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A Study of Physical and Mechanical Properties using Kenaf Core as Coarse Aggregate Replacement in Concrete

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ABSTRACT

Kenaf is well known for its one of the highest rankings of biomass producers compared to other fibre crops which excessive amounts of biomass could lead to contamination of soil due to its pollutants elements. Not only that, the high demand for aggregate for concrete production requires massive use of natural stone materials which leads to the destruction of the ecological balance of the environment. As in Malaysia, kenaf core is commonly used and available in abundance after the processing of kenaf stems for bast fiber production. Thus, this research aims to determine the physical and mechanical properties of kenaf core as fine aggregate replacement in concrete. There were 45 samples of the concrete cube of 100 mm x 100 mm with the percentage used of 0, 5, 15 and 25 % kenaf core replacement. A density test was conducted as well as a compressive strength test to obtain the objectives of the study. Findings reveal that the control sample still has the highest value of compressive strength of 34.7 MPa while 5 % of kenaf core concrete shows 28.50 MPa which slight decrease in the value in comparison. The value then gradually decreases as the percentage of the kenaf core increases. The density test also reveals that 25 % kenaf core shows the lowest value of density by 1419.78 kg/m^3 compared to normal concrete. Thus, this indicates that the optimum percentage of kenaf core used was 5 % even though it still did not surpass 0 % concrete.

Keywords: Kenaf Core; Concrete; Aggregate Replacement; Failure Mode; Density; Compressive Strength

INTRODUCTION

Concrete can be described as one of the oldest and most common construction materials that have been used for the past decades. This can be explained as it is mainly used due to its low cost, durability, high workability, material availability as well as ability to sustain in extreme weather. As matter of a fact, the production of concrete is 10 times higher compared to steel by tonnage [1]. To add to this description, other materials such as steel and polymers are more expensive materials and less common than concrete materials. As we all know that concrete is a brittle material that contains high compressive strength. However, it has a lower tensile strength in comparison to steel. Despite the usage and purpose of concrete have not changed much over the past decades but modern concrete has carried an evolution of improving and combining the concrete materials over thousands of years. As the building industry expanded in Malaysia, so did the demand for cement, which in turn fueled the growth of infrastructure development in the country.

As for the study, the selected fiber or composite element is kenaf or also known as Hibiscus Cannabinus. It is well known for its fiber plant that has been grown for the resources which provide food and the fiber itself. Originally, kenaf plants were found natively in the east-central of Africa due to its common wild plant of tropical and subtropical Africa and Asia. Thus, usage of kenaf as fiber element in concrete can help in repairing and rehabilitation purposes may give a great impact in engineering application towards sustainability. In addition, a review on potentials of kenaf fibre in bio-composite production [2] stated that it has been proved that kenaf also has a higher assimilation rate of carbon dioxide compared to other plants. Generally, kenaf can be used as raw material as well as an alternative to wood in pulp and paper industries in order to avoid the destruction of the forest [2]. Not only but it is also used as non-woven mats in automotive industries, fibre boards and textiles. In Malaysia, cost of kenaf is RM 4.40 per kg whereby when it is compared to synthetic fibres is very low. Even if the price is low, the flexibility of its usage is outstandingly wide. This can be explained kenaf crop has been found to be a crucial source fibre when it comes to composites and other industrial applications. Generally, kenaf can be used as raw material as well as an alternative to wood in pulp and paper industries in order to avoid the destruction of the forest [2]. Not only but it is also used as non-woven mats in automotive industries, fibre boards and textiles. In fact, the natural and wood fibre plastic composite managed to gain significant interest over the past few decades. It says that the retail value in the industry has emerged grown up to 16 % since 1998 and is estimated valued to be over RM 3301.50.

The natural elements can be described as an essential asset that needed to be protected. Apart from being one of the assets to the environment globally, it is also one of the key factors to improve the quality of building construction. This could be specifically towards the material used in construction or even construction components. This is because numerous studies analyze huge impacts were taken when they introduced the usage of the natural element in the construction field. This includes indoor green building, aquatic elements as well as green building technology. To add more facts to this statement, the research said that the usage of raw natural materials plays a decisive role in the construction of building in terms of sustainability and environment [3]. Thus, in general, the overall quality of building nowadays is coping well with the usage of the natural element as composite or even replacement materials in construction components. This also could help to quantify the social impact of the building as the main mission of striving for truly sustainable structures achieved [3].

According to a review on applications of biocomposite materials based on 27 natural fibers from renewable resources [4], the usage of biocomposite has been considered as global growth in various sectors such as the domestic sector, building materials, aerospace industry, circuit boards, and automotive applications over the past decade. This indicates the importance of biocomposite usage in the current growth of industries. According to literature [5], biocomposite material contains natural fibres which provide tonnes of benefits such as recyclability, biodegradability, renewability and high specific strength in many levels. Furthermore, the usage of these biofibers can reallocate the ecological and economical concerns in the industrial materials. Hence, the usage of this material in construction industries will obviously provide to reduce the usage of natural resources that have been provided to humanity over years. As for kenaf concrete, commonly, in the context of kenaf, the mechanical properties of cellulose 24 fibres rely on the cellulose content as well as the spiral angle that creates the band of microfibrils in the inner secondary cell wall. This inner secondary cell wall then being made with the fibre axis. To be more accurate, the structure and properties of natural fibres depend on many factors such as their age, source, quality of the harvest, the position of the plant, body of the plant from which the fibre is extracted, and the extraction techniques and the environmental conditions of the site [2].

As from previous research on this kenaf in concrete, the closest research of kenaf has been conducted by Affendi and Yatim [6]. This research can be considered as quantitative study. It consists of several types of testing to achieve its objective whereby to study the bonding kenaf fibrous concrete and normal concrete interface. The normal concrete grade used in this research was 35 MPa. Meanwhile, kenaf fibrous concrete used were 25, 35, and 45 MPa. The usage of kenaf fiber in total volume concretes was 50 mm. This research indicates the study of kenaf as an admixture in concrete whereby several tests have been conducted to acquire the physical properties of the fibrous concrete. Based on the result, the compressive strength test for kenaf fibrous concrete increase parallel with the number of concrete grades. To be exact, the compressive strength for grade 25 MPa and 35 MPa recorded a compressive value of 28.05 MPa and 29.01 MPa, respectively. However, for grade 45 MPa it stated the highest value of compressive strength by 37.38 MPa. They claimed that the compressive strength of kenaf fibrous concrete and normal concrete can be considered lower compared to normal concrete with the same grade. However, this research also stated that the compressive strength of bonding kenaf fibrous concrete can be increased parallelly with increasing the concrete grade. This surely explained that in order to achieve higher strength and compressive strength of concrete, the concrete grade itself must be increased.

Moreover, one of the findings in the elongation at break result was the decrease of the composite was due to the lower elongation at break of kenaf fibre compared to UP matrix. The elongation at break of kenaf fibre was 1.6 % while the kenaf core was 2 % [7]. In other words, the higher the fibre content will lead to lower elongation at the break of its composite. Meanwhile, as the fibre content was up to 40 %, the UP was insufficient to wet the fibre fully. Thus, this also led to weak interfacial bonding between the fibre and the matrix. Hence, when force was applied, the tendency to fail was higher rather than fail to elongate [7]. In another word, it has been observed that the elongation at break for both composites fail due to higher fiber content. It also concluded that the higher the cellulose content, the longer fibre and the smaller the fibre diameter significantly increase the mechanical properties of the composite concrete. Moreover, in the study conducted Hassan *et al.* [8], it has been observed that there were several important data that need to be studied in terms of the mechanical and physical properties of the bricks. In terms of physical properties, the density of the bricks shows the variable samples have lower density compared to the control sample. Thus, this indicates that the usage of the kenaf core slightly reduced the density of bricks which aligns with the features of lightweight bricks. However, in terms of mechanical properties, the compressive strength indicates the strength of bricks decreases as the kenaf core increases.

Furthermore, the usage of fiber content in this study was 1, 2 and 3 % (by weight of cement) with various lengths of 10, 20 and 30 mm in mortar 50 mm cubes [9]. Based on the result, it shows that the compressive strength of the composite mortar increased by 2 % of fiber volume. This refers to 10 and 20 mm lengths. Meanwhile, it decreased for other mixes at all curing ages. Furthermore, the highest or maximum strength was observed at 2 % fiber volume with 10 mm fiber length. This indicates that there is a non-statistically significant difference in the compressive strength in mortar that contains 1-3 % fiber volume with 10 mm length [8].

Apart from that, it has been observed that there were several important data that need to be studied in terms of the mechanical and physical properties of the bricks. In terms of physical properties, the density of the bricks shows the variable samples have lower density compared to the control sample. Thus, this indicates that the usage of the kenaf core slightly reduced the density of bricks which aligns with the features of lightweight bricks. However, in terms of mechanical properties, the compressive strength indicates the strength of bricks decreases as the kenaf core increases. The fact that the usage of kenaf bast only represents 10 % compared to the kenaf core which is 90 % of the total kenaf plant [10], strongly proves that kenaf core is a material that needed to be studied for its further usage instead of being a waste to the environment.

EXPERIMENTAL DETAILS

Generally, the concrete mix design used the ratio 1:2:4 which reflects the proportions of cement, fine aggregates and coarse aggregates. Thus, the methodology of this study started with a typical mix concrete layout sheet whereby is used to measure the concrete mixing percentage. This indicates a proper and better way of laying out each mixing parameter for every material used in terms of volume. Not only that but by specific measurement of the percentage used, a lower possibility of waste would occur throughout the whole process.

Material used

Cement

OPC is known for its general uses in construction purposes where it provides special properties that are not required such as reinforced concrete buildings, bridges, pavements, and where soil conditions are normal. The OPC used in this study was according to the BS EN 197-1: 2011 which falls under cement type 1. EN 197-1:2011 can be described as The European Standard which provides the specifications of 27 distinct common cements, 7 sulfate resisting common cements as well as 3 distinct low early strength blast furnace cements and 2 sulfate resisting low early strength blast furnace cements and their constituents. Commonly it is being used for concrete in masonry units. Moreover, the curing period of OPC is less compared to PPC. This also helps to reduce time consumption for this study. Thus, OPC was used as the main binder in the concrete mixture.

Kenaf core

The raw material of kenaf core were collected from the UiTM laboratory storage, Shah Alam. National Kenaf and Tobacco Board conducted expandable research on the properties and performance of kenaf. These organizations have been showing great support regarding any research activities related to kenaf to achieve any data or develop new data. Basically, the raw kenaf core were extracted from the plant using a water retting process as shown in Figure 1.

Figure 1: Kenaf core

Coarse Aggregate

Granite aggregates was used during the concrete mixing in this research. Commonly, granite formed naturally from dump stone quarried, crushed, and produced in various sizes. Thus, in this research, it is used as a coarse aggregate in concrete mixing. Coarse aggregate works to provide solid and hard mass concrete with cement and sand. It also provides bulk to the concrete. The selected coarse aggregate used in the concrete mixing is 10 mm aggregate and being obtained at Kajang Rock Quarry near Semenyih. In this study, the coarse aggregate can be described as well-graded aggregate as it was obtained in a quarry in which they had already sieved aggregate size adequately.

Fine Aggregate

Basically, the mining sand was chosen due to its easy accessibility as well as being cheaper than other fine aggregate. However, the mining sand were checked beforehand in order to prevent any mixing with other materials. This material also was obtained at Kajang Rock Quarry near Semenyih. Similar to the coarse aggregate, the fine aggregate also was well-graded as it was obtained in the same quarry.

Water

Water is the main ingredient which works well when mixed with cement and it forms a paste that binds other components together such as aggregate. Moreover, the usage of water in mixing causes the hardening of concrete through a process of hydration. However, the quality also influenced the requirement of concrete mixing.

Design mix

Regarding the design mix, in this study, there was a 4 different percentages of Kenaf Core mixture ratio designed whereby it includes the variations of 0, 5, 15 and 25 %. Thus, Table 1 explains the mix proportions of the kenaf core concrete design with 10 % of wastage in kg/m^3. After successfully carrying out the design mix, the casting process proceeded under detailed supervision and observation. Later, all samples were compacted using a vibration machine available in the UiTM laboratory in order to ensure minimized or even zero possibility of void produced in the concrete samples.

Table 1: Total mix proportion of kenaf core concrete with 10 % of wastage

	0 %	5 %	15 %	25 %	Total (Kg/m^3)
Fine aggregate	7.99	7.99	7.99	7.99	31.96
Water	2.11	2.11	2.11	2.11	8.44
Cement	3.90	3.90	3.90	3.90	15.6
Coarse aggregate	9.76	9.27	8.30	0.00	34.65
Kenaf core	0.00	0.49	1.46	9.76	19.97

On top of that, Ordinary Portland Cement used the water cement ratio of 0.54. Moreover, this study also consisted of 45 samples of the concrete cube of 100 mm^3. The process then proceeded towards finding the related data of dry density as it covers the physical properties of concrete as well as compressive strength which reflect the mechanical properties of concrete. The day of curing was set on the 3rd, 7th and 28th days for each sample.

Dry density test

Basically, the information obtained from this test can be related to determining the yield and the relative yield of the concrete. Not only that but it also can be used to calculate the air content of the mix. Generally, denser foamed concrete produces higher compressive strength and a lower volume of voids. After each day of curing, each sample of the concrete specimen was taken out for density test according to ASTM C 642. Then, these samples were to change into Saturated Surface Dry or also known as SSD condition whereby the water was removed from the surfaces of concrete. After that, the SSD weight of samples in the air (C) was measured and then left out dry for a few hours (A). Finally, the samples were placed underwater in a bucket and weight underwater (D) was obtained. Equation (1) was used to obtain the density for each sample.

$$\text{Dry density (bulk density)} = A/\,(C-D) \qquad (1)$$

A= mass of oven-dried sample in air, (g)
C= mass of saturated surface-dry sample in air, (g)
D= mass of sample in water after immersion, (g)

Compressive strength test

This compressive strength test was used to determine the value of compressive strength of the kenaf core as coarse aggregate replacement in the concrete. As in theory of mechanics, the compressive strength value demonstrated by the test explained the capacity of a kenaf core concrete to withstand loads tending to reduce size. The concrete cube samples were tested under a compressive strength test according to British Standard (BS EN 12390-3: 2002). The concrete cube kenaf core concrete samples were loaded to failure with the maximum load they can sustain. Thus, it produced the compressive strength value according to its failure force. First and foremost, the weight of each concrete sample was recorded before carrying out the test. After that, the plate of the testing machine was wiped clean to make sure the reading of the compressive strength is accurate and precise. Next, the sample was positioned correctly, and the door was closed for safety reasons. As for the study, the 45 samples of cube test of 100 x 100 x 100 mm were tested under detailed supervision and observation. The cubes are evaluated with a compression machine after 7, 14, and 28 days of curing, and thus were tested at the proper angles to the casted position. The reading was recorded as the compression starts.

RESULTS AND ANALYSIS

This section of this research paper discusses the failure modes, density and compressive strength results of kenaf core concrete and normal concrete as well as the optimum percentage for this study. These results complement the objectives of this research.

Failure mode

Figure 2 until Figure 5 visualized the end result of failure mode for each kenaf concrete in the study. One of the biggest observations that can be made was the cement matrix and aggregate spalling on the Kenaf Core Concrete meanwhile the control sample shows no obvious spalling due to the compressive strength test. This can be explained as, during the failure process, kenaf core concrete specimens visualized the slow pace of development of the crack. This can be concluded that the higher the kenaf core content, the higher the number of cracks that can be observed on the surface of the specimens. This can be more specific as the cracking usually occurs when shrinkage forces produced greater strength than concrete strength. To support this statement, the moisture content increased linearly as the used percentage of kenaf core in concrete. The increment of this moisture content was due to a high level of cellulose content . Logically, the increasing of moisture content will automatically reduce the concrete's compressive strength and durability as well as visualise more cracks when the load is applied [11].

Figure 2: 0 % kenaf core

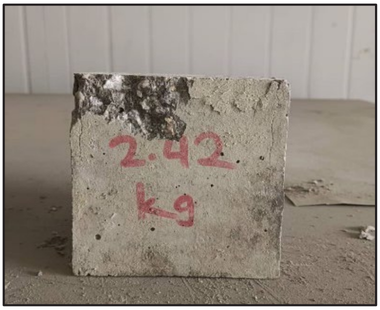


Figure 3: 5 % kenaf core

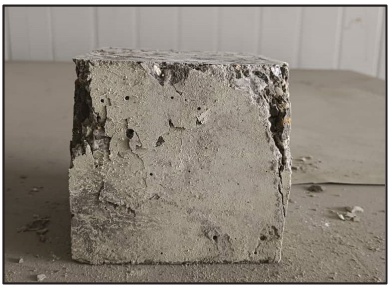
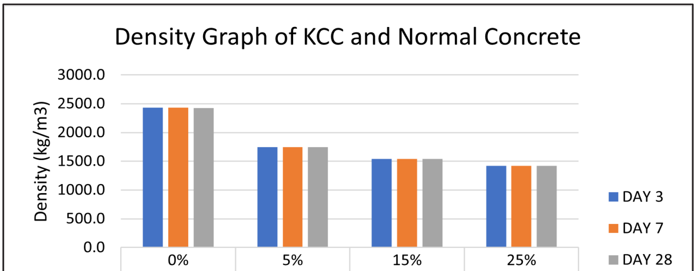


Figure 4: 15 % kenaf core

Figure 5: 25 % kenaf core

Density

Figure 6 explains the density of the graph between kenaf core concrete and normal concrete. An obvious observation can be made as the value of density concrete decreases when the kenaf core percentage increase. This can be explained by day 28 of curing shows kenaf core concrete with 25 % shows the lowest value of density by 1419.78 kg/m^3 compared to normal concrete which has a value of 2422.30 kg/m^3. However, the data shows slight differences between kenaf core content of 25 % and 15 % by 1.2 %. Meanwhile, the highest value of density can be shown in the control specimen as it provides 2422.30 kg/m^3 compared to another specimen. It also can be concluded that the usage of kenaf core in concrete is more suitable for lightweight concrete as it reveals the features of low density compared to normal concrete. This can be approved as a study conducted shows lightweight concrete can be defined by BS-EN 206-1 are not less than 800 kg/m^3 and not more than 2000 kg/m^3 [12].



	0%	5%	15%	25%
DAY 3	2430.0	1746.7	1540.0	1423.3
DAY 7	2433.3	1745.8	1541.1	1420.4
DAY 28	2422.3	1744.9	1540.9	1419.8

Figure 6: Density graph of kenaf core concrete and normal concrete

Compressive Strength

In Figure 7, it can be observed that the control specimen of 0 % achieved the highest value of compressive strength on day 28 days of curing by 32.23 MPa while 5 % of kenaf core indicates slight difference value of 28.50 MPa. Meanwhile, the kenaf core concrete of 25 % obtained the lowest value compressive strength after 28 days with 13.77 MPa. The reduction of strength can be analysed during the mixing process as it may does not blended well with other materials which eventually occurs lower bonding reactions. Besides that, the higher the percentage of kenaf core in concrete, the lower the compressive strength obtained in the compressive strength test. These characteristics are influenced by the presence of lignin, hemicellulose and pectin as they provide hydrophilic properties [13].

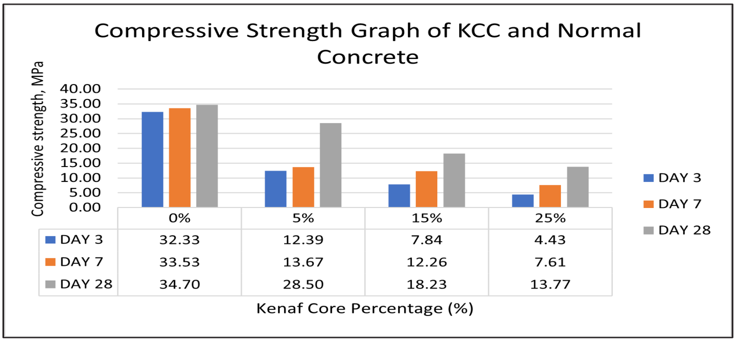


Figure 7: Compressive strength of kenaf core concrete and normal concrete

Relationship between Compressive Strength and Density

Figure 8 managed to show that one conclusion can be made which is the higher the density of concrete, the higher the compressive strength. This can be shown as 0 % kenaf core provided higher compressive strength linearly with the density value. A denser concrete commonly produced higher compressive strength as it has lesser voids and porosity revealed at the surface of the concrete. By saying this, the smaller the void in concrete, the lesser the possibility for the concrete to be permeable to water and other infiltrated element [14].

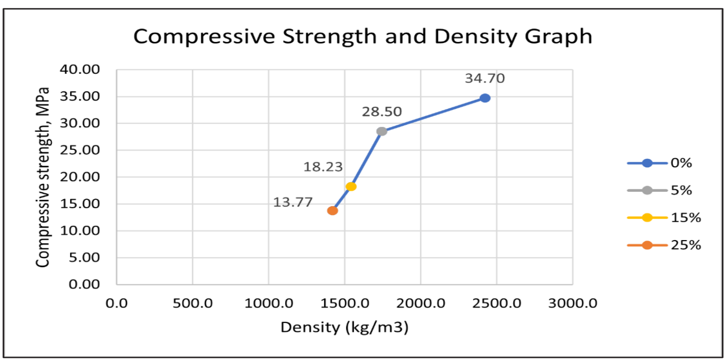


Figure 8: Compressive Strength versus Density graph

Optimum percentage of kenaf core in concrete

From Figure 9, it can be observed that the control sample or 0 % kenaf core percentage shows the highest value of compressive strength obtained compared to other samples. However, in terms of a comparison study between added kenaf core percentages, it can be stated that 5 % produced a higher value of compressive strength compared to 15 % and 25 % by 28.50 MPa.

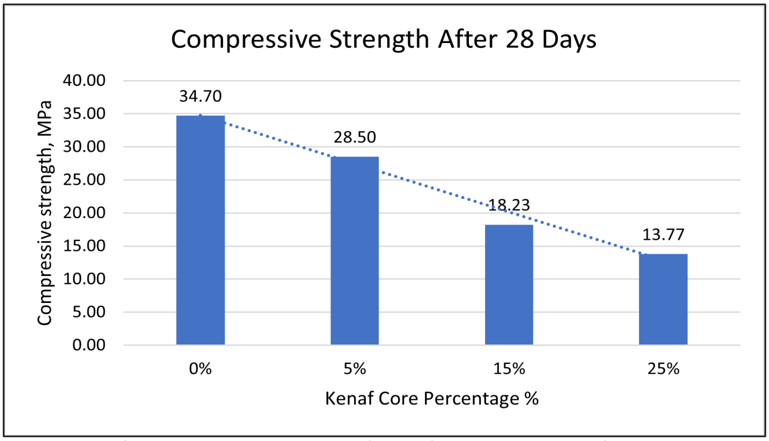


Figure 9: Compressive strength of kenaf core concrete after 28 days

CONCLUSIONS

This can be concluded that the higher the kenaf core content, the higher the number of cracks that can be observed on the surface of the specimens. The data indicate that the higher the percentage of kenaf core, the lower the density. This is due to the replacement of the kenaf core as it has a low density of 0.31 kg/m^3. However, this also indicates that the increase in the kenaf core works linearly as the increase of porosity. In addition, in terms of density, the lowest percentage of kenaf core also shows the value of 1744.89 kg/m^3 as it allocates the range of lightweight features in concrete. The value of compressive strength of the kenaf core concrete achieved the highest reading with 5 % with 28.50 MPa of kenaf core compared to other percentages. However, it still does reach the expected compressive strength value of 30 MPa as designed in DOE. Based on data analysis from each test, the most optimum ratio percentage of kenaf core in concrete is 5 % as it shows similar values compared to the control sample.

In Malaysia, biocomposite technology can be described as a new alternative indication towards current development. However, it still holds high potential and a bright future for further continuous research on kenaf flexibility in the industrial aspect. By saying this, also indicates a proper commercialization strategy and approach are crucial to achieving the main goal of using this fiber. As for the study, the best conclusion that can be made is that the usage of kenaf core in concrete is reliable under specific processes and treatments. Moreover, the findings from the study also enlighted that the kenaf core concrete produces the features of lightweight due to its density and the material weight itself. A detailed and specific treatment should be conducted on the kenaf before being used in any procedure related to the mixing process which is Sodium Hydroxide, NaOH has been found as an effective approach in terms of removing the impurities on the surface of kenaf which eventually improved the mechanical properties. Besides that, a combination of kenaf with other natural fiber also can be one of the major recommendations for this study. This is because the combination of other synthetic fiber can help to decrease the rate of utilization of the synthetic fiber.

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