A study on the effects of the cement and mineral aggregates replacement with waste materials

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Abstract. Concrete is a large-scale building material with an important impact on environment mainly due to the production technology of cement and also because it consumes depleting mineral resources as aggregates. Therefore, it is necessary to find ways to replace some of its components in order to diminish its pollution effect. One of these is the partial replacement of cement with other cementitious materials and/or the replacement of mineral aggregates with renewable ones. The aim of this study was to investigate the effects on density, compressive strength, and split tensile strength of the concrete in the case of cement replacement by fly ash in a proportion of 10%, 20% and 30% of the volume, in the case of aggregates replacement by 20% of the volume with aggregates made of waste, and then these two cases combined. Even if the experimental results revealed the decrease of mechanical properties by replacing cement and the mineral aggregates, the smaller density of the developed concretes represents an important advantage.

1. Introduction

All over the world a general concern is to find solutions to decrease the environmental pollution and greenhouse gas emissions. In building materials industry this means the development of sustainable and ecological products. A sustainable and ecological building material is that in whose production are used non-depleting, low cost, and locally available raw materials, and its manufacture process implies reduced greenhouse gas emissions and a low level of energy consumption.

Concrete is a building material which has an important impact on the environment in all respects: its usual raw materials are of depleting category, the cement used in its composition is not very cheap or everywhere available, and its manufacturing process is a very high energy consumer, releasing very large quantities of CO₂. All these issues can be partially solved by finding alternative cementitious materials (instead of cement) and renewable raw materials for the partial or total mineral aggregates replacement. Among the cementitious materials, there are numerous alternatives, from industrial by-products such as fly ash (FA), blast furnace slag or silica fume, to plants ashes such as corn cob ash, wheat ash, rice husk ash, and others. For mineral aggregates replacement, there are even more possibilities, from new produced lightweight aggregates like expanded perlite, expanded clay or expanded polystyrene, to industrial by-products like blast furnace slag, or different types of waste (glass, plastics, lignocellulosic materials or agricultural waste). If the availability criterion is taken into account, FA can be used as cementitious material in Romania because it is a by-product derived from the thermal power plants, a still very large industry in this country. FA is an industrial waste generated
by the coal combustion in thermal power plants. Its production efficiency/output coal: FA is 1:0.3-0.4 [1] which means that for every ton of burned coal, it results 0.3 - 0.4 tons of FA that is disposed as landfills, leading to important land occupation and environmental pollution [2].

FA physical and chemical properties vary according to the properties of the burned coal [1]. FA has some advantages over the Portland cement, such as lower heat of hydration, which can lead to a higher strength concrete (depending on the ash class), and it is widely available and cheaper than conventional cement. As disadvantage, it develops a slower rate of concrete strength, but by using additives, the hydration rates can be accelerated [3].

All over the world many investigations in very different directions have been made to find alternative solutions for mineral aggregates replacement. A relative new approach is the use of plants for this purpose, the main advantages this presents for concrete manufacturing being represented by their high renewability, availability, low cost and low density [4]. Among the plants used in building materials development are: hemp, kenaf, flax, jute, banana, sisal, pineapple, cotton, rice [4, 5].

Maize represents a very important crop in Romania, in 2015 this country being on the second position in EU-28 production [6]. Corn cob represents an agricultural waste, 15% of the total corn production. Its principal constituents are: 39.1% cellulose, 42.1% hemicellulose, 9.11% lignin, 1.7% protein and 1.2% ash [7]. Corn cobs density of 212 kg/m³ and their high content of 77.52% oxygen promote them for being used in lightweight concrete production. They have a very high water absorption capacity of over 327% after 15 days of immersion, but also a quite good resistance of about 5 minutes to direct flame exposure, compared to a few seconds of the expanded polystyrene [8].

According to the above-mentioned reasons, corn cob may be considered an alternative material for mineral aggregates used in concrete composition if there are found solutions to minimize its main disadvantage, namely the high capacity of water absorption.

The aim of this study was to investigate the effects on density, compressive strength, and split tensile strength of the concrete in the case of cement replacement by fly ash in 10%, 20% and 30% by volume, in the case of aggregates replacement by 20% by volume with aggregates made of waste and then these two cases taken together. Although, there were many studies on the effects of FA on the concrete, the present research used this type of concrete as reference for the concrete recipes with 20% by volume of corn cob aggregates and FA. The novelty of this paper is represented by the analysis of the effects of FA on the vegetal concrete with 20% by volume of corn cob aggregates.

2. Materials and methods

The present research aimed to investigate the effects of fly ash and corn cobs on the concrete mechanical properties. For this purpose, starting from a reference concrete strength class 25/30, produced according to Romanian Standard NE012-1: 2007, were developed concrete recipes with 10%, 20% and 30% vol. cement replacement by FA, a concrete recipe with 20% vol. of mineral aggregates replacement by corn cob aggregates and then these two variants were combined in order to study the interconnection between fly ash and corn cobs.

The RC contained the following components:

- Portland cement CEM II/A-LL 42.5R, with granulated blast furnace slag and limestone, produced in Romania;
- natural sand (0-4 mm diameter) and gravel (sort 4-8 mm) extracted from riverbeds;
- water as to ensure a water/cement ratio of 0.43;
- additives: a policarboxilate based superplasticizer (Sika Plast 140) and a rhodanid based accelerator (Sika BE5); the superplasticizer was used to obtain a smaller water/cement ratio and to improve the concrete 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 eight concrete compositions, as follows:

- RC – a reference concrete of strength class 25/30;
- CFA10 – a concrete with 10% vol. of FA as cement partial replacement;
- CFA20 – a concrete with 20% vol. of FA as cement partial replacement;
• CFA30 – a concrete with 30% vol. of FA as cement partial replacement;
• CCC20 – a concrete with 20% vol. of corn cob granules as partial replacement of mineral aggregates;
• CCCFA 20-10 – a concrete with 20% vol. of corn cob granules as partial replacement of mineral ones and 10% vol. of FA as partial replacement of cement;
• CCCFA 20-20 – a concrete with 20% vol. of corn cob granules as partial replacement of mineral ones and 20% vol. of FA as partial replacement of cement;
• CCCFA 20-30 – a concrete with 20% vol. of corn cob granules as partial replacement of mineral ones and 30% vol. of FA as partial replacement of cement.

The source of the used FA was Holboca Thermal Power Plant, Iasi County, Romania.

The vegetal aggregates were made of corn cobs shredded in granules smaller than 5 mm and then treated with 40% sodium silicate solution in order to diminish their very high absorption capacity of 294% to 127% comparative to their dry weight. The apparent density of the corn cob aggregates was 398.43 kg/m³.

The concrete was poured into cylinder moulds with 100 mm diameter and 200 mm length. There was measured the apparent density and then tests were performed to determine compressive and splitting tensile strength, according to SR EN 12350-6 and SR EN 12390 part 3 and SR EN 12390 part 7, respectively. Three samples were tested for each property mentioned above. Because the samples dimensions were different to those required by 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. The concrete density

The concrete density evolution from pouring up to the age of 28 days it is shown in figure 1. It can be observed that the slope degree of the density evolution is particular for each concrete recipe.

![Figure 1. The evolution of concrete density, from casting till 28 days of curing [kg/m³].](image-url)
RC registered a 1.2% density decreasing along the 28 days curing period, while the CCC20 a 2.63% smaller density. The smallest density decreasing of all was that of CFA10, by 0.58%, and the biggest one that of CCCFA 20-30, by 5.6%. Of the CFA category, the highest diminish was of CFA20, by 3.74%. Of the CCCFA group, the smallest diminish was of CCCFA20-10, by 3.20%.

According to figure 2, the increasing volume of the cement replacement by FA determined a decrease of the concrete density; the smallest density of the CFA group was registered by CFA30 with a value of 2118.47 kg/m³, by 3.82% smaller than of the RC. The concrete recipe with only corn cobs registered a density diminish by 9.1% compared to RC. It seems that the association of FA with corn cobs aggregates had very positive effects, whereas the group of CCCFA registered the smallest density of all, under 2000 kg/m³, with a decrease between 12.93% and 10.70% compared to RC.

![Figure 2. Concrete density at 28 days, [kg/m³].](image)

3.2. Concrete compressive strength

The values of compressive strength of the developed concrete recipes are presented in figure 3. One can notice that FA led to the decrease of this property by 7.98%, 17.47%, and 34.19% for 10%, 20%, and 30% vol. of cement replacement, respectively. The 20% vol. of mineral aggregates replaced by corn cob ones determined a strong compressive strength diminish, by 61.12%. FA association with corn cob aggregates revealed even smaller compressive strength than CCC20, between 2.55% and 24.72%, compared to CCC20.

![Figure 3. Compressive strength of the concrete [N/mm²].](image)
3.3. **Concrete splitting tensile strength**

The values of splitting tensile strength are presented in figure 4. Regarding this property, FA decreased the RC performance. The concrete recipe with 20% vol. corn cob aggregates registered a diminished splitting tensile strength by a little more than 50%. By using cement replacement with FA in the concrete with corn cobs, it was obtained an improvement of the above mentioned property by 4.9% and 23.53% in the case of using 20% vol. and 10% vol. of FA instead of cement, respectively.

![Figure 4. Splitting tensile strength of the concrete [N/mm²].](image)

4. **Conclusions**

The aim of this study was to investigate the effects on density, compressive strength, and split tensile strength of the concrete in the case of cement replacement by fly ash in 10%, 20% and 30% by volume, in the case of aggregates replacement by 20% by volume with aggregates made of waste and then these two cases combined. There were quantified their effects on density, compressive strength, and split tensile strength of the obtained concrete.

According to the obtained experimental results, the more fly ash was added for cement replacement, the more the density of the concrete decreased. The association of fly ash with corn cobs aggregates had very positive effects on reducing the concrete density after 28 days of curing. FA led to the decreasing of the concrete compressive strength but added a plus to the RC performance in terms of concrete splitting tensile strength, when using 10% vol. and 20% vol.; by using cement replacement with FA in the concrete with corn cobs, it was obtained an improvement of the splitting tensile strength.

Even if FA concretes registered smaller values for mechanical properties, but still appropriate for structural use, their advantage is the smaller density than RC, that lead to lighter structures, with positive effect on the seismic building behaviour. The concretes with fly ash and corn cobs were lightweight concretes, with possibilities of use in non-structural purposes like closures, wall finishes and concrete screeds.

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