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Manufacturing of building blocks using Hempcrete

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ABSTRACT: Hemp (Cannabis sativa) is an agricultural crop that can be used as a building material in combination with lime and cement. A composite building material that combines a cementitious binder (building limes and cement) with hemp shives, the woodycore of the hemp stalk is generally referred to as hemp concrete (HC). However,industrial facilities to separate hemp shives and fibres are currently not available in India. HC has many advantages as a building material but it is not load-bearing and must be used in combination with a load-bearing RCC frame.The aim of this research was to evaluate the feasibility of using both hemp shives and fibres in a HC to determine an optimal mix of the different binding agents and to investigate if adding cement binder would improve mechanical strength of the material. The effects on compressive strength of pre-mixing the binder or creating perforations in the test specimens were also investigated.

KEYWORDS : Concrete, Fibers, Hempcrete, Lime, OPC

1. 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 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 fibres agrees with the development of agricultural activities and farming prosperity. The addition of industrial hemp fibres 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-fibre-reinforced concrete. 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.

1.1. Hempcrete

Hempcrete is a bio-composite mix made up of hemp shive, lime, cement and water. There has been extensive research undertaken on the thermal, acoustic, and mechanical properties of hempcrete. It has low density, good thermal and acoustic insulation properties, and can passively regulate humidity in a built environment. However it also has low compressive strength and modulus of elasticity. Thus hempcrete cannot be used as a direct load bearing material but can used as an infill material in timber stud walls.

Fig. 1 Hempcrete Block

1.2. Hemp

Hemp (Cannabis sativa) is an agricultural crop that can be used as a building material in combination with lime and cement. Hemp is a fast growing annual crop (1.5 - 4m height) which is mainly grown for its high tensile strength natural fibre which grows in the stem around the woody core of the plant. This woody core of the plant is chopped up into small sizes (5-25mm) (hurd/shive) and mixed with lime, water and a small quantity of cement (to accelerate setting time) to form a bio-composite mix called hempcrete.

Fig. 2 Chopped Hemp Fibre

1.3 Cementitious Binders

The lime-based cementitious binder used in HC consists of the following main components

1.3.1 Hydraulic Lime

Hydraulic lime sets by reaction with water called hydration.When a stronger lime mortar is required, such as for external or structural purposes, a pozzolan can be added, which improves its compressive strength and helps to protect it from weathering damage. Pozzolans include powdered brick, heat treated clay, silica fume, fly ash, and volcanic materials. The chemical set imparted ranges from very weak to almost as strong as Portland cement.

1.3.2 Non-Hydraulic Lime

Non-hydraulic lime is primarily composed of (generally greater than 95%) calcium hydroxide, $Ca(OH)_2$. Non-hydraulic lime is produced by first heating sufficiently pure calcium carbonate to between 954° and 1066°C, driving off carbon dioxide to produce quicklime (calcium oxide). This is done in a lime kiln. The quicklime is then slaked – hydrated by being thoroughly mixed with enough water to form a slurry (lime putty), or with less water to produce dry powder — a hydrated lime (calcium hydroxide). Hydrated lime naturally turns back into calcium carbonate by reacting with carbon dioxide in the air, the entire process being called the *lime cycle*.

1.3.3 Ordinary Portland Cement

Portland cement is by far the most common type of cement in general use around the world. This cement is made by heating limestone(calcium carbonate) with other materials (such as clay) to 1450 °C in a kiln, in a process known as calcinations, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix to form calcium silicates and other cementitious compounds. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement', the most commonly used type of cement (often referred to as OPC). Portland cement is a basic ingredient of concrete, mortar and most non-specialty grout. The most common use for Portland cement is in the production of concrete. Concrete is a composite material consisting of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape desired, and once hardened, can become a structural (load bearing) element. Portland cement may be grey or white.

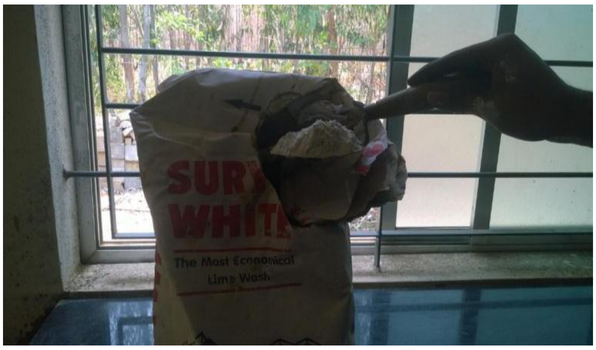

Fig. 3. Unhydrated Lime

TABLE 1: Physical Properties Of Binders

Binders	Density (g/cm^3)	Specific area (cm^2/g)
Lime	2.20	4200
Cement	2.98	3214

2. OBJECTIVES AND METHODOLOGY

2.1 OBJECTIVES

The aim is to investigate the potential of producing local hemp masonry blocks, using traditional mixes and local raw material.

1) Study the physical properties of Hempcrete
   a) Specific gravity of Hempcrete
   b) Fire resistance of Hempcrete
   c) Water absorption
2) Identify mechanical properties of hemp concretes using hemp shives and binder compositions.
   a) Compressive Strength
   b) Split tensile Strength
3) Investigate whether pre-mixing the binding agents with water before adding it to the hemp affects the final strength of the material.

4) Investigate whether adding OPC to the mix improves compressive strength and also the setting time of HC.

2.2 METHODOLOGY

The following steps were involved in implementation of the project and are not limited to,

- Collection of raw materials
- Mix design
- Casting and cubing of Cubes, Cylinders.
- Testing of Hempcrete
- Discussions and conclusions on the results obtained

3. TESTS CONDUCTED ON MATERIALS

3.1 Lime

Tests were conducted as specified in IS 1624:1986 (METHODS OF FIELD TESTING OF BUILDING LIME)

3.1.1 Visual examination

- **Procedure** - Examine the lime for colour and for state of aggregation, namely, lumpy, powdery, soft, hard, etc. Class C&D limes mostly used for whitewash have white colour. Lumpy form may indicate quick lime or unburnt limestone but the former may be differentiated by' its porous structure. The hydrated lime supplied should not contain coarse and gritty lime pieces larger than about 2'50 mm when rubbed in between the thumb and the finger.

- **Observation-** The lime sample tested was found to be white in colour and had powdery appearance. Therefore, it was classified as **class -C lime**, mostly used for white wash.

Fig. 4 Lime Sample

3.1.2 Ball test

Procedure - Make balls of about 50 mm diameter of quick lime mixed with just sufficient water to give a stiff paste, and leave them undisturbed for a period of six hours. Immerse in a basin of water.

Observation - Signs of disintegration within a few minutes show that lime may be of **Class C**. Very little expansion and numerous cracks sometimes seen on the surface show that lime may be of Class B or E. No signs of disintegration under water show that lime may be of Class A.

Result: It belongs to class 'C' lime

3.1.3 Specific gravity

This test covers determination of the density of lime and its specific gravity. The density of lime is defined as the mass of a unit volume of the solids.

Apparatus:

1) Le chatelire flask: the standard flask which is circular in cross section with special shape and dimensions
2) Kerosene, free of water.
3) Balance.
4) Holder.
5) Water bath.

Result: The Specific Gravity of lime =1.15

3.1.4 Impurity test

Procedure - Draw a known mass of freshly burnt quick lime from the kiln or quick lime supplied and place in a vessel containing sufficient quantity of water. Stir the contents well and allow them to: settle for two hours. Then pass the milk of lime with addition of' water, if necessary, through 850 micron IS sieve. Wash the residue containing unburnt or overburnt stone, cinder, sand or any other impurity with clean water tin it is free from lime. Transfer the residue to a metal tray with a jet of water. ; Allow it to settle and decant off the water from the tray: Dry the residue, cool and screen out any fines which may have resulted due to slaking. Dry the residue for 8 hours in hot sun and weigh.

Observation - The extent of residue calculated as percentage of the initial mass of material gives an idea about the burning efficiency of IS I 162. The presence of unreactive portions in the lime applied as given below: a) Class Band F will have residue not more than 10 percent, and b) Class C and D wiJ1 have residue not more than 5 percent.

Result: From the impurity test, the lime belongs to Class C

3.1.5 Plasticity test

Procedure - Mix the lime with water to a thick cream like consistency and leave preferably overnight. Then, spread it like butter with the help of a knife on a blotting paper.

Observation - A comparison with the behavior of performances of standard lime of known good quality with a little experience helps in judging its plasticity. If it is spreadable with ease without any gritty material and with soft strokes, then it may have good plasticity

Result : The lime shows good plasticity.

3.1.6 Workability

This procedure is largely a matter of judgement and is entirely left to the practical knowledge and experience of the mason or plasterer who uses the mortar. The test shall be performed on the same mortar as is subsequently required to be used in the construction. By throwing, with the same effort as for rough-cast work, a handful of the mortar on the surface on which it is to be used and by noting how much area is covered and how much mortar is picked up, the mason may be able to judge the workability. The spread of mortar on throw of a spadeful of mortar on trowel to the wall shall be at least double in size and greater part of it shall remain stuck to the wall for a good workability.

3.1.7 Standard consistency

This test method covers the determination of the normal consistency of hydraulic lime. That is by determining the amount of water required to prepare cement pastes for Initial and final time of setting test.

Apparatus:

1. Weight and weighing devices.
2. Glass graduates (200 or 250) ml capacity.
3. Vicat apparatus with the plunger end, 10 mm in diameter.
4. Electrical mixer , trowel and containers.
5. Mixing glass plate 30cm x 30cm.

Procedure:

1) Place the dry paddle and the dry bowl in the mixing position in the mixer.
2) Place all the mixing water in the bowl.
3) Add the lime to the water and allow 30 s for a absorption of the water.
4) Start the mixer at low speed for 30 s
5) Stop for (15 s) and make sure no materials have collected on the sides of the bowel.
6) Start mixing at medium speed for (1 min).
7) Quickly form the lime paste into the approximate shape of a ball with gloved hands
8) Putting hand at (15cm) distance, throw the lime paste ball from hand to hand six times.
9) Press the ball into the larger end of the conical ring, completely fill the ring with paste.
10) Remove the excess at the larger end by a single movement of the palm of the hand. Place the ring on its larger end on the base of the plate of Vicat apparatus.

11) Slice off the excess paste at the smaller end at the top of the ring by a single sharp-ended trowel and smooth the top. (Take care not to compress the paste).
12) Center the paste under the plunger end which shall be brought in contact with the surface of the paste, and tighten the set-screw.
13) Set the movable indicator to the upper zero mark of the scale or take an initial reading, and release the rod immediately. This must not exceed 30 seconds after completion of mixing.
14) The paste shall be of normal consistency when the rod settles to a point 10±1mm below the original surface in 30 seconds after being released.
15). Make trial paste with varying percentages of water until the normal consistency is obtained. Make each trial with fresh lime.
16). Prepare a table in the form:

Observations
Wt. of lime =300 gms

TABLE 2: Normal Consistency Of Lime

Sl. No.	% of water	Amount of water	IR	FR	Penetration
1	40	120	40	17	23
2	42	126	40	13	27
3	44	132	40	11	29
4	46	138	40	8	32
5	48	144	40	5	35

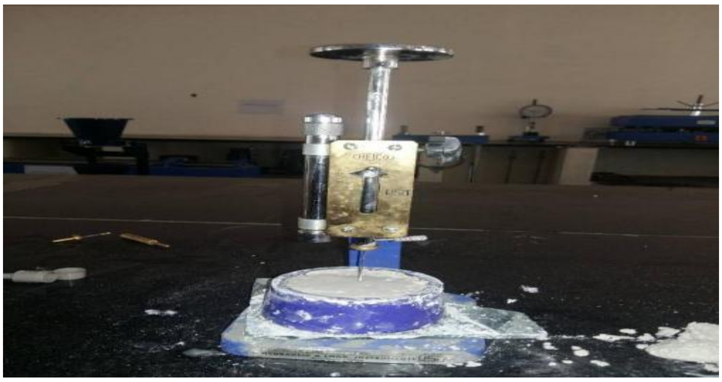

Fig. 5 Consistency test for lime

3.1.8 Setting time

This test covers determination of the time of Setting of lime by means of the Vicat needle.

Apparatus:
1. Vicat Apparatus with the needle end, 1mm in diameter.
2. Weights and weighing Device.
3. Glass Graduates (200 or 250) ml capacity.
4. A trowel and containers.

TABLE 3: Setting Time Of Lime

Setting Time	Time (min)
IST	60
FST	720

Result: The initial setting time=60 min
The final setting time =720min

3.2 Hemp Fibre

3.2.1 Specific Gravity

This test method covers the determination of Specific Gravity and Absorption of hemp aggregate. The specific gravity may be expressed as bulk specific gravity, bulk specific gravity SSD or apparent specific gravity. The bulk specific gravity and absorption are based on aggregate after 24hour soaking in water.

Calculations:
1) Specific Gravity:
a) Bulk specific gravity: - Calculate the bulk specific gravity as follow :
Bulk Specific Gravity = A /(B-C)
Where:
A=Weight of oven-dry test sample in air,(gm).
B= Weight of S.S.D. sample in air,(gm).
C=Weight of saturated sample in water,(gm).
b) Bulk Specific Gravity (SSD) = B / (B-C)
c) Apparent Specific gravity: - Calculate the apparent specific gravity as follows:
Apparent Specific Gravity = A / (A - C)

2) Absorption:
Calculate the percentage of absorption as follows:
Absorption% = [(B – A) / A]x100

Results : The specific gravity of hemp fibre was found out to be 0.65

4. MIX DESIGN

Hempcrete was moulded for 3 different types of samples. The samples were mixed at different mix ratios. The mix ratios are given at Table 5.1.The 1st sample was moulded with low water ratio.2nd sample was moulded with high water ratio.OPC was added in 3rd sample.

TABLE 4: Mix Ratio For Different Samples

Material	Sample 1	Sample 2	Sample3
Hemp Fibre	1	1	1
Water	1.5	2.9	2.9
Lime	1.5	2.5	1.5
Cement	-	-	1

The hemp fibre is chopped up to the length of 5 cm.It must constitute 62% of shives, 35% of fibres and dust particles must not be more than 3%.The fibre must be kept in water for 24 hours, in order to absorb water. The lime used can be of Class C, which is commonly used for whitewashing purpose. The lime has to be powdered and lumps must be avoided. Tap water can be used with moderate hardness ranging from 0-100 mg/l of the temperature of water was 27^{0}C.

When lime reacts with water heat is evolved which leads in evaporation of water. Therefore, the water required is very high as compared to cement. Also considering that the hemp absorbs more water, the water-binder ratio for the three samples are 100%, 120% and 120 % respectively.

4.1.1. Sample 1

TABLE 5: Quantity Of Materials For Sample 1

Material	Ratio	Quantity (kg)
Hemp	1	2
Water	1.5	3.1
Lime	1.5	3
Cement	-	-

4.1.2. Sample 2

TABLE 6: Quantity Of Materials For Sample 2

Material	Ratio	Quantity (kg)
Hemp	1	3
Water	2.9	8.7 l
Lime	2.5	7.5
Cement	-	-

4.1.3. Sample 3

TABLE 7: Quantity of materials for Sample 3

Material	Ratio	Quantity (kg)
Hemp	1	2
Water	2.9	5.81
Lime	1.5	3
Cement	1	1

Fig. 6 Moulding into cube

5. Observations and Discussions:

Fig. 7 Cubic block at 45 days

5.1 Compressive strength

The test method covers determination of compressive strength of cubic hempcrete specimens. It consists of applying a compressive axial load to molded cubes at a rate which is within a prescribed range until failure occurs. The compressive strength is calculated by dividing the maximum load attained during the test by the cross sectional area of the specimen.

- **Apparatus:**

1- Weights and weighing device.
2- Tools and containers for mixing.
3- Tamper (square in cross section)
4- Testing machine
5- Three cubes (150 mm side)

TABLE 8: Compressive strength for different samples at 45 days

Sample	Ultimate load (kN)	C/s area (m^2)	Compressive strength (Mpa)	Mean compressive strength (MPa)
1	15.8	0.0225	0.702	0.973
2	21.2		0.942	
3	28.7		1.275	

TABLE 9: Compressive strength for different samples at 60 days

Sample	Ultimate load (kN)	C/s area (m^2)	Compressive strength (Mpa)	Mean compressive strength (MPa)
1	18.1	0.0225	0.804	1.113
2	25.6		1.137	
3	31.5		1.40	

Result

The average compressive of Hempcrete is found to be 0.973 MPa and 1.113 for 45 and 60 days respectively. The strength of sample 3, which also constituted OPC was found to be higher than other samples.

Conclusion

The compressive strength of hempcrete is 1/20 to that of cement concrete. It is also found that the strength of concrete improves if cement is also added to it

Fig. 8 Block after tested for compression

5.2 Spilt tensile strength

This method covers the determination of the splitting tensile strength of Cylindrical hempcrete specimens.

Apparatus:

1. Weights and weighing device.
2. Tools, containers and pans for carrying materials & mixing.

3. A circular cross-sectional rod (φl6mm & 600mm length).
4. Testing machine.
5. Three cylinders (φ150mm & 300mm in height).

6- A jig for aligning hempcrete cylinder and bearing strips.

Fig. 9 After split tensile test

TABLE 10: Split tensile Strength @ 45 days

Sample	Ultimate load (kN)	Split tensile strength (Mpa)
1	**6.4**	**0.135**
2	**8.03**	**0.170**
3	**16.7**	**0.354**

TABLE 11: Split tensile Strength @ 60 days

Sample	**Ultimate load** (kN)	**Split tensile strength** (MPa)
1	**7.8**	**0.165**
2	**12.28**	**0.260**
3	**17.86**	**0.379**

Fig .10 Split tensile strength

5.3 Specific gravity of Hempcrete

Volume of hempcrete block = 150*150*150 =0.003375

TABLE 12: Specific gravity of hempcrete block

Sample	Mass of the block	Density (kg/ m^3)	Specfic gravity	Mean
1	3.02	895	0.895	0.817
2	2.727	808	0.808	
3	2.526	748	0.748	

Therefore, the specific gravity of hempcrete was found to be 0.817 which is lesser than that of water.This property of hempcrete makes it floatable in water.

Fig. 11 Hempcrete block Floating in water

CONCLUSIONS:

Hempcrete has very low compressive strength and elastic modulus which does not make it suitable as a direct load bearing structural material. Compressive of hempcrete increases with time. These particles can absorb water and hinder in the hydration process of the binding materials and thus result in a lower strength.

Another important property of hempcrete observed from the compression tests was the large deformation it can undergo after reaching the ultimate load . This shows hempcrete has a quasi-ductile behaviour unlike the sudden brittle failure associated with concrete.

When preparing the test specimens, it was observed that the specimens had a 'hard shell' with a softer core. This generated the idea of creating perforations in the test specimens in order to increase the surface of the hard shell, and to reduce the amount of soft core material.

Creation of perforations in a test specimen reduces its weight and creates air cavities. This will most likely also affect its thermal insulation properties,an aspect not studied in this research. It is interesting to note that while the total amount of material in the test specimen decreased due to the perforations, the compressive strength stayed the same. That is to say even though less material was used it gave similar compressive strength results.

For pre-mixed specimens generally compressive strength was higher and. However, conclusive results regarding the influence of pre-mixing the binder with water before adding it to the hemp on final mechanical strength were not obtained. It is concluded that violent mixing does not have an important impact on drying, final density and final vapour permeability.

For the sample 3, which also constituted OPC at 1:2.9:1.5:1 ratio the setting time decreased by 20% i.e., it could set 20 times faster than other samples. The sample also possessed slightly high strength compared to others

Due to large usage of hemp in volume the block became lighter and had low density. The average density of the block was found to be 0.817. Which was less than water hence, hempcrete blocks could float in water easily.

Due to quasi-ductile behaviour of hempcrete, it could be reused in the same form without much affecting it structural properties.

It was also found that the density is affected by water content of the sample. For higher water content the density decreases due to volume of voids. But this has a good impact on compressive strength. As strength is more for less density.

LIMITATIONS:

It has been established from the above research that hempcrete cannot be directly used as a structural material due to its low compressive strength and elastic modulus. Most of the research undertaken on hempcrete concentrates on the material properties. No significant research is available, which studies the composite structural behavior of hempcrete as infill in timber frame walls (the common application of hempcrete in buildings). Comprehensive structural research on hempcrete infill walls can find out if it can have any indirect structural benefits which can increase the load carrying capacity of such walls. If such research can predict the increase of wall strength due to hempcrete infill, then proper scientific design procedures can be established.

SCOPE FOR FURTHER STUDIES

This section gives a brief review of research undertaken on hempcrete to date. The research mainly concentrates on the thermal and mechanical material properties of hempcrete and how it varies with density and proportions of binder to hemp shive in the hempcrete mix.

Hemp shives have a highly porous structure and strong capillarity effects. Hemp is able to absorb large amounts of water (up to five times its own weight). For this reason, the manufacture of lime and hemp concrete by a conventional mixing and casting technique always requires a significant excess of water with respect to what is needed to slake the lime. This results in setting and drying times lasting several months, which is unacceptable in industry. Another concern with hempcrete is that its density largely depends upon the degree of compaction. It is difficult to maintain the same degree of compaction for casting hempcrete in large quantities.

The low density of hempcrete is one of the property which needs to be researched further. This property can be utilised in many ways hence there is a scope of research. Research can also be conducted with flyash,plasticizers on hempcrete. The action of admixtures may have positive results on hempcrete.

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