Vías (INVIAS), *Valor de azul de metileno en agregados finos y en llenante mineral,* Norma INV E-235, 2007.
31. Instituto Nacional de Vías (INVIAS), *Gravedad específica y absorción de agregados finos,* Norma INV E-222, 2007.
32. Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC), *Método para determinar la resistencia a la compresión de morteros de cemento hidráulico usando cubos de 50 mm de lado,* NTC 220, 1998.
33. *Simon Fraser University, Mineral Energy Dispersive Spectra (EDS).* [Online]. Available: http://www.sfu.ca/~marshall/sem/mineral.htm. Accessed on: Apr. 22, 2015.
34. Instituto Colombiano de Normas Técnicas y

Certificación (ICONTEC), *Concretos. Método de ensayo para determinar las impurezas orgánicas en agregado fino para concreto*, NTC 127, 2000.
35. M. Broekmans, "The alkali-silica reaction: mineralogical and geochemical aspects of some Dutch concretes and Norwegian mylonites", Ph.D. dissertation, *Utrecht University,* Utrecht, Netherlands, 2002.
36. N. Fatt and Y. Beng, "Potential alkali-silica reaction in aggregate of deformed granite", *Bulletin of the Geological Society of Malaysia,* vol. 53, pp. 81-88, 2007.
37. N. Fatt, "Microstructural characteristics of some alkali-aggregate reactive granites of Peninsular Malaysia", in *National Geoscience Conference,* Selangor, Malaysia, 2010, pp. 81-82.
38. N. Fatt, J. Raj and A. Ghani, "Potential Alkali-Reactivity of Granite Aggregates in the Bukit Lagong Area, Selangor, Peninsular Malaysia", *Sains Malaysiana,* vol. 42, no. 6, pp. 773–781, 2013.
39. D. Gomes, H. Conceição, V. Carvalho, R. Soares and L. Silva, "Influence of granitic aggregates from northeast Brazil on the alkali-aggregate reaction", *Materials Research,* vol. 17, no. 1, pp. 51-58, 2014.
40. *Hess pumice, Hess Pozz Flatlines the Alkali Silica Reaction (ASR) for Pennies a Yard.* [Online]. Available: http://www.hesspumice.com/pumice-pages/pumice-uses/pumice-pozzolan-mitigates-asr.html. Accessed on: Nov. 03, 2015.
41. P. Turker, K. Erdogdu and B. Erdogan, "Investigation of fire-exposed mortars with different types of aggregates", *Cement Concrete World*, vol. 6, pp. 52-67, 2001.
42. I. Netinger, I. Kesegic and I. Guljas, "The effect of high temperatures on the mechanical properties of concrete made with different types of aggregates", *Fire Safety Journal*, vol. 46, no. 7, pp. 425-430, 2011.
43. P. Mehta and P. Monteiro, *Concrete: Microstructure, Properties, and Materials*, 4th ed. New York, USA: McGraw-Hill, 2014.