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Sustainable Construction Material Using Hemp Fibers – Preliminary Study

Elie Awwad[1], Bilal Hamad[2], Mounir Mabsout[3], and Helmi Khatib[4].

[1]*Ph.D. Candidate – Sustainable Materials, Civil and Environmental Engineering, American University of Beirut, P.O. Box: 11-0236, Riad El-Solh, 1107 2020, Beirut, Lebanon, Tel: 961-3-890917, <eaa01@aub.edu.lb>*
[2]*(Corresponding Author) – Professor of Structures and Materials, Civil and Environmental Engineering, American University of Beirut, P.O. Box: 11-0236, Riad El-Solh, 1107 2020, Beirut, Lebanon, Tel: 961-1-350000/3460, <bhamad@aub.edu.lb>*
[3]*Professor of Structures, Civil and Environmental Engineering, American University of Beirut, P.O. Box: 11-0236, Riad El-Solh, 1107 2020, Beirut, Lebanon, Tel: 961-1-350000/3460, <mounir@aub.edu.lb>*
[4]*Laboratories Manager, Civil and Environmental Engineering, American University of Beirut, P.O. Box: 11-0236, Riad El-Solh, 1107 2020, Beirut, Lebanon, Tel: 961-1-350000/3462, <he00@aub.edu.lb>*

ABSTRACT

The paper reports on preliminary tests performed to produce a sustainable "green" concrete material using natural industrial hemp 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 industrial hemp 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.

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 through the choice of proper design, materials, construction techniques, and operations and maintenance of building systems. 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. It is common knowledge that quarries have bitten and depleted a significant portion of Lebanon's natural mountains and resources, a problem that is not easily repaired and in some cases impossible to recover. 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 of the issues in the construction industry that are of interest to 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. Adding such materials to concrete should result in a randomly, discrete, and discontinuous orientation of fibers whose main function is to bridge across cracks that develop in concrete, either as it is loaded or as it experiences environmental changes. Therefore, 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].

Recently, several preliminary research efforts at the American University of Beirut (AUB) have focused on sustainable building systems. They primarily examined sustainable design, innovative construction materials, and energy efficiency considerations. One research program tested the effect of using exchanged car motor oil on concrete mixes as an air-entrained agent. Results indicated that the used engine oil acted as a plasticizer, increased the air content, resulted in average losses in flexural strength, splitting tensile strength, and modulus of elasticity, yet the concrete compressive strength was not affected. The research findings were reported by Hamad et al. [2003a & 2003b]. Moreover, the sustainability theme was selected by FYP (Final Year Project) undergraduate teams at AUB which proves the increasing interest in the subject [Abou Assali et al. 2008, Boulghourdjian et al. 2009, and O. Abukar et al. 2009].

The variety and breadth of "sustainability" initiatives, from modest academic projects to limited research and practical building studies and implementations, have generated increased interest and set a path for researchers at AUB to address the topic using a more structured and sustained approach. This is leading to introduce further interdisciplinary initiatives that are focused on sustainable design.

LITERATURE REVIEW

The first use of fibers in reinforced concrete has been dated to the 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 [A. Naaman et al. 1990]. Local interest has been demonstrated through research work performed at AUB by Hamad et al. [2001 and 2003], and Harajli et al. [1997]. Research work covered the use of steel, glass, carbon, and polypropylene fibers and their effect on the structural behavior of reinforced concrete elements. 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 [W.H. Zhu et al. 1994, K. Al Rim et al. 1999, K. Bilba et al. 2007, and H. Savastano Jr. et al. 2008].

One interesting sustainable material gaining wide acceptance and currently adopted in Europe is the industrial hemp. Fibers can be extracted from the hemp plant and possibly used in concrete mixes. The fiber is one of the most valuable parts of the hemp plant (also called blast). Hemp fibers can be from 1 to 5 m long, running the length of the plant. 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, Z. Li et al. 2006, and K.L. Pickering et al. 2007]. One example of hemp usage is the manufacturing of concrete blocks in France. Hemcrete comprises a unique blend of specially prepared hemp and a special lime based binder, which together form a bio-composite building material. Hemcrete blocks have been developed to provide high insulation and acoustic properties. In Europe, buildings are being constructed using hemcrete blocks which end up to be fully insulated from the outside and no heating or cooling systems are used inside the building unit [Elfordy et al. 2008 and www.limetechnology.co.uk].

OBJECTIVES

The main aim of the research on sustainable materials is to investigate the use of natural fibers as stand-alone elements or with cement/concrete mixes to improve performance of construction components and reduce depletion in natural resources. The objective of this research is to identify new materials or create novel cement/concrete mixes that encapsulate sustainable elements while satisfying strength and improving performance requirements such as durability and thermal properties.

The new material is to be produced using elements that are naturally available such as agricultural industrial hemp. 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. Moreover, once hemp crops are found to be satisfactory in concrete mixes, the local harvesting of hemp is recommended. 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 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.

A preliminary feasibility study was set by the United Nations Development Program (UNDP) and the Ministry of Agricultural (MoA) project; it shows that the cost to produce industrial hemp is about $79 per dunum (1000 square meters & non-irrigated lands) and the corresponding products value is about $192 which include seeds and stalks, raw material to produce respectively oil and fibers [MoA/UNDP Report, 2009]. Therefore, the farming of industrial hemp is a beneficiary business, and would be strongly supported if additionally the use of hemp fibers in concrete would be proved to be satisfactory, resulting in demand increase and a prospering agricultural crop. A prospering and renewable agricultural crop that has multi-uses and endless array of applications starting from oil production and its applications in food market and medicine, clothes production from fibers, insulation materials used in automobile and building application, paper production, textiles production, and many others.

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/m3), 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.

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

Three types of fibers were used in the trial mixes: polypropylene fibers of density 0.905 g/cm^3 (as per manufacturer), steel fibers of density 7.84 g/cm^3, and hemp fibers of density 1.4 g/cm^3 (as per manufacturer). The natural hemp 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 UNDP/MoA project, the fibers were imported from Stemergy Renewable Fibre Technologies, Canada. One trial mix was prepared with local hemp fibers. An example on the volumetric ratio of the fibers follows: 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.

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.

The flexural test results are graphically presented in Figure 1. The use of the industrial hemp 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. Similar to the compression tests, specimens prepared with 0.75 or 1% hemp fibers and 20% reduction in coarse aggregate provided relatively good results. 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. Moreover, the use of industrial hemp 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.

Table 2. Cubes Compression Strength at 10 and 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

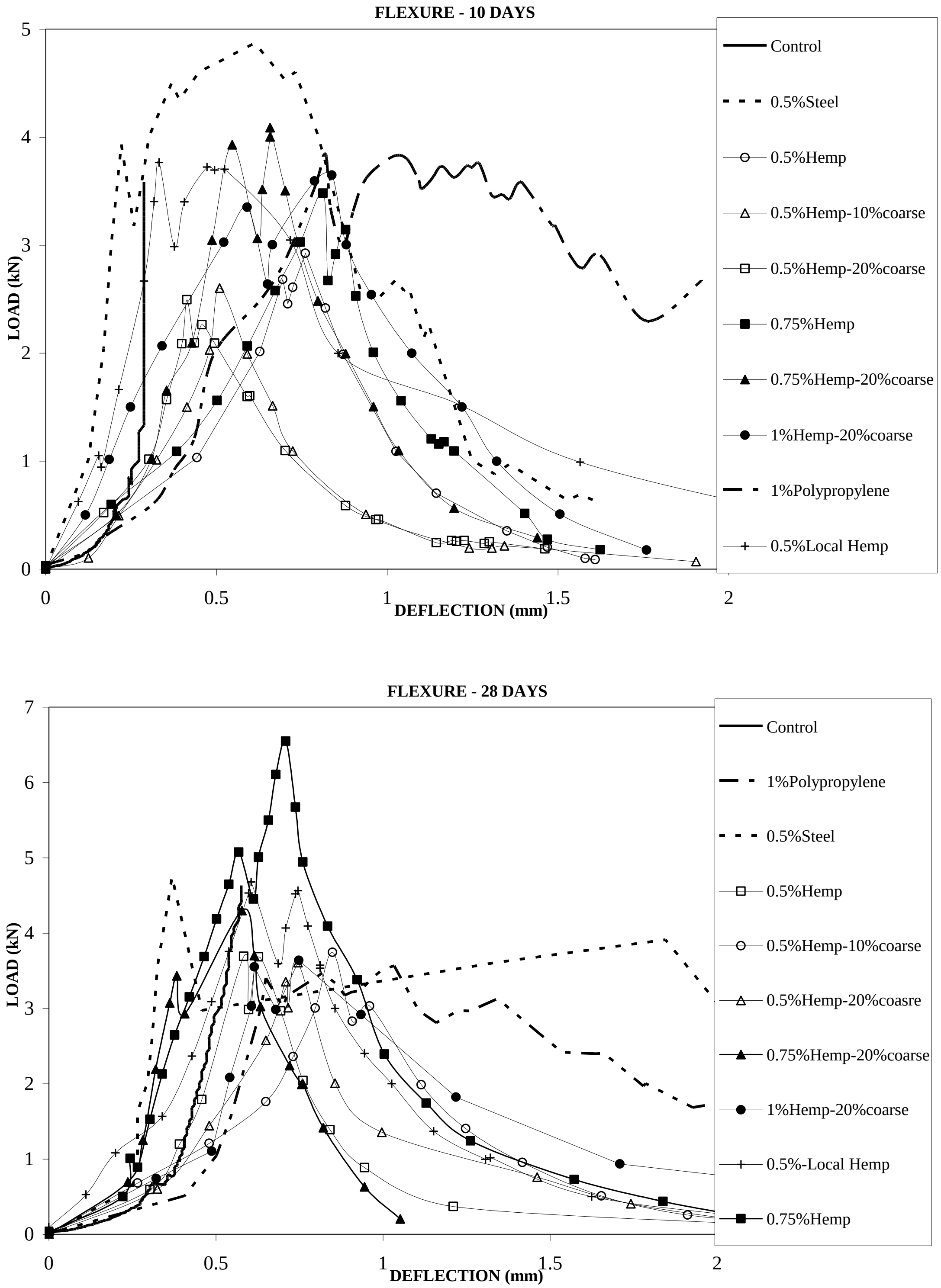

Fig. 1. Flexural Load-Deflection Curves of Beams Tested at 10 and 28 Days

It is worth noting that the compressive strength value and the flexural load-deflection behavior of the specimens prepared using the local industrial hemp fibers, produced under the supervision of the UNDP and MoA were significant; however, further future samples are required to confirm the results.

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. However, due to the variation in the test results of the small specimens and due to the relatively small number of tests, it is recommended to conduct more research to build up more significance to the test results. 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.

REFERENCES

Abou Assali, M., Al Akhdar, M., Dakhil, H., and Kazma, H. (2008). “Bechtel Building from Conventional to Sustainable.” *Final Year Project Report*, American University of Beirut, AUB (CIVE502, Project Co-supervisors: B. Hamad and M. Mabsout).

Abukar, O., Batal, R., Hamad, S., and Mousharafieh, J. (2009). “The Development of a Sustainable Housing Compound in Choueifat.” *Final Year Project Report*, American University of Beirut, AUB (CIVE502, Project supervisor: M. Mabsout).

Al Rim, K., Ledhem, A., Douzane, O., Dheilly, R.M., and Queneudec, M. (1999). “Influence of the Proportion of Wood on the Thermal and Mechanical Performances of Clay-Cement-Wood Composites.” *Cement & Concrete Composites*, Volume 21, pp. 269–276.

American Concrete Institute (ACI). (1996). A State-of-the-Art Report on “Fiber Reinforced Concrete.” *ACI Committee 544.1R-1996*.

Bilba, K., Arsene, M.A., and Ouensanga A. (2007). “Study of Banana and Coconut Fibers Botanical Composition, Thermal Degradation and Textural Observations.” *Bioresource Technology*, Volume 98, pp 58–68.

Boulghourdjian, N., Dabaghi, M., and Rbeiz R. (2008). “Sustainable Development of the AUB - AREC Farm.” *FEA Eighth Student Conference Proceedings*, American University of Beirut, AUB (Co-supervisors: M. Mabsout and B. Hamad).

Elfordy, S., Lucas, F., Tancret, F., Scudeller, Y., and Goudet L. (2008). “Mechanical and Thermal Properties of Lime and Hemp Concrete (Hempcrete) Manufactured by a Projection Process.” *Construction and Building Materials*, Volume 22, pp. 2116–2123.

Hamad, B.S., Harajli, M., and Jumaa, G. (2001). “Effect of Steel Fibers on Bond Strength of Tension Lap Splices in High Strength Concrete.” *ACI Structural Journal*, Volume 98, No. 5, September-October 2001, pp. 638–647.

Hamad, B.S., Najjar, S., and Jumaa, G. (2003). “Correlation between Roles of Transverse Reinforcement and Steel Fibers in Confining Tension Lap Splices in High Strength Concrete.” *ACI Structural Journal*, Volume 100, No. 1, January-February 2003, pp. 19–24.

Hamad, B.S., Rteil, A.A., and El Fadel M. (2003a). “Effect of Engine Oil on Properties of Fresh and Hardened Concrete.” *Construction and Building Materials*, Volume 17, pp. 311–318.

Hamad, B.S., and Rteil, A.A. (2003b). “Effect of Used Engine Oil on Structural Behavior of

Reinforced Concrete Elements." *Construction and Building Materials Journal*, Elsevier Publications, Volume 17, Issue 3, March 2003, pp. 203–211.

Harajli, M.H., and Salloukh, K.A. (1997). "Effect of Fibers on Development/Splice Strength of Reinforcing Bars in Tension." *ACI Materials journal*, Volume 94, No. 4, pp. 317–324.

Karaki, S., Ghaddar, N., Moukalled, F., and Chaaban, F. (2007). "Energy Analysis of AUB Buildings." Report produced by *Energy Research Center*, American University of Beirut.

Li, Z., Wang, X., and Wang, L. (2006). "Properties of Hemp Fibre Reinforced Concrete Composites." *Composites: Part A – Applied Science and Manufacturing*, Volume 37, pp. 497–505.

Ministry of Agriculture and United Nations Development Program. (2009). "Production and Marketing Assessments for Industrial Hemp in Lebanon." *A State-of-the-Art MoA/UNDP Report*.

Naaman, A., and Harajli, M. (1990). A State-of-the-Art Report on "Mechanical Properties of High Performance Fiber Concrete." *University of Michigan*, USA.

Pickering, K.L., Beckermann, G.W., Alam, S.N., Foreman, N.J. (2007). "Optimising Industrial Hemp Fibre for Composites." *Composites: Part A – Applied Science and Manufacturing*, Volume 38, pp. 461– 468

Savastano, H.Jr., Warden, P.G., Coutts, R.S.P., (2005). "Microstructure and Mechanical Properties of Waste Fibre Cement Composites." *Cement & Concrete Composites*, Volume 27, pp. 583–592.

Sedan, D., Pagnoux, C., Smith, A., and Chotard, T. (2008). "Mechanical Properties of Hemp Fibre Reinforced Cement: Influence of the Fibre/Matrix Interaction." *Journal of the European Ceramic Society*, Volume 28, pp. 183–192.

Zhu, W.H., and Tobias, B.C. (1994). "Air-Cured Banana Fibre Reinforced Cement Composites." *Cement and Concrete Composites*, Volume 6, pp. 3–8.

U.S. Green Building Council. (2005). "LEED® for New Construction & Major Renovations." *Leadership in Energy and Environmental Design (LEED)*, version 2.2, October 2005.

< www.limetechnology.co.uk >

< http://proquest.umi.com >