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# EFFECTS OF SEASHELL AGGREGATES IN CONCRETE PROPERTIES

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**Abstract**
In this project the use of mussel shell as fine and coarse aggregate in concrete is studied. Two different conventional concretes were designed, a non-structural concrete (NSC) and a plain structural one (SC). Then, the conventional fine and coarse aggregate was partially replaced with seashell. Initially, each size fraction (fine or coarse) was replaced separately using four substitution rates (25%, 50%, 75% and 100%). Finally, two low percentages (5% and 12.5%) were chosen to replace both fine and coarse fractions. All concretes (a total of 19 different mixes) were characterized in both fresh and hardened state (workability, compressive strength, longitudinal modulus of elasticity, weight loss and water permeability). The results permit to establish that the percentage of replacement should be limited to 12.5% of fine, coarse, or both fine and coarse aggregate. With this percentage the NSC and the SC, although with a worst performance than their conventional ones, show an accurately behavior.

**Keywords:**
Non-structural concrete, plain structural concrete, mussel shell, bivalve shell, seashell

## 1 INTRODUCTION

As it is well known, shell is about the 33% of the entire weight of the mussel shell residue. Thus, it can be confirmed that canning industry generates 25,000 t of seashell waste every year in Galicia. This waste is placed in landfills or it is used as agricultural fertilizer. Moreover, during last years the construction field has become increasingly aware of the need of a change towards sustainability. This has led to the development of some researches using mussel shell waste as construction material.

Different authors studies the use of different bivalve and mollusks, such as periwinkle, cockle, oyster [Sabri 2012], mussel or clam directly as aggregate for concrete [Falade 1995, Osarenmwinda 2009, Adegoke 2008, Agbede 2009, Barnaby 2004]. These studies concluded that concrete workability decreases when the seashells content increases, mainly due to flat and irregular shape of mussel shells particles [Agbede 2009, Eun-Ik 2005, Eun-Ik 2010]. Consequently, the consistency is a limiting factor to establish the maximum substitution rates [Falade 1995, Eun-Ik 2005]. In addition, the use of the bivalve shells reduces the compressive strength due to the decrease of paste–aggregate relation and the increase of closed porosity.

Thus, in this study, the behavior of concrete with partial replacement of natural aggregate with fine and coarse mussel shell aggregate is analyzed. Two types of concretes, non-structural concrete (NSC) and plain structural one (SC), are designed in order to use them in marine environment and foundations. Then, the conventional fine and coarse aggregate was replaced with seashell. Initially, each size fraction (fine or coarse) was replaced separately using four substitution rates (25%, 50%, 75% and 100%). Finally, two low percentages (5% and 12.5%) were chosen to replace both fine and coarse fractions. A total of 19 mixes were produced.

This research aims to study the effect of replacing natural aggregate with mussel shell aggregate in the designed concretes, analyzing workability, absorption, fresh and hardened densities, compressive strength, modulus of elasticity, weight loss and water permeability.

## 2 EXPERIMENTAL WORKS

### 2.1 Material properties

The cement used was CEM II/A-M (V-L) 42.5R, Portland cement with additions (CEM II), mixed (M) with a 6-20% (A-M) of siliceous fly ash (V) and limestone (L), and a 0-5% of minor components, compressive class 42.5 and high initial strength (R) (EN 197-1).

In order to maintain the target values in consistency, an additive was used; it was a naphthalene sulfonate condensate superplasticizer (Melcret 222). Its compatibility with cement and additions was guaranteed due to previous experience.

In this study natural and mussel shell aggregates were used. Both coarse and fine natural aggregate come from crushed limestone. The size fractions used were a sand 0-4 mm (NS), and two coarse aggregates, a 4-16 mm fraction (NG (4-16)), and 10-20 mm fraction (NG (10-20)). The physical properties of the aggregates were determined, according to Spanish Structural Concrete Code - EHE-08. Tab.º1 shows the limits that EHE-08 stablishes to concrete aggregates.

Three different fractions of mussel shell aggregates, obtained from mussel shell were used (Fig.º1): a mussel shell gravel (MG) and two mussel shell sands, one coarse sand obtained by crushing (CMS) and one fine sand obtained by grinding (FMS).

The mussel gravel has got an equivalent particle size distribution to that of the 4-16 mm fraction of natural gravel (NG (4-16)).

The two mussel shell sands were combined in order to obtain mussel sand with equivalent particle size distribution to that of the natural sand. The mix percentages used to obtain this new sand (MS) were 49.7% of FMS and 50.3% of CMS.

Tab.º 2 shows the characteristics and properties of these aggregates. According to the results of the X-ray diffraction (XRD) characterization, mussel shells are composed mainly of calcium carbonate (about 95%).

Shell, S (without treatment). Large: 76mm -wide: 37mm

Mussel Shell gravel, MG (heat treatment)

Coarse mussel shell sand, CMS (heat treatment and crushed)

Fine mussel shell sand, FMS (heat treatment and ground)

*Fig 1. Mussel shell aggregate*

*Tab.1: Natural fine and coarse aggregate properties.*

| | | NS | NG(4-16) | NG(10-20) | EHE-08 limits |
|---|---|---|---|---|---|
| Fineness modulus | | 3.71 | 6.20 | 7.37 | <10 (sand) |
| Fineness content (UNE-EN 933-1) | (%) | 11.54 | 1.49 | 0.42 | <1.5 (coarse aggregate) |
| Density (UNE-EN 1097-6) | (kg/l) | 2.67 | 2.61 | 2.66 | |
| Absorption (UNE-EN 1097-6) | (%) | 2.22 | 2.20 | 1.33 | <5 |
| Sand equivalent(UNE-EN 933-8) | (%) | 64 | - | - | ≥80 |
| Flakiness index (UNE-EN 933-3) | (%) | - | 14.02 | 7.21 | <35 |
| Los Ángeles Coefficient (UNE-EN 1097-2) | (%) | - | - | 23.10 | <40 |

*Tab.2. Mussel shell aggregate properties.*

| | (S) | (MG) | (CMS) | (FMS) |
|---|---|---|---|---|
| Heat treatment | No | 30min - 135ºC | 30min - 135ºC | 30min - 135ºC |
| Crushing process | No | No | Crushed | Ground |
| Fineness modulus | - | 5.38 | 1,9 | 4,64 |
| Particle density (kg/l) | - | 2.62 | 2.65 | 2.73 |
| Water absorption (%) | - | 2.17 | 2.56 | 4.12 |
| Sand equivalent (%) UNE-EN 933-8 | - | - | 99.3 | 68.2 |
| Flakiness index (%) UNE-EN 933-3 | - | 99.24 | - | - |
| Los Ángeles Coefficient (%) UNE-EN 1097-2 | - | 20 | - | - |
| Chlorides (1%) UNE-EN 1744-1 | - | 0.46 | 0.28 | 0.51 |
| Soluble sulphates (%) UNE-EN 1744-1 | - | 0.4 | 0.63 | 0.59 |
| Total sulphates (%) UNE-EN 1744-1 | - | 1.5 | 1.6 | 1.3 |
| Organic matter (visual) UNE-EN 1744-1 | - | Darker | Darker | Darker |
| Light particles (%) UNE-EN 1744-1 | - | 0 | 0.1 | |
| Organic matter (%) UNE 103204:93 | - | 0.27 | 1.49 | 2.15 |

### 2.2 Mixes design

Two different types of concretes, a non-structural concrete (NSC) and a plain structural one (SC) were studied. Both of them were designed with high slump values (fluid and liquid consistencies) in order to use mussel shell aggregate substitution percentages as higher as possible, thinking that the mussel shell incorporation would reduce the workability.

*Non-structural concrete*

The reference concretes were designed with fluid and liquid consistencies (quite high slump values) in order to use mussel shell aggregate substitution percentages as higher as possible, thinking that the mussel shell incorporation would reduce the workability.

A non-structural concrete (NSC) with a water/cement (w/c) ratio of 0.75 and with 225 kg/m$^3$ of cement was designed as reference. Then three series of mussel concretes were made: one series with only sand replacements (NSC MS), other series with only coarse replacements (NSC MG), and the last series with both coarse and fine replacements (NSC MS+MG).

So, in the first series, the fine natural aggregate (NS) was replaced by mussel shell sand (MS) using four substitution rates, 25%, 50%, 75% and 100%. In the second one, the natural coarse aggregate (NG (4-16) and NG (10-20)) was replaced by mussel shell gravel (MG) using the following substitutions rates: 25%, 50% and 67%. These replacement percentages are 37.5%, 74.9% and 100% when they are calculated over their equivalent particle size fraction (NG (4-16)). In the last series both coarse and fine aggregates were replaced. Percentages of 5% (5% of mussel shell sand and 5% of mussel shell gravel) and of 12.5% (12.5% of mussel shell sand and 12.5% of mussel shell gravel) were used.

The dosage of the reference concrete was adjusted according to the Bolomey method (Tab.º3). The quantity of additive was fixed in order to obtain a reference concrete with a liquid consistency (slump value between 16 and 20 cm). Non-structural mussel shell concretes were obtained replacing, by volume, natural aggregate with mussel shell aggregate using the aforementioned substitution rates. In Tab.º4 the different concretes studied are summarized.

*Structural concrete*

The dosage of the reference structural concrete (SC30) was adjusted to fulfill the requirements for marine environment (blocks dikes) and for foundations. It was designed with a w/c ratio of 0.50 and with a cement content of 260 kg/m$^3$.

Again, three series of mussel concretes were made: one series with only sand replacements (SC30 MS), other series with only coarse replacements (SC30 MG), and the last series with both coarse and fine replacements (SC30 MS+MG).

So, in the first series, the fine natural aggregate (NS) was replaced by mussel shell sand (MS) using four substitution rates, 25%, 50% and 65%. In the second one, the natural coarse aggregate (NG (4-16) and NG (10-20)) was replaced by mussel shell gravel (MG) using the following substitutions rates: 25%, 50% and 65%. These replacement percentages are 34.6%, 69.3% and 90.1% when they are calculated over their equivalent particle size fraction (NG (4-16)). In the last series both coarse and fine aggregates were replaced. Percentages of 5% (5% of mussel shell sand and 5% of mussel shell gravel) and of 12.5% (12.5% of mussel shell sand and 12.5% of mussel shell gravel) were used.

The maximum substitution rate of 65% has been fixed in order not to exceed the maximum sulfates content established in the EHE (1%) to the aggregates for structural concrete.

Again, according to the Bolomey method (Tab.º3), reference structural concrete mix was adjusted. Likewise the quantity of additive was fixed in order to obtain a reference concrete with a fluid consistency (slump value between 10 and 15 cm). Structural mussel shell concretes were obtained replacing, by volume, natural aggregate with mussel shell aggregate using the mentioned substitution rates above. In Tab.º4 the different concretes studied are summarized.

## 3 RESULTS AND DISCUSSION

### 3.1 Consistency, absorption and fresh and hardened densities

Fig.º2 shows slump values obtained depending on the mussel shell aggregate percentage used. As expected, an increase in this percentage leads to an increase in the water demand (because of the flaky mussel shell aggregate shape), resulting in a decrease in the slump. This decrease grows with the percentage of aggregate used. As well, it has been observed that the use of mussel shell gravel has more influence on consistency than the use of mussel shell sand. The concretes with percentages of 5% and 12.5% mussel shell sand and gravel show very similar consistencies to that of the reference concrete.

These results advised discarding some of the dosages, namely, SC30 MS 65%, SC30 MG 65%, NSC MG 50% and NSC MG 67% because of casting concrete couldn’t be done. The SC30 MG 50% shows a very low slump value, however, and despite being placed with many difficulties, it was decided to go on with it.

The density in fresh and hardened state shows downward trend as the percentage of mussel shell aggregate increases (Fig.º3 and Fig.º4). This decrease is higher when sand is used than when gravel is used, and it is due to the occluded voids produced by the shape of the mussel shell aggregate particles.

Finally it is noted that, in general, the use of mussel shell aggregate decreases concrete water absorption capacity (Fig.º5). This decrease is greater as higher is the percentage of mussel shell aggregate. The preferential horizontal orientation of flat mussel shell particles acts as a barrier to water penetration.

### 3.2 Compressive strength

The compressive strength decreases significantly as the percentage of mussel shell aggregate grows (Fig.º6). Regarding structural concrete, it is observed that the use of mussel shell sand or gravel reduces the compressive strength similarly. However, in some cases, the decrease caused by adding sand is slightly higher than that caused by adding gravel, so while the SC30 MS 25% compressive strength decreases a 37.5%, the reduction achieved with the SC30 MG 25% was of 23%. Furthermore, when the replacement rates increase up to 50%, strength losses reach a 41.5% and a 48.1% when sand and gravel are used respectively. When SC30 MS+MG 5% and SC30 MS+MG 12.5% concrete are studied, it can be seen that the target compressive strength of 30 MPa was reached.

*Tab.3. Structural and non-structural concretes mixes.*

| | Non-structural concrete | | Structural concrete | |
|---|---|---|---|---|
| Material | Volume ($dm^3$) | Weight (kg) | Volume ($dm^3$) | Weight (kg) |
| Water | 168.75 | 168.75 | 180.00 | 180.00 |
| Cement | 72.58 | 225.00 | 116.13 | 360.00 |
| NS(0-4) | 495.30 | 1322.46 | 435.08 | 1161.66 |
| NG(4-16) | 192.45 | 502.30 | 216.04 | 563.86 |
| NG(10-20) | 95.92 | 255.14 | 77.76 | 206.83 |
| Total | 1025.00 | 2473.64 | 1025.00 | 2472.35 |

*Tab.4. Concrete types.*

| | Concrete | %NS (natural sand) | %MS (mussel shell sand) | %(NG/Coarse) – %(NG/Gravel) | %(MG/Coarse) – %(MG/Gravel) |
|---|---|---|---|---|---|
| SC 30 | SC30 reference | 100 | 0 | 100-100 | 0-0 |
| | SC30 MS 25% | 75 | 25 | 100-100 | 0-0 |
| | SC30 MS 50% | 50 | 50 | 100-100 | 0-0 |
| | SC30 MS 65% | 35 | 65 | 100-100 | 0-0 |
| | SC30 MG 25% | 100 | 0 | 75-65.4 | 25-34.6 |
| | SC30 MG 50% | 100 | 0 | 50-30.7 | 50-69.3 |
| | SC30 MG 65% | 100 | 0 | 35-9.9 | 65-90.1 |
| | SC30 MS+MG 5% | 95 | 5 | 95-93.1 | 5-6.9 |
| | SC30 MS+MG 12.5% | 87.5 | 12.5 | 87.5-82.7 | 12.5-17.3 |
| NSC | NSC reference | 100 | 0 | 100-100 | 0-0 |
| | NSC MS 25% | 75 | 25 | 100-100 | 0-0 |
| | NSC MS 50% | 50 | 50 | 100-100 | 0-0 |
| | NSC MS 75% | 25 | 75 | 100-100 | 0-0 |
| | NSC MS 100% | 0 | 100 | 100-100 | 0-0 |
| | NSCMG 25% | 100 | 0 | 75-62.5 | 25-37.5 |
| | NSCMG 50% | 100 | 0 | 50-25.1 | 50-74.9 |
| | NSCMG 67% | 100 | 0 | 33.3-0 | 66.7-100 |
| | NSC MS+MG 5% | 95 | 5 | 95-92.5 | 5-7.5 |
| | NSC MS+MG 12.5% | 87.5 | 12,5 | 87.5-81.3 | 12.5-18.7 |

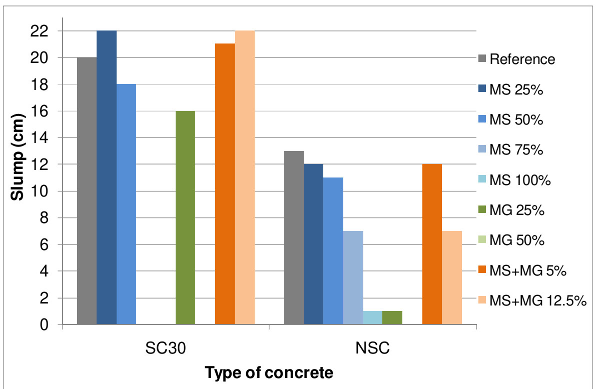


*Fig. 2: Consistency. Slump values.*

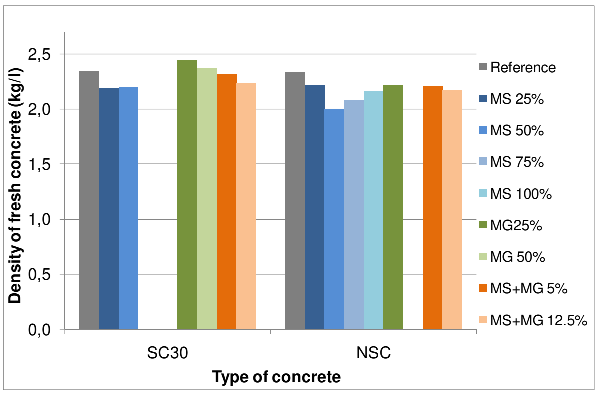


*Fig. 3: Density of fresh concrete.*

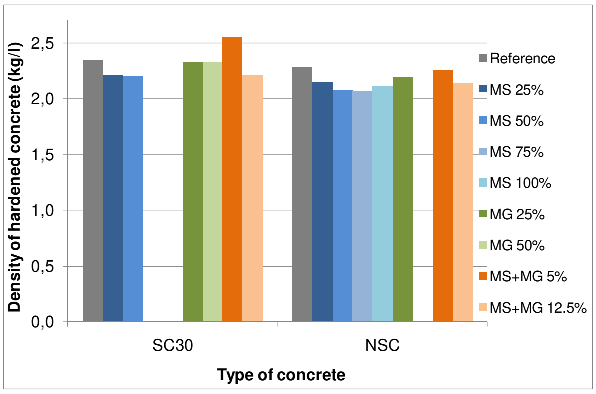


*Fig. 4: Density of hardened concrete.*

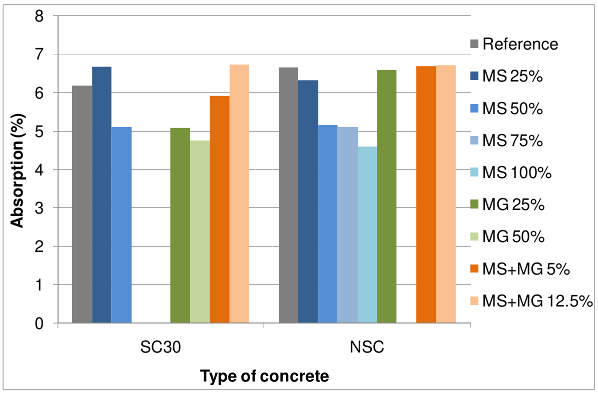


*Fig. 5: Water absorption.*

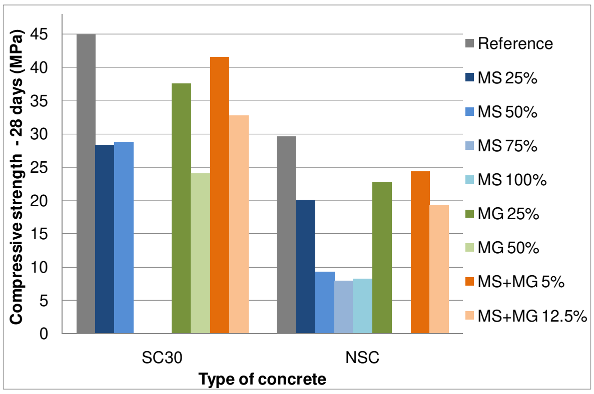


*Fig. 6: Compressive strength at 28 days. Structural and non-structural concrete.*

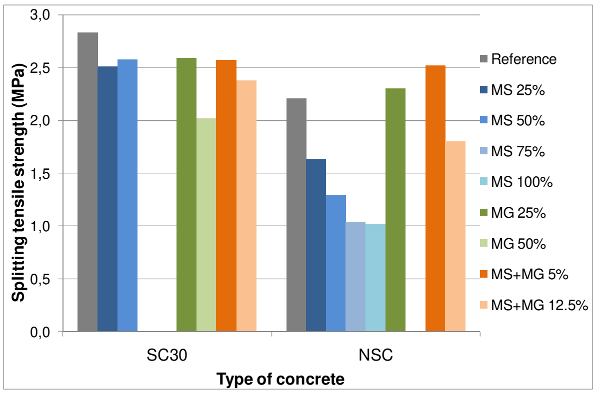


*Fig. 7: Splitting tensile strength.*

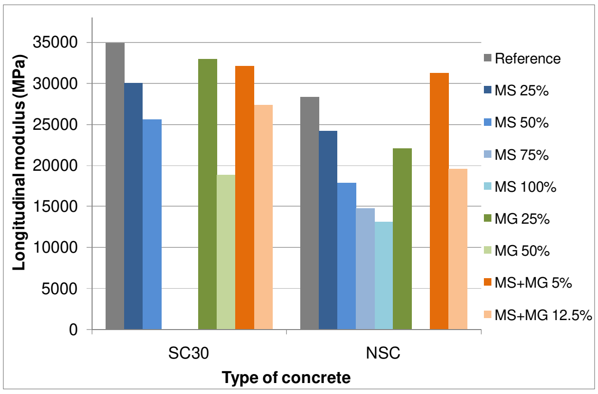


*Fig. 8: Longitudinal modulus.*

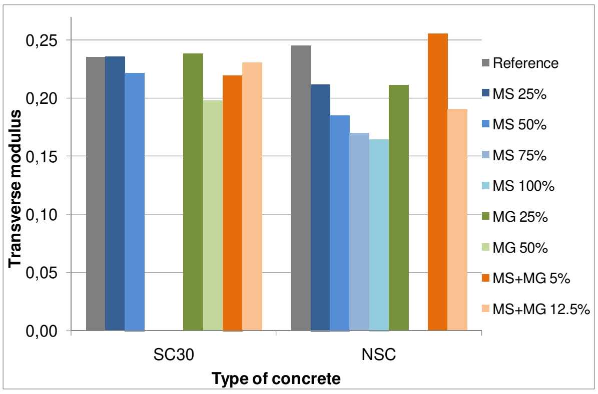


*Fig. 9: Transverse modulus.*

*Tab. 5.Water permeability.*

| Water permeability test | SC30 reference | SC30-MS 25% | SC30 -MS 50% | SC30-MG 25% | SC30-MG 50% | SC30-MS+ MG 5% | SC30-MS+ MG 12.5% |
|---|---|---|---|---|---|---|---|
| Maximum penetration (cm) | 2.83 | 2.23 | 1.25 | 0.95 | 0.00 | 1.10 | 0.98 |

Regarding non-structural concrete it can be concluded that the incorporation of mussel shell sand and gravel decreases compressive strength to the same extent. Thus, NSC MS 25% concrete shows a compressive strength decrease of 27%, and its corresponding NSC MG 25% of 24%. In some cases, again it was found that replacement rates over 25% are disposable, because they lead to compressive strength concretes under the minimum specified for non-structural concrete (15 MPa). Substitutions rates of 75% and 100% with mussel shell sand have provided concretes with a compressive strength lower than 10 MPa at 28 days.

These results indicate that substitution percentages over 25% should not be used as they provide considerably high compressive strength decreases. These too low compressive strengths could be hardly compensated with dosage modifications.

### 3.3 Splitting tensile strength

The splitting tensile strengths (Brazilian method) are collected in Fig.º7. Again, the use of mussel shell aggregates decreases this property. In this case, regarding structural concrete, the use of mussel shell aggregate leads to decreases of around 10%, independently of the percentage or fraction (sand or gravel) incorporated. However, when non-structural concretes are analyzed, it can be seen that when natural sand is replaced with mussel shell sand the decreases are, in general, much more remarkable, always higher than 25%.

### 3.4 Modulus of elasticity

In Fig.º8 and º9,longitudinal and transverse modulus of elasticity values of the different concretes are shown. It is noted that both of them decrease meaningfully with the incorporation of mussel shell aggregate. In accordance with compressive strength, the substitution rates lower than 25% keep the reductions of the modulus under the 25%. When substitutions rates are of 50% or 100% this decrease grows up to 50%.

Water permeability

In order to characterize durability of structural concrete, water permeability test (UNE 83310) has been carried out. The maximum water penetration values are shown in Tab.º5. These results indicate that water permeability decreases with the content of mussel shell aggregate, especially when the mussel gravel is used. Indeed, the water penetration of the reference concrete was of 2.8 cm, while it is of zero when the SC30-MG50% is analyzed. Finally, concretes with both mussel shell sand and gravel showed a water permeability of just 1 cm. It is noted again that the preferential horizontal orientation of flat and flaky mussel shell particles acts as a barrier to water penetration.

### 3.5 Weight loss

The weight loss over time has been controlled in 40x10x10cm samples (Fig.º10). The use of mussel shell sand increases weight loss even with small percentages of substitution (SC30 MS 25%). However, it seems that the use of mussel shell gravel does not affect this property, so SC30 MG 25% and SC30 MG 50% concretes show losses similar to that obtained with the reference concrete. Finally, SC30 MS+MG 5% and SC30 MS+MG 12.5% concretes showed weight loss values laid between both groups, being lower the ones of the SC30 MS+MG 5% than the ones of the SC30 MS+MG 12.5%.

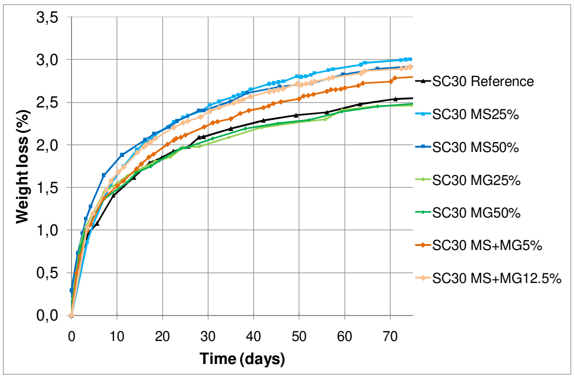


*Fig. 10: Weight loss.*

## 4 CONCLUSIONS

In this project the use of mussel shell as fine and coarse aggregate in concrete is studied. A non-structural concrete (NSC) and a plain structural one (SC30) were designed. Then, the conventional fine and coarse aggregate was partially replaced with seashell. Initially, each size fraction (fine or coarse) was replaced separately using four substitution rates (25%, 50%, 75% and 100%). Finally, two low percentages (5% and 12.5%) were chosen to replace both fine and coarse fractions. All concretes (a total of 19 different mixes) were characterized and the following conclusions can be drawn:

- The mussel shell aggregate shows flaky shape particles, which leads to an increase in the water demand of the concrete. As a result, the slump value decreases when the percentage of substitution used increases. It was also noted that mussel shell gravel has more influence on consistency than mussel shell sand.
- In general, the density in fresh and hardened state tends to decrease when the percentage of mussel shell aggregate raises, more with the sand replacement than with the gravel. This decrease is due to the occluded voids produced by the shape of the mussel shell aggregate particles.
- In addition, the use of mussel shell aggregate (sand and gravel) produces a detrimental effect on the mechanical properties of concrete (compressive and tensile strengths and modulus of elasticity). The substitutions over 25% of sand, gravel or both fractions show decreases in these properties hardly compensable with dosage modifications.
- In general, the use of mussel shell aggregate reduces water absorption. This property decreases when the mussel shell content increases. The preferential horizontal orientation of flat and flaky mussel shell particles acts as a barrier to water penetration. This effect has also been observed in permeability test, where water penetration decreases with the content of mussel shell aggregate, especially when mussel shell gravel is used.

It was thus noted that the concretes with replacement percentages up to 25% of natural aggregate by mussel shell aggregate (sand or gravel) and up to 12.5% (both sand and gravel together) are suitable for use in plain structural and non-structural concrete.

## 5 ACKNOWLEDGMENTS

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