

Analysis of the mechanical properties between High-strength and Self-compacting concretes, **using an additive and an admixture, for different reductions in water content**

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ABSTRACT

CONCRETE IS CHARACTERIZED BY ITS WORKABILITY, CONSISTENCY, LOW COST, AND RAPID DRYING TIME. ONCE HARDENED, IT IS CHARACTERIZED BY ITS HIGH STRENGTH, ABSORPTION CAPACITY, AND RESISTANCE TO WATER, ABRASION, AND OTHER FACTORS. FOR DIFFERENT STRESSES, IMPACTS, ENVIRONMENTS, AND CONSTRUCTION TECHNOLOGIES, TO CHOOSE PLACEMENT METHODS FOR DIFFERENT ELEMENTS AND STRUCTURES, SPECIAL CONCRETES HAVE BEEN DEVELOPED. IT POSSESSES SPECIFIC PROPERTIES SUITED TO PARTICULAR APPLICATIONS AND THE LIFESPAN OF THE STRUCTURES. AS A RESULT, ADDITIVES HAVE ALSO EVOLVED, AND FOR THE PURPOSE OF BETTER AND EASIER PLACEMENT AND HIGH DURABILITY MAKES SELF-COMPACTING CONCRETE (SCC) A SPECIAL TYPE AMONG SPECIALTY CONCRETES. IT IS WELL KNOWN THAT ITS MAIN PROPERTY IS FLUIDITY. TO ACHIEVE CONSIDERABLE STRENGTH, HIGH-RANGE WATER REDUCERS (HRWR) ARE USED, ALSO USED TO ACHIEVE HIGH STRENGTH FOR HIGH-STRENGTH CONCRETES (HSC). THESE REDUCERS ALLOW US TO ADJUST THE AMOUNT OF WATER REDUCED TO ACHIEVE DIFFERENT CONCRETE CONSISTENCIES AND DETERMINE ITS COMPRESSIVE STRENGTH.

KEYWORDS: SELF-COMPACTING CONCRETE, HIGH-STRENGTH CONCRETE, HIGH-RANGE WATER REDUCER, POLICARBOXILATE PC.

1. INTRODUCTION

Self-compacting concrete is a type of concrete that through its properties using superplasticizers, compacts by gravity, flowing between the formwork thanks to

its viscosity. It compacts without the aid of any mechanical system and maintains its homogeneity and stability throughout its application, preventing slurry bleeding and coarse aggregate blockage. SCC is characterized by a lower coarse aggregate content, a higher mineral fine content, and, in general, a smaller maximum aggregate size. Furthermore, SCC is typically produced with a low water-cement ratio, leading to increased strength, faster formwork removal, and quicker commissioning of structures. Furthermore, there are some places in the world, including Paraguay, especially in the Chaco region, where it hardly ever rains, water is salty if it can be found at all, and is a limited resource in terms of both quality and potability. If we ran out of water, it would take about three hours to continue pouring the concrete. All of this made us realize the importance of the water we have. [1]

According to EN 934-2:

- ▶ **Water reducer:** Allows a reduction in the water content of a concrete mix without affecting its consistency, or increases workability without changing the water content, or both effects.
- ▶ **Superplasticizer:** Allows a significant reduction in the water content of a given concrete mix without affecting its consistency, or increases workability without changing the water content, or both effects. Also known as HRWR (high-range water reducer). [9]. In this

work, a HRWR, superplasticizer based on modified polycarboxylates will be used. HSC aims a high level of strength through various factors, including the use of selected materials and low water-to-binder ratios. This results in a less porous, less permeable, and more durable structure. The predominantly spherical aggregates and their varying size distribution necessitate the use of admixtures to reduce the heat of hydration generated by the high Portland cement content. The hypothesis is whether HSC can be achieved through an analogous process by starting to design a SCC.

2. DEVELOPMENT

A characterization of the materials was performed to design concrete mixes. It was added silica fume and a HRWR with water reduction ratios of 0%, 2.4%, 5%, 10%, 20%, 30%, and 40%. The following material values were used to prepare the first batch of SCC for this study; subsequently, the water content was reduced.

- ▶ **Binder:** CEMEX Class IV/B(P) 32.5 N-SR cement, density 3.1 g/cm³, with 8% of its weight replaced by silica fume or microsilica, density 2.2 g/cm³.
- ▶ **Water:** The suitability of water for concrete production depends on its source. The UNE EN 1008 establishes:
- ▶ **Drinking water:** Suitable for concrete. No testing is required. (Water used from

the Madrid city water system).

- ▶ **Recovered water from concrete industry processes (e.g., wash water):** This is generally suitable for concrete, but the standard's requirements must be met (e.g., the additional weight of solids in the concrete when using this type of water must be less than 1% of the total weight of the aggregates in the mix).
- ▶ **Groundwater:** May be suitable, but must be verified. Natural surface water and industrial water: May be suitable, but must be checked.
- ▶ **Seawater or saltwater:** Can be used for mass concrete but is not suitable for reinforced or prestressed concrete. The maximum permissible chloride content in concrete must be observed for concrete reinforced with steel fibers or embedded metal parts.
- ▶ **Wastewater:** Not suitable for concrete. Combined water is a mixture of water recovered from concrete industry processes and water from another source.
- ▶ **Chemical properties:** The water was taken from Madrid's potable water system.
- ▶ **Harmful contaminants:** Tests must be carried out for sugars, phosphates, nitrates, lead, or zinc. If the results are positive, the content of each substance must be determined, or setting time and compressive strength development tests must be performed.
- ▶ **Admixture:** Dosage according to EHE-08: Permitted dosage < 5% of the cement weight (the effect of a higher dosage on Setting Time and Strength).

In this work, 1.25% of the weight of the cement was used. Concrete **additions** are fine materials that are normally added to concrete in significant proportions (around 5-20%). They are used to improve or obtain specific properties in fresh and/or hardened concrete. According EN 206-1. *Silica fume* consists essentially of spherical particles of amorphous silicon dioxide from the production of silicon and silicon alloys. It has a specific surface area of 18-25 m² per gram and is a highly reactive pozzolan. The standard dosage for silica fume is 5% to 10% max. of the cement weight. In this work, silica fume was used at 8% replacement. This gives the binder finer particles that provide better rheological properties, fill the empty spaces left by the cement, and give better granulometric distribution to the whole, better compactness, and therefore more impermeability, durability and compressive strength.

- ▶ **Aggregates:** Gravel was used as coarse aggregate, and a mixture of 90% washed sand and 10% marble dust as fine aggregate.

SCC: requires a higher quantity of fines than conventional concrete to achieve the necessary fluidity. Aggregates with a maximum diameter of 19.1 mm or 12.7 mm are preferred, but no larger. Although some researchers used aggregates 25 mm. The procedures included consistency-flow tests using the truncated cone method, visual inspections of fluidity, and non-segregation of the concrete components, also compressive

strength at 7, 28, and 56 days of age to determine when the concrete acquires HSC's properties. The results were graphed plotting the strength curves of the concrete. Silica fume was used as addition and a PC HRWR admixture. The mix design method is a simplified design, a modification [1] of the ACI 211.1 [2] code for CC. The ranges included within the European Guidelines for SCC [5] were also studied. The main function of HRWR is to disperse cement particles, achieving high levels of fluidity without the need of additional water, reducing the risk of bleeding and segregation, adjusting the water content and the dosage of the admixture. Superplasticizers can be classified into four categories according to their chemical composition: lignosulfonates (LS), naphthalene sulfonate (NS), melamine sulfonate (MS), and polycarboxylates (PC) are the most modern, 3rd generation superplasticizers. Currently, PC are the most widely used in SCC due to their high effectiveness in maintaining workability without the need for high doses [7]. The microstructure of SCC differs from that of conventional concrete, due to the mix design, especially the use of admixtures and the reduction in the volume and size of the coarse aggregate. The larger the coarse aggregate, the weaker the transition zone. The low water-to-fines ratio reduces porosity. Figure 1 shows the rheological parameters and the influences of components.

According to the Figure 2, the coarse aggregates (gravel) used are classified as having average or semi-round sphericity.

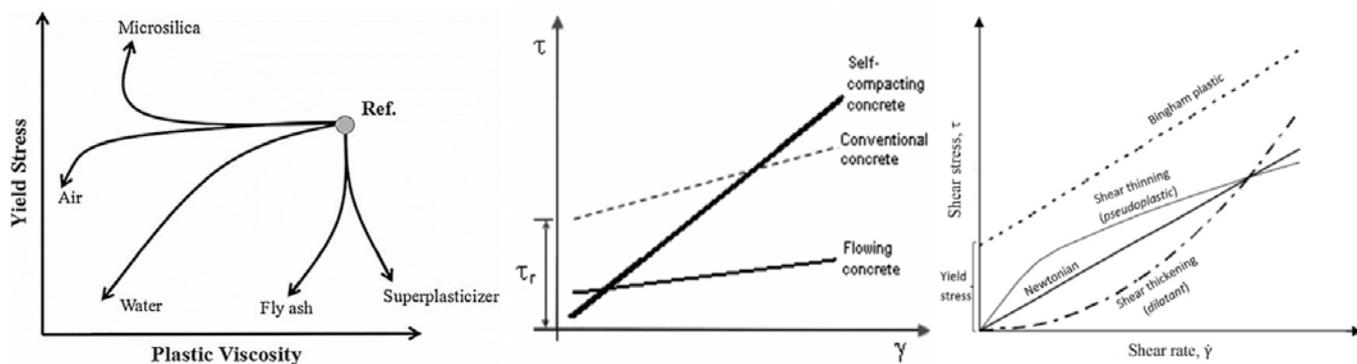


FIGURE 1 EFFECTS ON THE RHEOLOGICAL PARAMETERS OF WATER CONTENT, SUPERPLASTICIZER AND ENTRAINED AIR, OF FLOW ON SCC, CC CONVENTIONAL CONCRETE AND HSC [4]

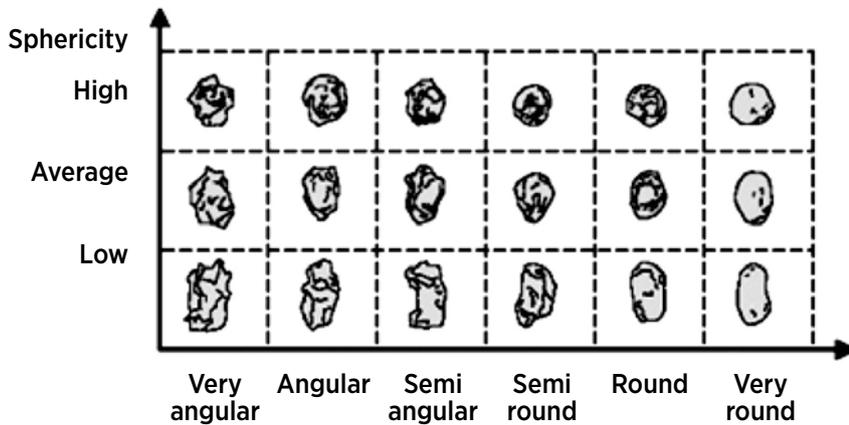


FIGURE 2
CLASSIFICATION ACCORDING TO THE SHAPE OF THE AGGREGATES

The results were analyzed to determine appropriate water reduction percentages for both self-compacting and high-strength concrete. Figure 3 helps with the results of slump flow and T50 to consider our SCC.

The validity of the hypothesis regarding the use of the methodology for designing SCC was verified, and the values for HSC were achieved. In regions where 62 MPa compressive strength concrete is commercially produced, high strength could be in the range of 83 MPa to 103 MPa. However, in regions where the maximum compressive strength for commercially available

concrete is 34 MPa, we could well call a 62 MPa compressive strength a HSC. The ACI Committee 363 [3] on HSC establishes that the specified design strength should be 41 MPa or greater, and its mix design table starts with 49 MPa concrete and ends at 84 MPa for 28 and/or 56 days of age [3].

2.1 Developed Methodology

We prepared SCC and HSC prior to UPM. From this, it was concluded that for SCC, when the proposed value of the coarse aggregate weight was set at 50%

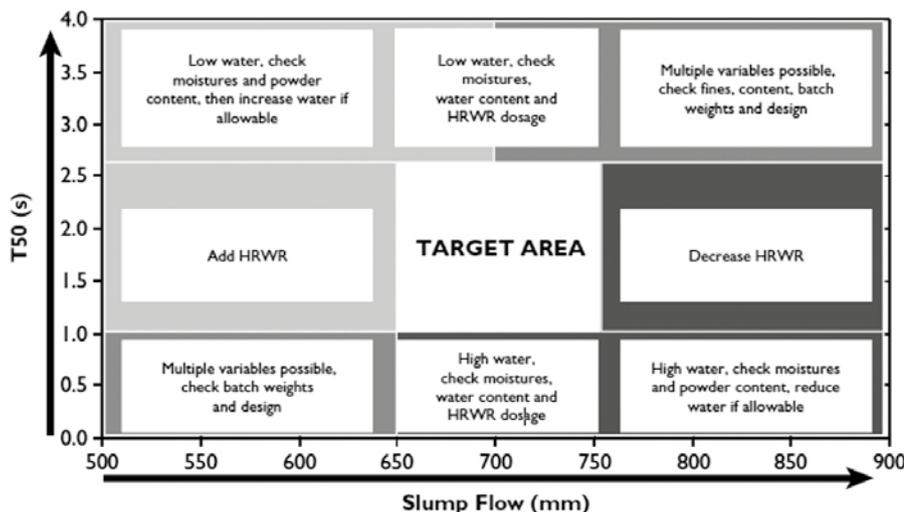


FIGURE 3
HUMIDITY ADJUSTMENT MATRIX OR WATER/BINDER RATIO AND ENERGY CONSUMPTION

of the compacted dry unit weight, the high variation in fluidity resulted in unsatisfactory strength [1]. Therefore, upon analyzing the theory, if the concrete is not self-compacting, the 50% criterion mentioned above is not only unnecessary, but it is recommended to use Table 5 of ACI 211.1 [2] for conventional concretes and enter the fineness modulus of the fine aggregate and the maximum diameter of the coarse aggregate to obtain the percentage for the concretes to be analyzed. At UPM we prepared mortars using locally available materials. Analysis of additive dosage and fluidity was conducted, and the water/cement ratio for mortars containing these components. The component materials were analyzed and characterized. A 1:3 mortar (binder: fine aggregate) was prepared with a water/binder ratio of 0.475 and 1.25% superplasticizer by weight of cement. Its behavior in the fresh state and its hardened mechanical strength at 28 days were observed. Rational proportioning of each concrete mix was performed using the ACI 211.1 method, and the HAC mix was determined using the simplified method of the ACI 211.1 code. Concretes with water reduction of 0%, 2.4%, 5%, 10%, 20%, 30% and 40% as a variable were made, keeping cement and additive content constant (1.25% additive of the weight of cement according to results of mortar tests). On Figures 4 and 5 we can see the red curve corresponding to the materials used for our concrete.

Three mortar 40 mm x 40 mm x 160 mm specimens were prepared. The flexural strength at 28 days averaged 14.1 MPa, and the compressive strength 34.93 MPa. Its density 2.226 g/cm³. Ten concrete specimens made for every case, with water reduction (the variable) of 0%, 2.4%, 5%, 10%, 20%, 30%, and 40%. The mixes consisted of 92% cement and 8% silica fume binder, 1.25% PC superplasticizer, gravel as coarse aggregate, and 90% sand and 10% marble dust as fine aggregate. The proportions of cement, addition, and gravel remained constant in the mix design (except for the SCC candidates, as conventional concretes according to ACI 211.1 [2] followed Table 5). The final component of the mix design was the fine aggregate. The specimens were cured in a humid chamber. Figures 6 to 8 shows us part of the testes performed.

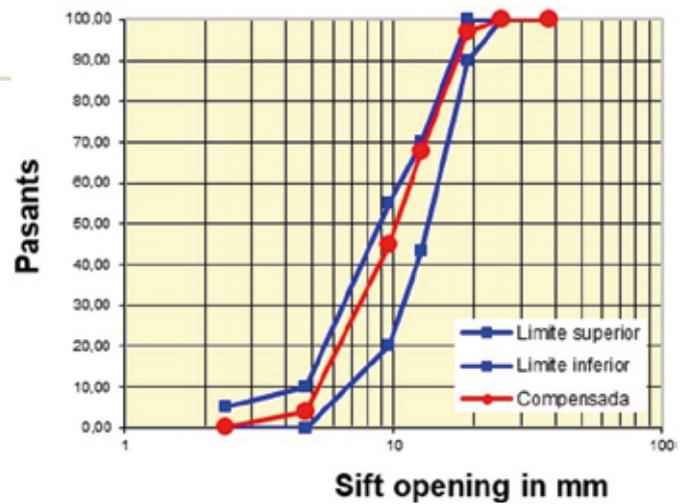
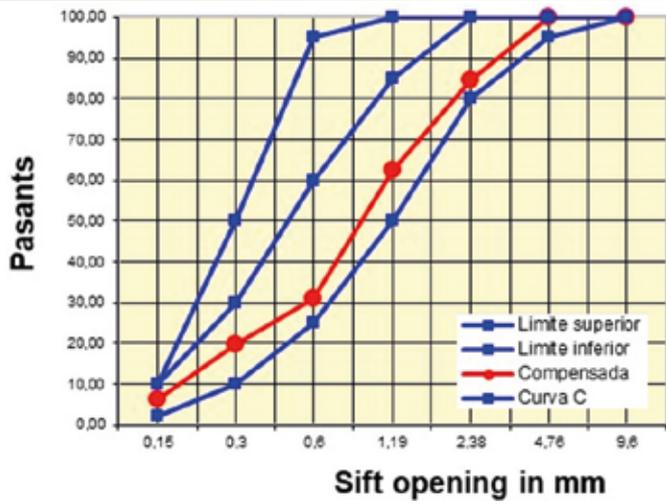


FIGURE 4

COMPENSATED CURVE OF FINE AGGREGATE WITH 90% SAND AND 10% MARBLE DUST (RESIDUE FROM THE MARBLE INDUSTRY). IRAM STANDARD 1548/71 AND 1568/71; NBR 7217/87 [10]. FINENESS MODULUS = 2.94. $D_s = 2.5 \text{ G/CM}^3$.

SOURCE: OWN ELABORATION

FIGURE 5

COARSE AGGREGATE CURVE (GRAVEL). CURVE LIMITS IRAM 1548/71 AND 1568/71 AND NBR 7217/87 [10], MAX. DIAM. 20 MM. $D_s = 2.55 \text{ G/CM}^3$; $PU \text{ COMP} = 1800 \text{ KG/M}^3$

SOURCE: OWN ELABORATION

2.2 Results

The series of results is shown in Table 1.

In Figures 9 and 10 it can be seen some of the graphs made by the universal machine, from which it was taken The elasticity Module E.

On Figure 11 the results are ordered by % of water reduction.

The results validate the initial hypotheses; however, this field of research is just beginning in order to find a better method for

proportioning HSC. For example, we started with SCC as an initial idea, but this could be done using other concrete mixes to improve the properties of different concretes, including their respective compressive strengths. On the other hand, the SCC achieved a T50 of 2.8 seconds and an average final diameter of 750 mm. It also exhibited a uniform thickness of the coarse aggregate (in this case, 20 mm gravel) without segregation, resulting in a homogeneous, well-distributed mass with few voids and good strength. Strength is a secondary desired property;

the most important is achieving self-compacting by gravity alone and the absence of segregation, among other properties in the fresh state of the SCC. According to European Guidelines (5), these results indicate a self-compacting concrete of category AC-E2, class SF2, suitable for doubly reinforced walls, columns, and pillars. (5).

Reviewing Zerbino's research (4), many materials have a threshold value below which movement does not occur. These materials are also known as viscoplastics. Fluids that respond to the Bingham model



FIGURES 6 TO 8

FRESH AND HARDENED TESTING

SOURCE: AUTHOR'S OWN WORK

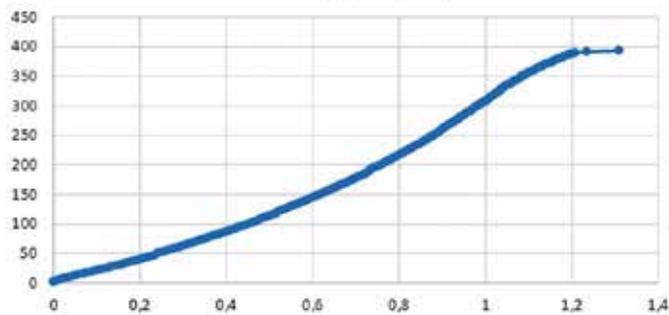
TABLE 1

DOSAGES OF THE CONCRETES CONSIDERED FOR THEIR STUDY IN THE FRESH AND HARDENED STATE

Dosage in kg starting with 2.4% reduction of water based on estimates with the test mortar									
Serie	Cement	Microsilica	Gravel	Sand	Marmoline	Water	Superplastifier	Water reduction	Tipe/A(cm)
1	425	37	900	615	63	207,89	5,78	2,40%	22
2	425	37	1080	567	57	170,4	5,78	20%	20
3	425	37	1080	425	37	192	5,78	10%	22
4	425	37	900	738	82	202,35	5,78	5%	HAC/Φ75
5	425	37	1080	558	62	149	5,78	30%	14
6	425	37	1080	414,5	46	213	5,78	0%	25
7	425	37	1080	894	99	128	5,78	40%	4

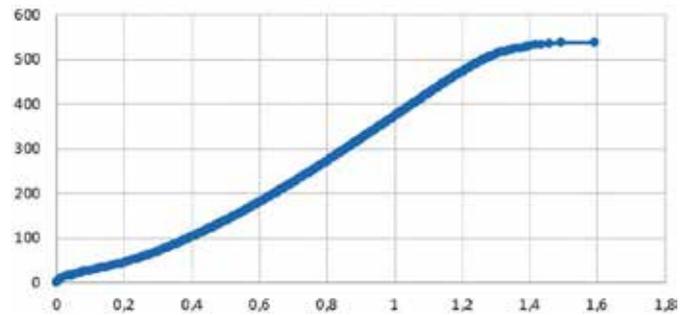
Source: AUTHOR'S OWN WORK

Compresión KN (Resist Comp/10 (Mpa) vs Deformación (mm)

**FIGURE 9**

4 SERIES (REDUCTION 5% SCC)

Compresión KN (Resist Comp/10 (Mpa) vs Deformación (mm)

**FIGURE 10**

5 SERIES (REDUCTION 30%)

TABLE 2

COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY, INDIRECT TENSILE STRENGTH AND DENSITY

Serie	Compress strength in Mpa			E (Mpa)	Indirect tension in Mpa (28 d)		Density (g/cm³)
	7-8 d	28 d	56 d	28 d	Serie	28 d	28 d
1	24,45	39,33	43,12	38931	1	3,02	2,365
2	42,33	56,17	56,54	38205	2	2,14	2,416
3	30,65	47,74	52,11	46465	3	1,69	2,416
4	34,14*	38,15	42,25	30999	4	1,90	2,409
5	53,85	>60	>60	39167	5	3,19	2,472
6	29,89	40,53	45,90	37500	6	1,30	2,434
7	37,26	38,26	46,35**	41048	7	2,63	2,237

NOTE: *13 DAYS OLD. **44 DAYS; SOURCE: AUTHOR'S OWN ELABORATION

NOTE: (>60) The press has a safety mechanism before reaching its maximum capacity of 600 kN. for compression specimens (10 cm x 10 cm x 10 cm), this mechanism is activated when the specimens reach approximately 60 MPa of compressive strength. *SCC.

behave as Newtonian fluids above the threshold. This model is one of the best representations of the behavior of cement paste, mortar, and concrete; it uses two parameters to characterize movement: the shear threshold (τ_0), which represents the resistance to deformation under static conditions, and the plastic viscosity (μ), which can be associated with an increasing resistance

to movement according to equation 1.

$$[1] \quad \tau = \tau_0 + \mu\gamma$$

Materials that behave as dilatant or pseudoplastic above the threshold stress are better represented by other models, such as the Herschel-Bulkley model according to equation 2, where a and b are constants. This model has also

been used to represent the behavior of SCC.

$$[2] \quad \tau = \tau_0 + a\gamma^b$$

There are fluids whose viscosity can change even under constant applied stress; these include thixotropic fluids. A thixotropic fluid has a structure that breaks down during movement and reforms upon returning to rest. Concrete, depending on the nature of

the cement, mineral admixtures, and chemical additives, may or may not exhibit a thixotropic response. In practice, thixotropic behavior manifests as a loss of fluidity when the material is left at rest and a recovery of its flowability when a certain amount of energy is subsequently applied. This aspect has a practical interest considering that this loss of fluidity or recovery of the structure will result in a significant reduction of pressure on the formwork. Although cement paste is essentially water and cement particles, its behavior is quite different from a suspension of inert solids. Attractive forces exist between the particles, leading to the formation of flocs. Shortly after contact with water, rapid reactions occur, resulting in the dissolution of ions, and then hydrated products begin to form on the particle surfaces. These membranes that form around the flocs rupture during mixing, which explains why the effort required to move the system varies depending on the rate of deformation.”

According to European Guidelines (5), the SCC used in this research corresponds to class SF2 for walls and columns and VS2/VF for lower segregation of said concrete.

3. CONCLUSIONS

The HSCs were obtained with 10, 20 and 30% of water reduction. To improve strength requires to increase the coarse aggregate content, as verified by the initial and subsequent results of this research. Therefore, the hypothesis is confirmed. Furthermore, we propose using Table 3 of ACI 363 for the

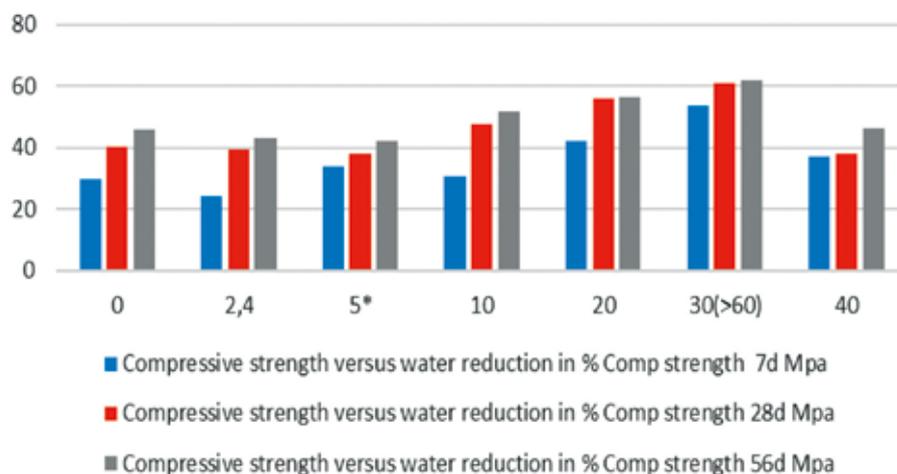


FIGURE 11

COMPRESSIVE STRENGTH (MPA) VERSUS % WATER REDUCTION

SOURCE: AUTHOR'S OWN ELABORATION

coarse aggregate content, which provides an even higher content of coarse aggregates, potentially leading to higher strengths than those found in this study. In HSC, the amount of coarse aggregate notably favors the compressive strength according to ACI 363 (3), the rest of the dosage is achieved using the methodology of ACI 211.1 (2) used. We hope this work will open up a range of research that can lead to more precise dosing methods. Using the same percentage of admixture as for SCC, greater compressive strength can be achieved by reducing the water content and dosing the remaining

components as if it were conventional concrete. This results in water reductions of 10, 20, and 30 percent higher than those of SCC concrete and the reference concrete considered with 0% water reduction. And it achieved strengths that qualify them as HSC.

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