Mechanical Properties of Ultra High Performance Concrete with calcium carbonate as a substitute of cementitious material

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Abstract:

The influence of calcium carbonate -as a filling material- on the mechanical properties of an Ultra High Performance Concrete (UHPC) featuring silica fume and cement as cementitious materials, was evaluated. Properties like compressive, flexural, and tensile strength, as well as the elastic modulus were evaluated for three different calcium carbonate substitution rates (47%, 35,5% and 24%), and were all compared to a reference mixture of UHPC with no substitution. A better packaging of dry materials, leading to improvement in compactness and resistance, was observed when a higher quantity of calcium carbonate was used. Results of 56-day-compressive strength were higher for samples with calcium carbonate compared to those of the reference mixture, but presented a different trend for other properties. Temperature measurement led to develop a viable methodology to substitute the cementitious material for carbonate calcium or any other filling material.

Keywords:

UHPC, calcium carbonate, cement, tensile strength, silica fume and concrete.

1. Introduction

The use of Ultra High Performance Concrete (UHPC) is known since the beginning of 1990s (Dils et al.) and, from that decade to the present, this type of concrete has been increasingly used worldwide in order to evaluate its behavior in different application areas (Wille et al.).

UHPC is mainly produced with cement, fine silica sand, silica fume, steel fibers, additives and a low water/cement ratio. These types of concrete feature a high proportion of cementitious material to reach high tensile and compressive strength (Allena and Newtson), although a big part of this cementitious material has no reaction.

UHPC has a wide range of applications worldwide due to its better mechanical properties (Kusumawardaningsih et al.). However, it is not potentially used for structural purposes in civil works (Magureanu et al.) in different Latin American countries due to the high cost of its main manufacturing components (Wang et al.). Currently, diverse filling materials (used in adequate proportions) are being studied in order to reduce the amount of cementitious material of UHPC, contributing to sustainability and, of course, to tensile strength and durability. Such materials could include: pozzolans, quartz fluor, glass powder, basalt, silica fume, and calcium carbonate, among others (Russell and Graybeal). In addition, different manufacturing and mixing procedures are evaluated so to obtain the best UHPC properties (Osorio Gamboa and López Villamarín).

In this case, sustainability refers to lower costs of future maintenance and repair of structures made with UHPC in comparison to those made with conventional concrete. Studies indicate the energy required to produce 1 m^3 of UHPC could approximately double the one required to produce conventional concrete (Schmidt y Jerebic). However, deeper and more realistic analyses on life cycle costs (Russell y Graybeal)are needed, as some reports mention how, at the end of its life cycle UHPC can be grinded and separated into sand and fibers (Sedran et al.). Then, the recycled sand could be used to replace the sand used to make self-compacting concrete without losing fluidity or compressive strength. In addition, the environmental impact could be diminished by reducing the amount of Portland cement, steel fiber, and the use of high-range water-reducing admixtures in UHPC. In addition, and although sustainability of this type of concrete is not its main objective, this research also contributes to these matters as it looks for a substitute to reduce the quantity of cement used.

2. Testing Methods

For this research the cementitious materials used included: cement 42.5R (Argos S.A) having a density of 3.09 g/cm^3, and fineness of 4971 cm^2/g; silica fume with density around 2.01 g/cm^3; calcium carbonate having a specific gravity of 2.7 g/cm^3 and fineness of 3898 cm^2/g; sand of silica having a specific gravity bulk of 2.44 and absorption of 0.56%; steel fiber and high-range water-reducing/super-plasticising admixture with a base of modified polycarboxylic ethers.

Four UHPC mixtures featuring the same relation water/cementitious material were used. The percentage of fiber and superplasticizer was 2% and 3% respectively. The influence of the variation of contents of cement and calcium carbonate on workability and temperature change was observed. In order to have a pattern sample, slopes of heat gain were calculated to make an analysis of maximum and minimum temperature values (Figure No. 1). This analysis was fundamental to the selection of mixtures. Discretization values are presented in Table 1.

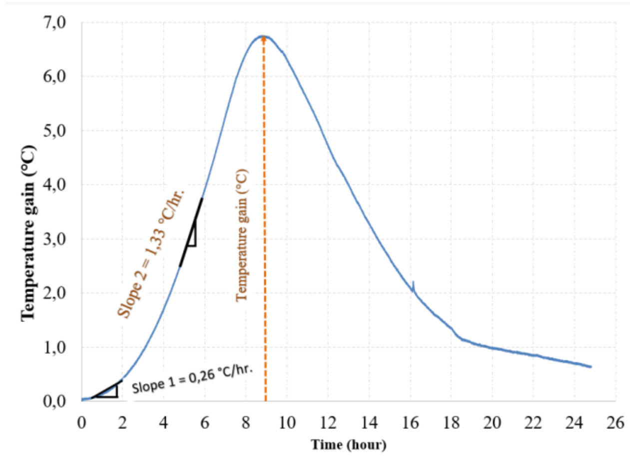

Figure No. 1 Temperature gain in pattern sample

Table 1 Criteria for mixture discretization.

	Temperature gain °C	*Slope (°C/h)*
Average	6.7533	1.1694
Std Deviation	0.8749	0.1384

The mechanical characterization of the different mixtures of UHPC, was carried out based on the ASTM C1856 / C1856M-17 *"Standard practice for fabricating and testing specimens of Ultra-High Performance Concrete"*. Following the parameters indicated in Table 1, a selection of mixtures was done taking into account the optimal interval, as presented in Figure No. 2 and Figure No. 3. These optimal intervals were obtained based on the standard deviations of the average of maximum temperature and slope growth (taken from temperatures between 2°C and 4°C).

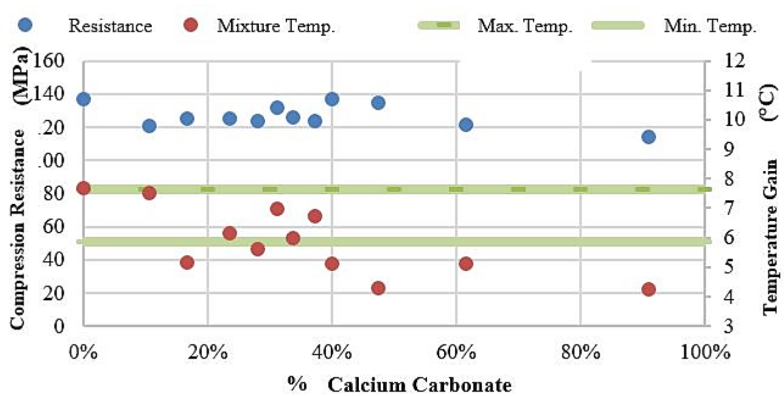

Figure No. 2 Resistance & Maximum Temperature Gain vs % Carbonate

Mixtures featuring 24% and 35.5% are within temperature and slope range. In addition, the compression of the pattern mixture is persistent and, therefore these inclusion rates were selected as low and middle calcium carbonate rates for a UHPC. On the other hand, the mixture featuring 47% is out of the selection optimal range but it keeps its resistance in respect to the pattern mixture and, in consequence, is the one selected as the UHPC mixture with a high inclusion rate of calcium carbonate.

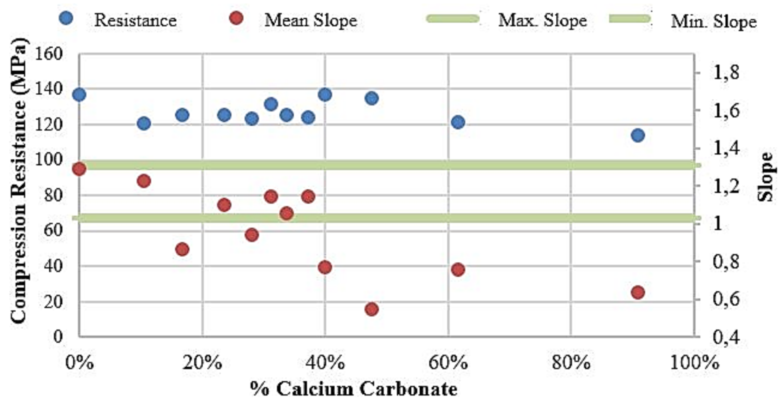

Figure No. 3 Resistance & Slope vs % of Carbonate.

Mixtures selected in this research went through a normalization process in order to determine the setting times of each one (Gaspar-Tébar). Figure 4,**¡Error! No se encuentra el origen de la referencia.** presents the normalization properties of these mixtures, all of which were made taking into account the setting time of the pattern mixture. It was found that as the percentage of calcium carbonate is increased, the setting time decreases. This latter property is directly proportional to the specific heat generated by the mixture.

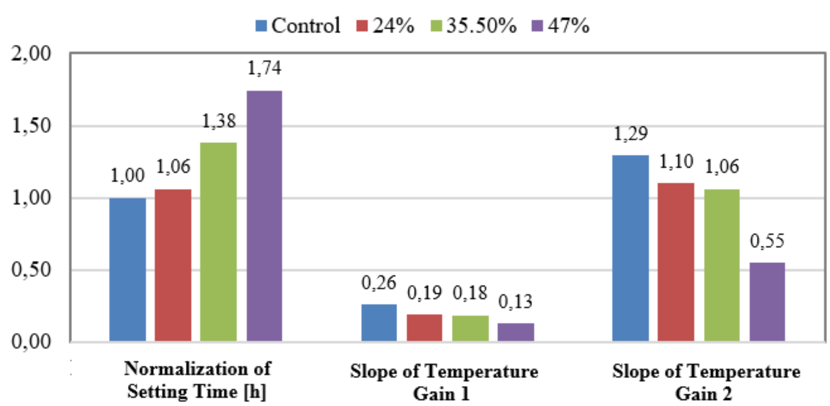

Figure No. 4 Mixture properties according to calcium carbonate content.

The tested mixtures have self-compacting properties. All the mixtures report workability values obtained with both static and dynamic mini slump test, featuring a coincidence with results obtained by Dils (Dils et al.). Compactness values presented by the curve slopes of different selected doses are reported below, using slope curves proposed by Fuller and Funk as a reference (Figure No. 5).

The granulometric composition of the dry components in the mixture allows an optimal particle accommodation which, in turn, improves compactness and may produce high resistance in concrete.

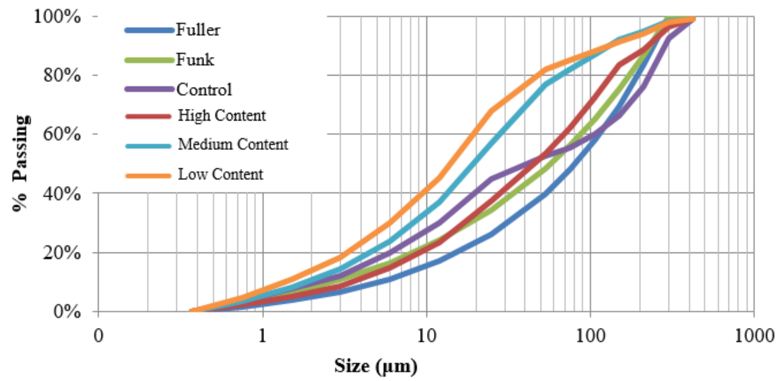

Figure No. 5 Compactness slope curves of tested mixtures.

3. Results

Results of the tests carried out on the mixtures, in order to evaluate properties of compression resistance, flexural and tensile strength in samples of 7, 28 and 56 days of age, and the elasticity module in samples of 28 and 56 days of age, as well as the averages obtained from three tested samples in each age of trial and each mixture, are presented hereunder.

3.1. Compression Resistance

Results of the tests performed on cubic and cylindric specimens after 28 days are similar to those reported by (Kusumawardaningsih et al.) as compression values in cylinders are higher than compression resistance in cubes. These values usually tend to be inverted since resistance in cubes is higher than those in cylinders. In this case, results may be due to the higher density in UHPC (in comparison to conventional concrete) because of the size of its components. Results obtained by (Magureanu et al.) also report that the increase in compression resistance is a consequence of fiber content.

Figure No. ***6*** shows results for resistance and compression in cubes and cylinders after 7, 28 and 56 days. Compression resistance of pattern samples in cubes, compared to other samples, show no meaningful difference in terms of those results obtained in the laboratory.

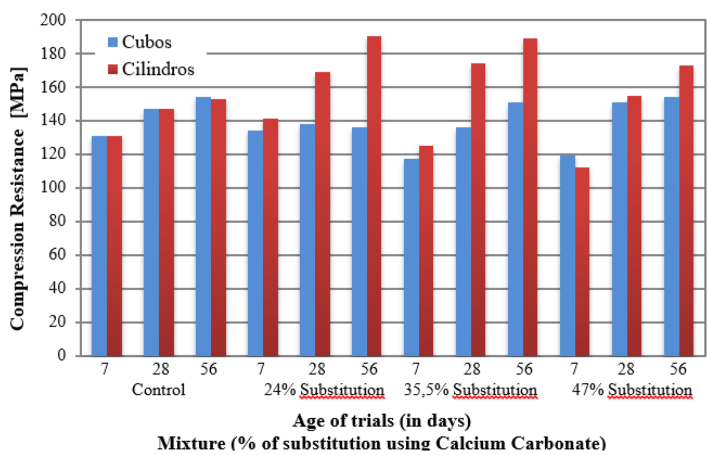

Figure No. 6 Results of compression resistance in 7, 28 and 56 days trial period for all mixtures.

3.2. Elastic modulus

Figure No. 7 shows results of the elastic modulus of all four types of mixtures proposed. For mixtures with 35,5% of Calcium Carbonate and 28 and 56 days of age, highest result for Young´s modulus was 46641MPa and 46871MPa.

At the same time, Poisson’s ratio was higher for different samples depending on the content of Calcium Carbonate and the curing age. Specifically, the highest value of this ratio was 0,243, and it was observed in the mixture with 35,5% of Calcium Carbonate and 28 days of age, while in the control mixture this ratio was 0,198%. In the case of the mixture with Calcium Carbonate of 47% and an age of 56 days, the highest value of Poisson’s ratio was 0,224, being higher than that of the pattern sample which was 0,206.

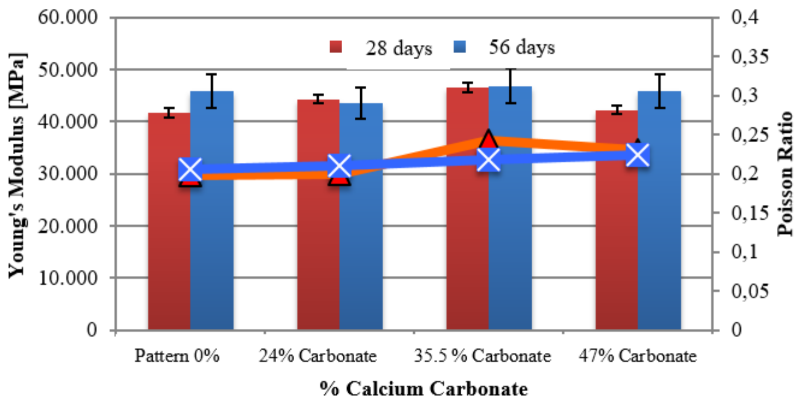

Figure No. 7 Results after 28 and 56 days for Young’s Modulus and Poisson Ratio.

3.3. Flexural strength

Figure No. ***8*** shows results of flexural strength of bars featuring the four types mixtures proposed. Flexural strength in the 56-day pattern mixture was above those of mixtures with calcium carbonate. Those mixtures with 24% of calcium carbonate showed a 7% decrease in flexural strength when compared to the pattern mixture. On the other hand, those mixtures with 47% and 35.5% of calcium carbonate showed a 24% decrease of flexural strength.

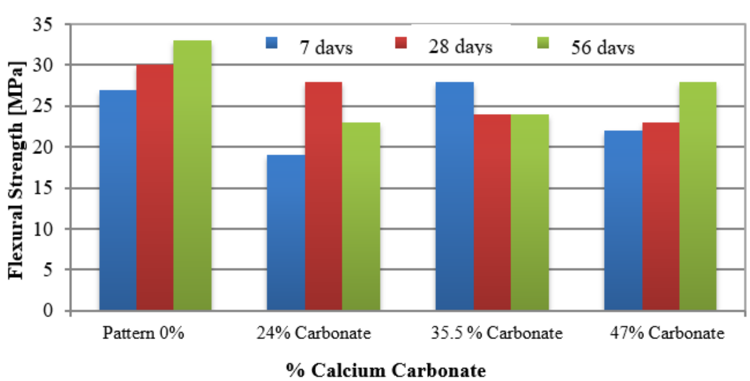

Figure No. 8 Results of Flexural Strength after 7, 28 and 56 days for all mixtures tested.

3.4. Tensile strength

Figure No. 9 shows results obtained for tensile strength. In the case of the pattern mixture with 56 days of age, tensile strength was above those with calcium carbonate. Mixtures with 47% and 35.5% calcium carbonate substitution featured a 37% decrease in tensile strength. In the case of mixtures with 24% calcium carbonate substitution such decrease was 20%. It means, the latter shows the best behavior among mixtures with calcium carbonate substitution.

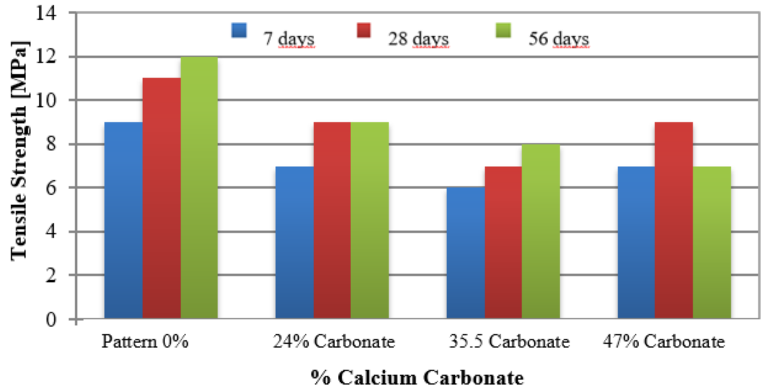

Figure No. 9 Results of tensile strength for 7, 28 and 56 day mixtures.

4. Conclusions

Materials for manufacturing ultrahigh performance concrete with calcium carbonate as cementitious material were typified. Compression resistance between 154MPa and 174.3 MPa was detected in samples of 28 days of age, which indicates that a higher quantity of calcium carbonate features dry materials with better graded composition than those samples without it.

- This methodology allowed to conclude that samples with low, medium or high content of calcium carbonate feature a higher compression resistance and flexural modulus than those of the pattern sample. This may be the result of a better particle accommodation which, in turn, leads to a high compactness of dry materials.
- Higher values for compression resistance and flexural modulus in samples of 28 and 56 days of age were obtained for mixtures with 35,5% and 47% calcium carbonate substitution.
- It seems that calcium carbonate has a negative effect in respect to properties like tensile and flexural strength. In all the cases the pattern sample featured a higher tensile and flexural strength.

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5. Acknowledgements

The authors of this work acknowledge and thank the support given by Cementos ARGOS, COLCIENCIAS (project No.63881), and the Civil Engineering Department of Pontificia Universidad Javeriana.