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Concrete Masonry Blocks Reinforced with Local Industrial Hemp Fibers and Hurds

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ABSTRACT

The current research reports a study on green concrete masonry blocks produced with industrial hemp fibers and hurds. The behavior of hemp-reinforced masonry blocks is investigated. The incorporation of hemp in concrete would result in aggregates reduction and save natural resources. Raw and unprocessed hemp material was used. The compressive strength, water absorption, density, and the thermal conductivity of the hemp masonry blocks are monitored. Four concrete mixes were prepared: a control mix (no fibers) and three hemp-concrete mixes with about 1%, 2%, and 4% hemp material by concrete volume. The mixing criteria considered the practical concerns as for the masonry blocks manufacturing plant in the local market. The tests results confirm the potential of incorporating raw hemp material in local masonry blocks while satisfying minimum strength, water absorption, density, and reducing thermal conductivity requirements.

Keywords. Sustainable materials, natural fibers, industrial hemp, fibers volume fraction, aggregate reduction, thermal conductivity, construction industry.

INTRODUCTION

The rapid ascending interest in sustainable development has been the case in many developed countries. It is due to the fact that the depletion of raw materials and resources has been extensive and almost non-controllable leading to major environmental impacts and concerns. For example, the production of paper, power, and concrete has exploited natural resources such as trees, fossil fuel, and rock aggregates, respectively. Sustainable development aims at saving natural resources without negatively affecting the living standard of societies and communities.

Sustainable construction materials are gaining more interest worldwide because of their positive environmental impact and alleviation role. Sustainable materials must complement the performance requirements and the saving of natural resources. In the construction industry, concrete is one of the main components that contribute to the natural resources depletion due to the large amounts of aggregates consumed during the production process. Besides, the cement production contributes to the greenhouse gas production affecting global warming and climate change, i.e. every one ton of cement production results in about one ton of CO_2 emission. The current trend is to produce a durable concrete of high performance, instead of a very high strength concrete and less durable. Durable concrete is expected to last longer and to sustain its quality when exposed to freeze and thaw, chlorides and chemical attacks, and dynamic and impact loads, without being deteriorated. Sustainable materials and buildings are characterized by their long-term cycle cost and durability, compared to traditional materials where the initial cost is only of concern. Using concrete for construction is causing rapid material depletion and is leading to drastic environmental impact on the nature and surroundings. This issue has been of major concern worldwide and particularly in the local context of Lebanon.

Sustainable concrete material may be described as a concrete recycled from existing concrete material, or a green concrete produced by incorporating waste materials and reducing the use of natural aggregates. In general, it is of interest to produce a new material with an acceptable performance while saving on natural resources. The reduction of aggregates agrees well with some of the sustainable interests, while the use of agricultural fibers agrees with the development of agricultural activities and farming prosperity.

The addition of industrial hemp fibers and hurds into concrete masonry blocks would result in the reduction of the aggregate material used and the improvement of thermal properties, similarly to hemp-fiber-reinforced concrete (Awwad, 2010 & 2011). It is worth noting that in the current research, the hemp material is added as raw material, without any treatment, in order to simplify the manufacturing process. The use of hemp as an agricultural waste material in concrete masonry blocks would promote a wide market for industrial hemp usage.

Concrete masonry blocks are mainly used, as non-load bearing members, for partitioning and external façade, in any construction job. When the thermal properties of the masonry units are improved, the result is mainly reflected in improving the insulation potential of the building units. Consequently, the demand for air conditioning would be decreased resulting in major savings with respect to fuel demand and consumption. Specifically, nowadays fuel crisis have been reflected in the sharp increase in the fuel prices worldwide and locally, which has exhausted the economical status of developing countries, affecting mostly the poor community. Besides, the addition of hemp material to the masonry units may result in light-weight masonry units, which are sought for and favored as non-load bearing units in the construction field; for example with high-rise buildings where the load is very crucial in designing concrete structural elements.

Locally, non-load bearing masonry units are extremely and mainly used in all construction projects for partitioning jobs.

The aim of this research is to investigate some of the performance characteristics of industrial hemp-reinforced concrete masonry blocks, in terms of compressive strength, density, water absorption, and thermal conductivity. The output may set a corner stone for further research.

BACKGROUND

The conventional trend for the production of any material focuses on its properties, shape, strength, and other "practical" concerns, while ignoring the raw material availability and the potential for its depletion. However, nowadays the trend is shifting toward finding production technologies which encapsulate the saving on natural resources. Many researchers are interested in investigating non-conventional construction materials, one of which is the use of industrial hemp fibers and hurds in construction materials applications. One example is Hempcrete used as a construction material containing hemp hurds, especially in France. Hempcrete is a mixture of hemp hurds and lime (possibly including sand, pozzolan or cement) used as a material for construction and insulation. It is marketed under various names such as Hemcrete and Isochanvre. The hempcrete material is known to have good thermal insulation properties. In addition to its thermal properties, the hempcrete block may be considered as a lightweight material due to the partial substitution of some of the concrete aggregate materials with the hemp fibers or hurds (Allin, 2005). Other applications include the use of hemp fibers instead of asbestos fibers with the cement mortar. Also, the inner core or the shive part of the harvested hemp plant is blended with materials like lime to produce hempcrete, a building composite suitable for the creation of walls, floors, roof insulation and plasters. Hemp-based products have been used for centuries in timber-framed buildings and for restoration purpose.

The first use of Fiber-Reinforced Concrete (FRC) dates back to the 1870s. Since then, research work attempted to improve the tensile strength of concrete by adding iron waste, wood, steel wires, and other material. Fibers used in concrete were artificial such as steel, iron, carbon, glass and others, and natural such as bamboo, jute, coconut, sisal, hemp and others. High performance fiber-reinforced concrete is intended to provide strength requirements, provide a durable concrete, and achieve a toughness behavior after the first crack point. The post-cracking behavior of fiber-reinforced concrete is of major interest. Compared to the plain concrete with no fibers, the fiber-reinforced concrete has a ductile behavior under tensile loading; whereas, the plain concrete has a brittle failure after the maximum load is reached (Naaman, 1990).

Synthetic fibers and natural fibers have been investigated and tried in both cement and concrete mixes. The advantage of using natural fibers, like jute, sisal, coconut, banana, hemp, and others in fiber-reinforced concrete is the saving on natural resources. Natural fibers are in most cases classified as waste materials compared to industrial or synthetic fibers that are produced from other raw materials. Due to their large availability, low cost, and renewable resources, natural fibers were considered in fiber-reinforced cements. In developing countries, many types of locally available natural vegetable fibers have been used in cement-based composites.

Most of the previous research on natural fibers applications has been conducted on fiber-reinforced cement rather than on fiber-reinforced concrete. Fiber-reinforced cements are mixes made of cement mortar in the absence of coarse aggregate. Sedan et al. (2008) investigated the use of hemp fibers in reinforced cement. The influence on the setting time of cement was investigated in the presence of hemp fibers. The hemp fibers were provided by la Chanvrière de l'Aube, France. The fibers density was found equal to 1.53 grams per cubic cm. As for the composite mechanical performance, an increase in the flexural strength was evident with optimal fiber content, whereas Young's modulus decreased in the fiber mix. Also, it was clear that the alkali treatment improved the fiber strength in addition to the fiber-matrix adhesion.

A research on concrete blocks made of a mixture of lime and hemp shives (also called hurds) using a projection process was performed. The blocks thermal and mechanical properties were measured such as flexural and compressive strengths, and hardness (Elfordy, 2008). The thermal and mechanical properties were found to increase with the density increase. A compromise between thermal insulation and mechanical properties should be defined, depending on the type of construction. If non-structural (non-load bearing) elements are intended, then low thermal conductivity and low strength blocks are favored; whereas, if the blocks are part of the structural integrity (load bearing) then denser, stronger, but with lower insulation properties blocks are adopted.

The suitability of bast fibers of flax and hemp for thermal insulation was evaluated in a separate research (Kymäläinen, 2008). The research found that the flax and hemp fibers were suitable for insulations due to their thermal properties.

In a latest full and local research, conducted at the American University of Beirut (Awwad, 2010 - 2012), the behavior of industrial hemp fibers incorporated in concrete mixes was investigated in terms of flexure, compressive, and tensile strength in addition to the modulus of elasticity, slump, and thermal properties. The hemp-reinforced concrete was tested as a stand-alone material, and then it was incorporated in structural beam elements in order to investigate the synergetic performance in the presence of steel reinforcement. It was found that the addition of hemp fibers up to 1.0% by volume of concrete allowed the possibility of reducing the coarse aggregate quantities up to 30% by volume of concrete. The presence of hemp fibers affected the new material properties such as strength, workability, and thermal conductivity. Although the compressive strength was partially reduced by the addition of fibers and the aggregate reduction, the compensation was reflected in the flexural performance. The flexure strength was not significantly decreased and moreover the failure was ductile instead of brittle. The ductile flexure failure is very favorable in most concrete structures and members, especially with the case of dynamic, impact, and fatigue loadings. In addition to ductility, the thermal conductivity of the new material was reduced, which implies a better insulation property and results in reduction of air conditioning load demand. The research ended by recommending the use of local hemp material in concrete masonry blocks as non-structural elements, used for partitioning jobs, due to the expected insulation and lighter weight properties.

A feasibility and economical study was set by MoA/UNDP report (2011), within the scope of the Sustainable Land Management Programme for Livelihood Development in Lebanon-Industrial Hemp Project, adopted the masonry hemp construction units and plaster production material, using hemp hurds and fibers. The study mentioned the mutli-benefits of hemp masonry blocks in terms of strength, thermal conductivity and others. Primary mixes for hemp masonry blocks and plaster material are provided, based on international research and documentations. Local research is still in its preliminary phases compared with international research, except one main research conducted by Awwad (2010 - 2012); thus, hemp-masonry blocks need further investigation. The current study sets a corner stone for hemp-masonry blocks local manufacturing potential, by focusing on local production process and availability of materials.

OBJECTIVES

The aim of this research is to investigate the potential of producing local hemp masonry blocks, using traditional mixes and local raw material. The hemp production has been launched and monitored locally. The stalk of the plant consists of fibers (soft and flexible) and hurds (hard and rigid). Many manual and automated processes have been set to separate and cut fibers and hurds (MoA/UNDP Report, 2009). However, this research focuses on the use of the plant stalk without any major mechanical processing or treatment. The stalks were only shredded using available and cheap agricultural cutting tool used primarily for cutting wood logs to produce sawdust. The output is a mix of fibers and hurds hemp materials. Thus, no special treatment was considered which would minimize the cost of hemp masonry blocks production. Although the use of fibers in concrete without prior treatment is not possible because the bond is weakened and the tensile properties are not enhanced in the presence of fibers (Awwad, 2010 - 2012), with the hemp masonry blocks the fibers are used only as space fillers and no improvement in tensile properties is expected. The main objective for using hemp material in masonry blocks is to reduce the aggregate consumption and the block density, while improving the thermal and acoustic properties. In this study, the strength, density, absorption, and thermal properties are considered and investigated.

EXPERIMENTAL PROGRAM

In Lebanon, the use of masonry blocks in construction is as non-bearing load or non-structural members, i.e. for partitioning works. Although in some rural areas, and very rarely, the masonry blocks have been used as structural walls members in the absence of any reinforced concrete vertical members, because of their high and adequate quality; however, masonry blocks are considered as non-bearing load type.

In the current research four mixes were planned to produce control and hemp masonry blocks. The masonry blocks produced are 40x20x10 cm (referred to as 10 cm blocks), classified as non-load bearing blocks, and the thermal blocks are produced with dimensions 30x30x5 cm. The tests performed are the compressive strength, density, and water absorption (ASTM C 90, C 129, and C 140), in addition to the thermal conductivity test (ASTM C 518).

The concrete mixes, considered in this study, consisted of a mix of blended fine and medium coarse aggregates, cement, and minimum water content. Water is only added to keep the particles wet and provide a zero slump for the mix. No sand was used in the mixes. Note that in other masonry plants, sand may be added. However, in this research all mixes were adopted and modified based on the control mix adopted in the masonry plant.

The control mix (mix 0) was prepared using about 80 Kg of fine and medium coarse aggregates, 6 kg cement, and minimum water to have a zero slump mix. The control mix produced 6 (10 cm) blocks and 1 thermal block (30x30x5 cm), i.e. equivalent to 8 (10 cm) blocks.

Mix 1 was prepared with the same constituents as for the control mix, in addition to 500 g of hemp material, which is about 1% by concrete volume, based on a hemp density of 1.4 g/cm^3 (Awwad, 2010 & 2011). Mix 1 output was 9 masonry blocks (no thermal block).

Mix 2 was prepared with about 80 Kg of fine and medium coarse aggregates, 7 Kg cement, and minimum water to keep zero slump mix, in addition to 1,000 g of hemp material, which is about 2% by concrete volume. Mix 2 output was 8 (10 cm) blocks and 1 thermal block (30x30x5 cm), i.e. equivalent to 10 (10 cm) blocks.

Mix 3 was prepared with about 40 Kg of fine and medium coarse aggregates, 5 Kg cement, and minimum water to keep zero slump mix, in addition to 1,500 g of hemp material, which is about 4% by concrete volume. Mix 3 output was 7 masonry blocks.

The average of three specimens is considered for a better statistical representation of the results. For example, the compressive strength of the masonry blocks is the average result of three specimens from every mix.

Table 1. Different Mixes of Masonry Blocks.

Mix	Fine & Medium Coarse		Cement		Hemp		Water	No. of Blocks 40x20x10 cm
	(Kg/m^3)	(Kg)	(Kg/m^3)	(Kg)	(g/m^3)	(g)	(L/m^3)	
0 (Control)	2210	80	170	6	NA	NA	50	8*
1	2210	80	170	6	1700	500	50	9
2	2210	80	198	7	3400	1,000	60	10*
3	1105	40	142	5	5100	1,500	43	7
*With 1 thermal block (30x30x5 cm), which is equivalent to 2 (40x20x10 cm) blocks.								

TEST RESULTS AND ANALYSIS

To monitor the quality of concrete masonry blocks, international standards are set and defined, one of which is the American Society for Testing and Materials (ASTM) standards. The monitoring tests considered in the current research are compression, water absorption, and density tests, in addition to the thermal conductivity test.

The compression strength test is performed to investigate the quality of the masonry blocks. It directly relates to the vertical compressive strength of the block, influencing the stand alone criteria of the blocks. ASTM C 129 sets a minimum criterion of 4.1 MPa, as an average of three specimens, or 3.45 MPa for individual specimen tests. Table 2 presents the results of the compression test, in terms of average, and lower and upper bounds, at 14 and 28 days of concrete age. It is worth noting that the addition of hemp material into the concrete mix is random; therefore, the location and orientation of fibers are random, knowing that the mixing process is optimized in order to best spread the hemp material. Besides, it is well known that natural fibers, when added to concrete mixes, may intermingle and undergo balling instead of mixing within the concrete matrix.

Table 2. Compression Test Results, ASTM C 129, at 14 and 28 Days Concrete Age.

Mix	Based on Net Area - At 14 days			Based on Net Area - At 28 days		
	Minimum (MPa)	Maximum (MPa)	Average (MPa)	Minimum (MPa)	Maximum (MPa)	Average (MPa)*
0	11.1	12.4	11.7	12.1	13.3	12.7^{a}
1	4.3	5.5	4.9	5.6	9.7	7.7^{b}
2	4.7	5.5	5.1	4.6	7.6	6.1^{bc}
3	2.5	2.6	2.6	3.0	3.8	3.4^{c}
* Means with common superscript letter are NOT significantly different.						

Thus, it is expected to have a wider variation in the compression results (difference between minimum and maximum values) compared with those of the control mix (no hemp). As illustrated in Figure 1 and compared with ASTM C 129, the average results do satisfy the specifications requirements, except for mix 3. The compression results are satisfactory, knowing that the raw hemp material was used, without any processing or treatment.

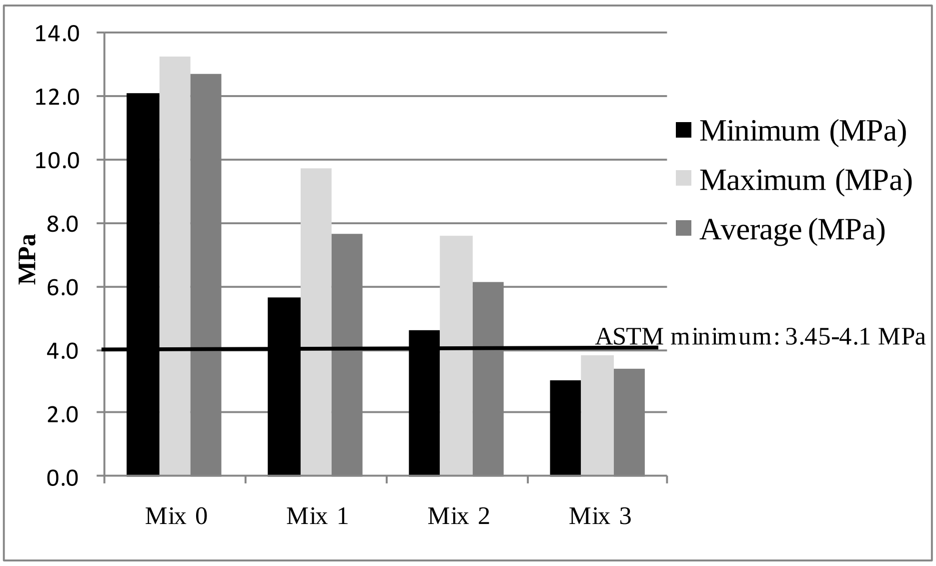

Figure 1. Compressive Strength Test Results – 28 Days, ASTM C129.

A statistical analysis was performed for the compression test results, at 28 days of concrete age. The general linear model procedure for one-way ANOVA (Analysis of Variance), Tukey, and Scheffè tests methods were adopted to compare the means of all mixes, with a 95% level of confidence (Bluman, 2007). Referring to Table 2, the following can be determined:

- All hemp mixes mean results are significantly different from that of the control (mix 0).
- The mean result of mix 1 is significantly different from those of all other mixes, except the mean result of mix 2.
- The mean result of mix 3 is significantly different from those of all other mixes, except the mean result of mix 2.

The statistical analysis shows the significant decrease in the compression results due to the addition of hemp material, compared with the control (no hemp) mix. It is expected that when the hemp fibers are added, the compression results decrease (Awwad et al., 2010 - 2012); expected since the addition of hemp material (soft part) partially replaces the aggregate material (hard part) in the mix. Moreover, mixes 1 and 2, and similarly mixes 2 and 3, are not significantly different. Among the hemp mixes, mix 2 is not significantly different from mixes 1 and 3. The best optimum mix would be the one where the added quantity of hemp material would be available to compensate the reduction in coarse aggregates, while the mix would still be workable and adequate.

ASTM C 90 and C 129 set minimum criteria for the water absorption and oven-dry density of masonry blocks. Accordingly, the oven-dry density ranges are below 1680, 1680 to 2000, and more than 2000 Kg/m^3 for light, medium, and normal weight masonry blocks, respectively. Thus, although the local blocks are used for non-bearing load applications, they can be considered as normal weight blocks instead of lightweight blocks, refer to Figure 2. However, the addition of hemp reduced the blocks density about 1% to 15%, resulting in lighter masonry blocks, as presented in Table 3. The decrease in the density of hemp blocks reflects less wall load in a building structure.

Table 3. Water Absorption and Oven-Dry Density Tests Results, ASTM C 90 and C 129.

Mix	Absorption (Kg/m^3)	Difference w/r. to Control	Oven-Dry Density (Kg/m^3)	Difference w/r. to Control
0	158	0%	2399	0%
1	171	8%	2371	-1%
2	168	6%	2275	-5%
3	223	41%	2038	-15%

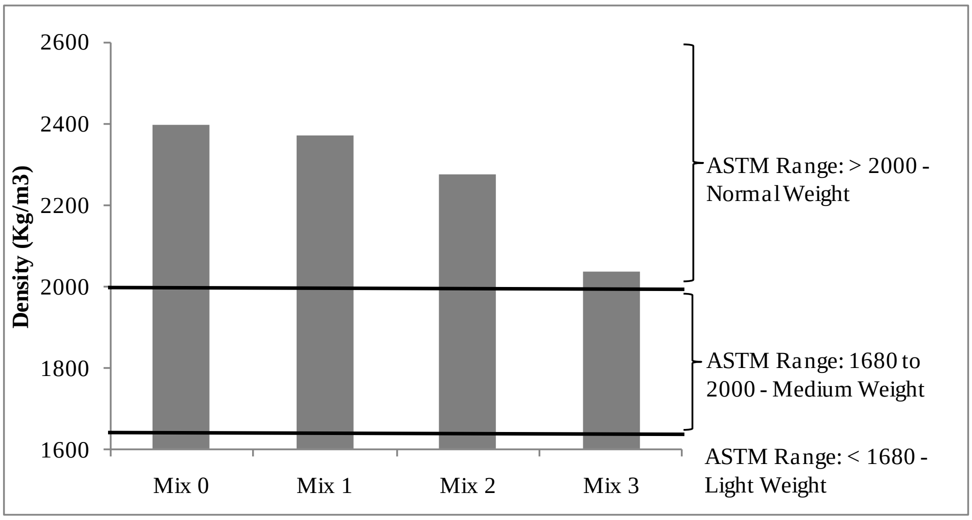

Figure 2. Density Test Results, ASTM C 90 and C 129.

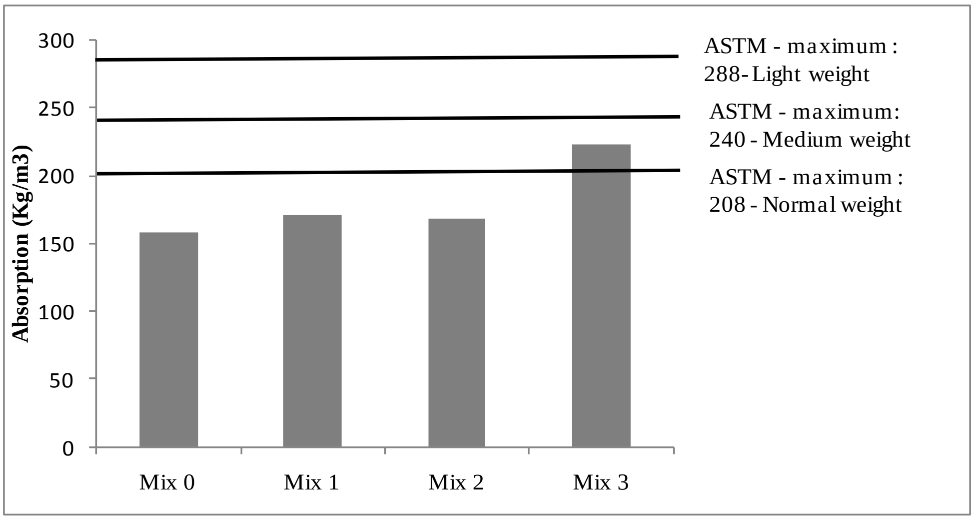

Figure 3. Water Absorption Test Results, ASTM C 90 and C 129.

The water absorption test was performed to investigate the water absorption of the concrete masonry blocks, in order to simulate the performance of masonry blocks under wet conditions. According to ASTM C 90, the maximum water absorption is 288, 240, 208 Kg/m^3 for light, medium, and normal weight masonry blocks, respectively. Table 3 presents and Figure 3 illustrates the water absorption results of all mixes. The water absorption results are acceptable and way below the maximum allowed in ASTM C 129. The increase in the water absorption of the hemp masonry blocks ranged between 6% and 40%, depending on the quantity of added hemp materials.

To investigate the effect of hemp material on the thermal conductivity of masonry blocks, ASTM C 518 for thermal block (30x30x5 cm) test was adopted. Table 4 presents the thermal conductivity results of two mixes: mix 0 (control) and mix 2. The presence of hemp material resulted in a decrease of about 20% in the thermal conductivity. Note that the thermal conductivity varies with the density of the tested material. Thus, the values determined in this research are only for the specific mixes adopted. Therefore, decreasing the density of hempcrete blocks not only produces lightweight material but also results in higher thermal insulation. This is favorable in the building construction industry, because it results in less dead loads on the foundations and less required heat loads.

Table 4. Thermal Conductivity Test Results, ASTM C 518.

Mix	Watt/m.K	Difference w/r. to Control
0	1.248	0%
2	0.984	-21%

CONCLUSIONS AND RECOMMENDATIONS

In this research, the behavior of hemp masonry blocks, prepared using raw (untreated) hemp material was investigated. A control mix 0 (no hemp) and three other hemp-reinforced concrete mixes were considered. Hemp mixes 1, 2, and 3 were produced based on the control mix, and by adding 0.5, 1.0, and 1.5 Kg of hemp material, respectively. The effects of adding hemp material on the compressive strength, water absorption, and density, in addition to thermal conductivity were monitored.

The compression results were satisfactory, although the addition of hemp materials partially reduced the compressive strength, yet the strength results still satisfied the ASTM C 129 minimum requirements for non-load bearing applications. Similarly, the water absorption and the oven-dry density test results were satisfactory according to the ASTM C 90 and C 129 standards. The thermal conductivity results showed that the addition of hemp material resulted in about a 20% decrease in the thermal conductivity of hemp masonry block, depending on the hemp mix density.
Mix 2 can be selected as a typical mix for further investigation, because the compression results of mix 2 were not significantly different from those of the other hemp mixes 1 and 3, and all the above mentioned ASTM performance requirements are satisfied. The current research demonstrated the potential of incorporating raw unprocessed hemp material into masonry blocks to produce lighter blocks with higher thermal insulation properties. The raw hemp material was used, without any processing or treatment.

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