The mechanical properties and the freeze-thaw resistance of an ecological micro concrete made with sunflower stalks

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Abstract. The aim of this study was to analyze the density, compressive strength, tensile strength and the freeze-thaw resistance of a cement micro concrete made with sunflower stalks that replaced 20%, 35%, 50%, 60%, 80% and 100% of the sand from its composition. The results showed, in general, a decrease of the analyzed properties, but the use of 20% and 35% sunflower stalk aggregates led to the improvement of the splitting tensile strength. A significant advantage of this type of micro concrete was its density, being obtained a lightweight building material, with up to 822 kg/m³.

1. Introduction

Currently, an important goal of researchers is to find alternative solutions to build cheaper, more environmentally friendly and at the same time using sustainable materials. Sustainable materials are generally those made from natural or recycled raw materials, whose production has a reduced impact on the environment, requiring reduced amounts of energy and non-renewable resources. While the solution of recycled raw materials has been extensively studied, research into alternative variants of renewable raw materials is at the beginning. In general, renewable raw materials are by-products or waste of plant or animal origin.

Ecological concrete is most often the result of using a waste category material as a partial or total replacement of cement, sand and/or aggregates or that concrete whose production process does not significantly affect the environment. The ecological concrete is a revolutionary material that has a very low environmental pollution effect compared to the conventional concrete.

Excessive use of aggregates causes depletion of these natural resources, and reckless mining activities to extract these materials could lead to environmental problems, such as landscape damage and disruption of the ecosystem, water, soil and air pollution [1, 2].

Construction materials made by using annual plants can have the appropriate properties to meet modern design requirements such as sustainability in construction, efficiency in operation and carbon footprint reduction. The high porosity of the plant aggregates and their low apparent density recommend them for use in the composition of the concrete, giving it improved qualities of thermal and acoustic insulation compared to the classical concrete.

The vegetable aggregates have a high flexibility which translates into a non-fragile plastic and elastic behavior, increased ductility beyond the point of maximum mechanical strength and a high deformability under pressure.
The use of vegetal aggregates such as sunflower stems in concrete has advantages in terms of a combination between the use of agricultural waste, low gas emissions and their local availability. Their high oxygen content makes them a good thermal insulator. By chopping, sunflower stems can be used as aggregates in lightweight concrete production, being a sustainable alternative solution for currently marketed variants, such as expanded clay or expanded polystyrene, which are highly energy-consuming.

Aggregates from sunflower stems are ultra-light, with a bulk density of 105±2 kg/m³ and a water content of 9.4% measured in a room at (20±2)°C and (35±5)% relative humidity. Similar results were obtained for hemp (103±2 kg/m³) and sunflower stem (105±2 kg/m³) [3]. By comparison, the relative density of wood particles is 305.8±66 kg/m³ [3]. The internal porosity of the sunflower stem is very high and tends to enhance the absorption of water in the sunflower aggregates.

The aim of this study was to analyze the density, compressive strength, tensile strength and the freeze-thaw resistance of a micro concrete made with sunflower stalks that replaced 20%, 35%, 50%, 60%, 80% and 100% of the sand from its composition.

2. Materials and methods

The present research aimed to investigate the effects of sunflower aggregates on the micro concrete mechanical properties. For this purpose, starting from a reference micro concrete (RC) strength class 16/20, micro concrete recipes with 20%, 35%, 50%, 65%, 80% and 100% vol. mineral aggregates replacement sunflower stalks granules were developed.

2.1. Materials

The RC contained the following components:

- Portland cement CEM II/A-LL 42.5R, with granulated blast furnace slag and limestone;
- natural sand (0-4 mm diameter) and gravel (class 4-8 mm) extracted from riverbeds;
- water as to ensure a water/cement ratio of 0.52;
- additives: a polycarboxilate based superplasticizer and a rhodanide based accelerator; the superplasticizer was used to obtain a smaller water/cement ratio and to improve the mortar workability; the accelerator was used to enhance the cement hydration process, necessary especially in the case of concrete with vegetal aggregates.

The study involved the development of 7 micro concrete compositions, as follows:

- 1 recipe of reference micro concrete, RC, with 320.19 kg/m³ cement and 706.77 l/m³ mineral aggregates with maximum diameter of 8 mm, which served as a starting and comparison basis for micro concrete compositions made with sunflower stalk aggregates as a partial and total replacement material for mineral aggregates.
- 6 micro concrete recipes with sunflower aggregates (granules smaller than 5mm and fibers smaller than 25 mm obtained by sunflower stalks shredding and then treated with sodium silicate solution) as a replacement material for conventional aggregates by 20%, 35%, 50%, 65%, 80% and 100%, noted with SFC20, SFC35, SFC50, SFC65, SFC80 and SFC100, respectively.

2.2. Methods

2.2.1. Determination of the apparent density of the fresh and hardened micro concrete. The apparent density measuring of the fresh and hardened micro concrete was determined according to [4] and [5] and consisted in determining the mass of a micro concrete sample and relating it to the volume of the respective sample in compacted state.

For the determination, a watertight metal container of cylindrical or parallelepiped shape (including the molds for the molding of the tests on mechanical strengths) having the smallest dimension equal to at least four times the maximum size of the concrete aggregate granules was used. As a result, it was taken the arithmetic mean of 3 determinations, rounded with max. ±5 kg/m³.

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2.2.2. *Determination of compressive strength.* Micro concrete specimens were tested under mono-axial compression, with a hydraulic concrete press that carries a uniformly distributed load on the surface of the specimen, figure 1, according to [6]. The specimens were loaded perpendicularly, in the casting direction casting, figure 2.

For the evaluation of the compressive strength, the average of three tests was calculated. The value of the compressive strength was determined using the formula (1) [6]:

\[
f_c = \frac{F_{\text{max}}}{A_c} \left[ \frac{N}{\text{mm}^2} \right]
\]

where \( F \) – maximum force applied to the specimen, expressed in [N]; \( A_c \) – the compressed area perpendicular to the direction of application of the load, expressed in [mm²].

![Figure 1. Micro concrete testing for compressive strength.](image)

2.2.3. *Determination of flexural tensile strength.* The determination of the flexural tensile strength was done on prisms simply recessed, subjected to bending by applying a concentrated force in the middle of the opening, according to the standard. The rupture occurred in the maximum bending moment section, through a crack that appeared in the stretched area, under the concentrated force, splitting into two tubes, figure 2.

According to [7], the flexural tensile strength, \( f_{cf} \), is given by the relation (2):

\[
f_{cf} = \frac{3}{2} \cdot \frac{F_b}{d_1d_2} \left[ \frac{N}{\text{mm}^2} \right]
\]

where \( F_b \) – breaking force, expressed in [N]; \( l \) – distance between the two supports, expressed in [mm]; \( d_1, d_2 \) – the average width, respectively the average height of the cross-section, expressed in [mm].

![Figure 2. Specimens tested for flexural tensile strength.](image)
2.2.4. Determination of the splitting tensile strength. The determination of tensile strength by splitting was performed on cylinders with a diameter of 100 mm and a length of 200 mm. This test consisted of compressing a specimen after two diametrically opposed generators, as it is seen in figure 3.

![Figure 3. Micro concrete samples testing to splitting tensile strength.](image)

Splitting tensile strength ($f_{ct}$) was calculated using the formula (3) [8]:

$$f_{ct} = \frac{2F_b}{\pi bh} \left[ \frac{N}{\text{mm}^2} \right]$$

where $F_b$ – breaking force, expressed in [N]; $\pi$ – value of pi number; $b$ – the average width of the breaking cross section, expressed in [mm]; $h$ – the average height of the breaking cross section, expressed in [mm].

The tests were performed according to the [8]. For testing, a hydraulic press was used, recording the value of the breaking force. The breaking force was applied perpendicular to the direction of casting of the concrete, continuously and evenly, until breaking. The average of the results of three tests was calculated and then interpreted.

2.2.5. Determination of the micro concrete’s resistance to freeze-thaw cycles. The determination of the freeze-thaw resistance of the micro concrete samples (figure 4 and figure 5) was carried out in accordance with the provisions of [6] and [9]. This test was performed by measuring the variation of the compressive strength of the micro concrete samples (figure 6). To perform the tests, 10 cm cube-shaped specimens were used.

The working method required that all micro concrete specimens be placed in the water bath at (20±5)°C, four days before the actual testing began.

The water level was initially up to 1/4 of the height of the specimen, after 24 hours it increased to 1/2 of the height of the specimens, then up to 3/4, followed by 3 days after the initial introduction into the water the specimens were at least 20 mm in totality below the water level. To achieve full saturation, they were kept completely immersed in water for 24 hours.

![Figure 4. Concrete samples held in refrigerated enclosure at (-17)°C.](image)
Figure 5. Micro concrete samples kept in a water bath at (20±5)°C.

The air temperature in the refrigerator was adjusted so that it gradually dropped in about 1 h to (-17)°C, and then constant for 3 h. After the freeze cycle, the thaw begun by completely immersing the samples in water, at a temperature of (20±5)°C, for 4 hours.

Samples were subjected to 50 freeze-thaw cycles.

The loss of compressive strength (\(\eta\)) was determined by the formula (4) [9]:

\[
\eta = \frac{R_m - R_t}{R_m} \times 100
\]

(4)

where \(R_m\) – the average compressive strength of the reference samples [N/mm²]; \(R_t\) – the average compressive strength of the samples subjected to freeze-thaw cycles [N/mm²].

Figure 6. Compressive strength testing of the micro concrete samples subjected to 50 freeze-thaw cycles.

3. Experimental results

3.1. The micro concrete density

Figure 7 graphically represents the values of the density of micro concrete compositions, recorded at the time of casting and after the maturation period of 28 days. As for the density of micro concrete compositions with sunflower aggregates, it registered significant decrease, both at casting and after 28 days, between 11% and 60%.

For a percentage of mineral aggregates replacement with vegetable aggregates of over 35%, lightweight micro concrete compositions were obtained.

The increase of the percentage of plant aggregates caused the density decrease from 1845.3 kg/m³ to 822 kg/m³ for micro concrete made only with plant aggregates.
3.2. Micro concrete compressive strength

Figure 8 exhibits how the values of compressive strengths of the mortar samples tested at the age of 28 days are plotted. Micro concrete with vegetable aggregates showed significant decreases in compressive strength, being closely related to their density. For a percentage of replacement of mineral aggregates up to 50%, compressive strengths between 14.8% and 5 N/mm² were recorded. A replacement of 20% of the mineral aggregates led to a decrease of this parameter by around 24% of the obtained concrete, while a 100% replacement value to around 95% decrease. The micro concrete with 50% sunflower aggregates obtained a compressive strength value of 5.48 N/mm², very similar with Autoclaved Cellular Concrete.

3.3. Micro concrete flexural tensile strength

The values of flexural tensile strength are presented in figure 9. Flexural tensile strength registered a 17.48% decrease in case of SFC20, 49.50% in case of SFC50 and 90.21% in case of SFC100.
3.4. Micro concrete splitting tensile strength

The values of splitting tensile strength are presented in figure 10. The 20% and 35% of the mineral aggregates’ replacement had positive influence over the splitting tensile strength of these micro concrete compositions. A value of 50% of sunflower aggregates led to a small decrease of this parameter by around 14%, and 65% to a decrease of 50%. The micro concrete compositions with 80% and 100% of plant aggregates led to a very strong decrease of the splitting tensile strength of around 90%.

![Figure 10. Splitting tensile strength of the micro concrete [N/mm²].](image)

3.5. Freeze-thaw resistance of the micro concrete

Figure 11 indicates the values registered at the compressive test by the micro concrete samples subjected to 50 freeze-thaw cycles, comparatively to each of their reference samples that were kept in relative constant temperature and humidity.

The sunflower stalk aggregates improved the freeze-thaw resistance in the case of 20% using. While RC compressive strength decreased by 22.80% as compared to their reference samples, SFC20 registered a decrease of this parameter by 8.34%. SFC35 and SFC50 had a compressive strength decrease of 31.68% and 39.17%, respectively, with around 9% and 16% smaller than RC. The micro concrete compositions with over 65% of sunflower aggregates did not resist to the 50 cycles of freeze-thaw.

![Figure 11. Freeze-thaw resistance of the micro concrete [N/mm²].](image)
4. Conclusions

The experimental tests revealed that the sand replacement from the reference micro concrete composition with sunflower stalks granules led to the following conclusions:

- A lightweight micro concrete was obtained for replacement volumes bigger than 35%, with densities between 1845.30 kg/m³ up to 822 kg/m³ in the case of total replacement.
- Compressive strength of the samples decreased along with plant aggregates increasing quantity. A 50% replacement of the sand led to an almost 75% smaller value of this parameter.
- In case of the flexural tensile strength, a decrease resulted as well, SFC50 registering around 50% smaller value than RC.
- The sunflower granules led to an improvement of the splitting tensile strength in the case of 20% and 35% replacement rate due to the presence of the sunflower stalk fibers; till this replacement level, these fibers had an positive influence on this parameter.
- In the case of SFC 20, the tested samples obtained a higher resistance to the 50 freeze-thaw cycles, the compressive strength decrease comparative to their own reference sample being by 14.46% smaller than RC.

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