Evaluation of Hygrothermal Properties of Hemp in Concrete as a Sustainable Construction Material

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Abstract

The use of sustainable building materials is a top priority since the construction sector is one of the biggest worldwide greenhouse gas emitters. Fast-growing and sustainable hemp has emerged as a possible replacement for conventional concrete as a construction material. In comparison to conventional concrete, hempcrete, a composite material comprised of hemp hurd and cement binders, has higher insulation and hygrothermal characteristics. This paper gives a general overview of hemp's usage in concrete as a sustainable construction material, outlining its self-curing qualities, prospective uses, and advantages for the environment. We also look at the potential and problems that come with using hempcrete, such as supply chain constraints, regulatory obstacles, and the need for additional research and development. In the conclusion, we contend that the incorporation of hemp into concrete has the potential to revolutionise the building sector by giving designers and builders a green and ethical option.

Keywords: Hemp, Hygrothermal, Hempcrete, Sustainable, Self-curing

1. Introduction

The term agro waste describes the leftovers and by-products produced by farming activities such crop cultivation, animal rearing, and forestry [1]. Typically, these materials are thrown as garbage and being burnt, posing risks to the environment and public health [2]. However, agro waste may also be a useful resource that is used in a variety of purposes, including as the production of fuel, agriculture, and electricity [3]. Agricultural waste may be used as a sustainable and green replacement for conventional building materials in the construction sector. Among other building materials, agricultural waste may be converted into insulation, particleboard, fiberboard, roofing tiles and bricks [4]. These materials are perfect for building since they are inexpensive, lightweight, and have good insulating qualities [5]. The form of waste produced from farming and its causes are shown in figure 1 and figure 2 [6].

Fig. 1: Form of Agro Waste

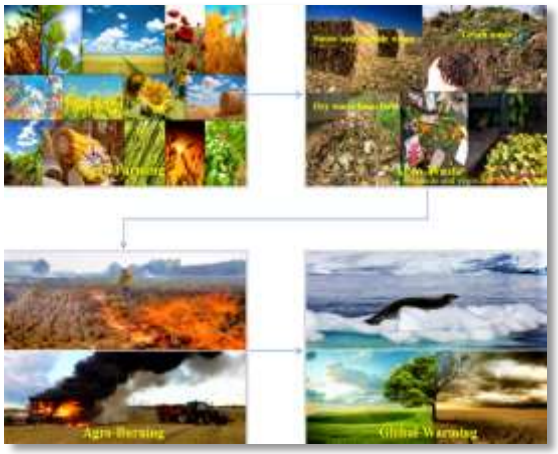

Fig. 2: Agro Cycle

Another agricultural waste with numerous useful qualities is hemp. For thousands of years, people have utilised hemp, also known as industrial hemp, as a versatile plant for a variety of uses [7]. It is a variety of the Cannabis sativa plant that is produced especially for commercial purposes such the production of fibre, seeds, and oil. Due to its potential as a sustainable crop and its numerous industrial uses, demand for hemp has recently returned. Clothing, paper, and construction materials can all be made out of hemp fibres [8]. The naturally grown hemp plant and dried hemp hurd powder shown in figure 3 and figure 4 [9].

Fig. 3: Hemp Plant

Fig. 4: Hemp Hurd Powder

The woody core of hemp plants, known as hurds, are combined with a lime-centred additive to form hempcrete, sometimes stated to as hemp concrete, which is used for construction [10]. As an eco-friendlier substitute for conventional concrete, this sustainable construction material has grown in popularity in recent years. Hempcrete provides several benefits over traditional concrete, such as a less carbon footprint, superior insulating capabilities, and a built-in fire resistance [11]. Additionally, compared to many other crops, hemp is a fast-growing, pesticide-free crop that require little water [12]. Thus, hempcrete is a socially and environmentally responsible option for builders seeking to reduce their influence on the environment [13]. Hempcrete is developing as a creative solution that has the potential to revolutionise the construction sector as interest in sustainable building techniques [14]. Here are some of the advantages of using hempcrete:

i. Low carbon footprint: Hempcrete uses less energy to make and absorbs carbon dioxide during the curing process, it has a substantially smaller carbon footprint than ordinary concrete [15].
ii. Better insulating capabilities: Due to its strong thermal insulating qualities, hempcrete can help in reducing building energy consumption and heating expenses [16].
iii. Natural resistance to pests and mold: Hempcrete's inherent resistance to pests and mould can assist to enhance indoor air quality and minimise the need for harmful chemicals [17].
iv. Excellent breathability: Hempcrete is very breathable, allowing moisture to escape from the building [18].
v. Lightweight: Hempcrete is substantially lighter than conventional concrete, making transportation and installation easier and less expensive [19].
vi. Renewable resource: In comparison to many other crops, hemp grows quickly and is a renewable resource which requires less water. As a result, it is a socially and environmentally conscious option for sustainable building techniques [20].
vii. Durability: Hempcrete is extremely durable, and it has been used throughout Europe for more than three decades without showing any indications of deterioration [21].

Overall, using hempcrete has a number of benefits over using regular concrete, such as a smaller carbon footprint, better insulating qualities, built-in resistance to pests, and better interior air quality [22].

2. Methodology

To determine the properties of hemp and hemp concrete, hemp hurds were transported from the surrounding area. We have harvested hemp hurd, split into smaller pieces of around 10 cm, and dried for about 20 days in the sun light. After the hemp hurd got dried, it was thoroughly crushed in herb grinder to make it in a powder form. XRD, EDXRF and Botanical tests were performed to identify the physical properties and chemical composition of hemp hurd [23].

Fineness, specific gravity, soundness, consistency, initial and final setting time, crushing value, flakiness, and elongation are some of the initial tests which are used to discover the physical properties of cement, fine aggregates, and coarse aggregates that were performed in the laboratory [24].

As per IS 456-2000, the optimal mix proportion was created and the mix design (M25) was acquired. Hempcrete is made by mixing of cement, fine aggregates, coarse aggregates, hemp hurd and water. Here fine aggregates are partially replaced with hemp hurd at 5%. The cubes of size 150mm x 150mm x 150mm [25].

To determine the reduction in water requirement for curing, the hempcrete blocks of size 150mm x 150mm x 150mm were casted in order to check it’s working and reduction in water requirement for curing. Moisture content was monitored using a moisture meter after 7, 14, and 28 days. All the parameters were checked and compared with normal concrete blocks [26].

2.1 Test on Cement

Various Cement Testing Methods are used to determine cement's qualities, including its specific gravity, strength, fineness, consistency, etc. These testing are essential before use in construction work. The following are the tests conducted on cement in the laboratory:

- **Fineness Test: (IS:4031-Part 1-1996)**
  The surface area of the cement particles per unit mass is measured by a fineness test, which is used to improve the appropriate grinding of cement.
  Result: Ultratech PPC was used and 6.5%.
- **Normal Consistency Test: (IS:4031-Part 4-1988)**
  The consistency of cement is the minimal amount of water required to begin the chemical reaction between water and cement. This test aids in determining the least amount of water necessary to create cement paste.
  Result: The consistency of cement was obtained 33%.
- **Setting Time Test:**
  Initial setting time of cement: (IS:1043-Part 5-1988)
  It is the time between adding water to cement and when the paste begins to become rigid.
  Result: The Initial setting of cement was found 34 min.
  Final setting time of cement: (IS:1043-Part 5-1988)
  The paste is deemed to have completed its ultimate setting time when it completely loses its plasticity. It is the period of time required for cement paste or concrete to adequately harden and acquire the shape of the casting mould.
  Result: The Final setting of cement was found 590 min.
- **Soundness Test: (IS:1043-Part 3-1988)**
  The expansion of cement after it begins to set has been measured by the soundness of cement.
  Result: The expansion of cement was found 3 mm.
- **Specific Gravity Test: (IS:1043-Part 11-1988)**
  Due to the connection to viscosity and density, cement's specific gravity is an essential property. It is one of the parameters used to determine cement density.
  Result: The specific gravity of cement was found 3.14 g/cc.
- **Compressive Strength Test: (IS:1043-Part 7-1988)**
  Compressive strength, a property of cement, refers to how much load it can hold when combined with ordinary sand and water to create a hardened mass.
  Result: The compressive strength of cement mortar of ratio 1:3 was 47 Mpa.

2.2 Test on Aggregates

Aggregates may be utilised for a variety of applications and are essential to the construction industry. The benefits of using aggregates in the production of concrete are numerous. Their main function is to reinforce concrete, which strengthens its structure and reduces the likelihood of fractures. As a result, aggregates must undergo quality testing before being used in construction [27].

The aggregates are evaluated for qualities like as strength, toughness, hardness, shape, and water absorption etc. The following are the aggregate testing methods:

- **Flakiness and Elongation Test: (IS:2386-Part 1-1963)**
  This test determines the quantity of flaky and lengthy aggregate in the sample as a whole.
  Result: The value of Flakiness and Elongation Index was obtained below 25%.
- **Crushing Value Test: (IS:2386-Part 4-1963)**
  The aggregate crushing value is the measure of how resistant aggregates are being crushed when a compressive force is progressively applied.
  Result: The value of crushing test was found 10%.
- **Abrasion Test: (IS:2386-Part 4-1963)**
  The abrasion test is used to evaluate the aggregate toughness and abrasion resistance.
  Result: The value of abrasion test was found 15%.
- **Impact Value Test: (IS:2386-Part 4-1963)**
  It can be described as the aggregate's resistance to failure by an impact load. To evaluate an aggregate's toughness, or simply its capacity to withstand sudden loading or impact loading, an impact value test is required.
  Result: The value of impact test was found 12%.

2.3 Test on Concrete

In order to evaluate the workability and strength of concrete of M25 grade, slump test and compressive strength test were performed [28].

- **Slump Test: (IS: 1199-1959)**
  The ease in transportation, placement, compaction, finishing, and resistance to segregation of concrete mix is known as workability. In more technical words, it's the feature of concrete that determines how much productive internal labour is required to achieve complete compaction.
  Result: The water-cement ratio was obtained 0.45.
- **Compressive Strength: (IS: 516-1959)**
  The ability of concrete to bear loads before failing is known as its compressive strength. It provides information about the concrete's properties.
  Result: The Compressive Strength of M25 grade of concrete at 28 days was found 24 Mpa.

2.4 Test on Hemp Hurd

In order to find the chemical composition of hemp hurd and type of species found in nearby Chitkara university, Baddi, Himachal Pradesh, India from where samples have been taken, some tests have been done as below [29].

- **EDXRF:**
  Energy Dispersive X-ray Fluorescence (EDXRF) is one of the two main kinds of X-ray Fluorescence techniques used for elemental analysis applications.
  Result: The quantitative result of hemp hurd powder shown in table 1 and elements found in hemp hurd powder shown in figure 5.

Table 1: Quantitative Result of Hemp Hurd

Quantitative Result

Analyte	Result	[3-sigma]	Proc.-Calc.	Line	Int.(cps/uA)
Ca	74.297 %	[0.138]	Quan-FP	CaKa	95.1482
Fe	9.546 %	[0.037]	Quan-FP	FeKa	118.7890
K	7.851 %	[0.040]	Quan-FP	K Ka	10.7827
Si	3.799 %	[0.086]	Quan-FP	SiKa	0.5221
Mn	1.375 %	[0.015]	Quan-FP	MnKa	12.5830
S	0.983 %	[0.014]	Quan-FP	S Ka	0.8801
Al	0.793 %	[0.202]	Quan-FP	AlKa	0.0335
Ti	0.717 %	[0.027]	Quan-FP	TiKa	2.2875
Zn	0.186 %	[0.007]	Quan-FP	ZnKa	4.5124
Cr	0.146 %	[0.012]	Quan-FP	CrKa	1.0055
Cu	0.130 %	[0.007]	Quan-FP	CuKa	2.6683
Sr	0.128 %	[0.004]	Quan-FP	SrKa	7.0199
Rb	0.025 %	[0.004]	Quan-FP	RbKa	1.2779
Zr	0.024 %	[0.003]	Quan-FP	ZrKa	1.4009

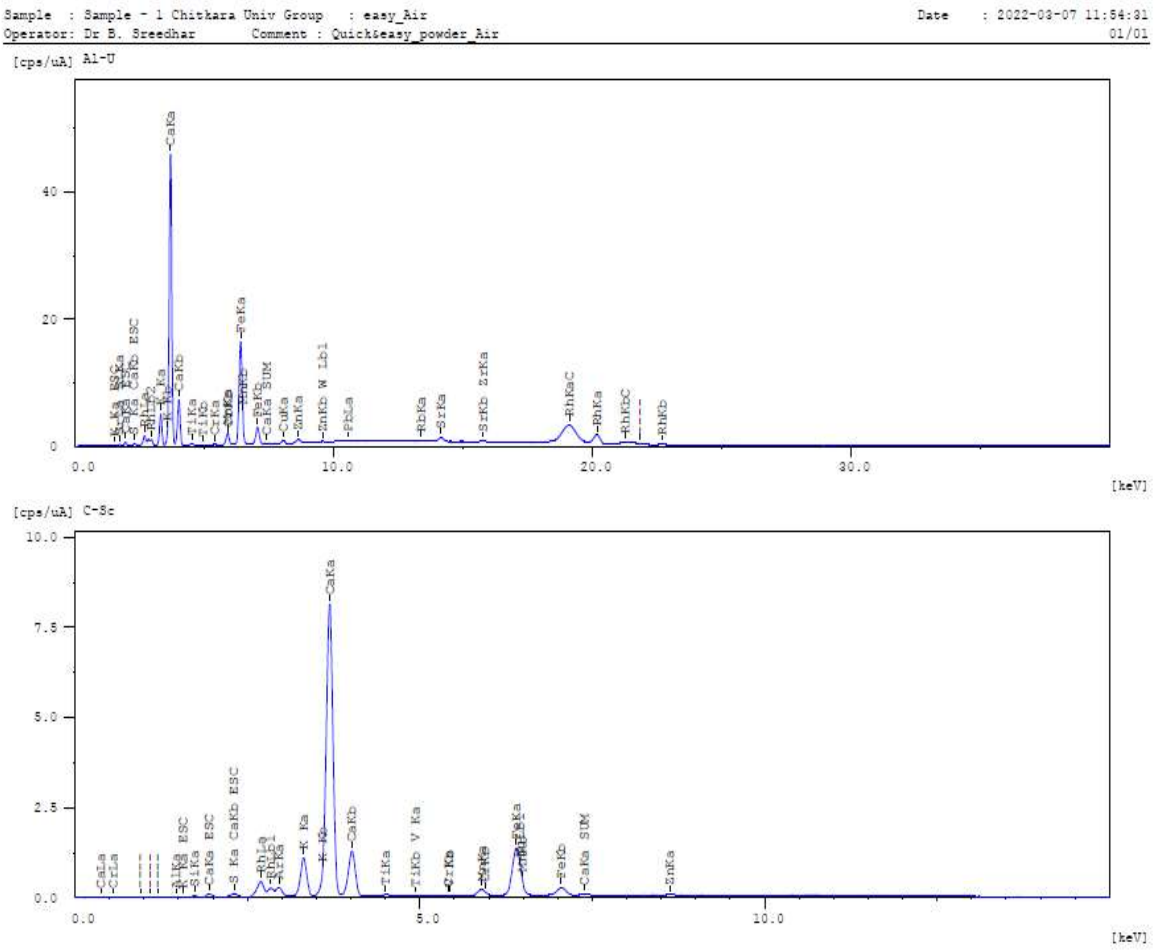

Fig. 5: Elements Found in Hemp Hurd Powder

- **XRD:**

  A technique to determine a material's underlying crystal structure; it enables the confirmation of the crystallinity and structure of a sample but does not provide any chemically related information.

  Result: Structure of hemp hurd shown in the form of graph in figure 6.

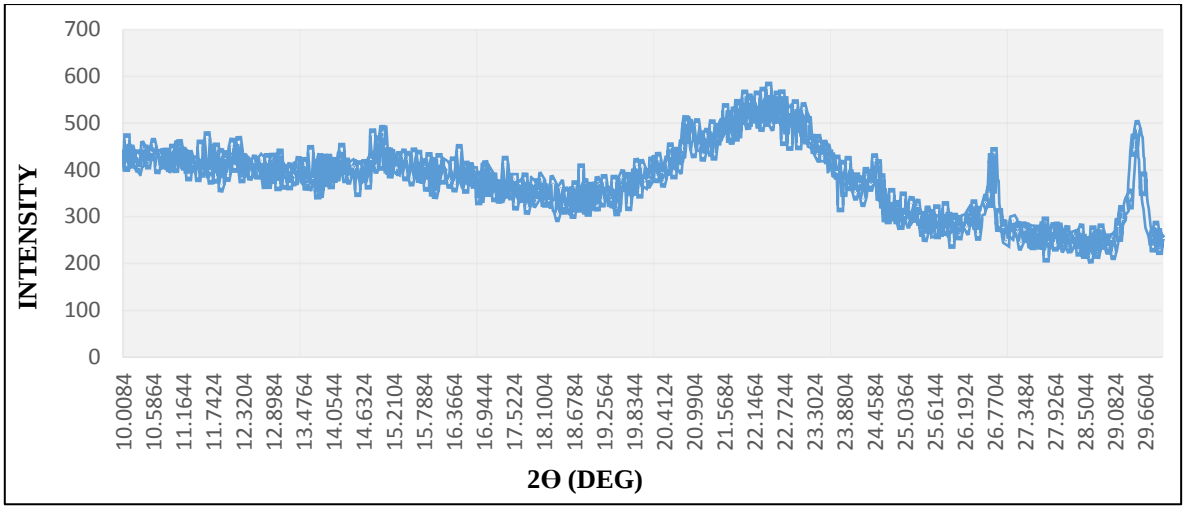

Fig. 6: Structure of Hemp Hurd

2.5 Self-curing Hemp Concrete

Self-curing in concrete refers to providing a constant supply of water to the concrete so that it may use it throughout the hydration process's heat release and prevent water molecules from evaporating within the concrete mass [30],[31].

If the concrete is not properly cured, microcracks develop as a result of the loss of water molecules from the concrete, and shrinkage ensues. The typical curing process only includes interactions between concrete on its surface, not within the concrete mass [32],[33].

The microscopic inclusions in self-curing concrete are scattered throughout the whole concrete mass, which stores the additional water molecules required for hydration and release during the hydration process. As a result, this treatment method is more successful and lowers self-desiccation [34],[35],[36].

- **Mix:** 5% replacement of fine aggregates with hemp hurd and mixed with cement, fine aggregates, coarse aggregates, water for M25 grade concrete as per IS:10262-2009 & IS:456-2000.

  Result: The concrete made up of hemp do not require water for curing as shown in figure 7.

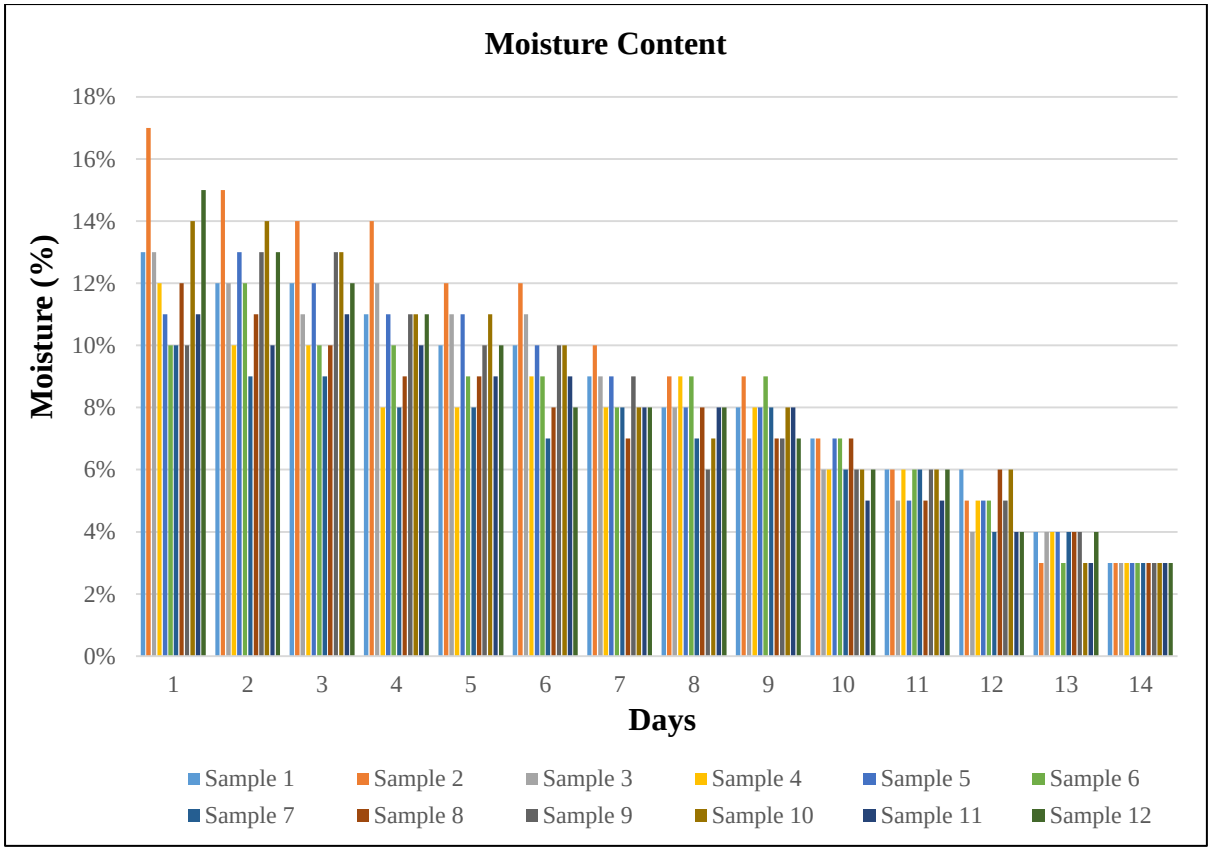

Fig. 7: Moisture Content Measured in Hemp Concrete for 28 Days

The Processing of hemp hurd from drying to mixing in concrete is shown in figure 8. The processing of hemp concrete blocks and measurement of moisture content in hemp concrete blocks with the help of moisture meter is shown in figure 9.

Fig. 8: Processing of Hemp Hurd and Concrete Blocks

Fig. 9: Processing of Hemp Concrete Blocks and Moisture Content Measurement

3. Result and Discussion

After performing all the initial tests and experiments (as per IS codes) on cement, aggregates, concrete and hemp, the results obtained shows the hygrothermal properties of hemp concrete.

3.1 Test Result of Cement, Aggregates and Concrete

All the test were conducted on cement, aggregates and concrete in the laboratory as per IS codes. The result obtained from the experiments with respect to the IS specified value are given in table 2.

Table 2: Findings of the Test on Cement, Aggregates, and Concrete

Sr. No.	Name of Test	IS Code	IS Specification	Result

1	Fineness	IS:4031-Part 1-1996	<10%	6.5%
2	Normal Consistency	IS:4031-Part 4-1988	-	33%
3	Initial Setting Time	IS:1043-Part 5-1988)	30 min	34 min
4	Final Setting Time	IS:1043-Part 5-1988	600 min	590 min
5	Soundness	IS:1043-Part 3-1988	<10 mm	3 mm
6	Specific Gravity	IS:1043-Part 11-1988	3.12-3.15	3.14
7	Compressive Strength (1:3)	IS:1043-Part 7-1988	-	47 Mpa
8	Crushing Value	IS:2386-Part 4-1963	<30%	10%
9	Abrasion Value	IS:2386-Part 4-1963	<30%	15%
10	Impact Value	IS:2386-Part 4-1963	<30%	12%
11	Slump Value	IS: 1199-1959	-	45%
12	Compressive Strength (M25)	IS: 516-1959	25 Mpa	24 Mpa

3.2 Test Result of Hemp hurd

The Energy Dispersive X-ray Fluorescence test was conducted on Hemp powder at CSIR - Indian Institute of Chemical Technology, Hyderabad, India. The results obtained was beneficial and satisfactory in term for the use of hemp hurd in concrete.

The main element found in the hemp hurd powder was calcium, Iron, Potassium and Silica. These elements are beneficial in terms of quick setting, improvement in strength, minimizes water requirement and better binding. The test was conducted under the condition as provided in figure 10.

```
Sample   : Sample - 1 Chitkara Univ
Operator: Dr B. Sreedhar
Comment : Quick&easy_powder_Air
Group    : easy_Air
Date     : 2022-03-07 11:54:31

Measurement Condition
------------------------------------------------------------------------------
Instrument: EDX-8000   Atmosphere: Air   Collimator: 10(mm)
------------------------------------------------------------------------------
Analyte               TG kV   uA      FI   Acq.(keV) Anal.(keV)  Time(sec)    DT(%)
------------------------------------------------------------------------------
Al-U                  Rh 50   50-Auto ----  0 - 40   0.00-40.00  Live- 100    30
C-Sc                  Rh 15  283-Auto ----  0 - 20   0.00- 4.40  Live- 100    30
```

Fig. 10: Hemp Powder Measurement Condition

There are different elements which were found in the hemp hurd by performing EDXRF on the sample. The percentage of element found in the hemp hurd is given in table 3.

Table 3: Percentage of Major Elements Found in Hemp Hurd

Sr. No.	Element	Result
1	Calcium	74.3%
2	Iron	9.5%
3	Potassium	7.8%
4	Silica	3.8%

X-ray diffraction test was conducted on hemp powder in Punjab University, Chandigarh and the result obtained was crystalline. The hemp powder was examined under XRD and it was found that it is a crystalline structure as shown in figure 11.

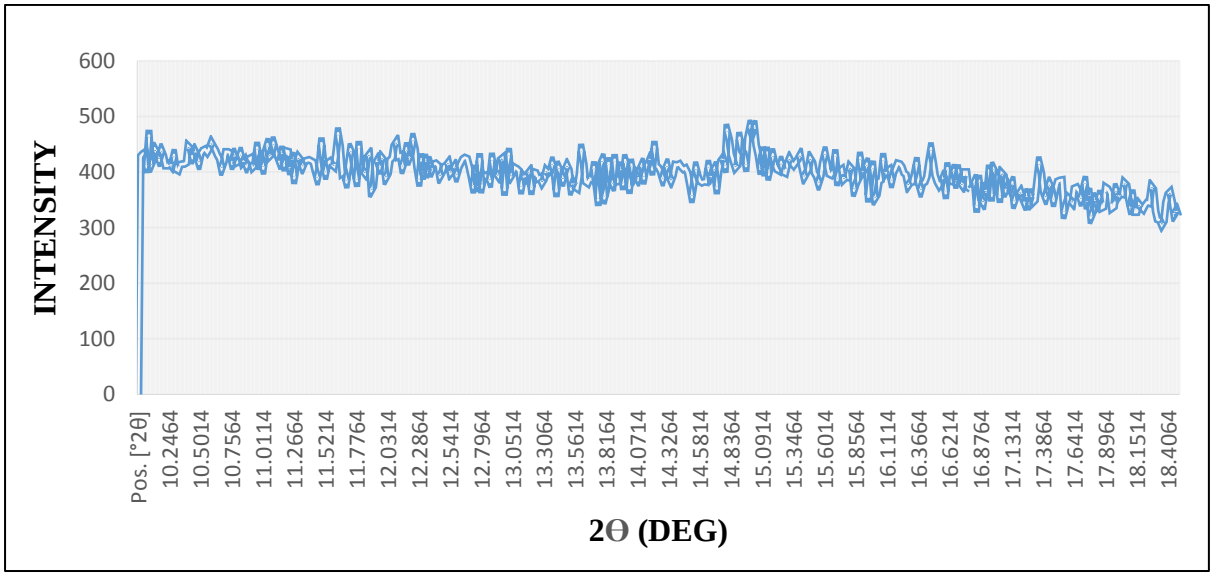

Fig. 11: Crystalline Structure of Hemp Hurd

The self-curing hemp concrete was made by mixing of cement, aggregates and hemp hurd. The M25 grade of hemp concrete cubes of size $150mm^3$ were casted with partial replacement of fine aggregates with hemp hurd. The percentage of hemp hurd was kept 5% and 12 cubes were casted. Beside this, M25 grade of 12 normal concrete cubes of size $150mm^3$ were casted on same day at same condition as well [37]. After 24 hours of casting of hemp concrete cubes and normal concrete cubes, the moisture content was measured with moisture meter for about 28 days [38]. The moisture content values of hemp concrete cubes and normal concrete cubes were taken up for about 28 days as given in table 4 and table 5.

Table 4: Moisture Content Present in Hemp Concrete Blocks

Days→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sample 1	13%	12%	12%	11%	10%	10%	9%	8%	8%	7%	6%	6%	4%	3%
Sample 2	17%	15%	14%	14%	12%	12%	10%	9%	9%	7%	6%	5%	3%	3%
Sample 3	13%	12%	11%	12%	11%	11%	9%	8%	7%	6%	5%	4%	4%	3%
Sample 4	12%	10%	10%	8%	8%	9%	8%	9%	8%	6%	6%	5%	4%	3%
Sample 5	11%	13%	12%	11%	11%	10%	9%	8%	8%	7%	5%	5%	4%	3%

Sample 6	10%	12%	10%	10%	9%	9%	8%	9%	9%	7%	6%	5%	3%	3%
Sample 7	10%	9%	9%	8%	8%	7%	8%	7%	8%	6%	6%	4%	4%	3%
Sample 8	12%	11%	10%	9%	9%	8%	7%	8%	7%	7%	5%	6%	4%	3%
Sample 9	10%	13%	13%	11%	10%	10%	9%	6%	7%	6%	6%	5%	4%	3%
Sample 10	14%	14%	13%	11%	11%	10%	8%	7%	8%	6%	6%	6%	3%	3%
Sample 11	11%	10%	11%	10%	9%	9%	8%	8%	8%	5%	5%	4%	3%	3%
Sample 12	15%	13%	12%	11%	10%	8%	8%	8%	7%	6%	6%	4%	4%	3%

Note: After 14 days onwards, the moisture content remained the same.

Table 5: Moisture Content Present in Normal Concrete Blocks

Days→	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Sample 1	7%	5%	4%	4%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 2	7%	6%	5%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 3	6%	5%	4%	4%	4%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 4	6%	6%	5%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 5	7%	5%	5%	4%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 6	7%	6%	5%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 7	6%	5%	4%	4%	4%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 8	7%	5%	5%	4%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 9	6%	6%	5%	4%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 10	6%	6%	6%	4%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 11	5%	5%	4%	3%	4%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Sample 12	6%	4%	4%	4%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%

Note: After 14 days onwards, the moisture content remained the same.

The average value of 12 samples were taken up for about 28 days. The moisture content of hemp concrete cubes was compared with normal concrete cubes as shown in table 6 and comparison graph shown in figures 12.

Table 6: Average Moisture Content Values of Hemp Concrete and Normal Concrete

Days	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Hemp Concrete	12%	12%	11%	11%	10%	9%	8%	8%	8%	6%	6%	5%	4%	3%
Normal Concrete	6%	5%	5%	4%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%

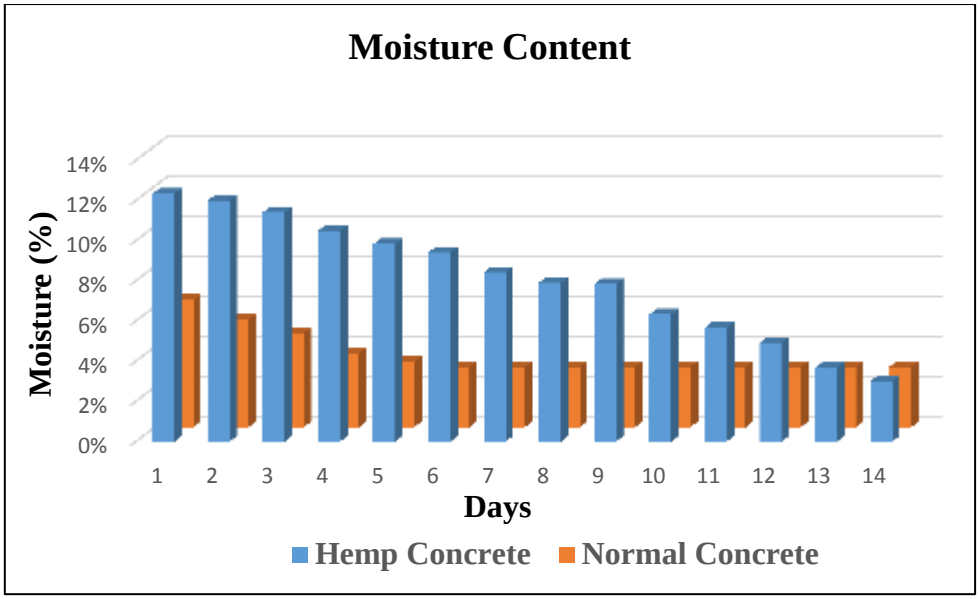

Fig. 12: Comparison of Moisture Content Between Hemp Concrete and Normal Concrete for 14 Days

4. Conclusion

On the basis of literature review and experimental work, there are some conclusions mentioned below:

- Concrete made from hemp do not require water for curing resulting in saving of water.
- Labour cost and water handling cost for curing of normal concrete is decreased by around 100% and the cost of aggregates is reduced by 5%.
- Replacement of some amount of aggregate will partially solve the problem of land erosion.
- Use of Hemp hurd (agro-waste) will effectively utilize the waste and convert into usable form.
- Hemp concrete is lightweight and helps in reducing overall weight of the structure.

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