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PRELIMINARY STUDIES OF HEMP AND RECYCLED AGGREGATE CONCRETE

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Abstract
This paper reports on preliminary tests conducted on Hemp and Recycled Aggregate Concrete (HRAC), a sustainable concrete material prepared by partial replacement of natural coarse aggregates (NA) with recycled concrete aggregates (RCA) and incorporating hemp fibers in the concrete mix. The aim of this study was to evaluate the effect of such replacement on the hardened mechanical properties of concrete. For this purpose, six concrete mixes were prepared, where natural coarse aggregates were partially replaced by RCA or by hemp fibers or by both and where the hemp fiber length was varied between 20mm and 30mm. For each mix, specimens were prepared and tested for compressive strength, modulus of elasticity, flexural strength and splitting tensile strength. The results showed that a replacement of 50% of NA by RCA decreased the compression strength and the modulus of elasticity by around 10%, while the inclusion of hemp fibers decreased them by 25%. HRAC mixes had a compression strength 30% lower than the control mix. While the flexural strength and the splitting tensile strength also decreased by an average of 10% when 50% of NA was replaced by RCA, although the inclusion of hemp fibers had no significant negative effect on the modulus of rupture. As for fiber length, 30mm length fibers showed slightly better results for compression strength and modulus of elasticity, opposed to the flexural and tensile strengths which were higher with 20mm fibers.

Keywords:
Sustainable concrete materials; recycled aggregates; hemp fibers.

1 INTRODUCTION

Like many other industries, the construction industry is rendering its practices towards being more sustainable and environment friendly. Thus, many efforts are being made aiming towards minimizing the depletion rate of natural resources and lessening the negative social and environmental impacts. In light of these efforts, the commonly used conventional concrete mixes have been claimed to be non-environmental friendly due to several concerns related to the depletion of natural resources and high energy consumption needed for the production of its raw materials. Examples of sustainable techniques that are used to reduce the impact of concrete production on natural resources include the use of renewable resources, the implementation of energy efficient systems, the use of recycled materials, and the use of “green” construction materials such as concrete mixes incorporating natural fibers.

Construction and demolition wastes (CDW) can be defined as a mixture of surplus materials generated during new construction, renovation, and demolition of buildings, roads, bridges, and other structures [Cheng et al. 2013]. Moreover, the construction sector produces another source of cementitious based CDW that comes from quality control procedures. Common practice requires the sampling and laboratory testing of standard cylinders. These tested cylinders constitute a significant portion of the dumped CDW. CDW are generated worldwide and have become an environmental burden. Therefore, the incorporation of such wastes in concrete mixes has become a commonly proposed dual solution in minimizing waste disposal and conserving natural resources.

The compressive strength of recycled aggregate concrete is on the average 10% less than those of concrete with only natural aggregates, while the reduction in the modulus of elasticity is less than that [Rahal et al. 2007].

Furthermore, the mechanical properties of concrete decrease with the increase of the percentage of replacement of natural aggregates by recycled concrete aggregates [Etxeberria et al. 2007].

On the other hand, the use of natural fibers in concrete has significantly increased in the recent years. It is considered an advantage since it saves on natural resources and in most cases these fibers are considered as waste materials and have a very low cost compared to other type of synthetic fibers which are made from other raw materials.

The effect of adding hemp fibers into plain concrete mixes was of interest in a few studies. It was found that the compressive strength and the modulus of elasticity tests results of the hemp concrete decreased with respect to normal concrete while the splitting tensile strengths were similar [Awwad et al. 2012].

Other studies investigated the effect of the incorporation of natural fibers like wood, banana, sisal, jute and bamboo in concrete [Bilba et al. 2007 and Savastano et al. 2008].

Natural fibers, specifically hemp, are also used as composite materials in several construction applications [Li et al. 2006 and Sedan et al. 2008].

2 MATERIALS AND MIX PROPORTIONS

All recycled coarse aggregates used in this research were from the same source. Normal strength concrete cylinders were collected and stored at a local ready mix plant. The cylinders were the waste product of regular tests conducted at the batching plant on mixes prepared and delivered to the different clients. After collection, the cylinders would be crushed to a maximum size of 20mm.

The properties of the natural and recycled concrete aggregates used in the study are presented in Table 1.

Tab. 1: Coarse aggregates properties

	NA	RCA
Specific gravity (Oven-Dry)	2.59	2.30
Absorption (%)	1.93	5.37
Dry rodded unit weight (kg/m^3)	1653	1401
Wear (%) (Los Angeles Abrasion)	22.16	29.04

Hemp fibers were imported from Hemp Traders, USA and cut the lengths of 20mm and 30mm and then treated and soaked in a sodium hydroxide solution (NaOH) at 6% by weight for 48 hours. The fibers were then washed using distilled water and left to dry at ambient temperature. The hemp fibers have a density of about 1,400 kg/m^3.

The cement was a general use (GU) type, according to the American Society for Testing and Materials [ASTM C150].

For mixes containing fibers, the percentage of fibers in the mix is 0.75% by volume of concrete with a reduction of the volume of coarse aggregates by 20% by volume of concrete, which are the optimal percentages found by the study of [Awwad et al. 2012].

The percentage of replacement of natural aggregates by RCA is 50% in mixes containing recycled concrete aggregates.

The different mixes are presented in Table 2 and the batching weights for each mix are presented in Table 3.

Tab. 2: Percentage of RCA and hemp length for the different mixes

Mix Name	% Replacement of NA by RCA	Hemp fiber length (mm)
N	0	No Fibers
R	50	No Fibers
N-H20	0	20
R-H20	50	20
N-H30	0	30
R-H30	50	30

3 EXPERIMENTAL PROGRAM

3.1 Compressive Strength

For each mix, 3 cylinders (10x20 mm) were cast and cured in water and then tested at 28 days according to [ASTM C39 2010].

3.2 Modulus of Elasticity

For each mix, 2 cylinders (15x30 mm) were cast and cured in water and then tested at 28 days according to [ASTM C469 2014].

3.3 Flexural strength

For each mix, 3 standard beams (10x10x35 mm) were cast and cured in water and then tested at 28 days according to [ASTM C78 2016]. The test setup is shown in Figure 1.

3.4 Splitting tensile strength

For each mix, 2 cylinders (10mm * 20mm) were cast and cured in water and then tested at 28 days according to [ASTM C496 2017].

Fig. 1: Flexural strength test setup

Tab. 3: Batching weights in kg per meter cube of concrete for each mix

	Cement	Water	NA	RCA	Sand	Fibers
N	400	216	905	0	763	0
R	400	216	452.5	452.5	763	0
N-H20	400	216	585	0	763	10.5
R-H20	400	216	292.5	292.5	763	10.5
N-H30	400	216	585	0	763	10.5
R-H30	400	216	292.5	292.5	763	10.5

Tab. 4: Mechanical strength tests results

	Compression (MPa)	Modulus of Elasticity (GPa)	Modulus of Rupture (MPa)	Splitting Tensile (MPa)
N	39	33.2	5.25	2.64
R	35	31.4	4.60	2.53
N-H20	28	26.0	5.10	2.51
R-H20	25	23.7	4.65	2.31
N-H30	32	27.2	4.95	2.30
R-H30	26	24.3	4.50	2.10

4 RESULTS AND DISCUSSION

The results of the mechanical strength tests are shown in Table 4 and Figure 2.

4.1 Compressive Strength

The replacement of 50% of NA by RCA reduces the compressive strength of concrete by approximately 12%, while the incorporation of hemp fibers reduces it by an average of 25%. HRAC mixes containing both RCA and hemp fibers have a compressive strength 30% lower than the control mix.

Additionally, mixes containing 30mm fibers had a slightly higher compressive strength than those containing 20mm fibers.

4.2 Modulus of Elasticity

Similar to compressive strength tests, mixes with partial replacement of NA by RCA have a modulus of elasticity 10% lower than the control mix. HRAC mixes resulted in a 27% decrease in the modulus of elasticity with respect to the control mix.

4.3 Flexural Strength

The modulus of rupture decreases by 10% for RCA mixes, although it is not affected when hemp fibers are incorporated. It can also be noticed that 20mm fibers have a better effect on the flexural strength compared to 30 mm fibers.

Figure 3 shows the difference in the state after rupture between a beam containing hemp fibers and one not containing fibers.

4.4 Splitting Tensile Strength

The replacement of 50% of NA by RCA reduces the splitting tensile strength of concrete by around 10%, with fiber incorporation also decreasing it by an average of 10%.

Fig. 3: State after rupture with fibers (top), without fibers (bottom)

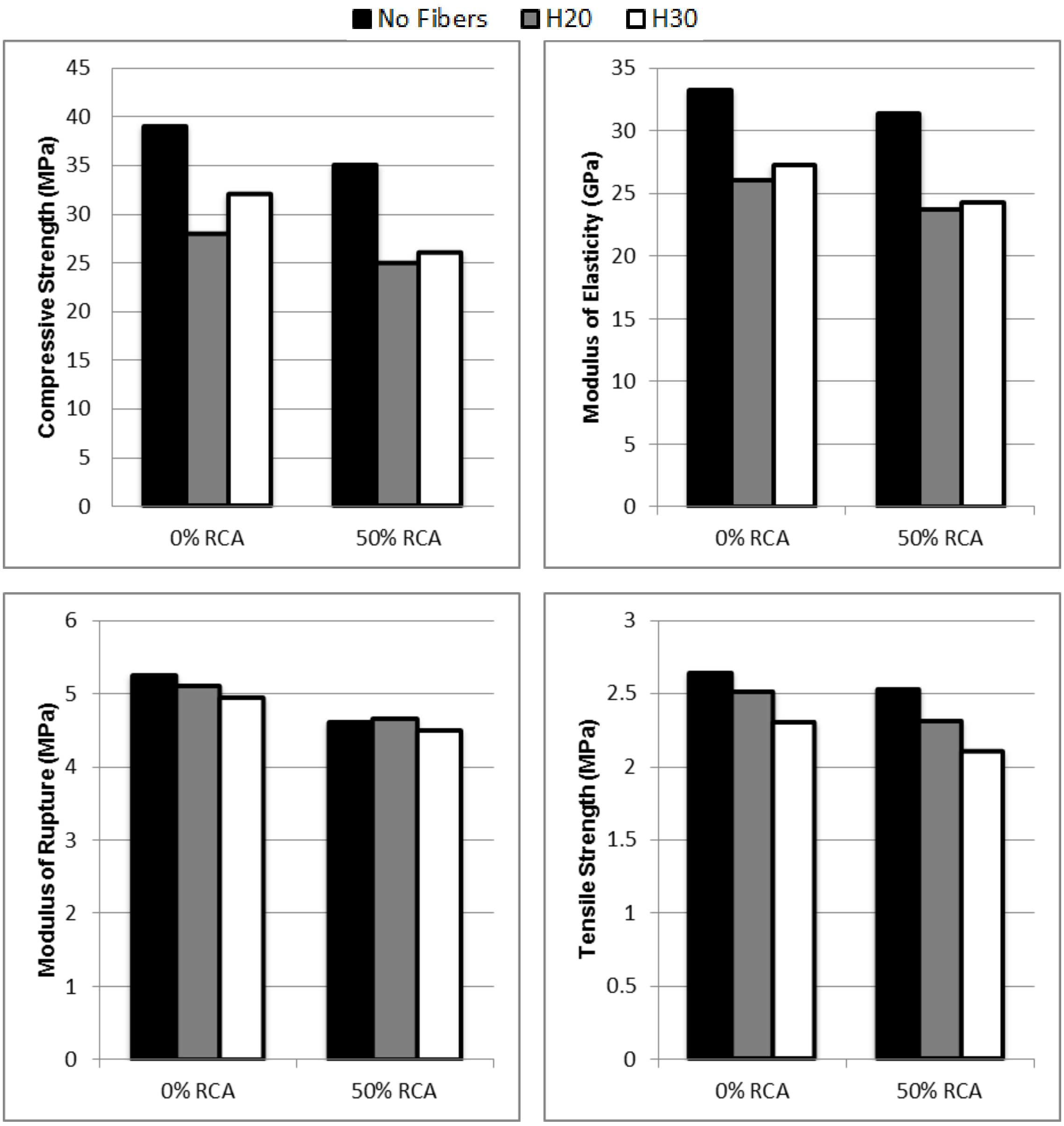

Fig. 2: Mechanical strength tests results

5 CONCLUSIONS

In the reported study, the mechanical properties of HRAC, prepared by partial replacement of natural coarse aggregates with a combination of recycled concrete aggregates (RCA) and hemp fibers were studied.

The hemp fibers were added in a volumetric percentile of 0.75 of the concrete volume, with a coarse aggregate reduction of 20% of the concrete volume.

The percentage of replacement of NA by RCA used was 50%.

Based on test results, it was concluded that the decrease in the compressive strength and modulus of elasticity of HRAC compared to normal concrete mix is significant (around 30%).

On the other hand, the decrease in the modulus of rupture and splitting tensile strength is less significant (10 to 15%).

Further research is needed to study other factors affecting the mechanical properties of HRAC, such as the chemical treatment used on the fibers and the interaction between the maximum size aggregate and the hemp fiber length.

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