PRELIMINARY STUDIES ON THE USE OF NATURAL FIBERS IN SUSTAINABLE CONCRETE

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ABSTRACT

The paper reports on preliminary tests performed to produce a sustainable "green" concrete material using natural fibers such as industrial hemp, palm, and banana leaves fibers. Such material would increase the service life and reduce the life cost of the structure, and would have a positive effect on social life and social economy. The demand for the agricultural fibers for concrete production would be a major incentive to Lebanese farmers to benefit from the social impact on the habitat level of living. In the preliminary program reported in this paper, cubes and standard flexural beams were tested to evaluate the structural and physical performance of concrete mixes prepared with different volumetric ratios of added fibers and different proportions of aggregates. Test results indicated that the use of natural fibers resulted in reducing the coarse aggregate quantity without affecting the flexural performance of concrete. However, no clear trend was determined in the cubes compressive strength test results.

Keywords: sustainable materials, natural fibers, energy efficiency, building systems, construction industry

INTRODUCTION

The word "sustainable" is becoming very common worldwide. The trend goes beyond the practice of design and construction, since the awareness of the current population is a crucial factor for the success of this tendency. Sustainable building systems can have a direct implication on the betterment of livelihood conditions of communities. Unfortunately, the extraction of natural aggregates has lead to establishing human-made quarries that have drastic environmental impact on the nature and surroundings. This issue has been of major concern worldwide and particularly in Lebanon. Therefore, the aim of this research is to focus on creating or leading the way to find solutions and means for a better sustainable construction design.

BACKGROUND

Sustainable materials are currently widely considered and investigated in construction engineering research. Some examples of sustainable research worldwide are the use of recycled concrete aggregates, coal fly ash, ground clay brick and pervious paver block system (http://proquest.umi.com).

Further, substantial research work has been conducted on fiber-reinforced concrete which is a concrete primarily made of a mix of hydraulic cement, aggregates, water and reinforcing fibers. Fibers used are typically produced from steel and synthetic fibers such as polypropylene, nylon or fiberglass. Fiber reinforced concrete satisfies the strength, ductility and durability requirements of a high performance concrete material. Moreover, fiber reinforced concrete including mainly steel, glass or other synthetic fibers, in addition to natural fibers, have been used in many applications such as slabs on grade, airports and pavements, tunneling, rock stability and shotcrete works (ACI 544.1R, 1996).

The current research on sustainable concrete using natural fibers falls within the interest of researchers at the American University of Beirut (AUB).

LITERATURE REVIEW

The first use of fibers in reinforced concrete has been dated to 1870's. Since then, researchers around the world have been interested in improving the tensile properties of concrete by adding wood, iron and other wastes (Naaman & Harajli, 1990). Local interest has been demonstrated through research work performed at AUB by Hamad *et al.* (2001 ; 2003), and Harajli & Salloukh (1997). In addition to industrial fibers, natural organic and mineral fibers have been also investigated in reinforced concrete. Wood, sisal, jute, bamboo, coconut, asbestos and rockwool, are examples that have been used and investigated (Zhu & Tobias, 1994; Al Rim *et al.,* 1999; Bilba *et al.,* 2007; Savastano Jr. *et al.,* 2008).

One interesting sustainable material gaining wide acceptance and currently adopted in Europe is the industrial hemp. The main characteristics of the hemp fiber are strength, durability and resistance to ultraviolet light. In Europe and China, hemp fibers are used to strengthen cement and are used as composite materials in many construction applications (Sedan *et al.,* 2008; Li *et al.,* 2006; Pickering *et al.,* 2007). Hemcrete blocks have been developed to provide high insulation and acoustic properties (Elfordy *et al.,* 2008; www.limetechnology.co.uk).

OBJECTIVES

The main aim of the research on sustainable materials is to investigate the use of natural fibers with cement/concrete mixes to improve the performance of construction components and reduce the depletion in natural resources. The output may be considered to fit the criterion of sustainable building design since, when compared with regular cement or concrete mixes, it is expected to: (i) improve physical characteristics and structural performance thus requiring less material; (ii) reduce material and energy resources depletion; (iii) provide a material with better thermal property and therefore increase energy efficiency; and (iv) contribute to sustainable living through improving livelihood conditions of rural and farming communities by using agricultural or recycled waste products.

MEASURABLE INDICATORS

The effect of natural admixtures usage on concrete mixes can be interpreted mainly by the reduction of aggregates quantities. Consequently, producing similar or even better mixes with less aggregate quantities results in a sustainable concrete. The use of local natural fibers in concrete would increase the demand for natural fibers that are plentifully available such as palm and banana trees leaves, in addition to hemp crops that can be locally harvested (MoA/UNDP Report, 2009). Hemp would be an advantageous substitute to its sister illegal drug plant. Growing hemp requires no pesticides, replenishes the soil with nutrients and nitrogen, controls erosion of the top soil and produces a lot of oxygen. The demand for the hemp and other fibers for concrete production would be a major incentive to Lebanese farmers to grow this plant and benefit from the social impact on the habitat level of living.

EXPERIMENTAL PROGRAM

Concrete trial mixes with different volumetric ratios of natural admixtures were prepared to assess the adequacy and practicality of mixing with natural fibers in the research. In all trial mixes, a unique concrete mix was adopted. The batching weights per cubic meter of concrete were: 880 kg medium coarse aggregate (coarse oven-dry density = 1600 kg/m^3), 810 kg sand, 400 kg cement, and 272 liters water (w/c = 0.68).

The variables in the trial test program included the type of fibers, the volumetric ratio of the added fibers and the reduction in the amount of coarse aggregates measured as a percentage of the volume of concrete. The variables are shown in Table 1.

Five types of fibers were used in the trial mixes: polypropylene fibers (Harbourite® 320) of density 0.905 g/cm^3 (as per manufacturer), steel fibers (Dramix ZP 305) of density 7.84 g/cm^3, hemp fibers of density 1.4 g/cm^3 (as per manufacturer), banana leaves fibers of density 0.70 g/cm^3 (as determined in laboratory), and palm leaves fibers of density 0.80 g/cm^3 (as determined in laboratory). Fibers average length (L) and diameter (d) are 3 cms and 0.6 mm, respectively, *i.e.,* an aspect ratio (L/d) of 50 was targeted.

The natural fibers were treated and soaked in a sodium hydroxide solution (NaOH) at 6% by weight for 48 hours. After soaking, the fibers were washed with water and left to dry.

The industrial hemp fibers were provided by the United Nations Development Program and Ministry of Agriculture (UNDP/MoA) project; the fibers were imported from Stemergy Renewable Fibre Technologies, Canada. The palm and banana leaves fibers were cut and prepared at the laboratory. Also, one trial mix was prepared with local hemp fibers, provided by UNDP/MoA project. As an example on the volumetric ratio of the fibers, if a parameter of 1% is used, it implies that the corresponding fibers volume is determined as 1% of the concrete volume. Then the fibers weight is determined by multiplying the fibers volume by the fibers density.

TABLE 1

Identification of the Trial Mixes

Mix No.	Mix Type	Fibers (%)	Coarse Aggregate Reduction (%)	Types of Test Specimens			
				Cube 10d	Beam 10d	Cube 28d	Beam 28d
1	Polypropylene	1.0	-	1	1	1	1
2	Steel	0.5	-	1	1	1	1
3	Control	-	-	1	1	1	1
4	Control	-	-	3	3	3	3
5	Control	-	-	2	2	2	2
6	Hemp	0.5	-	1	1	1	1
7	Hemp	0.5	10	2	2	2	2
8	Hemp	0.5	20	2	2	2	2
9	Hemp	0.75	-	2	2	2	2
10	Hemp	0.75	20	1	2	2	2
11	Hemp	1.0	20	1	2	2	2
12	Local Hemp	0.5	-	2	2	2	2
13	Palm	0.5	-	3	3	3	3
14	Palm	0.5	10	3	3	3	3
15	Palm	0.5	20	3	3	3	3
16	Palm	1.0	-	2	2	2	2
17	Banana	1.0	-	2	2	2	2

Two tests were conducted using the prepared trial mixes: the flexure strength test using beams (20x5x5 cm) and the compressive strength test using cubes (7x7x7 cm). The specimens were tested at 10 and 28 days. The mixes are presented in Table 1.

TEST RESULTS

The compressive strength results presented in Table 2 indicate that the cubes tests prepared with different fibers, different fibers volumetric ratios and different reductions in coarse aggregate, showed large variations in the test results as compared to the control specimens with no fibers. The variation in the results could be attributed to the relatively small size of the cube which may result in erroneous data compared with 15x30 cm standard cylinders. However, one could still conclude that the performance of cubes prepared with 0.75 or 1% hemp fibers and 20% reduction in coarse aggregate is satisfactory as compared with cubes prepared using the control mixes, in addition to the cubes with 1% banana, 1% palm and 0.5% palm with (10-20)% reduction in coarse aggregate.

According to Naaman & Harajli (1990), compressive strength improvement implies an increase in modulus of elasticity, strain at maximum stress and toughness of stress-strain curve. However, some fibers such as steel, glass and polypropylene do not improve compressive strength based on testing cylinders results. The compressive strength results cannot be predicted and determined with only cubes (7 cms); additional research will be needed, based on more representative samples, such as standard cylinders.

TABLE 2

Cubes Compression Strength at 10 & 28 Days Age

Compression Tests (Kg/cm^2)		
	10 days	28 days
Control 1	226	233
Control 2	294	331
Control 3	310	359
1% Polypropylene	172	202
0.5% Steel	280	213
0.5% Hemp	164	211
0.5% Hemp-10% coarse	222	277
0.5% Hemp-20% coarse	176	173
0.75% Hemp	262	370
0.75% Hemp-20% coarse	275	350
1% Hemp-20% coarse	240	329
0.5% Local Hemp	268	380
0.5% Palm	208	271
0.5% Palm-10% coarse	199	256
0.5% Palm-20% coarse	203	274
1% Palm	250	341
1% Banana	254	329

The flexural test results are graphically presented in Figures 1 and 2. The use of the natural fibers in concrete mixes has beneficial effects with respect to increasing the flexural strength and providing a ductile post-cracking behavior of the fiber reinforced concrete mix, especially for the industrial hemp samples. Similar to the compression tests, specimens prepared with 0.75 or 1% hemp fibers and 20% reduction in coarse aggregate provided relatively good results. As for samples prepared with 0.5% palm with (10-20)% coarse aggregate reduction and with 1% banana fibers, the results were satisfactorily but to a lesser extent. It is worth noting that the increase in the flexural strength has been evident in the 28 days tests more than in the early 10 days tests, which could be attributed to the fact that the interfacial bond between the fibers and the concrete matrix is more mature after 28 days.

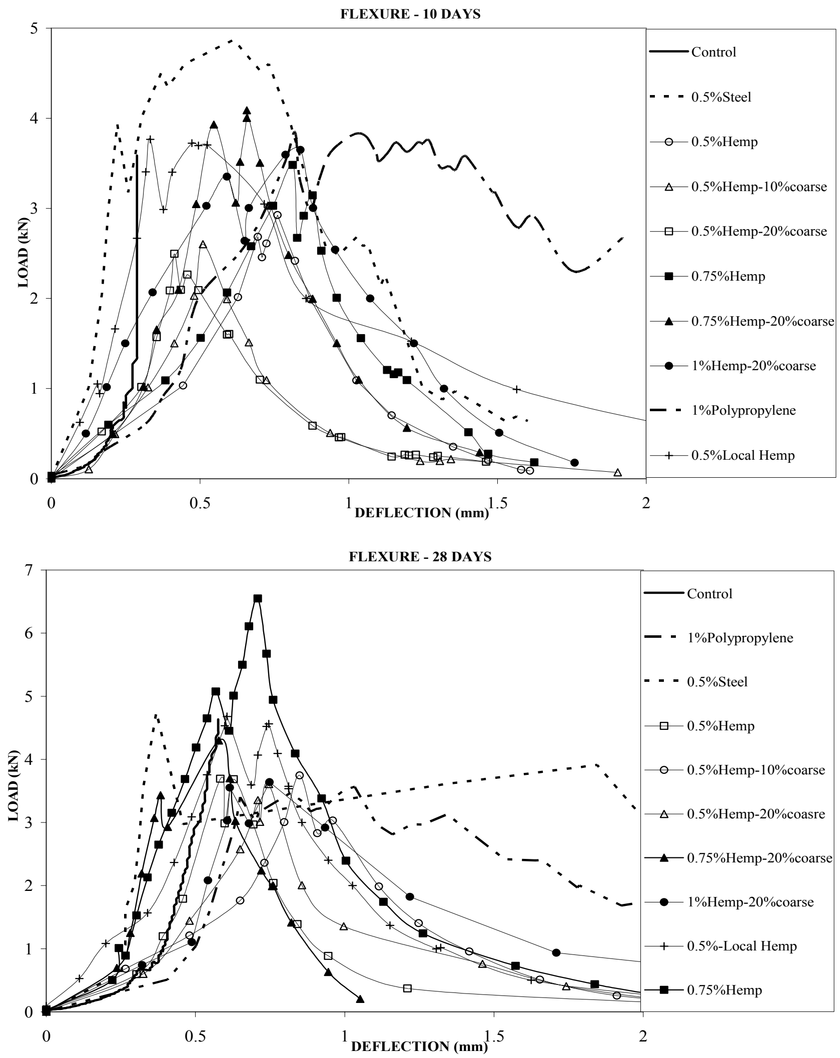
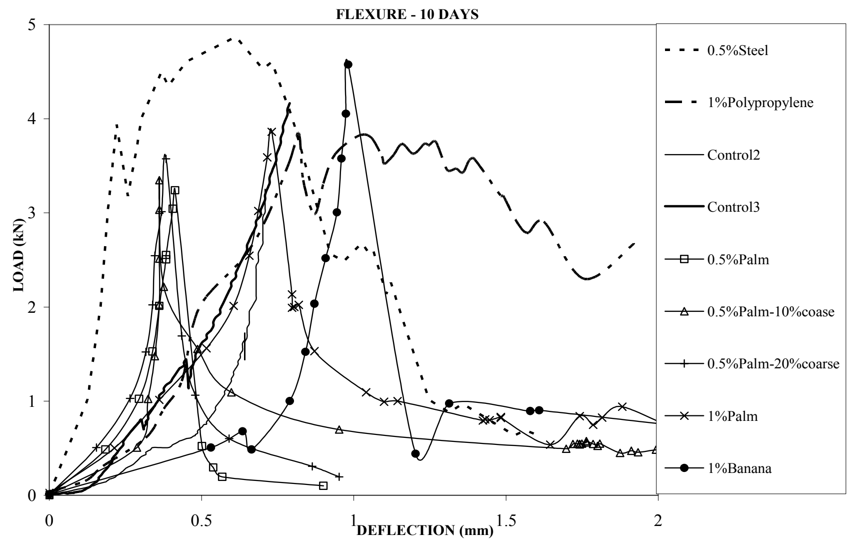


Figure 1. Flexural load-deflection curves of beams tested at 10 and 28 days, for hemp fibers.



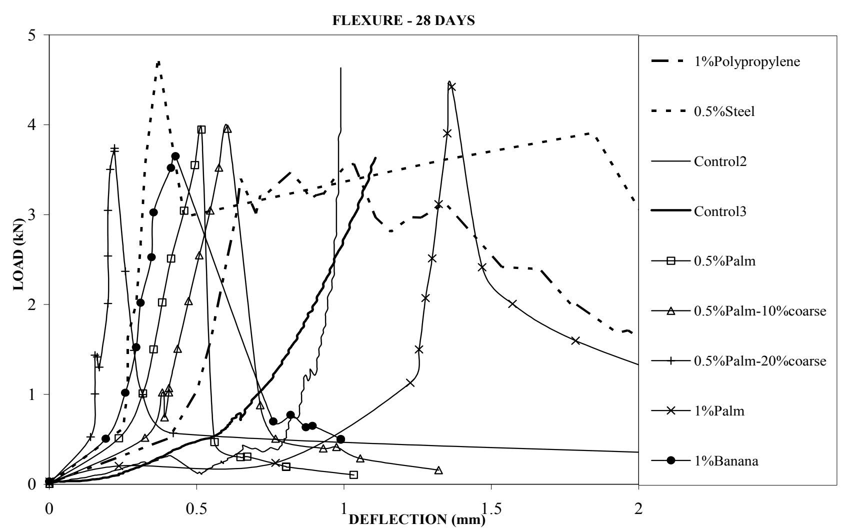


Figure 2. Flexural load-deflection curves of beams tested at 10 and 28 days, for palm and banana fibers.

Moreover, the use of natural fibers allowed the reduction of coarse aggregate quantity without affecting the flexural load-deflection performance; thus, reducing the natural resource consumption and resulting in a sustainable concrete material. As for the other natural fibers, palm and banana, the post-cracking behavior was less than that of the industrial hemp. It is obvious from both Figures 1 and 2, that the industrial hemp performance is better at the post-cracking phase compared to palm and banana samples. However, it does not mean that the palm and banana fibers are not effective, at least they provided a post-cracking behavior that is not sudden compared to the control samples.

The research results are mainly significant in proving the use of the industrial hemp fibers as an additive to the concrete mix while saving about 20% of the coarse aggregates, provided that the strength characteristics and performance are almost not affected. Besides, the post-crack behavior is more ductile, and can allow the new concrete mix to absorb more dynamic load and not allowing a sudden failure.

In this preliminary research, no statistical analysis was performed due to the limited number of samples with different fibers and coarse reduction percentages.

CONCLUSIONS AND RECOMMENDATIONS

Based on the preliminary test results, the use of industrial or local hemp fibers in concrete mixes would result in promising compression and flexural strength values and behavior and reduction in the consumption of coarse aggregates, as compared to the control samples in addition to the palm and banana samples. However, due to the variation in the test results of the small specimens, it is recommended to conduct more research. Further research shall include standard 15x30 cm cylinder tests and standard 15x15x50 cm flexural beams. Tests shall include Slump Test, Density, Brasilian Test, Flexural Test, Compression Test, and Modulus of Elasticity Test. Besides, the Thermal Conductivity properties can be investigated using 5x5x30 cm block Test. The future research shall be presented in other papers to be published upon completion of the testing program.

The preliminary test results for palm and banana fibers were acceptable but not as with the industrial hemp fibers; moreover, the preparation process of the fibers is not simple and needs to be updated to include mechanical processing for large quantities production. Also, it is worth noting that the palm and banana fibers are thicker and less dense than the hemp fibers, which could be the main reason behind the better performance of industrial hemp fibers samples.

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