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SYNERGIC EFFECTS OF SUNFLOWER STALKS AND SODIUM SILICATE IN DEVELOPING AN ECOLOGICAL CONCRETE

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Abstract

Building industry is a very large domain in the global economy and it has a lot of consequences over the environment through many and different aspects. These consequences are various, from the more and more extended area of construction up to gas emissions released during materials manufacture and transportation, construction process, exploitation of buildings and, finally, their deconstruction. The concrete, the most used material in construction industry all over the world, must become greener and greener every passing day. Involving natural and renewable raw materials in concrete composition is a variant to develop an ecological concrete that sustain a healthier environment by using less of depleting mineral resources and by decreased gas emissions released into the atmosphere. This research has a high degree of novelty due to its aim to study the effects of sunflower stalks used as partial replacement of the mineral aggregates from the concrete composition, combined with the effects of sodium silicate used as additive. There were developed concrete recipes with sunflower stalks shredded and treated with 40% sodium silicate solution as 20%, 50% and 80% replacement of mineral aggregates with regular concrete additives and then was supplementary added sodium silicate in 5% of the cement volume from the concrete composition. Tests were carried out on the density and compressive strength of the concrete at 28 days and 3 months and on its flexural and splitting tensile strength at 28 days. The results showed that the sodium silicate addition has positive effects on the concrete compressive strength and had no or a small negative effect on its density and tensile strength.

Keywords: compressive strength, glass water, renewable resources, tensile strength, vegetal aggregates

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1. Introduction

Sustainability had become a predominant keyword in many European Union policies which encourage recycling and the wastes used as a resource (Blengini et al., 2017). Wastes disposal represents a risk for the environment during the entire life cycle of the landfill where they are thrown away, even if it is made in an ecological manner (Kim and Arama, 2018). Accordingly, in the constructions research domain there is a substantial interest in finding ways to diminish the quantities of waste that put in danger the environment by incorporating them into different building materials. Concrete is a material used on a large scale in constructions and in large quantities, so it represents an adequate solution to incorporate in its composition different type of wastes, from fly ash and silica fume (Narattha et al., 2018), up to the non-metal fraction from waste printed circuit boards (Premur et. al., 2018).

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Worldwide, the development of ecological concrete variants using different annual plants in its composition has an increasing trend. The plants represent a natural and renewable resource that, if it is properly treated, can replace totally or partially the mineral aggregates from the conventional concrete composition.

Between the advantages of using plants as raw materials into the concrete composition are the smaller density of the concrete (below 1800 kg/m^3), their renewability that leads to an increased sustainability of the concrete, a decreased thermal conductivity compared to conventional concrete that enhance the indoor comfort of the buildings. This type of raw material has the adequate properties of good acoustic absorbents that recommend them for using in acoustic rooms or noise barriers (Oancea et al., 2018). Vegetable waste, such as grass, pine leaves or corn cobs used in sandwich panels, have a sound absorption coefficient similar to that of polyurethane foam or mineral wool. Stuff has recently been proposed with absorbent applications with excellent performance at medium to high frequencies. But not all natural materials satisfy absorption performance. For example, wood and cork, due to their structure, have poorly absorbent properties Concrete produced from agricultural waste is considered to have good thermal properties. Hemp, palm shell, coconut shell, rice husk husks, corn cobs, pistachio nuts, tobacco waste are among the most used waste for this purpose. Since aggregates (sand as fine aggregate and gravel as aggregate) represent about 60-80% of the concrete volume, the successful use of such solid agricultural waste as a total or partial replacement of conventional aggregates contributes to saving energy, preserving natural resources and cost reductions for the production of building materials (Asdrubali, 2007).

As disadvantages, vegetable fibers are more susceptible to fungal and parasitic infestations, and much less resistant to fire than mineral ones. Research on the use of agricultural waste in the production of concrete is relatively recent, and studies are needed to prove their long-term sustainability (Asdrubali, 2007). Due to the fact that the organic matter is subject of decomposition, it is routinely subject of pyrolysis (Gupta et al., 2018). Transformed in ash, it is incorporated into concrete as additive or as cement partial replacement (Akhtar and Sarmah, 2018; Maroušek et al., 2014).

Among the very used plant studied as a component of lightweight building material is the hemp, and the obtained material was named hempcrete and it is a mixture made of hemp aggregates and a hydraulic and aerated setting binder. The high porosity of hemp particles determines the lightness, deformability and absorbent capacity of the hempcrete (Cazacu et al., 2016; Nozahic and Amziane, 2012). Hempcrete have the apparent density between 200 and 500 kg/m^3 and a thermal conductivity between 0.06 and 0.12 W/mK, measured at 0% RH, these values depending on the compactness level of the material. It is used to rendering, to build walls, as a roof insulation material or as floor (ground) insulation (Amziane and Arnaud, 2013).

A plus in developing the ecological character of the vegetal concrete is given by the use of the local resources, in order to decrease their ecological footprint and, in the same time, the costs caused by transport from large distances. This is the reason why in this study was used a very similar plant with hemp as microstructure and chemical composition, namely sunflower. The microstructure of sunflower stalks has the honeycomb shape, and the marrow of the stem contains 95% air (Nozahic and Amziane, 2012). The wood part of the hemp and sunflower has a cellulose content of 50% and 40% by weight, respectively. The lignin content is 28% for hemp and 18.3% for sunflower, these rates being variable with the soil conditions, plant species and crop age of plants. The pectin is equal for both plants (6%). Sunflower aggregates are ultralight, with a bulk density of 105 ± 2 kg/m^3 and a water content of 9.4%, measured at 20±2^{0}C and 35±5% relative humidity. Hemp has similar bulk density (103 ± 2 kg/m^3) (Nozahic et al., 2012). Thermal conductivity of sunflower aggregates is a little smaller than the hemp ones, 0.050 W/mK and 0,055 W/mK, respectively (Chabannes et al., 2015).

Sunflower stalk is formed of bark and marrow. Its bark is a wooden material made of cellulose, lignin and pectin, with a density of around 500 kg/m^3. The sunflower marrow is different from the bark because is not a wooden material, containing 95% air (Chabriac et al., 2016). It represents almost 60% of the sunflower stalk volume and has a very small bulk density, 37 ± 2.2 kg/m^3 (Nozahic et al., 2012).

A difference between hemp and sunflower is that the hemp needs a special mechanism to eliminate its fibrous part and afterward it is shredded, while sunflower stalk can be entirely shredded and used as aggregates in concrete (Chabannes et al., 2015). Another method for using sunflower stalks as alternative of phytomass disintegration is in the biogas production (Maroušek, 2013).

Sunflower is largely available in Romania, but also in Europe and at the global level. Romania had 1139×10^3 Ha cultivated area with sunflower in 2018, 27.5% of the total cultivated area of European Union 28 (Eurostat, 2019).

When vegetal aggregates are used into cement-based concrete, an effect of set-retarding takes place because their lignocellulosic structure is partially solubilized by the alkaline character of the concrete (Bilba et al., 2003). Moreover, according to Sedan et al., 2008, the pectin from the plant aggregates has the ability to trap Ca^{2+} ions, an important factor in the hydrate's formation.

Another issue of the vegetal use into concrete is their porous structure that cause the water absorption from the concrete mix and, in this way, to hydration deficit of the cement (Nozahic and Amziane, 2012). All these are issues that lead to a very difficult bond realization between the vegetal aggregates and the mineral binder (Khazma et al., 2008).

The adhesion between vegetal aggregates and the matrix depends on the surface chemistry, roughness and the porosity and water affinity of the lignocellulosic material (Nozahic and Amziane, 2012).

Some studied measures to improve the bond between the plant aggregates and cement paste refers to additives use (Khazma et al., 2008; Wei et al., 2000) or vegetal aggregates treatments (Harbulakova, 2014; Le Troëdec et al., 2009). As treatments of the vegetal aggregates can be mentioned their soaking in water-based solutions, alkaline solution treatments (Nozahic and Amziane, 2012) or aggregate coating with linseed oil (Monreal et al., 2011), paraffin wax (Al-Mohamadawi et al., 2016; Nozahic and Amziane, 2012) or sucrose (Khazma et al., 2008). Nozahic and Amziane (2012) studied three types of sunflower particles treatments: soaking them in a calcic lime solution, linseed oil coating and paraffin wax coating. The best results were obtained by calcic lime solution (alkaline solution) and paraffin wax. Pretreatment of natural fibers may require more effort, increase costs, and consider the compatibility of cement matrix modifiers with its effect on fiber-cement interface properties (Harbulakova, 2014). Therefore, it is more logical to improve the initial mechanical properties and durability of natural fiber-reinforced cement composites by modifying the cement hydration reaction.

Sodium Silicate (SS), named also liquid glass, is a high alkaline solution, with pH = 11.3÷13.4, that is water soluble, non-inflammable, non-reactive in normal environment conditions. Its density ranges between 1.38 and 1.56 g/cm^3 (PQ Corporation, 2004). SS is made from soda ash and sand heated to 1100-1200ºC (LaRosa-Thompson et al., 1997). It is used in very different industries, such as: in constructions, as binder in mortars with high acid resistance and in shotcreting and filling mortars, as additive in paints or for waterproofing or fire protecting of different types of porous surfaces, as setting-accelerator additive in mortars and concretes or for soil stabilization; in textile industry as stabilizer or thickening agent in bleaching; as adjuvant clarifying agent in water purification; as binder in paper industry; as flotation agent in extractive industry; as binder of different coverings for anticorrosive protection; as binder in paints industry or as catalyst in chemical industry (PQ Corporation, 2004).

SS forms a gel on the surface of the material by losing its constitution water, which hardens and gives mechanical strength to the treated material (Carcea and Gherghe, 2009). In concrete, it modifies the physical properties of the Portland cement, reduces the material permeability and modifies the setting time in cold weather. It is a non-toxic, odorless, no fumes producer and easy to use substance (PQ Corporation, 2004). SS forms a hydrate gel in cement-based concrete, so the water mobility is reduced and the occurrence of free water is diminished. This fact leads to the decrease of thermal conductivity of the concrete (Al-Khafaji, 2015).

As a sealant used in cement and concrete industry, SS improves the chemical and physical resistance of the bridges, walls, floors, traffic barriers, slabs, storage tanks, building blocks. SS acts like linseed oil, blocking the pores close and from the surface of material, but do not cover the top of surface (LaRosa-Thompson et al., 1997). As admixture, the SiO_2 from its composition reacts immediately with CH from the cement, forming C-S-H groups, and raising the pH of the cement paste, accelerating the hydration and decreasing the setting time. Used in modest dosages, it improves the concrete strength, but if it is used in higher dosages, SS can cause lower strengths of the concrete (LaRosa-Thompson, 1997).

Because it is recommended to treat the vegetal aggregates with alkaline solutions in order to reduce their lignocellulosic compounds that have a great influence on the setting time of the concrete, to obtain a better hydration at the interface between vegetal aggregates and binder, and to create a more adequate transition between the vegetal aggregates and the cement paste (that has also an alkaline character), a SS solution with 40% concentration was adopted as treatment. This alkaline solution determines a rougher surface of the vegetal material, in this way an improved aggregates/binder bond and a low contact angle wettability of the aggregates surface being obtained (Nozahic and Amziane, 2012). Moreover, this solution was chosen due to its properties in fire and antiseptic protection of lignocellulosic materials.

Same SS solution but with different concentration (100% namely) was adopted as additive into the fresh concrete mix in order to improve or to speed up the hydration process of the cement, thus the water from the mix not to be absorbed mainly or entirely by vegetal aggregates.

This research studied the effects of sunflower stalks used as partial replacement of the mineral aggregates from the concrete composition, combined with the effects of sodium silicate used as additive to accelerate the cement hydration. From literature review, it seems that this kind of approach is a novelty aspect in vegetal concrete research developed up to now. Its aim was to improve the mechanical properties of the concrete with sunflower stalks aggregates. For this purpose, in this study were developed concrete recipes with mineral aggregates partially replaced by shredded sunflower stalks treated with 40% SS solution, and concrete recipes with shredded sunflower stalks treated with 40% SS solution and 100% SS solution as additive in the fresh concrete mix. As additive, it was used a quantity of 5% from the cement volume.

Tests were carried out on the density and compressive strength of the concrete at 28 days and 3 months and on its flexural and splitting tensile strength at 28 days. The results of the carried tests want to offer a vision about the efficiency of the sodium silicate addition on the density and mechanical properties of the fresh concrete mix made with different percentages of sunflower stalk aggregates.

2. Material and methods

In this research were developed 7 concrete recipes, noted as follows:

- RC-reference concrete, that is a standard concrete of 25/30 Strength Class;
- CTSF20-concrete with 20% vol. of treated sunflower aggregates as replacement from the total quantity of mineral aggregates;
- CTSF50-concrete with 50% vol. of treated sunflower aggregates as replacement from the total quantity of mineral aggregates;
- CTSF80-concrete with 80% vol. of treated sunflower aggregates as replacement from the total quantity of mineral aggregates;
- CTSF20-SS-concrete with 20% vol. of treated sunflower aggregates as replacement from the total quantity of mineral aggregates and sodium silicate solution with 100% concentration;
- CTSF50-SS-concrete with 50% vol. of treated sunflower aggregates as replacement from the total quantity of mineral aggregates and sodium silicate solution with 100% concentration;
- CTSF80-SS-concrete with 80% vol. of treated sunflower aggregates as replacement from the total quantity of mineral aggregates and sodium silicate solution with 100% concentration.

RC composition contained cement CEM II/A-LL 42.5R (notations according to EN 197-1, 2011), two sorts of mineral aggregates (sand of 0-4 mm diameter and river gravel of 4-8 mm diameter), and two types of additives (a policarboxilateter based superplasticizer and a rhodanid based accelerator).

A water/cement (W/C) ratio of 0.43 was used in RC composition. In the concrete recipes with sunflower aggregates, the W/C ratio was higher and variable, according to the plant percentage involved, due to the fact that these had an absorption capacity higher than the mineral aggregates. The W/C ratio for the concrete recipes with 20% of vegetal aggregates was 0.58, for the concrete recipes with 50% of vegetal aggregates was 0.73 and 0.88 for those with 80% vegetal aggregates, in order to maintain the same level of workability of the concrete mix.

The components and the quantities used in the developed concrete recipes are presented in Table 1.

Sunflower aggregates were manufactured as follows (Fig. 1):

- the stalks of sunflower plants were shredded with an electric mill for fodder chopping, resulting granules smaller than 5mm from the stalk marrow mixed with fibers smaller than 25 mm from the lignocellulosic part of the stalk (the shell);
- the chopped sunflower stalks were treated with a 40% Sodium Silicate (SS) solution; it was applied this particular treatment as this being an efficient method to reduce the big absorption capacity of the sunflower aggregates with 75% (from 402% up to 100%) and to improve the compressive strength of the concrete made with this type of aggregates compared to the concrete made with untreated vegetal aggregates, as presented in a previous study by Helepciuc et al. (2018) for each 100 *l* of dried sunflower aggregates bulk were used 43.5 *l* of 40% SS solution;
- the treated vegetal aggregates were then dried in a natural ventilated room at 25±2^{0}C until constant mass was achieved.

The policarboxilateter based superplasticizer and the rhodanid based accelerator were added in a quantity equal to 2.5% of the cement volume.

Sodium silicate solution of 100% concentration was used as additive into the concrete composition in a quantity equal to 5% of the cement volume. Its use intended to accelerate the cement hydration process additionally to the use of a commercial accelerator, due to the fact that the presence of high absorption lignocellulosic material into the concrete composition will determine that the water mixed into the composition will be absorbed mainly by this and the cement hydration process will not be complete due to the lack of the sufficient available water. Also, by SS addition was intended to obtain better mechanical properties of the concrete, taking into account the improved behavior of the sunflower aggregates after their treatment with this type of solution proved in a previous published study by Helepciuc et al. (2018).

For density determination, compressive strength test and splitting tensile strength test were used cylinders with 100 mm diameter and 200 mm in length, and for flexural tensile strength test were used 100x100x550 mm prism molds. Three samples of each concrete recipe were used for each test. The density of fresh and hard concrete was determined according to EN 12350-6 (2010) and EN 12390-7 (2006), the compressive strength according to EN 12390-3 (2009/AC:2011), flexural tensile strength according to EN 12390-5 (2009), and the splitting tensile strength according to EN 12390-6 (2010).

Table 1. The developed concrete recipes

Concrete recipe	*Cement [vol. %]*	*Sunflower aggregates [vol. %]*	*Mineral aggregates [vol. %]*	
			Sand 0-4 mm	**River gravel 4-8 mm**
RC	29.00	0.00	44.00	27.00
CTSF20	29.00	14.20	35.20	21.60
CTSF50	29.00	35.50	22.00	13.50
CTSF80	29.00	56.80	8.80	5.40
CTSF20-SS	29.00	14.20	35.20	21.60
CTSF50-SS	29.00	35.50	22.00	13.50
CTSF80-SS	29.00	56.80	8.80	5.40

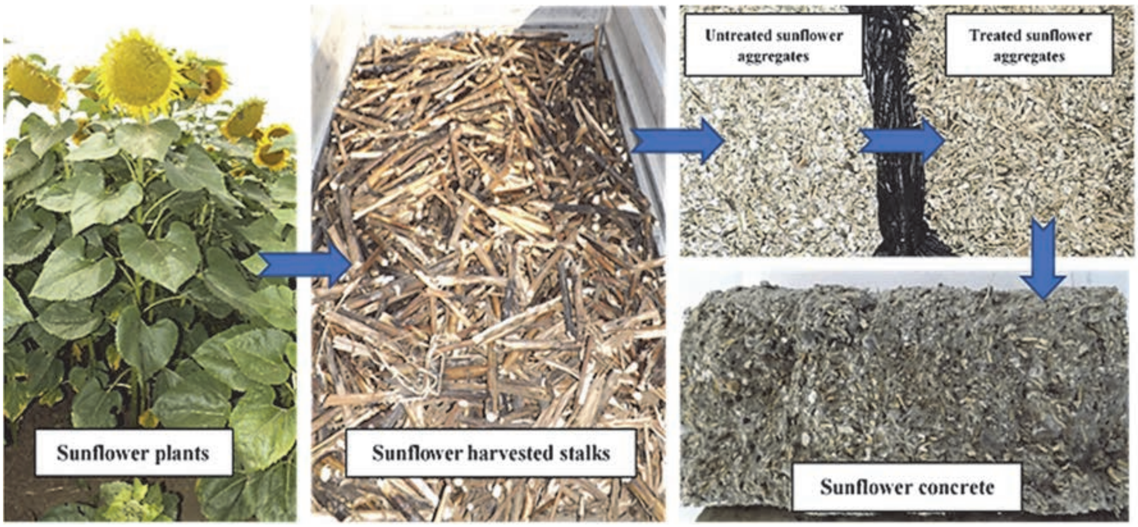
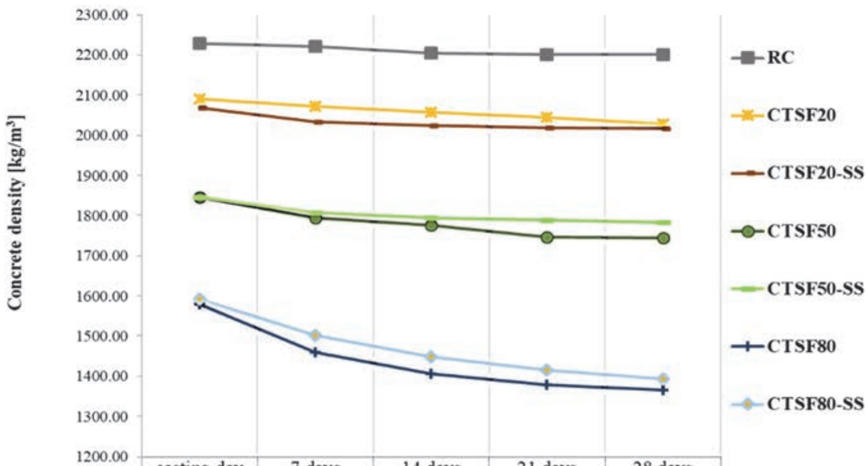


Fig. 1. Stages of the production process of the sunflower concrete



	casting day	7 days	14 days	21 days	28 days
RC	2228.17	2221.80	2204.61	2201.43	2201.62
CTSF20	2090.02	2072.83	2056.92	2045.46	2028.27
CTSF20-SS	2069.01	2034.00	2025.09	2018.72	2016.17
CTSF50	1846.20	1795.27	1776.17	1746.25	1744.34
CTSF50-SS	1846.20	1808.00	1795.27	1788.90	1782.54
CTSF80	1578.82	1459.77	1406.93	1378.92	1365.55
CTSF80-SS	1591.55	1502.42	1448.31	1415.21	1392.92

Fig. 2. The evolution of concrete density, from casting till 28 days of curing [kg/m^3]

3. Results and discussion

3.1. Density

As it is observed in Fig. 2, the slope of the density evolution graphic from casting till 28 days of curing period is bigger with the increasing of replacement rate of mineral aggregates by sunflower ones. This is due to the fact that the higher rate of vegetal aggregates was used, a higher W/C ratio was involved in order to maintain the same level of workability as RC. This means that the supplementary quantity of water added beside that used in RC was absorbed by the plant aggregates and not used in the cement hydration process. While RC registered a density decrease of 1.2% during the 28 days of curing period, the values obtained by CTSF20, CTSF50 and CTSF80 were 2.9%, 5.5% and 13.5%, respectively. The SS addition led to smaller rates of concrete density decreasing: CTSF20-SS density decreased by 2.5%, CTSF50-SS by 3.4%, and CTSF80-SS by 12.5%. This means that SS contributed to the use of a part of supplementary water in the cement hydration process also, not only in plant`s absorption.

It is observed that in the case of 20% replacement, the density graphic has a particularity, in the sense that SS addition led to a smaller density of the mix compared to the mix without this additive. This fact can be determined by the fact that the same quantity of SS additive added in the mix as in the case of CTSF50-SS and CTSF80-SS was available to be absorbed by a smaller quantity of vegetal aggregates.

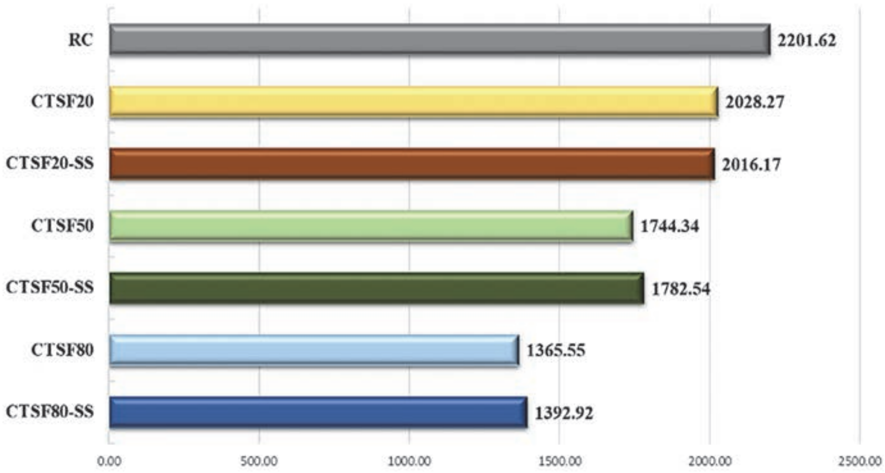


Fig. 3. Concrete density at 28 days [kg/m^3]

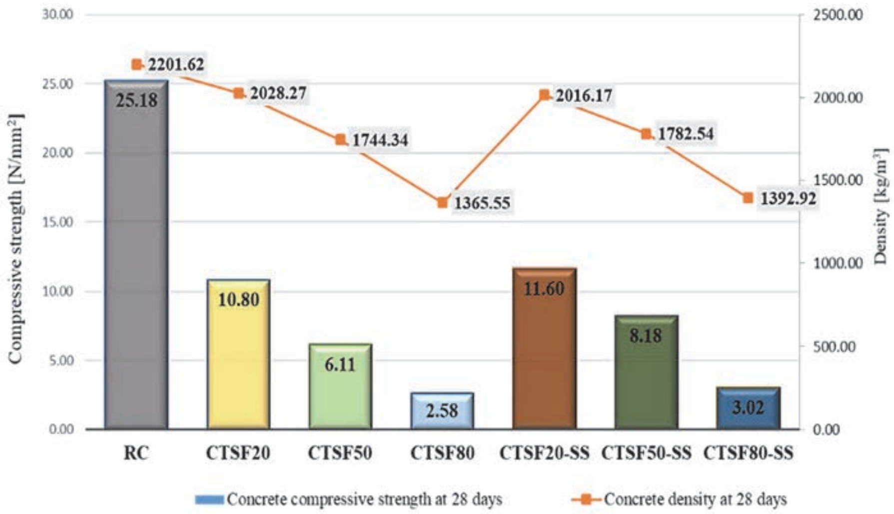


Fig. 4. Compressive strength and the density of the concrete at 28 days [N/mm^2]

This means that, in the case of the recipe with 20% replacement of the mineral aggregates, the vegetal aggregates suffered a swelling in a higher rate from their total quantity than in the case of the recipes with 50% or 80% replacement, occupying more volume in the concrete mix. This increased swelling of the vegetal aggregates determined by the absorption of SS additive led to a smaller density of the mix CTSF20-SS than CTSF20, both in the fresh and dry state (Figs. 2, 3).

In Fig. 3 are presented the concrete densities after 28 days of curing. It can be easily noticed that the higher rate replacement of mineral aggregates by sunflower ones was applied, higher is the concrete density decreasing. By using a 20% replacement rate, it is obtained a concrete lighter with almost 8.0% than the RC. The 50% replacement rate led to about 21.00% decrease of concrete density, and 80% replacement rate to 38.00% in the case of the recipes without SS additive. In the case of concrete recipes with SS addition, only for CTSF20-SS was obtained a smaller density with 7.00% than the variant without this additive; CTSF50-SS and CTSF80-SS registered an increase of their density with compared to the similar recipes without SS additive the explanation is the same as that from the Fig. 2.

According to Fig. 3, it is observed that the 50% and 80% mineral aggregates replacement by sunflower aggregates led to a density of around 1750 kg/m^3 and 1400 kg/m^3 of the concrete, respectively. According to C155 (2013), this means that lightweight concretes are obtained. Ecological lightweight concrete can be obtained also using different type of wastes, like chopped plastic bottles, wood waste or polystyrene granules (Ciocan et al, 2018).

3.2. Compressive strength

In Fig. 4 are presented the compressive strength and density values obtained for the developed concrete recipes tested at 28 days. According to Fig. 4, it can be mentioned that, even the increasing rate of mineral aggregates replacement by sunflower aggregates determined significant decrease of compressive strength, the SS solution addition improved the performances of the vegetal concrete with sunflower stalks by 7.41%, 33.94% and 16.90% in the case of CTSF20, CTSF50 and CTSF80, respectively. The results are in agreement with those obtained by Al-Khafaji (2015) for 5%, 10% and 15% use of SS in a conventional concrete recipe. The best results were obtained by the author for 10% of SS addition, in this case being obtained also the decrease of initial cost of construction by decreasing with 12% the layer thickness of a rigid pavement in the case of a highway design calculus.

From the point of view of compressive strength correlation with the density of the concrete, it can be observed that there is a strong direct dependence between them, as the density decreasing lead to lower compressive strength values.

In the case of CTSF20-SS, even if the density is smaller than in the case of CTSF20, the compressive strength is higher; this can be explained by the fact that a higher quantity of SS solution was active per measure unit of vegetal aggregates than in the case of the recipes with 50% and 80% replacement rate of the mineral aggregates, and, that led to a stronger adhesion of the cement matrix to these, knowing that the alkaline solutions determine partial solubility of the lignocellulosic components and a more rough surface of the vegetal aggregates (Nozahic and Amziane, 2012).

3.3. Flexural tensile strength

From the flexural tensile strength point of view (Fig. 5), the SS solution effect is almost opposite to that from the compressive strength case; the SS solution addition led to flexural tensile strength decrease of CTSF20 and CTSF50 by 23.62% and 30.28%, respectively. In case of CTSF80, it can be observed an improvement of the flexural tensile strength by 78.75%, fact explained as follows: the vegetal major rate from the concrete composition favors the SS absorption in the lignocellulosic aggregates structure and the SS effect is one of fibers strengthening, ensuring an enhanced flexural strength of the CTSF80-SS compared to CTSF20-SS and CTSF50-SS. In these two cases, the flexural stress is bigger than the strength because the SS solution remain more in the cement paste mix, being subjected to the evaporation process along the curing period. In this way additional pores are formed, that lead to flexural tensile strength decrease of the concrete. Moreover, at 80% replacement rate, the quantity of the vegetal aggregates is predominant in the total quantity of aggregates (vegetal and mineral aggregates). The material is obtained mainly by the clotting of the vegetal aggregates smeared with cement paste. So, when the vegetal aggregates dry out and their volume decreased, in the concrete structure appear less air voids between the vegetal aggregates and binder mixed with the mineral aggregates because the quantity of the mineral mix is pretty small compared to recipes with 20% and 50% rate of aggregates replacement. Even in the fresh state, the concrete obtained with 80% of sunflower aggregates is not as compact as the concrete with smaller quantity of vegetal aggregates. Also, the vegetal aggregates are strengthened by the action of the cement paste and SS additive, and their shape of granules and fibers creates more interlocking as their rate increases in the concrete mix. In this way, a bigger flexural tensile strength of the concrete is obtained.

3.4. Splitting tensile strength

In Fig. 6 are presented the splitting tensile strength values registered by the developed concrete recipes from this study.

Regarding the splitting tensile strength, it can be noticed a decrease of its values along with the vegetal aggregates rate increasing. CTSF20 registered a splitting tensile strength smaller by almost 44% than the RC, CTSF50 one by about 68% smaller and CTSF80 by about 72%. The SS addition had a negative effect on the CTSF20 that led to forward decrease of splitting tensile strength with about 34%, and had almost no effect on the strength of CTSF50 and of CTSF80. These results can be put in relation with the concrete density. The density decreasing of 7% obtained by the SS addition in the case of the recipes with 20% replacement of the mineral aggregates led to the splitting tensile strength decrease also. The same principle was followed in the case of density increase of 2.2% and 2% of CTSF50-SS and CTSF80-SS, respectively.

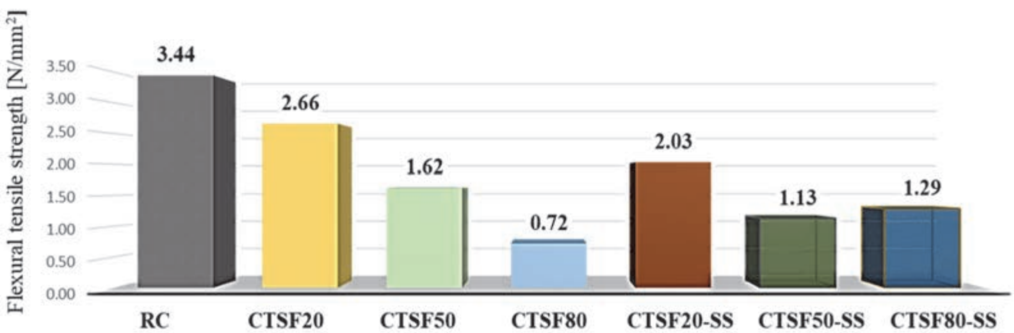


Fig. 5. Flexural tensile strength of the concrete at 28 days [N/mm^2]

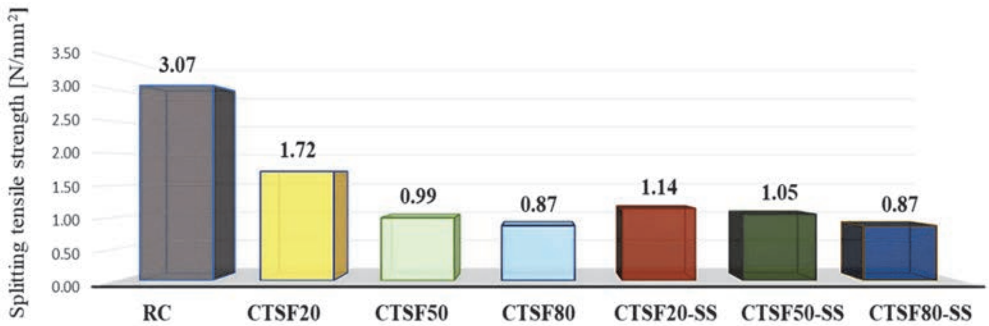


Fig. 6. Splitting tensile strength of the concrete at the 28 days [N/mm^2]

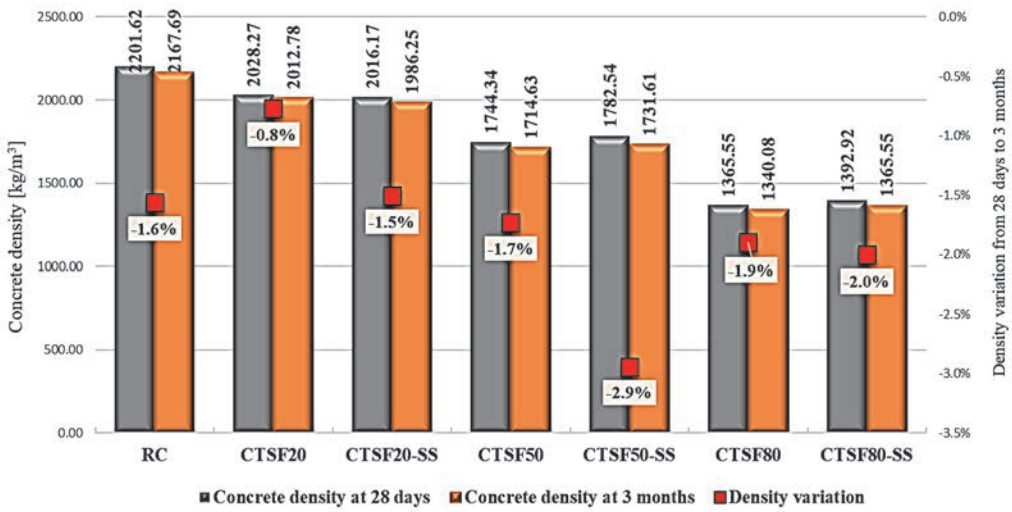


Fig. 7. Concrete density at 28 days versus 3 months [kg/m^3]

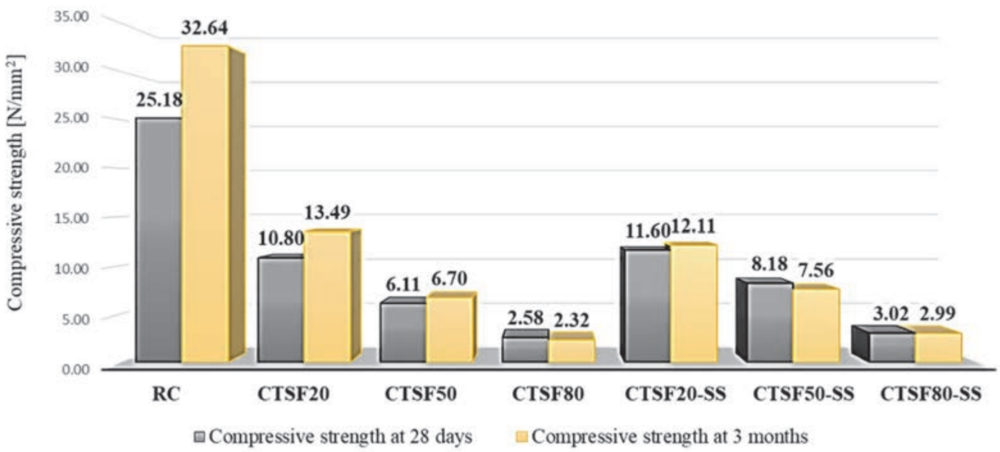


Fig. 8. Compressive strength of the concrete at 28 days versus 3 months [N/mm^2]

3.5. Evolution of the density and compressive strength from 28 days to 3 months

In Fig. 7 are presented the concrete recipes densities after 3 months from the casting day compared to those measured after 28 days.

The concrete density registered small percentages of decreasing from 28 days up to 3 months, between 0.8% and 2.9%. What it is worth to be mentioned is that, in the case of 20% and 50% replacement rate of mineral aggregates by the sunflower ones, the SS addition doubled the decrease rate of the concrete density. Only in the case of 80% replacement rate, its effect was almost zero.

From the evolution in time point of view, the compressive strength of the concrete continued to increase in the case of concrete recipes with up to 50% of vegetal aggregates (Fig. 8). After this replacement rate, compressive strength decreased in time, over 3 months analysis.

When SS solution was added into the recipe with small vegetal percentage, it lightly improved its compressive strength but this improvement decreased along the vegetal aggregates' quantity increase, up to a zero or small negative influence in the case of CTSF80-SS and CTSF50-SS, respectively (Fig. 8).

4. Conclusions

This study aimed to analyze the density and mechanical properties of an ecologic concrete made with sunflower aggregates as 20%, 50% and 80% replacement of the mineral ones. Then, it was studied the effect of using a 100% SS solution as admixture in 5% of the cement volume. The results revealed that:

- The concrete density decreased along the increase of the sunflower aggregate percentage; the replacement rates of mineral aggregates by sunflower ones led to lightweight concrete obtaining; by using SS as admixture, the concrete density had, in general, a small increase.
- Increasing rate of sunflower aggregates determined significant decrease of compressive strength, but SS solution had a positive effect on this property by enhancing it by 7.41%, 33.94% and 16.90% in the case of CTSF20, CTSF50 and CTSF80, respectively.
- In the case of flexural tensile strength, the increasing rates of shredded sunflower aggregates led to smaller values than RC, and the SS addition had a positive effect only in the case of CTSF80.
- The splitting tensile strength decreased along the increasing rate of sunflower aggregates; in the case of this property, SS had a negative effect only in the case of CTSF20; in CTSF50 and CTSF80, it had a positive or neutral effect.
- After 3 months, the density of the concrete recipes with SS admixture decreased twice more than the ones without SS in the case of 20% and 50% replacement rate of mineral aggregates with sunflower ones; this density decrease was accompanied by the compressive strength increase in time, both for the concrete recipes with and without SS admixture.

The results obtained for this type of vegetal concrete recommends this material to be used in non-structural purposes, like the closure elements (armed or unarmed), the replacement of the ceramic bricks, the wall panels, the partitions, the filling of the prefabricated beams, or the monolithic over-, for civil, agro-industrial or industrial buildings. Due to its lightweight character, the sunflower concrete can lead to decrease of the total mass of buildings, a very useful factor in the case of buildings behavior during a seism movement.

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