Improving the Energy Saving and Mechanical Properties of Masonry Produced Using Hemp Hurd with Bast Fibre in Interlocking Blocks

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***Abstract*— This research was carried out to improve the properties of masonry produced using hemp to acquire the strength according to the standard for non-load bearing concrete blocks, TIS 58/2533, and meet the standard for energy conservation of building materials according to the Ministerial Announcement by Thailand's Ministry of Energy. This research used finely chopped hemp hurd with bast fibre as the material for interlocking block masonry. Sample products were produced using varying amount of hemp and 2 types of binders, lime and hydraulic cement. Property of hemp was improved with $Al_2(SO_4)_3$. Tests were performed for compression strength, thermal conductivity coefficient and specific heat capacity. OTTV was calculated based on the specifications of the Ministerial Announcement. Research results found that the masonry produced using hemp stalk with bast fibre at the ratio by weight of hemp: hydraulic cement: sand at 0.5:1:2 where hemp properties were improved using 10% $Al_2(SO_4)_3$ by weight of hemp had the compression strength of 2.64 MPa. This was the highest ratio of hemp for the mixture for the compression strength to meet the standard for non-load bearing blocks. In terms of heat properties of this sample, it found that the thermal conductivity coefficient was 0.164 W/m°C, specific heat was 1.18 kJ/kg°C, its density was 890 kg/m^3 and the OTTV results where the highest calculations was for the Southeast side was 21.35 W/m, lower than the standard requirement for energy conserving building materials which specified OTTV to be no more than 50 W/m. Therefore, this masonry produced using hemp stalks with bast have the strength comparable to non-load bearing blocks and heat-related properties according to the standard criteria for energy efficient office buildings.**

***Keywords*—hemp, hurd fibre, bast fibre, hemp stalk, energy efficient masonry, interlocking block**

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I. Introduction

Construction has significant impact on global warming. There are pollution emissions from construction activities and embedded pollution in construction materials. Development of low-carbon materials are a better alternative for sustainable and environmentally friendly construction [1]. Studies reported that general production of construction materials creates much more pollution in comparison to production of bio-based construction material [2]. Using bio-based construction materials help reduce pollution and they have low thermal conductivity which is beneficial for the overall energy efficiency of a building [3]. This is aligned with the development framework for energy efficient construction material that Thailand has prioritized in their mandate. Monitoring, promotion and supporting measures and mechanisms had been set up to assist tangible results for energy conservation.

Thailand has many agricultural wastes that were used in researches for development of construction materials such as vetiver, bamboo scraps [4], corn husk [5] and rice husk [6]. Hemp is the new economic crop that was legalized to be grown at industrial scale. Previously hemp was grown for its fibre and the cultivation period was 90 days. The hast fibre were used for textile industry and the stalk core were left as waste and later utilized in construction materials such as hempcrete and hemp concrete for light load work because they have low compressive strength [7]. However, they have good heat related properties [8, 9], are light weight, have low density and can absorb carbon up to approximately 50% of its volume [10]. At the present hemp is being grown more for its flowers to extract Cannabidiol or CBD. This is because new legal conditions enabled cultivation of hemp flowers. Cultivation of hemp for its flowers requires 120 days cycle and the stalk together with bast fibre is waste after harvest. Therefore, research should be

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undertaken to use waste stalk with bast fibre for construction material and develop it into non-load bearing concrete blocks with heat prevention properties according to the specifications for energy efficient construction materials in the Ministerial Announcement by Thailand's Ministry of Energy [11].

This research used hemp as the mixture in masonry formed using interlocking block mold. It is a production process that does not leave waste or require energy for the incineration process so it is an energy conservation production method. Hemp was used to reduce the weight of the masonry and increase its insulation properties but at the same time its weakness in the compression strength must be improved so that it is comparable to the standard specification for non-load bearing concrete block which indicated that the compressive strength must not be less than 2.5 MPa [12]. In addition, the properties related to heat must be appropriate for being construction materials for energy conservation buildings where the properties tested are used to calculate the Overall Thermal Transfer Value (OTTV) according to the Ministerial Announcement [13]. The result was compared to the criteria for energy conserved buildings for office building which specified that OTTV must be less than 50 W/m^2 [11] according to the Ministerial Announcement.

II. RESERCH METHODOLOGY

This research used finely chopped hemp which are natural aggregate materials as the main material for masonry. The binders used were lime and hydraulic cement mixed with sand and water. The details of the research materials, production process, tests and analysis are sown in Sections II-A to II-C respectively.

A. *Research Materials*

Materials used in the production of construction material from hemp stalk include:

(1) Binder material: lime and hydraulic cement
(2) Fine sand available local construction market. The physical characteristics are as shown in Fig. 1 and its properties are as shown in Table I.

Fig. 1. Fine sand.

(3) Hemp stalk with bast are waste material from hemp cultivation for flowers which 120 days old. When chopped finely it has the volume to weight ratio of 5.41 cm^3/g. The size distribution is as shown in Table II where the largest size is no more than 9.525 mm and has physical characteristics as shown in Fig. 2. The components of the aggregate are composed hurd fibres and bast fibre as shown in Figs. 3(a) and (b) respectively.

Fig. 2. Finely chopped hemp stalk with bast.

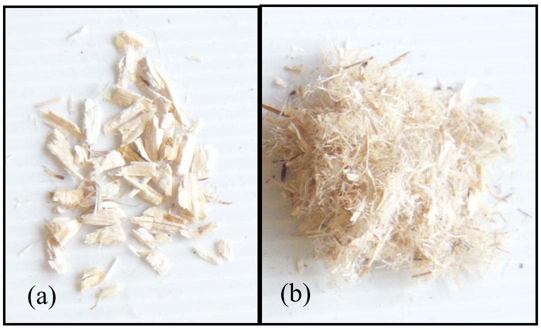

Fig. 3. (a) Hurd fibre form hemp (b) Bast fibre from hemp
The components of the aggregate are composed hurd fibres and bast fibre.

(4) Aluminum Sulfate ($Al_2(SO_4)_3$) is as shown in Fig. 4.

Fig. 4. Aluminum sulfate.

Production of Masonry from Hemp Hurd with Bast Fibre

The production process of the samples is as follows.

(1) Bake the sand and hemp to dry then weigh the sand, binder and water according to the formula (sample formula is as indicated in Table III).

(2) Prepare hemp in the mixing bowl, add water and leave for 5 minutes.
(3) Add sand into the mixing bowl, leave for 5 minutes then add binder material and mix all the aggregates together and mix well.
(4) Form the masonry using the well-mixed aggregates using sand-cement interlocking mold. Dimensions of sample is 30 in length 10 cm in width and 12.5 cm thick as shown in Fig. 5.

TABLE I. PROPERTIES OF SAMPLE SAND

	Regular	Test Results
1.	Liquid Limit (L.L.)	NP
2.	Plastic Limit (P.L.)	NP
3.	Plastic Index (P.I.)	NP
6.	Largest size	<4.750 mm.
7.	Aggregates passing sieve #200	6.88%

TABLE II. COMPONENT OF FINELY CHOPPED HEMP AGGREGATES

Sieve size (mm.)	% passing by weight
9.525 (No. 3/8)	100.00
4.750 (No. 4)	96.33
2.360 (No. 8)	71.80
1.180 (No.16)	49.97
0.600 (No.30)	31.81
0.300 (No.50)	8.24
0.150 (No.100)	4.71

TABLE III. FORMULA FOR SAMPLES

No.	Symbol	Hemp: Binder: Sand (w:w:w)	% wt. Moisture	% wt. Hemp
1. Binder= Lime				
1.1	HL-0.2	0.2 : 3 : 0	31.25	6.25
1.2	HL-0.4	0.4 : 3 : 0	41.21	11.76
1.3	HL-0.5	0.5 : 3 :0	52.69	14.29
1.4	HL-0.6	0.6 : 3 : 0	63.41	16.67
2. Binder= Hydraulic Cement				
2.1	HHC-0.2	0.2 : 1 : 2	39.47	6.25
2.2	HHC-0.4	0.4 :1 : 2	42.11	11.76
2.3	HHC-0.5	0.5 : 1 : 2	47.36	14.29
2.4	HHC-0.6	0.6 : 1 : 2	52.63	16.67

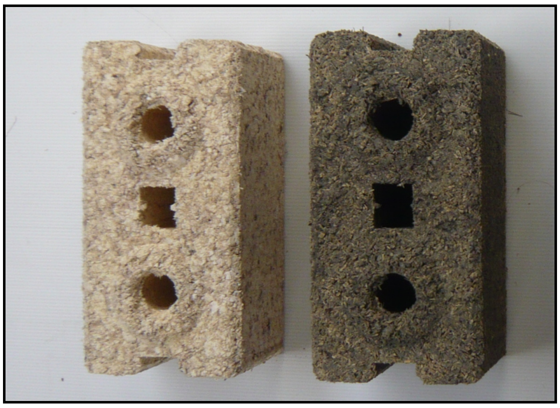

Fig. 5. Masonry samples produced using hemp hurd bast fibre in the form of interlocking blocks.

(5) Sample curing in open air under shades for 28 days.
(6) For property improvement using 10% by weight of Aluminum sulfate to hemp, dissolve Aluminum sulfate in water before mixing with hemp in step 2 and then follow mixing steps 3-5 respectively.

B. Testing and Analysis

- Compressive strength test was carried out using random sampling and concrete masonry material testing (TIS 109-2517) [14]. The compressive strength result was compared against the standard specification of compressive strength for non-load bearing concrete which indicated that it must be less than 2.5 MPa (TIS 58/2533) [12].
- Thermal properties were tested and assessed for the appropriateness for being energy conserving construction material.

The thermal properties include Thermal Conductivity Coefficient (k), Specific Heat (C_p) and density (ρ). These information were used to calculate the Overall Thermal Transfer Value (OTTV) according to Eq. (1) $OTTV_i$ was the overall thermal transfer value of the wall that is being considered which is the function of the coefficient of total heat transfer for opaque walls (U_w), the ratio of transparent walls (WWR), temperature different equivalent (TD_{eq}), the coefficient of heat transfer for transparent walls (U_f), the difference between indoor and outdoor temperature (ΔT_f), the solar heat gain coefficient through transparent walls or roofs (SHGC), the shading coefficient (SC) and the effective solar radiation (ESR) of transparent walls. However, for the case where only one material was used for opaque walls the WWR = 0 therefore $OTTV_i$ calculations in Eq. (1) will be reduced to Eq. (2).

$$OTTV_i = (U_W)(1 - WWR)(TD_{eq}) + (U_f)(WWR)(\Delta T) + (WWR)(SHGC)(SC)(ESR) \quad (1)$$

$$OTTV_i = (U_W)(TD_{eq}) \quad (2)$$

From Eq. (2), OTTV was the function of 2 main variables, U_w and TD_{eq}. U_w was the specific property of the material which include the thermal conductivity coefficient and the thickness of the wall material and TD_{eq} was the function of density, specific heat capacity, thickness, solar absorption coefficient of the external wall and the direction and bevel of the wall. TD_{eq} was a specific value indicated in the Ministerial Announcement of the Ministry of Energy [13].

The comparison of OTTV of the masonry from hemp with the criteria for energy conservation building design for office building that specified OTTV at no more than 50 W/m^2 [11] and against other masonry available in the Thai market using wall models for cases with no plastering and plastering on both sides are as shown in Figs. 6 and 7 respectively.

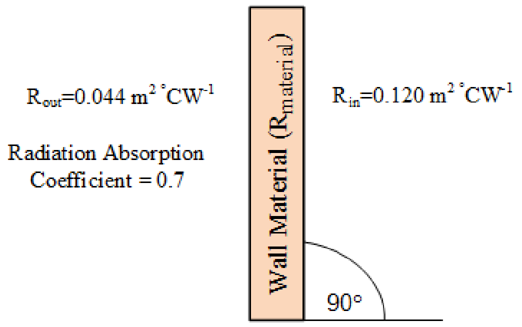

Fig. 6. Wall model for non-plastered wall with 1 type of masonry.

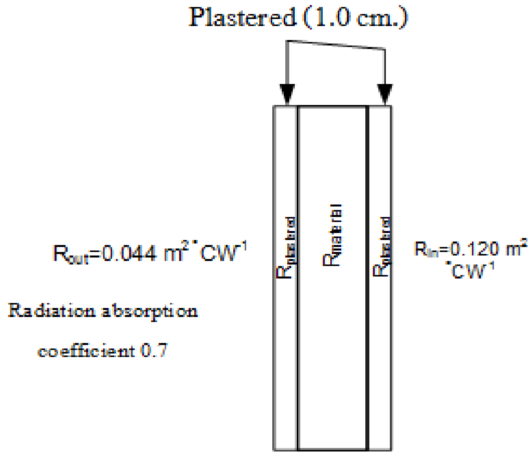

Fig. 7. Wall model for 2-sided plastered wall with 1 type of masonry.

III. Research Results

Result of compressive strength test for masonry produced from hemp stalk with bast using lime as the binder for 4 different scenarios are as shown in Fig. 8. The composition of hemp varied from 6.25%–16.67% wt. of aggregate. As shown in Fig. 8, it was found that all samples produced using lime as the binder for both cases of without improvement with aluminum sulfate and with improvement using 10% wt. of hemp of aluminum sulfate had compressive strength of less than 2.5 MPa. Therefore, masonry produced using lime as binder was not appropriate for being wall materials because its compressive strength was lower than the required standard.

The result of compressive strength test for masonry produced from hemp stalk with bast that used hydraulic cement as the binder mixed with sand at the ratio of cement: sand of 1:2 for all conditions were as shown in Fig. 9. The composition of hemp varied from 6.25%–16.67% wt. of aggregate the same as for masonry using lime as binder. As shown in Fig. 9, it was found that the 2 unimproved samples, HHC-0.2 and HHC-0.4 had the compressive strengths of 3.48 and 2.67 MPa respectively. Both were higher than 2.5 MPa therefore HHC-0.2 and HHC-0.4 achieved the compressive strength required for non-load bearing concrete blocks.

For the condition where the property hemp masonry produced using hydraulic cement as binder was improved using aluminum sulfate at 10% wt. of hemp it was found that there were 3 samples with compressive strengths higher than 2.5 MPa including HHC-0.2, HHC-0.4 and HCC-0.5 with compressive strengths of 6.14, 4.39 and 2.64 respectively. Therefore, samples HHC-0.2, HHC-0.4 and HCC-0.5 with improved properties using aluminum sulfate at10% wt. of hemp achieved the compressive strength required by to non-load bearing concrete block standard for masonry materials.

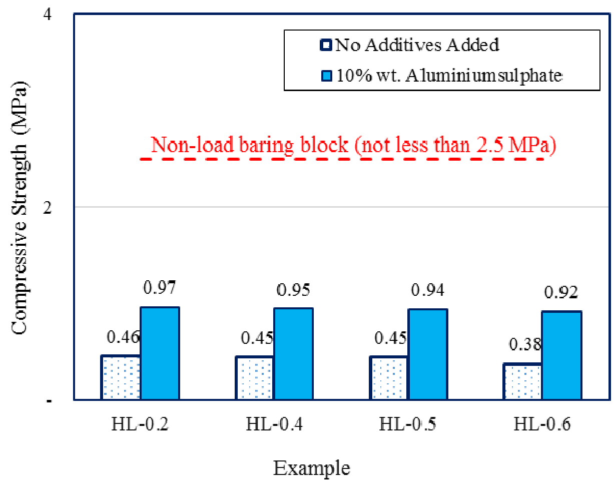

Fig. 8. Compressive strength test results for hemp masonry using lime as binder.

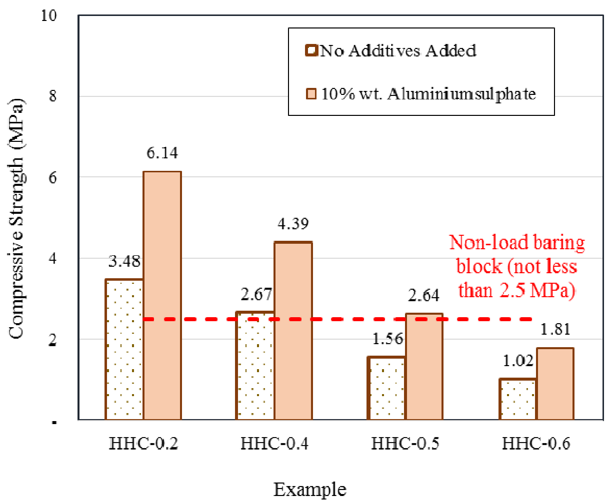

Fig. 9. Compressive strength test results for hemp masonry using hydraulic cement as binder.

Comparison of the compressive strength test results of masonry produced using hemp hurd with bast fibre and lime and hydraulic cement as binders as shown in Figs. 8, 9, indicated that using hydraulic cement as binder yield higher compressive strength than lime binder for both improved with aluminum sulfate and unimproved conditions. It was also found that the highest amount of hemp composition in masonry with compressive strength higher than 2.5 MPa was HHC-0.5 improved with aluminum sulfate at 10%wt. of hemp. The compressive strength for the condition was 2.67 MPa therefore this sample was selected for the thermal properties assessment and its appropriateness as energy efficient masonry according to the Ministerial Announcement of the Ministry of Energy [11].

The results of heat related properties of HHC-0.5 improved with aluminum sulfate at 10%wt. of hemp found that it had the thermal conductivity coefficient of 0.164 W/m°C, specific heat capacity = 1.18 kJ/kg°C, and density = 890 kg./m^3. The assessment for the appropriateness of the material was performed through OTTV calculations according to Eq. (2) from the calculation method specified in the Ministerial Announcement of the Ministry of Energy [13]. Results were compared to the criteria for energy conservation building of office buildings as specified in the Ministerial Announcement of the Ministry of Energy and to 4 other types of masonry found in the Thai masonry market including light-weight concrete, red-earth bricks, concrete blocks and interlocking blocks. OTTV for the condition of non-plastered walls are as shown in Table IV. Fig. 10 indicated that HHC-0.5 has OTTV = 21.35 W/m^2 which is the lowest OTTV compared to other materials. This showed that it has better heat prevention properties. Other than that for the OTTV of 2-sided plastered walls the results in comparison to light weight concrete, red-earth bricks and concrete blocks as shown in Table IV and Fig. 11 showed that HHC-0.5 still had the lowest OTTV. Therefore, it can be concluded that masonry made from hemp with the ratio by weight of hemp: hydraulic cement: sand = 0.5:1:2 had the properties appropriate for being energy efficient construction material according to the energy conservation criteria for office building as specified in the Ministerial Announcement of the Ministry of Energy.

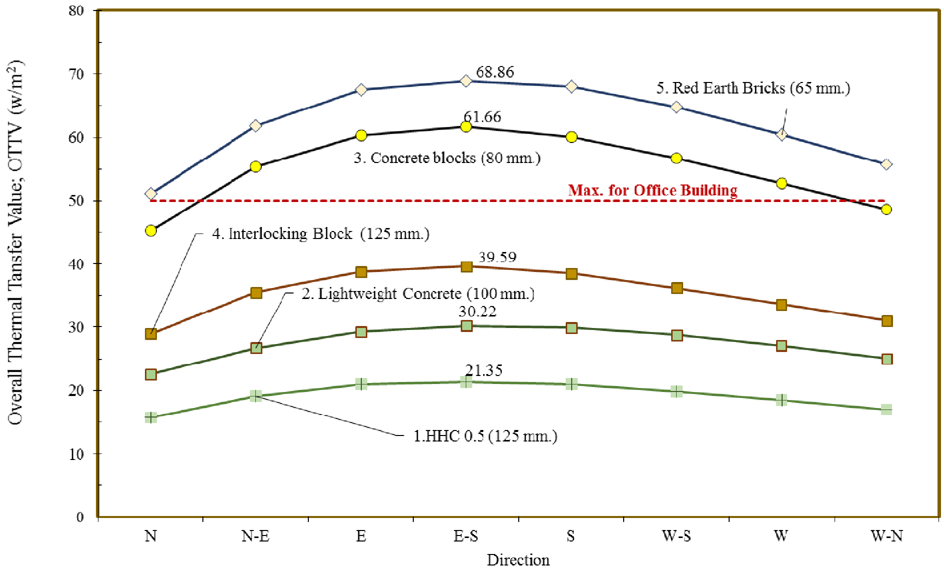

Fig. 10. OTTV of HHC-0.5 compared with non-plastered walls of other materials.

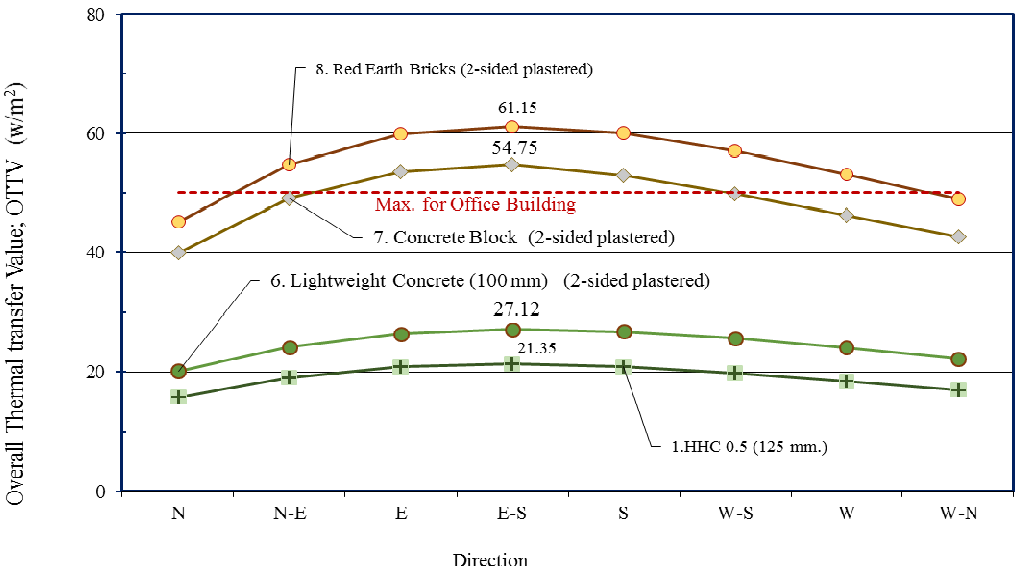

Fig. 11. Comparison of OTTV of HHC-0.5 with 2-sided plastered walls of other materials.

TABLE IV. OTTV RESULTS OF HHC-0.5 IN COMPARISON TO OTHER CONSTRUCTION MATERIALS IN THAILAND

	Northern wall	Northeastern wall	Eastern wall	Southeastern wall	Southern wall	Southwestern wall	Western Wall	Northwestern wall
1. HHC 0.5 –10% $Al_2(SO_4)_3$ (125 mm)	16	19	21	21	21	20	18	17
2. Lightweight Concrete (100 mm)	23	27	29	30	30	29	27	25
3. Concrete blocks (80 mm)	45	55	60	62	60	57	53	49
4. Interlocking Block (125 mm)	29	36	39	40	38	36	34	31
5. Red Earth Bricks (65 mm)	51	62	68	69	68	65	60	56
6. Lightweight Concrete (100 mm) (2-sided plastered)	20	24	26	27	27	26	24	22
7. Concrete Block (80 mm) (2-sided plastered)	40	49	54	55	53	50	46	43
8. Red Earth Bricks (2-sided plastered)	45	55	60	61	60	57	53	49

IV. CONCLUSION

The research results indicated that the masonry produced from hemp hurds with bast fibre using hydraulic cement as binder where the weight ratio of hemp: hydraulic cement: sand = 0.5:1:2, improved properties using aluminum at 10%wt. of hemp achieved the compressive strength of 2.67 MPa and had the highest OTTV for the southeastern wall of 21.35 W/m^2. The OTTV calculated was no more than 50 W/m^2 as specified by the standard criteria for construction material of energy conservation in office buildings. Therefore, the masonry produced from hemp hurds with bast fibre has the strength above the minimum required compressive strength of non-load bearing concrete blocks specified in TIS.58-2533 and the thermal properties according to the standard criteria for construction of energy conserving office buildings specified in the Ministerial Announcement by Thailand's Ministry of Energy.

CONFLICT OF INTEREST

The authors declare no conflict of interest

AUTHOR CONTRIBUTIONS

Nopphawit Itthithananchai prepared the samples and carried out laboratory tests; Roongarun Buntan performed data analysis; Komchai Thaiying consolidated the data and prepared the article; Sudniran Phetcharat and Theerawat Sinsiri are advisors of the research project; all authors had approved the final version.

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