14th Annual International Conference on Industrial Engineering and Operations Management
Dubai, United Arab Emirates (UAE), February 12-14, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240182
Published: February 12, 2024

Analysis of Hemp Stem Reinforced Concrete Composites

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Abstract

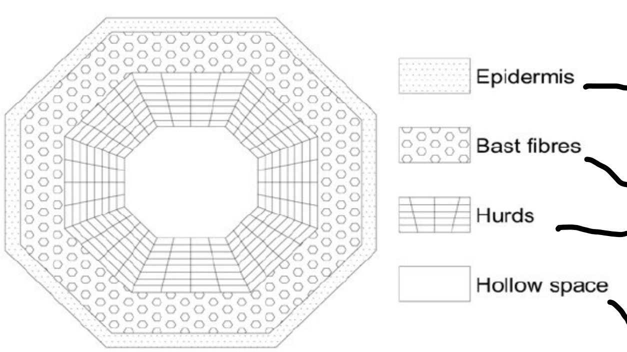
There have been prior efforts characterizing hemp fiber reinforced composites but not hemp stem reinforced composites. Here, we investigate preparation of hemp stem reinforced concrete specimens for analysis and testing. To align the hemp stems in a specific direction, we have devised a method using a plastic u-tube to hold the hemp stems materials in place. Without the u-tube, hemp stems can shift from their desired positions while pouring the concrete. Stems were arranged in a 0 and 0/90/0 orientations. A representative bunch of stems and their cross sections are provided. Based upon micromechanical models of predicting effective properties of stems, we have aligned and used NDSANDS module of ASCA. Effective properties of five representative stem volume elements are calculated using constituent properties. A set of hemp stem reinforced concrete composite specimens are prepared and presented towards conducting flexure tests and relevant analysis.

Keywords
Hemp, stem, concrete, composites, micromechanics.

1. Introduction
Commercial hemp production was revived in the United State in 2018 (Schluttenhofer and Yuan, 2018). Hemp can be grown for its fiber, grain, or chemical constituents. Initially, United States hemp production focused on non-intoxicating cannabinoids, but recently grain and fiber production and products have gained interest. Hemp stalks are comprised of fiber and hurd (Phipps and Schluttenhofer, 2022). In a cross-section of a stalk, the fibers are located towards the outer portion right underneath the epidermal layer. Below the fiber is a thick layer of hurd, which has a woody composition, but is softer and spongier. The interior of fiber-type hemp plant is typically hollow (Figures 1-3).

Actual hemp stem cross sections are shown in Figure 1. Stems comprise of the epidermal, fiber and hurd layers, with stalk having a hollow center. A representative cross-section of hemp stalk is shown in Figure 2. Figure 3 is a representative volume element for math-modeling to calculate the effective properties of the stem. Using NDSANDS (N Directional Stress AND Strength) model of the Automated System for Composite Analysis (ASCA) and representing the corresponding constituents (Epidermis, Bast Fiber, Hurd and Hollow Space) as matrix, coating 2, coating 1 and fiber, correspondingly. Table 1 shows the required parameters including stiffness properties of these constituents.

Figure 1. Stem Cross section



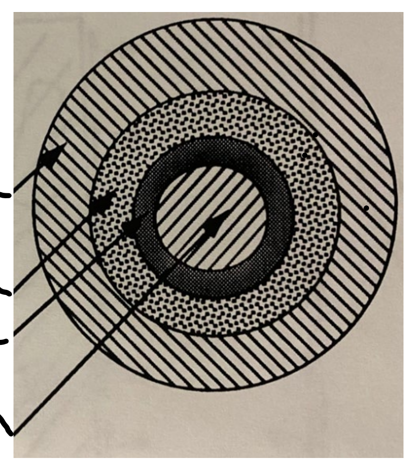


Figure 2. Representative Stem Cross Section [Morin-Crini, N., 2018]

Figure 3. Representative Volume Element for Math Modeling

Hemp fiber and hurd can be used in a wide array of products (Ingrao et al, 2015; Kolarikova et al, 2013; Mirski et al, 2017; Morin-Crini et al, 2018). Notably, hemp has been used to manufacture concretes (i.e., hempcrete). Hempcrete consists of hemp hurd mixed with a lime and water mixture. Recently, the International Code Council approved hempcrete into the International Residential Code as a building material for non-load-bearing and wall infill systems (International Residential Code. 2022). Notably, hempcrete is used as an insulation and is a non-load-bearing material.

Identification of methods to use hemp in load-bearing applications would further expand opportunities for potentially stronger and more environmentally sustainable products.

One challenge with using hemp in products is the need for expensive processing equipment (i.e., decortication). Use of whole stalks in materials could reduce the need for installing expensive decortication facilities, thereby reducing input and product costs. Little information is available about how intact hemp stems function combined with concrete materials. Previously, our work modeled hemp reinforced composite materials (Soni et al, 2023, June 12-15; Soni et al, July 28-30, 2023). Here, we create hemp stem reinforced concrete composite specimens for testing and modeling.

1.1 Objective

The purpose of this project was to analyze hemp stem effective properties using micromechanics model and constituent properties; and prepare hemp stem reinforced concrete composites (HSRCC) specimens for further research and development of innovative products.

2. Literature Review:

Commercial hemp production was revived in the United State in 2018 (Schluttenhofer and Yuan, 2018). Hemp stalks are comprised of fiber and hurd (Phipps and Schluttenhofer, 2022). Hemp fiber and hurd can be used in a wide array of products (Ingrao et al, 2015; Kolarikova et al, 2013; Mirski et al, 2017; Morin-Crini et al, 2018). Recently, the International Code Council approved hempcrete into the International Residential Code as a building material for non-load-bearing and wall infill systems (International Residential Code. 2022). Previously, our work modeled hemp reinforced composite materials (Soni et al, 2023, June 12-15; Soni et al, July 28-30, 2023).

3. Methods

Preliminary samples were produced by laying out hemp stalks in a mold and pouring a concrete mixture over top. It was observed stalks did not want to remain in place as the concrete was poured. A u-tube was utilized to hold the stalks in place while the concrete was poured into mold (Figure 4). Stalks were inserted into the u-tube (Figure 5) before being set into the frame. The frame consisted of a 12"x12"x2" wooden form (Figure 6) to pour the concrete and lay up the desired stem layers.

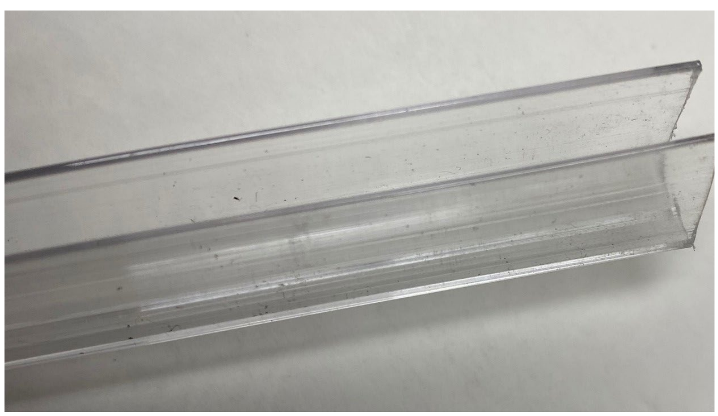


Figure 4. Plastic U tube helping stems to place in its intended locations

A number of panels were made with hemp stem reinforced concrete composite. Three cases of laminates, pure concrete, $(0/90/0)_t$ and two cases of $(0)_2$ laminates were prepared. A set of specimens with 2"x11" width and length were cut with different thickness dimensions. These specimens will be tested and analyzed. A comparison between the predicted and measured results will be done. The testing of panels with pure concrete and composite concrete will provide the significance of hemp stem reinforcements on their response characteristics.

Due to misalignment of hemp stalks leading to machining damage, an improvised method was developed for casting specimens. With this method, samples were directly setup in 2"x11" frames. A u-tube was still used to hold stems in place. Concrete was added to the frames and allowed to harden. With this approach, no cutting of samples is required.

Figure 5. aligning hemp stems

Figure 6. Preform for concrete pouring

4. Results and Discussion

We have developed a process of calculating effective properties of stem as a function of constituent properties. Same model can be used to compute the effective properties of hemp stem reinforced concrete composites. Table 1 shows Axial Youngs modulus E-A (MSI), Transverse Youngs modulus E-T (MSI), Axial Poisson's ratio V-A, Transverse Poisson's ratio V-T and Axial Shear modulus G-A (MSI) used for modeling properties. To compute effective properties, a representative stem volume element of 1 inch long was analyzed for five different hurds mechanical properties (Table 2). Testing the above-mentioned parameters in NDSANDS module and making different representative cases of stems with each value of hurds stiffness properties, effective stem properties are computed and given in Table 3.

Table 1. Representative hemp stem constituents, dimensions and properties

Constituent	Radius in	E-A (MSI)	E-T (MSI)	V-A	V-T	G-A (MSI)
Hollow Space	.1	1.00E-04	1.00-4	0.3	0.3	3.85E-05
Hurds	.3	0.4	0.4	0.36	0.36	0.147
Bast Fibers	0.35	5.8	5.8	0.3	0.3	2.23
Epidermis	0.355	1.00E+00	1.00E+00	0.3	0.3	3.85E-01

Table 2. Hurds properties used in computing effective properties of stem cross section.

E-A (MSI)	E-T (MSI)	V-A	V-T	G-A (MSI)
0.2	0.2	0.36	0.36	0.073529
0.4	0.4	0.36	0.36	0.147059
0.6	0.6	0.36	0.36	0.220588
0.8	0.8	0.36	0.36	0.294118
1	1	0.36	0.36	0.367647

Table 3. Effective properties of Hemp stems with 5 different values of Hurds given in Table 2.

EFFECTIVE ELASTIC PROPERTIES					
MATERIAL NAME:	Hurds-.2	Hurds .4	Hurds .6	Hurds-.8	Hurds-1
E11(Msi)	0.1652E+01	0.1780E+01	0.1882E+01	0.2034E+01	0.2162E+01
E22(Msi)	0.8985E+00	0.1060E+01	0.1179E+01	0.1365E+01	0.1512E+01
E33(Msi)	0.8985E+00	0.1060E+01	0.1179E+01	0.1365E+01	0.1[illegible]2E+01
V12	0.3124E+00	0.3196E+00	0.3236E+00	0.3276E+00	0.3300E+00
V23	0.2639E+00	0.2846E+00	0.3151E+00	0.3050E+00	0.3104E+00
V13	0.3124E+00	0.3196E+00	0.3236E+00	0.3276E+00	0.3300E+00
G12(Msi)	0.3980E+00	0.4530E+00	0.5034E+00	0.5610E+00	0.6141E+00
G23(Msi)	0.3554E+00	0.4125E+00	0.4481E+00	0.5231E+00	0.5769E+00
G13(Msi)	0.3980E+00	0.4530E+00	0.5034E+00	0.5610E+00	0.6141E+00
K23(Msi)	0.7131E+00	0.8922E+00	0.1064E+01	0.1239E+01	0.1407E+01

Additionally, we developed a method to create samples for testing hemp stalk reinforced concretes. Using this fixture (Figure 12), we have prepared at least twelve 2"X11" specimens and at least 36 specimens cutting 12"X12" panels. Figure 7 is a sample panel comprised of pure concrete. In Figure 8 and Figure 9 we show $(0)_s$ with old stems and new hemp stems (fresh harvested hemp stems), respectively. Figure 10 is composed of $(0/90/0)_t$ hemp stalk reinforced laminate using freshly harvested stems. This figure shows the complete panel and yz and xz cross sections.

Figure 7. Pure Concrete panel

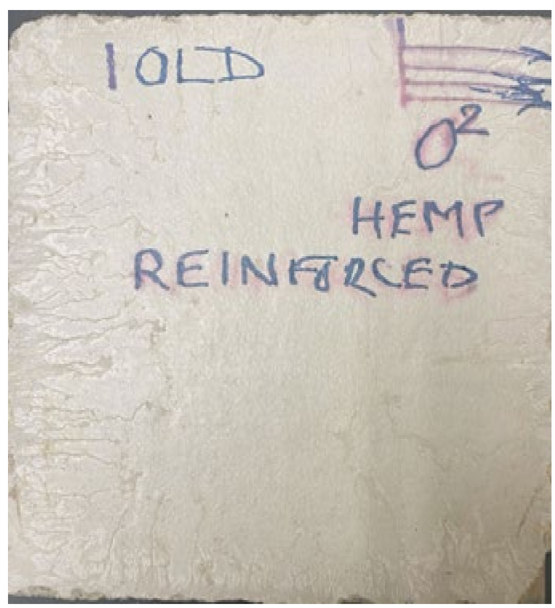


Figure 8. Old Hemp stems reinforced concrete panel $(0)_s$

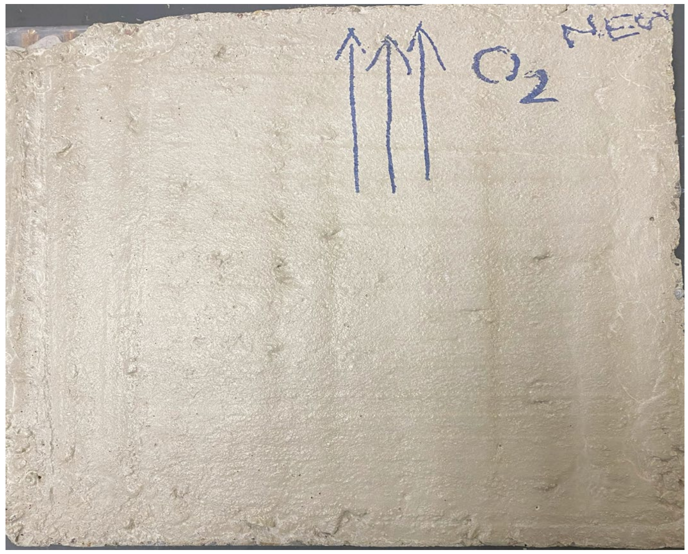


Figure 9. New Hemp stems reinforced concrete panel $(0)_s$

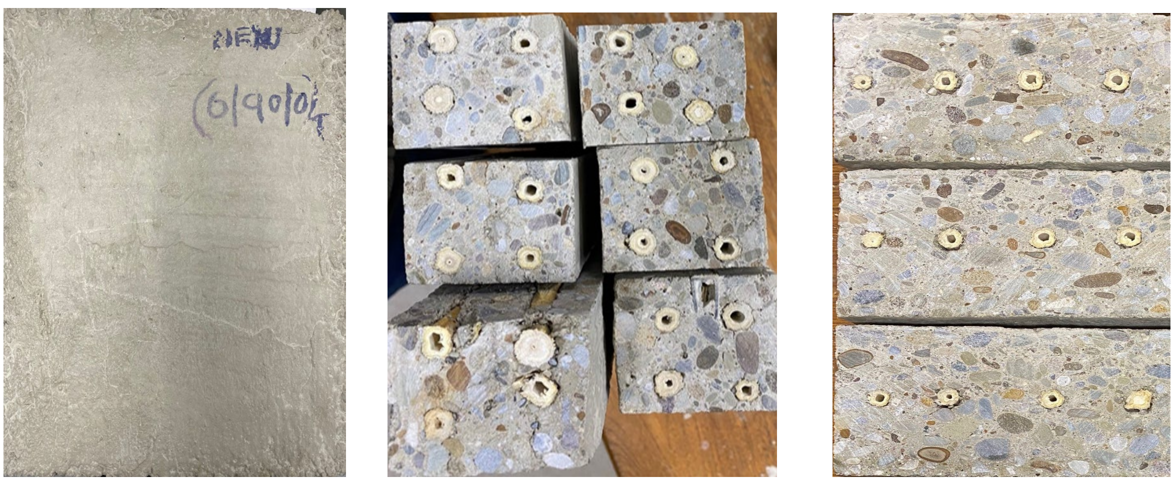


Figure 10. New Hemp stems reinforced concrete panel $(0/90/0)_t$ and yz and xz cross sections.

Figure 9 shows yz and xz cross sections of the panel. It shows that in both figures top and bottom stems were machined because of some misaligned stems.

Figure 11. New Hemp stems reinforced concrete panel $(0/90/0)_t$, cut in two perpendicular cross sections, yz and xz cross sections.

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To avoid this type of difficulties in aligning the stems, we have developed an improved fixture given in Figure 11. This helps us preparing specimen of desired dimensions.

Figure 12. Improved fixture to prepare 2”X12” HSRCC

Using the frame in Figure 12, we have prepared 12 specimens. We will do the modeling and testing of all these specimens. We have prepared a combination of specimens to study the effects of hemp stem reinforcements on effective response characteristics of concrete composites. We use these composite combinations to identify additional laminate formats and potential product applications. It is expected that the hemp stems are potentially excellent option for creating hemp stalk reinforced concrete composites.

5. Concluding Remarks

We used mathematical models to analyze effective properties of hemp stems. A frame for casting specimens was created and subsequently modified. A number of hemp stem reinforced panels and specimens are prepared. This work provides a route for preparation of samples for testing and analysis of specimens for innovative products.

Acknowledgement

This research is supported by USAA grant number NI231445XXXXG004 to Central State University.

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Biographies

Dr. Soni has PhD from University of Roorkee (renamed as IIT Roorkee) India, 1972. Dr. Soni has more than 40 years of experience in teaching and research related to systems engineering design, analytical and experimental mechanics of composite materials and structures. Dr. Soni retired from AFIT in December 2011. Before joining as an Associate Professor in the Air Force Institute of Technology in December 2005, Dr. Soni was involved in AdTech Systems Research Inc as President and CEO for more than 20 years (1984- 2005). Dr. Soni's recent studies include: a) Cost modeling of composite Aircrafts; b) Systems Engineering Approach to Integrated Health Monitoring System for Aging Aircrafts; and c) Ballistic response of co-cured adhesive bonded composite joints. Dr. Soni is author/ co-author of 100+ research publications in the field of mechanics of solids and structures with special emphasis on composites. Dr. Soni is a Fellow of the American Society for Composites and A Google Scholar. He has won numerous awards including Co-author of Air Force Materials Laboratory's Cleary Award publication, State of Ohio Edison Emerging Technology Award, Enterprise Spirit Award of Kettering Moraine and Oakwood Chamber of Commerce; and Engineering Science Foundation (Affiliate Society Council) Award for Outstanding Professional Achievement for his accomplishments. Co-author of First place winner of IEOM international Conference, Lisbon, Portugal in Modeling and simulation competition 2023. Dr. Soni is a Heartfulness meditation trainer for more than 30 years.

Dr. Sritharan has PhD Civil Engineering, Colorado State University, Fort Collins, CO; 1984. Dr. Sritharan is a *Professor of Water Resources Management,* C.J. McLin International Center for Water Resources Management, Central State University, Ohio. He is actively engaged in numerous areas of environmental engineering & water resources management research & education. His areas of research include Surface Hydraulics, Sub-surface Hydraulics, Water Resources Systems Analysis, Hydrology, Water Quality, and Environmental Engineering, and Irrigation and Drainage. He has worked on, a) Water Use and Stream-Aquifer-Phreatophyte Interaction Along a Tamarisk-Dominated Segment of the Lower Colorado River; b) Application of GIS in Evaluating the Potential Impacts of Land Application of Biosolids on Human Health, in Geospatial Technologies in Environmental Management, Geotechnologies and the Environment. Professor Sri has held various leadership positions such as, Dean of College of Science and Engineering and Founding Director of the Land Grant Program at Central State University. Co-author of First place winner of IEOM international Conference, Lisbon, Portugal in Modeling and simulation competition 2023.

Dr. Schluttenhofer has PhD from the Department of Plant & Soil Sciences, University of Kentucky, Lexington, KY; 2016. Dr. Schluttenhofer is a Research Assistant Professor of Natural Products at Central State University, Ohio. He is leading research and development efforts in hemp production and applications in Ohio. Current research activities focus on understanding production, processing, and new uses for hemp. He has worked on a) the chemistry of hemp cigarettes and vape products; b) using hemp grain as a feed ingredient for fish; c) elucidating impacts of manure application to hemp; and d) evaluating varieties and breeding new hemp cultivars. Co-author of First place winner of IEOM international Conference, Lisbon, Portugal in Modeling and simulation competition 2023.