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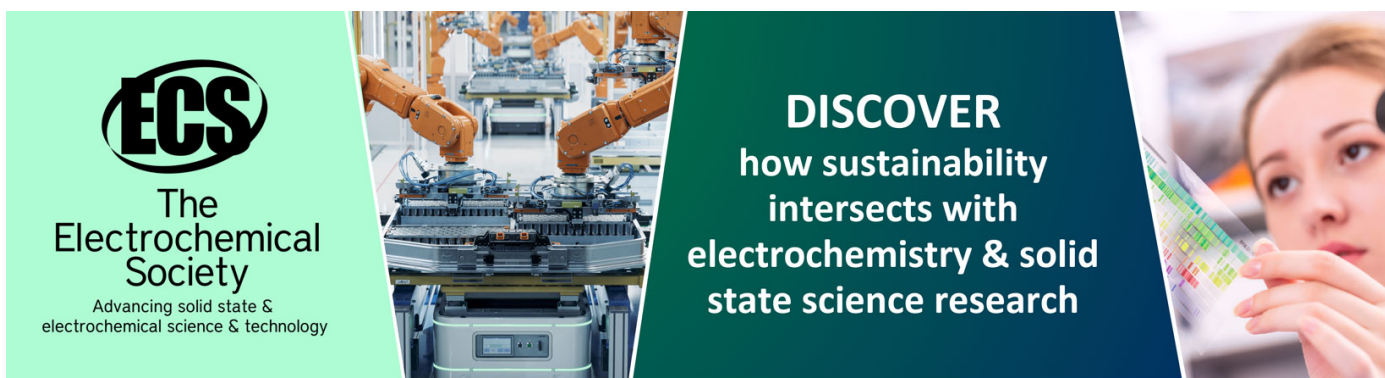
## The effects of sodium silicate on corn cob aggregates and on the concrete obtained with these agricultural waste

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# The effects of sodium silicate on corn cob aggregates and on the concrete obtained with these agricultural waste

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**Abstract.** In order to protect the environment and to reduce its pollution, the concrete greening is an important objective to accomplish this goal. Research across the world has expanded to replace some components of concrete with different kinds of alternative ecological materials, including agricultural materials that are readily renewable resources. They may partially replace the mineral aggregates, if they are used in a shredded form, and / or the cement from the concrete composition, if the ash resulting from their combustion is used. When used as an alternative of mineral aggregates, plant aggregates generally have a number of disadvantages, which requires finding a solution which reduces their water absorption, improves the interface between them and the cement matrix, and gives them durability in the resulting concrete. The present study investigated the effect of sodium silicate on plant aggregates made of shredded corn cobs, and on the concrete manufactured with this type of material as a replacement of mineral aggregates by 20%, 50% and 80% by volume. Experimental results revealed that sodium silicate reduced the water absorption of the grounded corn cobs, resulting a lightweight concrete with improved compressive and tensile strength compared to those of the concrete manufactured with untreated plant aggregates. The use of sodium silicate as a concrete additive resulted in an increase of the compressive strength of the concrete manufactured with 50% by volume corn cob aggregates, of the splitting strength in the case of concrete with 20% and 80% by volume vegetal aggregates, and of the density of the concrete manufactured with the highest percentages of plant aggregates which were investigated in this study.

## 1. Introduction

Research across the world has expanded to replace some components of concrete with different kinds of alternative ecological materials. So far, various natural, industrial or postconsumer waste has been used to improve the concrete properties and to reduce the environmental pollution risks by "saving" some of the raw materials [1 - 7].

The crop by-products were studied firstly as possible addition in concrete composition in order to improve its tensile strength, ductility and post-cracking behavior. But in the last years, an increasing interest to use this category of waste as a local available material emerged. Annual plants stems have a low density and high porosity that leads to the obtaining of a concrete with a lower density, lower thermal conductivity and higher permeability [8].

Agricultural materials may partially replace the mineral aggregates, being used in a shredded form, and / or cement from the concrete composition if the ash resulting from their combustion is used. When used as an alternative of mineral aggregates, plant aggregates generally have a number of



disadvantages, which requires the adoption of a solution that reduces their water absorption, improves the interface between them and the cement matrix, and gives them durability in the resulting concrete. The limited compatibility between cementitious binder and polysaccharide carbohydrates of the plant structure inhibits the setting process of the binder [9], and the high water absorption capacity of vegetal aggregates leads to weak interfaces between vegetal aggregates and cementitious matrix and, implicitly, to lower compressive strength of the concrete [8 - 10].

To obtain a concrete with improved mechanical properties, interventions can be made on the plant aggregates and/or on the binder [9]. Some examples of improvement measures applied on plant aggregates are: treatment with cellulose ether that creates water retention and reduces the water transfer [9], distillation for extracting the sugars, waterproofing with linseed-oil [10] or other hydrophobic coatings, eliminating the deleterious components of the plant particles by alkaline solutions or water, pretreatment with the cementitious binder paste, surface treatment with silanes soaking in a silica fume slurry, or fibres homification (fibres are subjected to drying and rewetting cycles [11]). Another method is the addition in concrete of setting and hardening accelerators [11]. For this study, it was adopted the plant aggregates treatment with an alkaline solution, namely sodium silicate (SS) and an accelerator addition in the concrete composition. The plant aggregates treatment with sodium silicate solution was used in other researches, but not on the corn cob aggregates.

The present study investigated the effect of SS on plant aggregates made of shredded corn cobs and on the concrete with this type of material as a replacement of 20%, 50% and 80% by volume of mineral aggregates.

## 2. Materials and methods

In order to diminish the very high water absorption capacity of the corn cob granules, it was adopted the treatment of corn cobs, shredded in granules smaller than 5-6 mm in diameter, with SS solution, in two concentration variants, 20% and 40%. The treatment consisted in the immersion of the corn cob granules in the SS solution. The wet granules were spread on a surface warmed at 45-50°C, in a naturally ventilated room with air temperature of 23-25°C, and were let to dry until they reached constant weight. After drying, the water absorption capacity was measured. Afterwards there were made concrete compositions with untreated corn cob granules, with corn cob granules treated with 20% SS solution, and with corn cob granules treated with 40% SS solution. After testing and determining the compressive strength of these concrete types, the composition with the highest compressive strength obtained was established as the most efficient variant of corn cob treatment. The corn cob granules treated in this variant partially replaced mineral aggregates and three types of concrete compositions, with 20% vol., 50% vol. and 80% vol. replacement rate, respectively were made. In order to improve the corn cob concrete properties, the last three concrete compositions were cast again, but this time 100% SS solution as additive in fresh mixture was used.

As a summary, in this study were developed the following concrete compositions:

- RC – a reference concrete of 25/30 Strength (manufactured according to [12]);
- CUCC50 – a concrete with 50% vol. of untreated corn cob granules instead of mineral aggregates;
- CTCC50-20 – a concrete with 50% vol. of treated corn cob granules with sodium silicate sol 20%, instead of mineral aggregates;
- CTCC50-40 – a concrete with 50% vol. of treated corn cob granules with sodium silicate sol 40%, instead of mineral aggregates;
- CTCC20-40 – a concrete with 20% vol. of treated corn cob granules with sodium silicate sol 40%, instead of mineral aggregates;
- CTCC80-40 – a concrete with 80% vol. of treated corn cob granules with sodium silicate sol 40%, instead of mineral aggregates;
- CTCC20-40 SS – a concrete with 20% vol. of treated corn cob granules with sodium silicate sol 40%, instead of mineral aggregates, and sodium silicate solution 100% conc. as additive;

- CTCC50-40 SS – a concrete with 50% vol. of treated corn cob granules with sodium silicate sol 40%, instead of mineral aggregates, and sodium silicate solution 100% conc. as additive;
- CTCC80-40 SS – a concrete with 80% vol. of treated corn cob granules with sodium silicate sol 40%, instead of mineral aggregates, and sodium silicate solution 100% conc. as additive.

The RC composition contained the following ingredients:

- natural sand (diameter 0–4 mm);
- river gravel (diameter 4–8 mm);
- Portland cement CEM II/A-LL 42.5R, with granulated blast furnace slag and limestone, produced in Romania;
- water to ensure a water/cement ratio of 0.43;
- additives: a polycarboxylate-based super plasticizer (Sika Plast 140) in 2% of cement volume, and a rhodanid-based accelerator (Sika BE5) in 2% vol. of cement volume.

In this study, sodium silicate solution for vegetal aggregates treatment and as additive in the concrete composition was also used. As additive, it was used 100% SS solution in a quantity equal to 5% of the cement volume. Sodium silicate is the common name for a sodium metasilicate compound,  $\text{Na}_2\text{SiO}_3$ , also known as glass water or liquid glass. It is available in aqueous and solid form and it is used in concrete, passive protection against fire, refractoriness, textiles, woodworking, and automobiles. The use of sodium silicate for the impregnation of industrial wood has been described since 1920. For example, [13] discloses a method for treating wood and wood materials to obtain fire resistant wood. Glass water is also used to protect wood and wood products by improving resistance to termites, rot and degradation.

SS solutions are very used to prevent excessive evaporation of the mixing water from the fresh mix concrete if it is applied during the curing period [14]. SS-based nanosilica is a pore filling material for concrete, with excellent positive effects on chloride attack [15]. The powder of SS is an alkaline activator in alkali-activated cementless mortars [16]. SS addition in concrete fresh mixture is recommended as an accelerator for Portland cement setting [17].

The concrete was poured into cube molds with the side of 150 mm and cylinder molds with 100 mm diameter and 200 mm length. On the cube samples the apparent density was measured, according to SR EN 12350-6, and then tests were performed to determine the compressive strength, according to SR EN 12390 part 3; on the cylinder samples the splitting tensile strength was determined, according to SR EN 12390 part 7. Each test was performed on three samples. Due to the fact that the samples dimensions were different to those required by the NE-012-1 standard, and in order to obtain comparable values with those from the scientific literature, the values of compressive and splitting tensile strength were compensated.

### 3. Experimental results

#### 3.1. Water absorption capacity of the corn cob granules

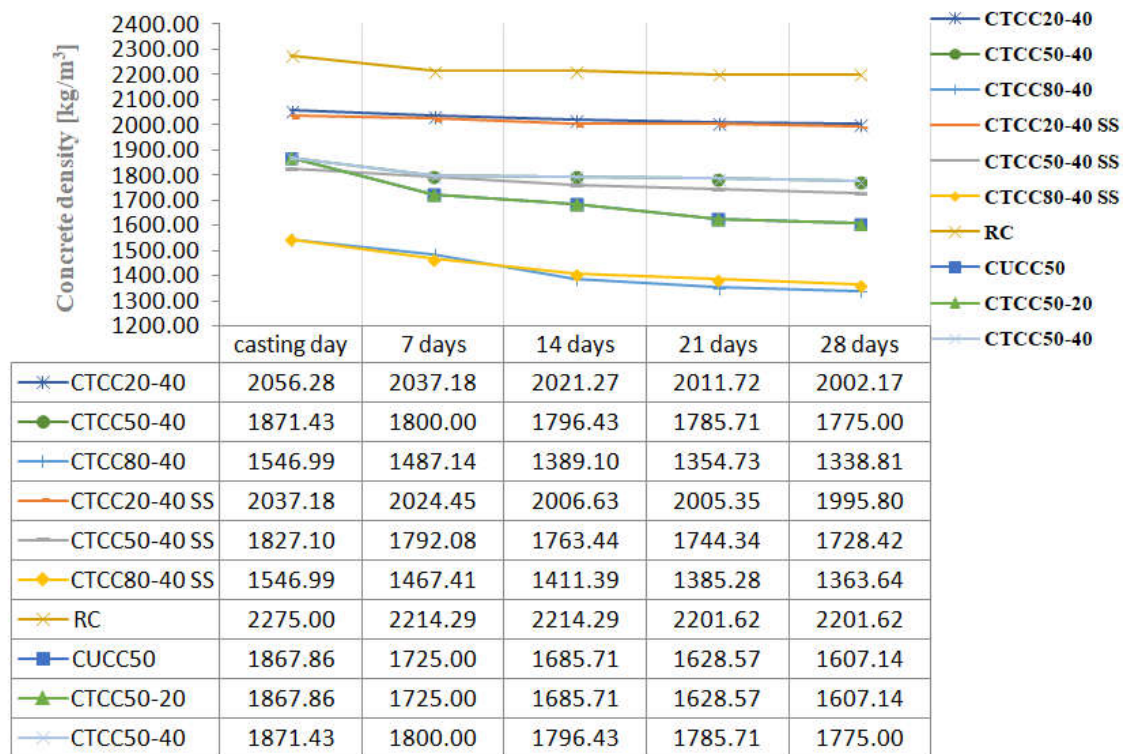
After the treatment application, the results revealed that the 20% SS solution decreased the water absorption capacity of the corn cob granules from 294% up to 181% compared to the untreated ones. The 40% SS solution usage obtained even better results, 127% water absorption capacity compared to the untreated granules.

#### 3.2. Concrete density

The evolution of the concrete density along the 28 days curing period is presented in figure 1. It can be observed that RC density decrease by 3.23% has been exceeded by CTCC20-40 SS, which registered a value of 2.03% decrease and by CTCC20-40 with a value of 2.63%. This means that the water quantity from the fresh concrete was used in very high proportion for cement hydration and it was not sucked by the vegetal aggregates and then evaporated. Both minimums implied the smallest analyzed quantity of corn cob aggregates, 20% vol., and SS addition improved the cement hydration.

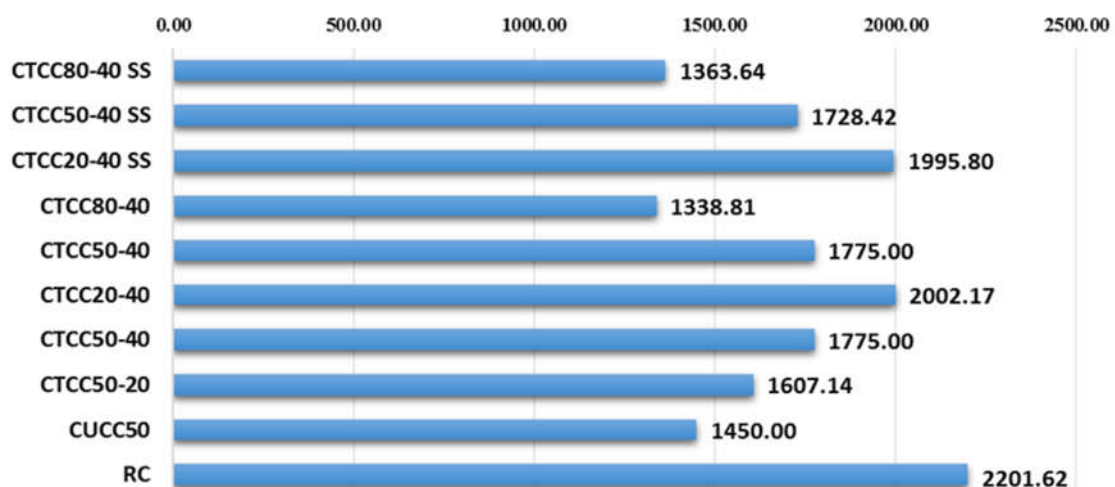
Next, the two recipes with 50% vol. corn cob aggregates were on a level below from cement hydration point of view, CTCC50-40 and CTCC50-40 SS, registering a density decreasing by 5.15% and 5.40%, respectively. In this case, SS didn't help more the cement hydration process.

The concrete compositions with the biggest quantity of corn cob aggregates, CTCC80-40 and CTCC80-40 SS, registered the biggest density decreasing by 13.46% and 11.85% respectively, this due to the fact that bigger quantity of vegetal led to a higher quantity of absorbed water, which was then evaporated during the curing period of 28 days. SS addition contributed to the cement hydration more than in the case of the concrete composition with 20% vol. corn cob aggregates.



**Figure 1.** The evolution of concrete density, from casting throughout the 28 days of curing [kg/m<sup>3</sup>].

The final concrete density after 28 days of curing is presented in figure 2.



**Figure 2.** Concrete density at 28 days, [kg/m<sup>3</sup>].



The application of 20% SS solution on the corn cob granules increased the concrete density by 9.77% compared to the one with untreated granules. The 40% SS solution treatment led to a supplemental 9.55% increase of the concrete density than the previous concentration. The SS addition led to a light decrease of the concrete density in the case of the recipes with 20% vol. and 50% vol. of corn cob aggregates, and a light increase in the case of the one with 80% vol.

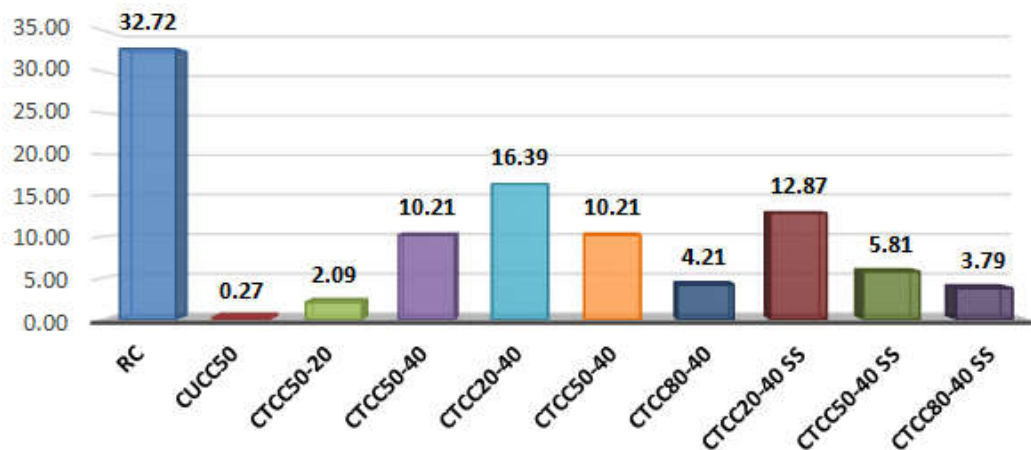
### 3.3. Concrete compressive strength

The compressive strength values of the concrete compositions developed in this research are presented in figure 3.

From the graphic of concrete compressive strength values, it can be observed that the mineral aggregates replacement by corn cob aggregates led to concrete compressive strength decreasing.

The treatment of corn cob granules with 20% SS solution in a variant and with 40% SS solution in another variant improved the concrete compressive strength by 6.74 fold and 36.81 fold, respectively.

The 100% SS addition led to a decrease of compressive strength by 21.47%, 43.09%, and 9.97% for the concrete composition with 20% vol., 50% vol. and 80% vol., respectively, of corn cob aggregates.



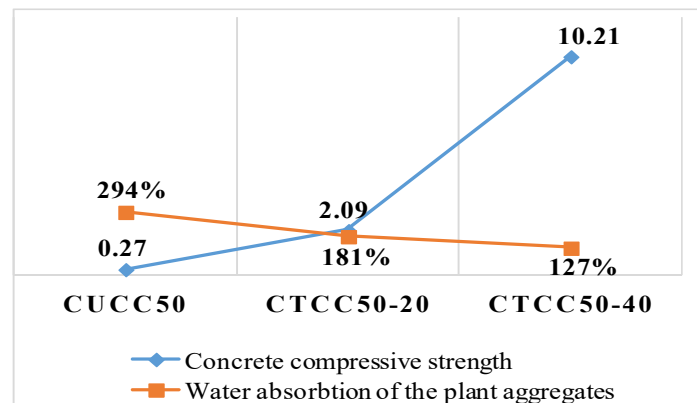
**Figure 3.** Compressive strength of the concrete [N/mm<sup>2</sup>].

The compressive strength of the concrete made of 20% vol., 50% vol. and 80% vol. of corn cobs treated with the most efficient SS solution followed a decreasing trend corresponding to the increase of the replacement rate. The increase of the replacement rate from 20% vol. up to 50% vol. decreased the compressive strength by 37.70%. The next replacement rate increase by 30% led to a supplementary decrease by 58.76% compared to the previous level.

Figure 4 presents the interconnection between water absorption capacity of the vegetal aggregates and the compressive strength of the concrete obtained with these as 50% vol. replacement of mineral aggregates.

From the graphic an inverse proportionality between the water absorption capacity of the vegetal aggregates and the compressive strength of the concrete can be observed: the decreasing of the water absorption capacity of vegetal aggregates contributed to the increasing of compressive strength of the concrete.

A reduction of water absorption capacity by 113% led to an increase of the concrete compressive strength by 674.07%. The water absorption capacity decreasing up to 127% compared to the untreated granules means 54% supplementary reduction compared to the value obtained after the granules treatment with 20% SS solution. This led to an improvement of concrete compressive strength by 388.52%. Overall, a 167% decrease of the vegetal water absorption capacity contributed to an improvement of the concrete compressive strength by 3681.48%.

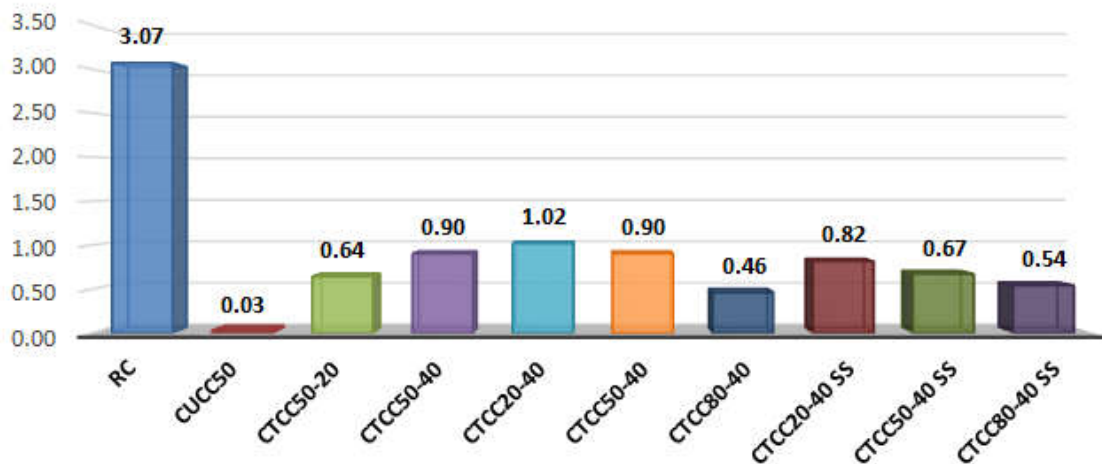


**Figure 4.** Evolution of compressive strength of concrete [N/mm<sup>2</sup>] compared to water absorption of vegetal aggregates [%].

#### 3.4. Concrete splitting tensile strength

In figure 5 are presented the values of the splitting tensile strength of the concrete compositions developed in this study.

As in the case of compressive strength, the treatment of corn cob granules with SS solution improved the concrete splitting test results. With the 20% SS solution treatment, it was obtained a splitting tensile strength of the concrete 20.33 times higher than the concrete composition with untreated corn cob granules. The 40% SS solution led to test results higher by 29 fold than the concrete with untreated vegetal aggregates and 40.62% higher than with the use of 20% SS solution. In conclusion, the most efficient treatment was the 40% SS solution.



**Figure 5.** Splitting tensile strength of the concrete [N/mm<sup>2</sup>].

Regarding the effect of the corn cob aggregates treated with the previously determined most efficient SS solution, a decrease of the splitting tensile strength along with the replacement rate increase was noticed. The increasing of the corn cob aggregate volume from 20% to 50% of the mineral aggregates quantity led to a reduction by 11.76% of the splitting tensile strength. The concrete composition with 80% vol. of corn cobs registered a 54.90% smaller value of the same property. The SS addition decreased the performances of the concrete compositions with 20% vol. and 50% vol. of corn cob aggregates by around 20% and 26%, respectively, but improved them in the case of 80% vol. of vegetal aggregates by 17.40%.

#### 4. Conclusions

The chemical composition of vegetal aggregates has a high impact on the mechanical properties of the concrete, due to the deleterious interactions between bio-aggregates and mineral matrix: they affect the setting and hardening process of cementitious binders, can diminish the concrete mechanical properties and can influence its durability.

The effects of SS solution on corn cob aggregates and on the corn cob concrete are:

- the SS solution decreased the water absorption capacity of the corn cob granules from 294% up to 127%, compared to the untreated granules;
- in general, the SS addition improved the cement hydration of the concrete;
- the SS addition led to a light decrease of the concrete density in the case of the recipes with 20% vol. and 50% vol. of corn cob aggregates, and a light increase in the case of the one with 80% vol.;
- the treatment of corn cob granules with 20% and 40% SS solution improved the concrete compressive strength by 6.74 fold and 36.81 fold, respectively;
- the 100% SS addition led to a decrease of compressive strength of the corn cob concrete;
- the compressive strength of the concrete made with 20% vol., 50% vol. and 80% vol. of corn cobs followed a decreasing trend corresponding to the increase of the replacement rate of the mineral aggregates;
- decreasing the water absorption capacity of vegetal aggregates contributed to the increasing of compressive strength of the concrete;
- the treatment of corn cob granules with SS solution improved the concrete splitting test results; the 40% SS solution led to test results higher by 29 fold than the concrete with untreated vegetal aggregates and by 40,62% higher than the use of 20% SS solution;
- splitting tensile strength decreased with the mineral aggregates replacement rate increasing;
- the SS addition decreased the performances of the concrete compositions with 20% vol. and 50% vol. of corn cob aggregates by around 20% and 26%, respectively, but improved them in the case of 80% vol. of vegetal aggregates by 17.40%.

The concrete with corn cob aggregates can be used in non-structural purposes like closures, wall finishes and concrete screeds.

#### Acknowledgements

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