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Evaluation of the incorporation of glass microspheres on the mechanical properties of self-compacting concrete

TRABAJO DE INVESTIGACIÓN PARA OPTAR EL GRADO ACADÉMICO DE BACHILLER EN INGENIERÍA CIVIL AMBIENTAL

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Resumen

El presente articulo está enfocado en analizar las propiedades del concreto con dosificación de microesferas de vidrio en 2%, 5% y 7% como reemplazo parcial del cemento. Según los lineamientos de la norma ACI 237 – R, la relación a/c aumentó a medida que se incrementaban las dosificaciones de HGM. A partir de ello se realizó ensayos de asentamiento, caja de paso L, embudo V, anillo J, temperatura, peso unitario, compresión y tracción. Observándose que, con las diversas combinaciones, se mejora notablemente las propiedades del concreto en estado fresco. Disminuyo la viscosidad, aumento la velocidad de flujo, incremento el asentamiento, uniformidad y capacidad de paso, siendo la combinación más incidente el del 7% de HGM. Sin embargo, las combinaciones de HGM en el concreto en estado endurecido se nota una reducción de resistencia de tracción y compresión respecto a la muestra patrón, pero cumpliendo con la resistencia solicitada de 350 kg/cm2. A pesar de eso, la dosificación del 5% tuvo una disminución casi despreciable. Siendo este ultimo la dosificación óptima para elaborar concreto autocompactante.

Palabras clave: Microesferas de vidrio (HGM), Concreto autocompactante (SCC), Trabajabilidad, Fluidez.

Abstract

This paper is focused on analyzing the properties of concrete with glass microspheres dosed at 2%, 5% and 7% as a partial re-placement of cement. According to the guidelines of the ACI 237 - R standard, the w/c ratio increased as HGM dosages increased. Based on this, slump, L-box, V-funnel, J-ring, temperature, unit weight, compression and tensile tests were carried out. It was ob-served that, with the various combinations, the properties of the concrete in the fresh state are significantly improved. Decreased viscosity, increased flow velocity, increased settlement, uniformity and flow capacity increase, with the most common combination being 7% HGM. However, the combinations of HGM in the hardened concrete show a reduction in tensile and compressive strength with respect to the standard sample, but they comply with the requested strength of 350 kg/cm2. In spite of this, the 5% dosage had an almost negligible de-crease. The latter being the most optimal dosage for making self-compacting concrete.

Keywords: Glass microspheres (HGM), self-compacting concrete (SCC), Workability, Fluidity.

Introduction

In today's society, technological advances represent a very important indicator for the development of a population, being closely connected to the concept of sustainable development, and the concern about environmental changes. This, taken to the branch of civil engineering, leads to the search for new technologies that meet the demanding requirements for residential constructions and industrial infrastructures, and at the same time, preserve ecosystems.[1]

Self-compacting concrete (SCC) emerged as a new technology in the 1980s, proposed by Professor Okumura, from the Universi-ty of Tokyo, due to the constant concern for improving durability problems in infrastructures. The main development of this new type of concrete is based on the improvement of workability, at the same time of its high resistance to segregation and time optimization.[2]

In recent years, glass microspheres (HGM) have been the subject of study, attracting attention due to their composition and their excellent behavior as a melting material for certain polymers. These elements are thin-walled glass particles with a size similar to powder, whose characteristics are their dimensions with a fairly contained diameter, their reduced density and their ability to resist compression and shear forces. All these qualities are very attractive for the area of civil engineering.[3]

According to the studies carried out by [3], where he investigated the rheological influence of the behavior of glass microspheres (HGM), evaluating a 5% addition to his mix design. The evaluation of the fluidity of the mix and the influence of the new addition was measured by tests such as slump, L-box and J-ring, in addition to the properties of the concrete in the hardened state by testing compressive, tensile and flexural strength. It was observed that the mixture added with HGM improved the properties of the SCC, however, it did not significantly decrease the properties in the hardened state.

In the work of [4], the addition of HGM to hydraulic concretes and polymeric mortars was evaluated, highlighting the low density and high compressive strength offered by these glass microspheres. In the methodology, they made a standard sample and another sample with HGM, trying to keep a water-cement ratio of approximately 0.45 in all samples. The percentage of addition used is 6.7% as a replacement of the aggregates, obtaining a slight increase in the compressive strength tests and a considerable decrease in the volumetric weight in a percentage of 17%.

Finally, according to [5], it focused on lightweight concretes where Portland cement was replaced by HGM in percentages of 3%, 6%, 9%. The tests performed were scanning electron microscopy and X-ray fluorescence, to characterize the physical and chemical properties of the HGM. The concrete was tested for compressive strength, water absorption, density and thermal insulation. The conclusions reached were that at 3% the compressive strength was improved, with less water absorption and thermal insulation.

Thus, the main objective of this research work is to evaluate and determine the best addition of HGM, performing a replacement of these glass microspheres by weight, at 2%, 5% and 7%, determining its fluidity in the fresh state, also fulfilling the requirements with which this SCC was designed in the hardened state.

Materials and test methods

The mix design followed the guidelines of the ACI 237 - R standard, which indicates the necessary parameters for a correct SCC, highlighting its high workability and fluidity[6]. In order to verify this design, it is necessary to compare the theoretical parameters with the laboratory experiences, thus the slump test is the basis to verify the correct aggregate dosage, water / cement ratio, the conformation and dosage in volume of the mortar, additive, etc. From this, the fluidity of the mix is measured, allowing to compare the expected requirements, being the trial and error technique what allowed the readjustment and validation of the mix design.

Once the standard mix was verified, the mix designs were made with the different replacements of HGM for cement. For this purpose, percentages of 2%, 5% and 7% were used, which replaced part of the weight of the cement obtained in the standard mix design.

In order to correctly evaluate the input under study, the dosage of the rest of the components of the mix design was not adjusted.

Characterization of materials

For the present investigation, Type I cement was used, which is intended for general structural use, according to ASTM C1157.[7]

With respect to the glass microspheres, the ones used were Potters Ballotini - Panamericana M247, whose classification according to the ASHHTO standard is Type I, according to the manufacturer's technical specifications, its chemical composition is mainly Silicon Dioxide (73%), Sodium Oxide (15%), Calcium Oxide (7%), Magnesium Oxide (4%), besides being of clear - transparent color with a minimum percentage of 70% of sphericity, a specific gravity of 2. 3 gr/cm and a compressive strength of 18.36 MPa. [8] In this way it is determined that the material has a chemically stable composition, being almost impossible to dissolve it with water. The manufacturing process of microspheres is generally based on the recycling of common glass, also made up of other elements resulting from industry, lime and high temperatures.[9]

In any mix design, it is necessary to characterize the aggregates that will make up the mix; thus, both gravels and sands were obtained from local quarries, and tests were performed on loose and compacted unit weight (ASTM C - 29), specific weight and absorption percentage (ASTM - C127, ASTM C - 128), moisture percentage (ASTM - C535), and granulometric analysis (ASTM C - 136).[10]

As with all SCC, the use of water-reducing admixtures is neces-sary in order to work with low water/cement ratios and also to provide fluidity and workability to the mix. Thus, a superplasticizing additive was used with a water reduction of up to 30%, with a dosage ranging from 0.5% to 2% of the weight of cement, with a density of 1.09 kg/L.[11]

With the aggregate properties defined, the ACI 237 - R standard was applied, obtaining the following results as a standard mix design, projected for a 600 mm slump:

Table 1. Weight per m3 of concrete

- Type I Cement	475.00 kg
- Fine Aggregate	990.46 kg
- Coarse aggregate - 1/2" Crushed Stone	683.09 kg
- Water	192.07 l
- Additive -Z Fluizante SR - 1000	7.13 l

- *Own elaboration –*

Based on them, compliance with the parameters established by the aforementioned regulations was verified. It is shown in Table 2.

Table 2. Comparison of mix design criteria ACI 237-R

	Norma ACI	**Designed**
- Ratio w/fines (Volume)	-	1.408
- Ratio a/c (weight)	0.32 - 0.45	0.45
- Total fines content (kg/m3)	386 - 485	475
- Coarse aggregate (% of volume)	28 – 32	29%
- Water	-	192
- Paste fraction (% by volume)	34 – 40	36.58%
- Fraction in mortar (% by volume)	68 – 72	71.95%
- Amount of cement (Kg/m3)	386 - 475	475

- *Own elaboration –*

With the mix design verified, we proceeded to make combina-tions of HGM at 2%, 5% and 7% of the weight of the cement, which functioned as a partial replacement of the cement.

Testing of SCC for freshness

In those that evaluate the SCC in a more fluid state, the slump test, V-funnel test, L-pass box, J-ring, unit weight in the fresh state and temperature measurement were considered. These tests determine the properties of the mix in the fresh state and allow a comparison to be made with respect to the influence of adding HGM.

The slump test was performed using the ASTM C1611 - 18 standard, which uses the modified Abrams cone shape, allowing measurement of the speed at which the concrete spreads in addition to the time T50 measured at the instant that runoff begins until the sample reaches a diameter of 500 mm. These parameters are mainly related to the viscosity of the concrete mix.[12]

Figure 1. Slump test

- Own elaboration -

The V-funnel test is another method to measure the fluidity of the SCC, taking time as the main measurement, evaluating the speed of the mixture to flow through very narrow spaces. The measurement starts from the opening of the lower gate and ends until the first beam of light is observed entering through the same gate.[13]

Figure 2. V-funnel test

- Own elaboration -

The L-box test, on the other hand, determines the passing capacity of the self-compacting concrete and the uniformity of the mix to be able to flow through obstacles, thus measuring the ratio of vertical and horizontal box heights (H2/H1 ratio), showing how uniform the SCC is, where when this value tends more to 1, it is said to have a better passing uniformity. In addition, by visual inspection it can be determined how much coarse aggregate is retained by the grids separating them from the mortar fraction.[13]

Figure 3. L-box test

- Own elaboration -

The J-ring test, on the other hand, is similar to the slump test, the difference is that the concrete has to be extended by means of obstacles, in this way the viscosity of the SCC is measured, as well as, in a more empirical way, the uniformity of the sample since the heights that the SCC has drained both externally and internally of the J-ring are related to each other.[13]

Figure 4. J-ring test

- Own elaboration -

For the tests described above, there is no regulation that re-stricts permissible values, however, there are reference values that help to determine a good quality of SCC. According to the European Federation for Specialist Construction Chemicals and Concrete Systems, they propose the following range of permis-sible values.

Table 3. Range of permissible values

WORKABILITY	
Settlement Flow (Abrams)	650 mm - 800 mm
Settlement Flow T50cm	2 s - 5 s
J-Ring	0 mm - 11 mm
Funnel V	More of 3 s
L-shaped box	H2/H1 = 0.8 - 1.0
U-box	H1 – H2 = 30 mm maximum
Stuffing box	90 % - 100%

- Source: European Federation for Specialist Construction Chemicals and Concrete Systems-

It is important to point out that the values shown above are highly dependent on the slump designed by the ACI237 - R Standard, and these values are taken as a function of this.

Testing of hardened concrete

In order to verify the established strength request, the compres-sive and indirect tensile strength test was performed. The con-crete design was for a f'c = 350 kg/cm2. Concrete specimens with a diameter of 15 cm and a height of 30 cm were prepared.

For the compressive strength test, the hydraulic press was used, obtaining the strength of the specimen by dividing the value obtained by the contact area of the equipment.[14]
Likewise, the indirect tensile test was performed according to the image shown below:

Figure 5. Compressive strength test

- Own elaboration -

Figure 6. Indirect tensile test

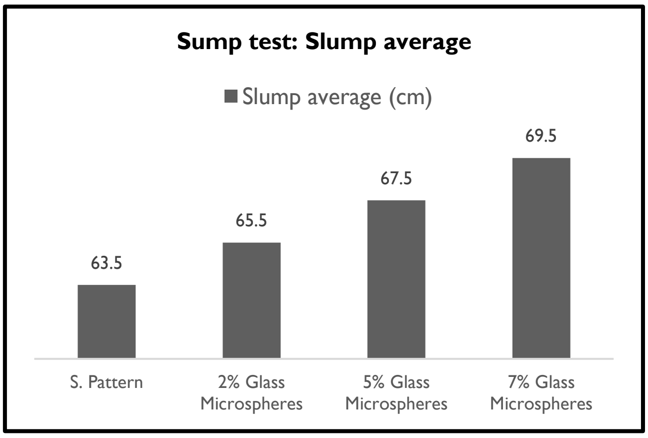
- Own elaboration -

Results and discussion

Properties of fresh concrete

The results (cm) obtained in the slump test performed for the standard sample and with the use of HGM. With the percentage of 2% HGM, an increase of 3.15% was obtained; for the use of 5% HGM, the mixture increased its diameter by 6.30% and for the use of 7% HGM, an increase of 9.49% was noted. These results compared with the standard sample. It is shown in Graphic 1.

Graphic 1. Slump test results



- Own elaboration -

For the standard sample, a diameter of 63.5 cm was obtained. This result is quite close to the one projected in the mix design according to ACI 237-R Standard, which is 60 cm. According to the study carried out by [3], where the slump obtained was 61 cm, this insignificant difference is mainly due to the different admixture used in the mix design. The author used the super-plasticizer Sika Viscocrete 2000, which has a higher water reduction, so its dosage is lower compared to the Z Fluidizing SR-1000 used in this research.

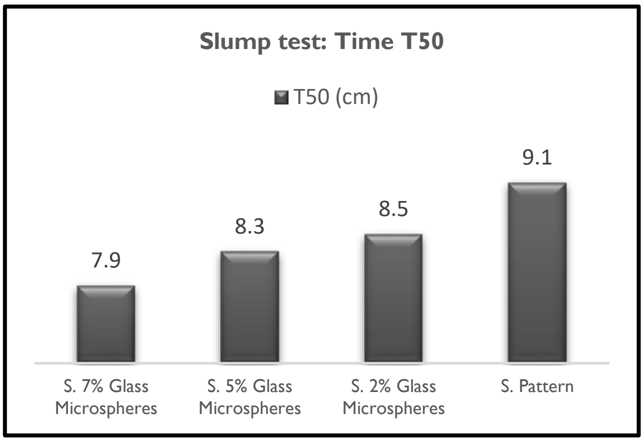
Also citing [15], in their proposal for the design of a SCC mix, they obtain extension values of 71 cm to 72 cm. These values are much higher than those shown in this research, but it should be noted that the procedure followed by the authors for the mix design was ACI 211, while for this research the ACI 237-R standard was followed.

With respect to the slump measurement obtained with the 5% partial replacement of HGM by cement, which was respectively 67.5 cm, generating an increase of 4 cm compared to the standard sample, [3] obtained very similar results, with an increase of 3.5 cm. Although the HGM samples were provided by different manufacturers, the most outstanding characteristic that HGM samples have in common is their 80% sphericity, as indicated in the technical data sheets.

With respect to the 2% and 7% dosages, it is remarkable to observe an increase of 2cm and 6cm, even though there are no recorded experiences, but [16] expose investigations with results where 3% and 9% dosages are applied, having increases of 2.8 cm and 7.0 cm respectively, noting that the increase of the slump is proportional to the percentage of HGM tested. It should be taken into account that the properties of HGM used are different from those used in this research, factors that affect the laboratory experience and results.

With respect to the T50 time, the following graph represents the comparative results obtained (s) for all the projected combi-nations, noting that with the 2% percentage of HGM, the flow time was reduced by 6.59%; for the use of 5% of HGM, the mixture reduced its flow time by 8.79% and for the use of 7% of HGM, a time reduction of 13.17% was noted, results compared to the standard sample. It is shown in Graphic 2.

Graphic 2. Slump test results – Tome T50

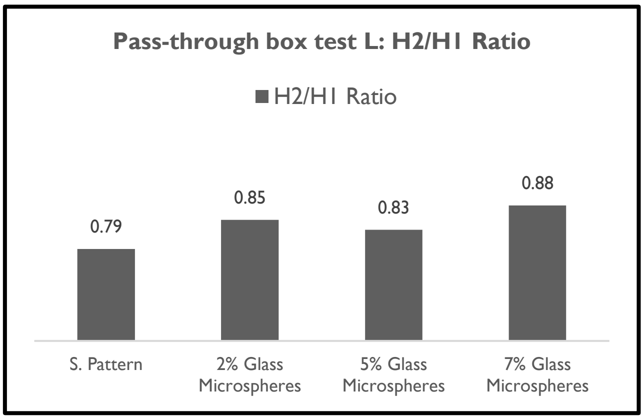


- Own elaboration –

When evaluating the T50 time, we can see that the sample with a 7% partial replacement of HGM by cement has a great impact with respect to the standard sample, being 1.2s faster in reaching 50cm of runoff diameter, for the percentages of 2% and 5% of HGM as partial replacement of cement, there is also a reduction in time being 0.6s and 0.8s respectively, evidencing that the higher the dosage, the greater the workability and fluidity of the mixture.

With respect to the test of the step box L. It is observed that with the percentage of 2% of HGM, the mixture was 7.59% more uniform; for the use of 5% of HGM, it was 5.06% more uniform and for the use of 7% of HGM, it was 11.39% more uniform in its runoff. Results compared to the standard sample. It is shown in Graphic 3.

Graphic 3. Pass-through box test L results



- Own elaboration –

When discussing the L-pass box test, experiences are recorded for the dosage of 5% HGM, the first place [3] shows the results of his tests both for his standard sample being 0.92 and for his addition of HGM at 5% being 0.94. In second place, Sergio Gómez also proposes a replacement of 5% HGM to the fine aggregate, obtaining values for his control sample that was 0.91 and for his HGM replacement that was 0.94.

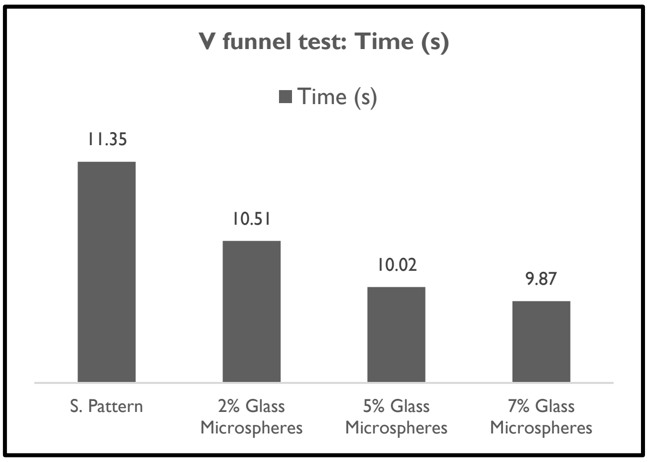
The values proposed in this research are 0.79 for the control sample and 0.83 for the 5% HGM sample as a partial replacement of cement. The difference in the proposed values is very marked in comparison with the experience of these authors, the reason for this situation can be very diverse, the main ones being; the slope of the surface where the test is carried out, this slope variation can benefit the runoff through the instrument causing the H2/H1 ratio to tend to 1; and the projected slump in the mix design, for the first author, it is designed with a slump of 65 cm to 70 cm, which clearly requires the SCC to have greater viscosity and fluidity. Other minor factors that intervene are the roughness of the instrument and the settling time recorded in the test.

However, in spite of this difference, the results show a great similarity in the increase of the H2/H1 ratio of approximately 0.2, which shows that regardless of the external factors that intervene in the execution of the test, they do not have to modify the difference that exists in the increase of fluidity, since at the end both the standard sample and the sample with addition of HGM are subjected to the same external factors in which the tests are executed.

With respect to the replacement of 2% and 7% of HGM, there is no evidence with respect to this test, however, the proportional-ity of the higher the percentage of replacement, the greater the tendency of the flowability, this is proven by the increase in the ratio of H2/H1 which is 0.6 and 0.9, highlighting that on this occasion the percentage of 2% has a greater incidence of flowability than the 5% replacement of HGM by cement.

The flow times obtained in the V funnel test are shown in the following graph, evidencing that with the percentage of 2% HGM, it was 7.40% faster to flow through the gate; for the use of 5% HGM, it was 11.71% faster to flow through the gate and for the use of 7% HGM, it was 13.04% faster to flow. Results compared with respect to the standard sample. It is shown in Graphic 4.

Graphic 4. V funnel test: Time (s)results



- Own elaboration –

In the V funnel test, we can cite [17] that as a mixture design proposal for a SCC and to evaluate its fluidity, they register in their test for a 650 mm slump a time of 10s. This time is quite close to the time proposed in this research, which is 11.35s, considering that the slump projected here is 600 mm. Since there is not a well-established standard for this test, the maximum and minimum time range is not known, however, according to Michael it is recommended for this test to have a minimum time of 6s or not to exceed 12s.

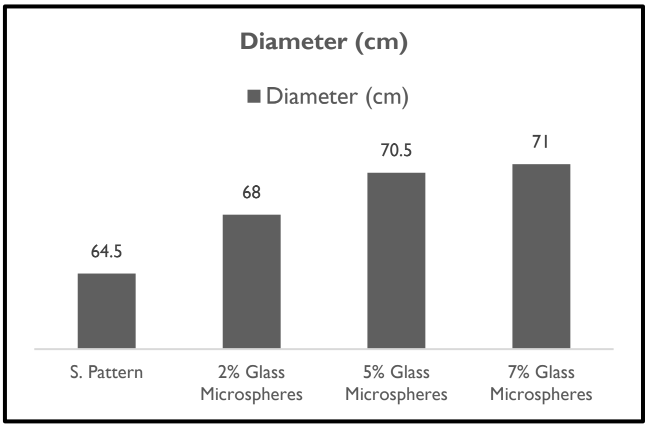
For the 2% partial replacement of HGM in the cement, there is a reduction of 0.85s; for the 5% percentage of partial replacement of HGM, a decrease of 1.33s; and for the 7% replacement of HGM, which had the greatest impact, the time was reduced by 1.48s. The above comparisons were based on the standard sample.

From this, the results with the different partial replacements of HGM by cement, in the V funnel test, continued to have the same trend of being more fluid, reducing the runnability times. These improvements in time continued as a function of the increase in percentage of glass microspheres.

In the J-Ring test, the average settlements obtained in the laboratory for the different HGM combinations are presented. The slumps presented had a resting time of 2 minutes. From this, it is determined that with the 2% percentage of HGM, the mixture increased its diameter by

5.43%; for the use of 5% HGM, there was an increase of 9.30% and for the use of 7% HGM, an in-crease of 10.85% was noted. Results compared with respect to the standard sample. It is shown in Graphic 5.

Graphic 5. J-ring test: Diameter (cm) results



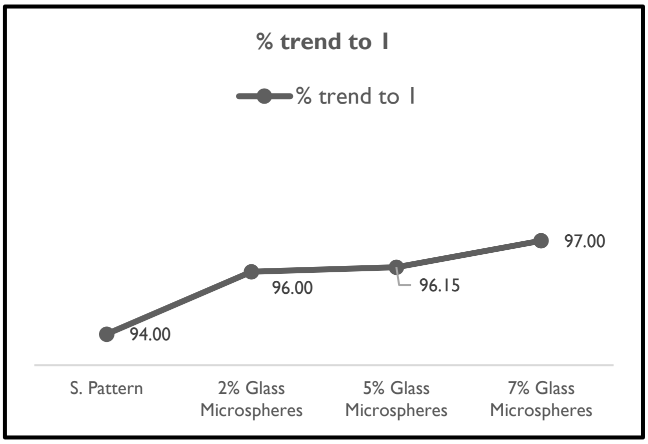
- Own elaboration –

The Japanese "J" Ring test measures the capacity of the SCC to flow through obstacles, very similar to the slump test. The investigations carried out by [3] show the following results for their standard CAC being 565 mm and for their SCC with the addition of 5% HGM being 634 mm (69 mm increase). Citing [15], in their SCC design proposal, they expose for the J-ring test diameter values of 72 cm and 73 cm.

The results in the execution of this test, we have for the standard sample a measurement of 645 mm and for the sample with a partial replacement of 5% of HGM by cement, a value of 705 mm (increase of 60 mm), we note that there is a variation of results, but not of the increase generated by the addition of HGM. The authors do not detail how long the sample was left to stand, but we can note that when compared to the 73 cm that they expose [15], its runoff with the J-ring is greater than that established by the settlement test, despite having passage obstacles. Here plays a very important role the time of rest that the sample is subjected, because the more time of rest is subjected, there is a tendency to increase its expansion diameter. For this research, 3 minutes of waiting time were available for taking the results.

Empirically, the uniformity of the mixture can be seen by a ratio H2/H1 (the uniformity tendency = 1). It is shown in Graphic 6.

Graphic 6. J-ring test: % trend to 1 result



- Own elaboration –

The unit weight and temperature tests. It is shown in Table 2 and Table 3.

Table 3. Unit weight

Sample	**Unit weight (kg/m3)**
Pattern	2398.97
2% Glass Microspheres	2373.75
5% Glass Microspheres	2326.03
7% Glass Microspheres	2305.68

- Own elaboration –

Table 3. Average temperature

Sample	**Average temperature °C**
Muestra Patrón	27.3°C
2% Glass Microspheres	27.5°C
5% Glass Microspheres	27.5°C
7% Glass Microspheres	27.8°C

- Own elaboration –

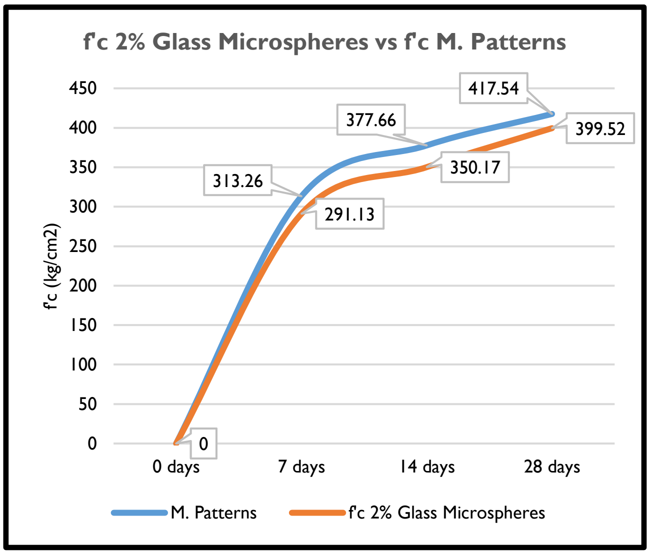
Properties of hardened concrete

With respect to the compressive strength tests, the samples were tested at 7, 14 and 28 days of water curing of the concrete.

For the standard sample, a strength of 313.26 kg/cm2 was obtained for 7 days and 417.54 kg/cm2 for 28 days.

For the 2% HGM as a partial replacement of cement, a strength of 291.30 kg/cm2 was obtained at 7 days and reached a strength of 399.52 kg/cm2 at 28 days. The strength of the latter was 4.32% lower compared to the standard sample.

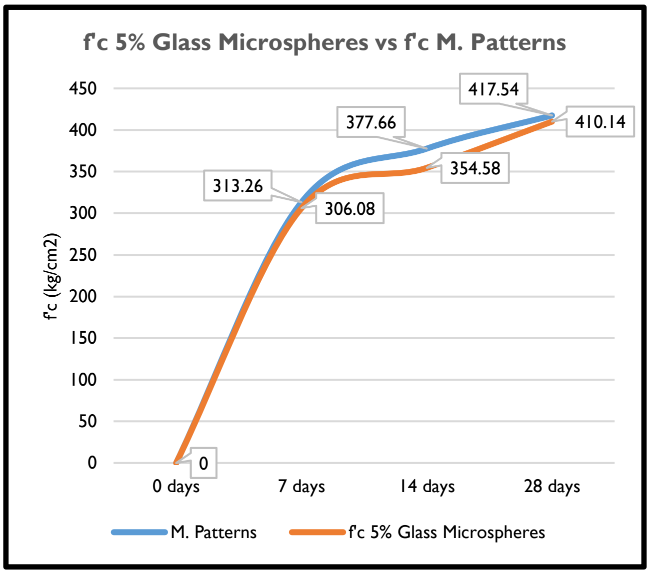
Graphic 7. f'c 2% Glass Microspheres vs f'c M. Patterns result



- Own elaboration –

For the 5% of HGM as a partial replacement of cement, a value of 306.08 kg/cm2 was obtained for the 7 days of curing and a re-sistance of 410.14 kg/cm2 for the 28 days. Thelatterwas 1.77% lower compared to the standard sample.

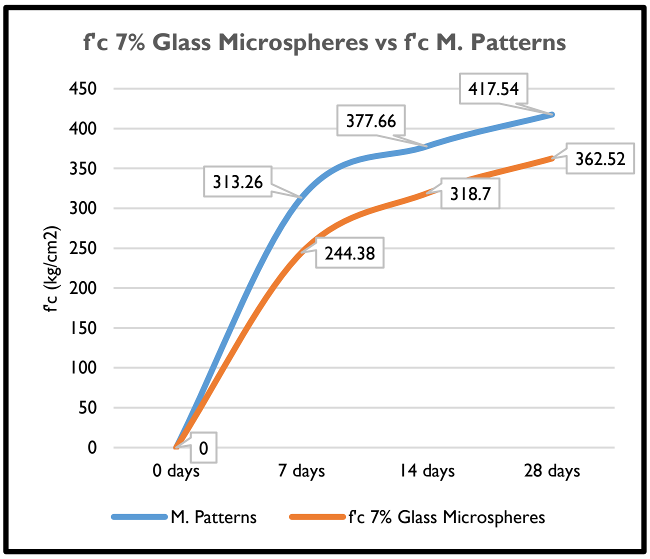
Graphic 8. f'c 5% Glass Microspheres vs f'c M. Patterns result



- Own elaboration –

And for the 7% of HGM as a partial replacement of cement, a value of 244.38 kg/cm2 was obtained for the 7 days of curing and for the 28 days a value of 362.52 kg/cm2 of resistance was obtained. The latter was 13.18% lower compared to the standard sample.

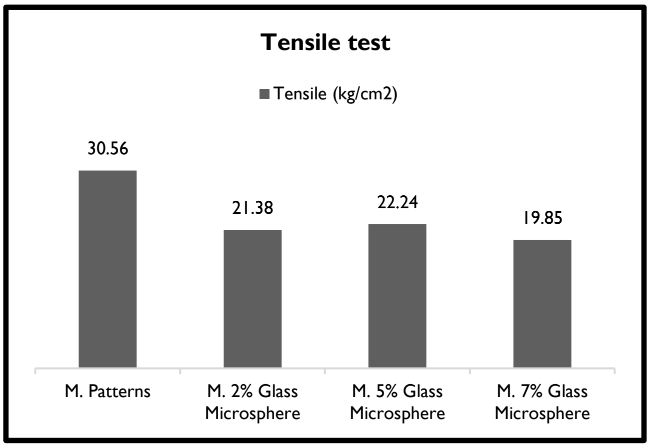
Graphic 9. f'c 7% Glass Microspheres vs f'c M. Patterns result



- Own elaboration –

For the tensile strength tests, the following results were obtained:

Graphic 10. f'c 7% Glass Microspheres vs f'c M. Patter Tensile strength (28 days) result



- Own elaboration –

As described by this test, the value of the indirect tensile test should be between 1.59√(f'c) and 2.2√(f'c) which are respective-ly 29.7 kg/cm2 and 41.2 kg/cm2, from this it is observed that the standard sample complies with the established with an average value of 30.6 kg/cm2.

In addition, it is observed that with the percentage of 2% of HGM, the sample reduced its value by 30.04%; for the use of 5% of HGM, it was reduced by 27.23% and for the use of 7% of HGM, a reduction of 35.05% was noted. Results compared with respect to the standard sample.

Conclusions

The standard applied for the mix design was ACI 237-R, for self-consolidating concentrate. According to the requirements of the standard, a water/cement ratio of 0.450 for design and 0.404 for construction (with corrections for humidity) was applied, which are permissible ratios according to the standard. To develop the ACI method, it was necessary to carry out a study of aggregates from the Tres Tomas Quarry (coarse material) and the La Victoria Quarry (fine material). The class of cement used was Type I and the glass microspheres had a minimum sphericity of 80%. The additive was a superplasticizer capable of reducing water by 40% and thus having a fluid slump.

The replacement of glass microspheres which were at 2%, 5%, 7% were with respect to cement. However, despite this, the water/cement ratio is still maintained, at 0.450 for design and 0.405 for construction. This allows an efficient comparison of the compressive and tensile strength of all combinations.

The background of the addition of this new admixture, involving percentages of 13%, clearly shows a decrease in the properties of the concrete in the hardened state. Based on this, the present investigation limited the dosage of HGM to 2%, 5% and 7%.

The addition of HGM in the concrete for the Slump test was favorable. Evidencing a proportionality as the percentage of addition increased. The dosage with 7% of HGM had the highest incidence in this test with a Slump of 69.5 cm, being 6 cm more fluid than the standard sample; in addition, for the time T50, this same sample obtained a time of 7.9s, taking an advantage of 1.2s with respect to the standard sample. From this, an decrease in the viscosity of the concrete can be deduced.

In the test of the L passage box, it can be concluded that all the combinations with HGM improved the passage fluidity through the vertical box. The value with the greatest impact was the replacement with 7% HGM, with a flow uniformity of 0.88 (H2/H1), being 11.39% more uniform than the standard sample; however, it should be noted that the 2% replacement had a more uniform tendency than the 5% replacement. This test was able to prove that additions with HGM can increase the uniformity of the slump, allowing flow through obstacles without generating segregation of the mortar with the stone.

In the V funnel test, it was found that the HGM replacement favored the decrease viscosity of the concrete, having a higher speed of passage through narrow openings. The most incident value was the dosage of 7%, with a time of 9.87s, thus being 1.48s faster than the standard sample. For the 2% partial replacement of HGM in the cement, there is a reduction of 0.85s; for the 5% percentage of partial replacement of HGM, a decrease of 1.33s. In all cases they were compared with respect to the standard sample.

In the test of Ring J, it is evident that the replacement of HGM favored the settlements and workability. The highest value obtained was 7%, with a settlement measurement of 71 cm, which is 6.5 cm more compared to the standard sample. Empirically, it was obtained that when replacing 7% of HGM, the tendency of uniformity was 97%. With respect to the 5% of HGM, a trend of 96.15% was obtained and for the 2% of HGM a trend of 96.00% was obtained. From the above percentages there is not a very significant difference, but compared to what was shown in the Step L box, there is a relationship of higher dosage of HGM - higher settlement obtained.

For the unit weight test, the tendency to decrease the weight of the concrete is clearly evidenced. This is mainly caused by being the material with the lowest density of the mix (1.09 g/cm3). In all cases, the concrete has a normal weight; however, the difference between the value obtained at 7% replacement of HGM and the standard sample is 93.kg/m3 respectively.

With respect to the temperature test, all samples were subjected to the same environmental conditions. Thus, the variation between them is minimal in all cases.

In the compressive strength test, all samples exceed the requested strength of 350 kg/cm2. However, the different combinations of HGM did not exceed the strength of the standard. The 5% HGM replacement was 1.77% lower than the standard, which is not very significant, while the 7% HGM sample, which decreased by 13.18%, shows a large decrease despite meeting the requested strength.

For the tensile strength test, it is evident that the 5% of HGM have the best performance of the combinations, however, they do not exceed the standard with a decrease of 27.23%.

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