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Assessment of Sponge Gourd (Luffa Aegyptiaca) Fiber as a Polymer Reinforcement in Concrete

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ABSTRACT

The crave for a sustainable green environment and yearning for lightweight structures in society today have prompted engineers to seek more alternative materials to reduce the negative sides of concrete structures. Often time, composite materials or fibers are incorporated into the concrete matrix to give better performance. In this regard, the fiber enhances the concrete aggregates against stresses. This study assessed the performance of Luffa aegyptiaca (sponge gourd), a natural fiber as a polymer reinforcement in concrete for better operation. Different layering arrangements were adopted (lamina, mesh, longitudinal, and disperse) to get the best fit. The compressive strength test, as well as the flexural strength test, among other tests carried out, indicated that laying the fiber longitudinally in the concrete matrix can give better performance in strength. The average compressive and flexural strength of 25.8 MPa and 10.2 MPa respectively are recorded for the longitudinal arrangement, which stands as the highest strength. The fiber can work well in improving concrete spalling. An extended study on the mechanical properties of the Luffa aegyptiaca to ascertain its performance is therefore recommended.

Keywords: Luffa Aegyptiaca Fiber, Strengths, Concrete

1. INTRODUCTION

The development of science and technology has shaped a need to develop engineering materials with lightweight, high strength with specific properties per service requirement at low cost and minimum energy consumption. Many composites used today are at the leading edge of materials technology; their use has been extended to advanced applications such as aircraft and aerospace structures. The idea of composite materials, however, has been existing for thousands of years. In early civilization, natural polymers were mixed with inorganic materials to achieve high strength composite materials used for construction. The Ancient Egyptians used the chopped straw to reinforce with mud bricks, Mongol warriors used a composite consisting of Bullock tendon, horn, bamboo strips, silk, and pine resin to produce High-performance archery bows. Albumen, rice, and blood were used to produce mortal, and glutinous paste from the rice was adopted for the great wall of China [1-3]. Since the early 1960s, there has been an increase in the demand for stronger, stiffer, and more lightweight materials for use in the aerospace, transportation, and construction industries. High-performance demands on engineering materials have led to the extensive research and development of new and better materials [4]. Composite materials used for structural purposes often have low densities, resulting in high stiffness to weight and high strength to weight ratios when compared to the traditional engineering materials. Besides, the high fatigue strength to weight ratio and fatigue damage tolerance of many composites also makes them an attractive option [5]. Concrete is one of the engineering materials widely adopted for building and constructing infrastructures such as bridges, buildings, silos, among others, owing to its ease handling to form different shapes and the low cost it offers. However, as a result of its nonlinear behavior, concrete possess some demerits such as (a) pore voids, which are the entrance point for liquids, gases, and chemically aggressive elements and saltwater which cause concrete deterioration; (b) its coarseness characteristic undermines its performance during high abrasion, which results in fatigue; (c) poor resistance to fire. An alternative remedy for such troubles is to incorporate polymer materials into the concrete. Polymer materials have mineral aggregates with good binding, durable, and elastic. The integration of synthetic fiber is appreciated to produce cheaper and flexible materials [6, 7]. In polymer concrete, there exist the resin that binds the inorganic aggregate rather than the water to cement binder used in the Portland cement concrete. The focus of the research is on the development of concrete with the embedment of Luffa aegyptiaca fibers in different arrangements and multiple layers for both compressive strength and flexural strength tests. It is a rapidly developing material with the attractive advantages of low density and cost compared to metals and other forms of fiber reinforcements. However, reinforcements are still needed to provide additional strength for concrete. The combination of these materials with properties different from the individual characteristics is produced. The constituent materials contained concrete and luffa fiber as reinforcement. The primary phase of composite materials is the concrete matrix phase, which is usually more ductile and less hard as well as holds the reinforcing phase normally stronger than the concrete matrix and transfer stresses between the reinforcements.

Most of the natural Luffa aegyptiaca fibers found today around the tropics are lignocellulosic in nature. Luffa acutangular and Luffa aegyptiaca (Figure 1), are the two major species grown and harvested as vegetables in Asia and Africa. Luffa grows straight arrow, curved, and grows about 200 mm in length [8,9]. Luffa family has found several uses such as edibles present in the market [10], as bath sponges, filler materials for production of composites, materials of adsorption in water treatments, for discoloration of reagent, extraction of harmful chemical and biological compounds, in the cosmetics industries among others [11]. In the present scenario, natural fibers have excellent potential to reduce not only CO_2 emissions but also save non-renewable resources by substituting artificial fiber reinforcements in composites. Traditionally, glass fibers and wool have been extensively used as building insulation material and reinforcement in the auto sector thermoplastics. Natural fibers are being explored more extensively by research institutions and automobile companies as environmentally friendly. Most of the best fibers being studied are obtained from naturally growing plants of flax, kenaf, sisal, and hemp. Flax, sisal, and hemp are processed into door cladding, seatback linings, and floor panels. Coconut fiber is used to make seat bottoms, back cushions, and head restraints, while cotton is used to provide soundproofing, and wood fiber is used in seatback cushions [12].

Figure 1. Luffa Aegyptiaca

2. MATERIALS AND METHODS

The author of this research adopted Luffa aegyptiaca as reinforcement material in concrete. Research on the strengthening of concrete with this fiber is limited since some of its mechanical properties, which can be linked with cement concrete has not been established. Querido et al. [13] adopted Luffa Cylindrical to strengthen cement composite matrix, workability, and constituency of the mix were better than the ordinary cement paste. Moreover, a limited deflection hardening behavior was observed. Luffa fiber has also been used to modify polystyrene matrix [14].

The materials used in this research were Luffa aegyptiaca fiber, sand (fine aggregate), granite (coarse aggregate), cement (Ordinary Portland cement), clean water and curing medium. The mix ratio adopted was 1:2:4 (cement: sand: granite) with water to cement ratio of 50%. All the materials were gotten within Akure metropolis in Nigeria. The luffa fiber is abundant in Akure and its suburb villages and can be acquired free.

2.1. TEST ON THE AGGREGATE

Particle size distribution analysis (with minimum sieves size 75µm or number 200) according to the British standard specification [15] was carried out for the fine aggregate obtained to determine the gradation of the soil. A little part of the sand was oven dried for 24 hours to remove the moisture, 200g of the oven-dried sample was collected for sieve analysis. The particle size distribution was calculated using the formulae presented in equations 1 and 2.

$$\%\, retained\ on\ the\ ith\ sieve = \frac{M_1}{M} \times 100 \quad (1)$$

$$f = 100 - \sum_{i=1}^{i} \%\, retained\ on\ the\ ith\ sieve \quad (2)$$

Where f is the % finer than the percentage retained on the sieve, M1 is the weight of the soil retained on the sieve from the top of the nest sieves, M is the total soil weight. Since the knowledge of fines is crucial to appreciate how soil can be used for construction materials or as the foundation for structures [16], hence the choice of a soil for specific use can be dependent on the varieties of particles embedded. Two coefficients, uniformity, Cu, and curvature, Cc, have been numerically measured to give information on the gradations. Equations 3 and 4 describe the two coefficients.

$$C_u = \frac{D_{60}}{D_{10}} \quad (3)$$

$$C_u = \frac{(D_{30})^2}{D_{10}\, D_{60}} \quad (4)$$

D60, D30, D10, are the diameter of the soil particles for which 60%, 30%, and 10% of the particles respectively are finer. The test was done on the granite (coarse aggregate) included the aggregate crushing to obtain the crushing value and the aggregate impact to obtain the impact value. Aggregate crushing value (ACV) test: To determine the ACV for the granites, the aggregate passing through 12.5 mm and retained on 10 mm British Standard (BS) sieve was oven-dried at a temperature between 100 and 1100C for 4 hours. The cylinder was filled in three layers, each layer tamped with 25 strokes of the tamping rod. The weight of the aggregate was measured and recorded as A. The surface of the aggregate was leveled, and the plunger inserted. The apparatus was then placed in the compression testing machine and loaded at a uniform rate until the sample failed. The sample was sieved through a 2.36 mm BS sieve, and the fraction passing through the sieve was weighed as C. The percentage ACV was calculated using Equation 5.

$$\%\, ACV = \frac{A}{C} \times 100 \quad (5)$$

The aggregates impact test was performed to determine the aggregate impact value of coarse aggregates according to [17]. Part of the sample which was oven-dried was taken. The cylinder was loaded with the aggregates in three layers and tamped with 25 strokes at each filling level. The aggregates' net weight was determined and recorded as A. The cup of the impact testing machine was fixed firmly in position on the base of the machine, and the whole of the test sample poured into it and again compacted with 25 strokes. The impact hammer was raised to 380 mm above the upper surface of the aggregates in the cup and allowed to fall freely onto the aggregates. The test sample was subjected to a total of 15 of such blows, each being delivered at an interval of not less than one second. The sample was removed and sieved through a 2.36 mm sieve. The fraction passing through was weighed as Y. The ratio of the weight of the fines formed, Y to the total sample, X was expressed as a percentage, as shown in Equation 6. The test was repeated 3 times to calculate the average value.

$$\%\, AIV = \frac{Y}{X} \times 100 \quad (6)$$

2.2. PREPARATION OF THE LUFFA AEGYPTIACA FIBER AND MOULD FABRICATION

After the dried Luffa fibers were acquired, they were slit opened, and the seeds were removed. In the research by Niharika and Acharya [18], when the Luffa was treated with different Alkaline and with some compounds such as NaOH, Benzylated and KMnO4, some of the elements present that can improve its mechanical properties were reduced or vanished. Hence the fibers were treated with clean water for about 3 hours and dried at room temperature of 250C; they were then kept inside polyethylene bags to avoid excessive loss of moisture. The Luffa fibers used were fabricated by hand lay-up technique in four different arrangements for the compressive strength test. Lamina, longitudinal, mesh, and dispersed in cubes, (figure 2). The fibers were cut to sizes putting in mind an adequate cover of 10mm from the edges of the formwork. For the compressive strength concrete cube, the fibers for lamina were cut into 130mm by 130mm, for longitudinal arrangement, was cut into 130mm by 70mm with a lap length of 15mm on the 70mm sides, fibers for the mesh arrangement was achieved by cutting them into 130mm by 45mm on both axis and the disperse arrangement was cut into pieces of varying sizes ranging from 30mm by 30mm to 50mm by 50mm. The different layering is as shown in Figure 3 Also, to achieve adequate laying for flexural strength test, the lamina arrangement was cut into 130mm by 80mm, the longitudinal arrangement was cut into 130mm by 80mm with a lap length of 30mm along the 130mm length, the fibers for mesh arrangement was achieved by cutting them into 130mm by 50mm on the long length and 60mm by 40mm on the short length, as for the disperse the fibers, were cut into pieces of varying sizes ranging from 30mm by 30mm to 50mm by 50mm. All these arrangements were carefully prepared and laid in three layers inside the mold with concrete placed in between them at each layer. During the preparation of the composite, a wooden mold cube of dimension (150 by 150 by150) mm was used for receiving the concrete composite for the compressive strength test and a mold sized (100 by 120 by 500) mm was adopted for the flexural strength test. The formworks were properly cleaned with oil to remove dust and particles before casting concrete into the mold.

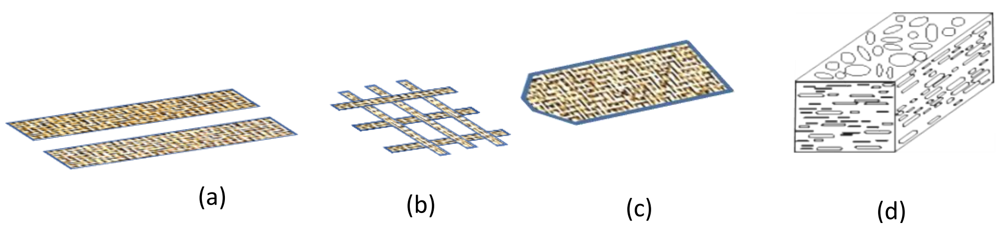

Figure 2. Different method adopted (a) longitudinal (b) mesh (c) lamina (d) dispersed

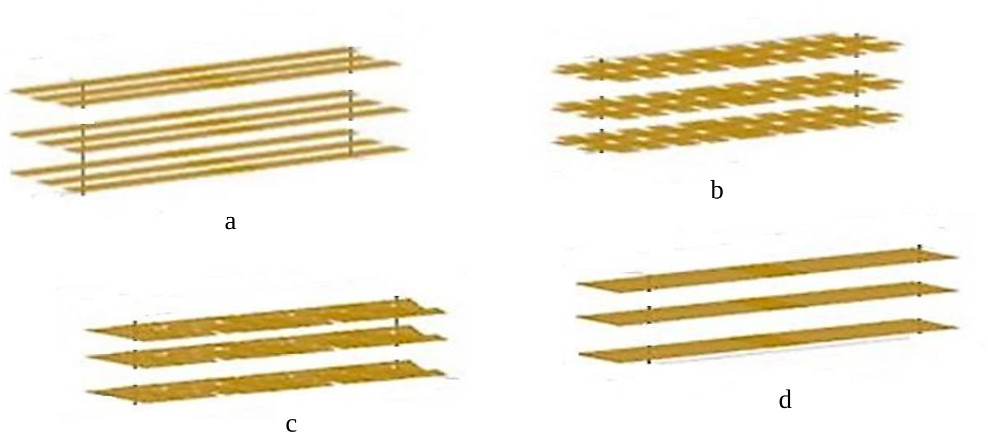

Figure 3. Different arrangements in the mold (a) longitudinal layer (b) Mesh layer (c) disperse layer and (d) lamina layer.

2.3. CASTING OF CONCRETE

Three specimens were cast for each of the arrangements, including the control specimens so that average value can be taken (for 7, 14, 21 and 28 days). The total number of the concrete cubes cast for the compressive strength test were 60 specimens. Also, the total number of 60 specimens were cast for the flexural strength test. Three points method was adopted for the flexural strength test, in this, the specimen was simply supported with steel support, a steel plate equivalent to the length of the specimen was placed directly on the specimen to distribute the load over it, and a point load was applied at the midpoint. Freshly prepared concrete was poured into one-third of each of the mold and compacted with 25 blows and leveled, the arranged Luffa fiber was then placed on the leveled surface, and another concrete was poured. The process was repeated three times with the placing of three arranged layers of Luffa fiber on the appropriately prepared mold for each. Concrete cover, as explained previously was ensured. After casting, the specimens were left in the formwork for about 24 hours for proper setting. The formwork was removed thereafter, and the weight of each of the specimens was measured and recorded. The specimens were then arranged into the curing tank to cure for 7, 14, 21, and 28 days, respectively. On the allotted days, three samples were removed for each of the arrangement, including the control sample, their weights were measured and recorded. The difference in the measurement between before and after curing gave the amount of moisture absorbed by the specimen. Both the compressive strength test and the flexural strength test were then carried out on the specimen, and their respective values were recorded.

3. RESULTS AND DISCUSSION

3.1. RESULTS OF THE AGGREGATE

The percentage of fines passing through different sieve sizes is presented in Figure 4. The sand is well-graded, ranging from fine gravel to fine sand. The coefficients, uniformity (Cu) and curvature (Cc), have been numerically calculated to ascertain how the particles are distributed. The coefficient of uniformity gave a value of 4, while the coefficient of curvature gave a value of 1.44, which confirms that the soil is well graded. The fine gravel contents are greater than the sand contents. This can promote rapid absorption of water and consequently, upon drying, can leave some pores if not properly mixed.

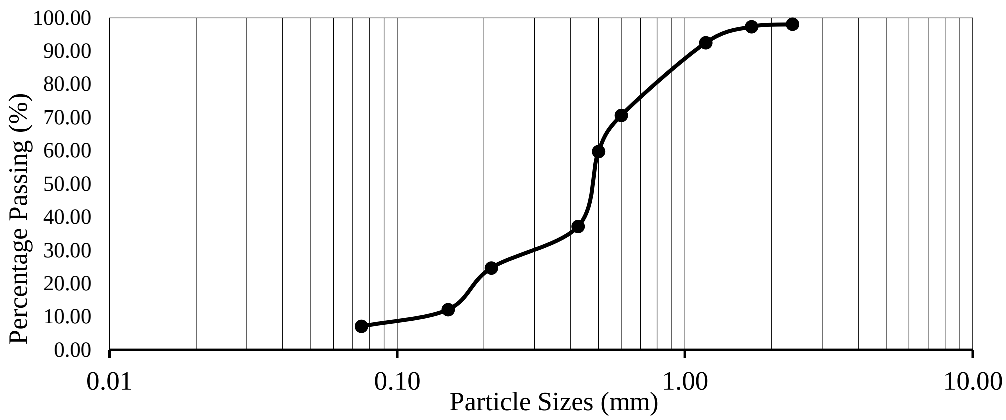

Figure 4. Particle size distribution chart for sand

The results of the aggregate crushing test (ACV) and that of the aggregate impact test (AIV) for the tested granites were 28.76% and 19.78%, respectively, which are adequate for concrete impact resistance. This means that aggregates of higher impact values are weaker than aggregates with lower AIV. Therefore, the coarse aggregate used is capable to produce concrete of good impact resistance. Aggregate Impact Value also indicates the degree to which the aggregates receive a shock. The result obtained from the aggregate impact value test carried out on the coarse aggregate shows that the aggregate is impact resistance according to BS: 882 [15] as its average AIV is less than 25%. While that of aggregate crushing value shows that the average ACV of 28.76% falls within the standard of 25% to 30% as specified by BS 812 [19, 20]. The recommended maximum ACV stipulated in BS 812 [19] for aggregates for concrete production is 30%.

3.2. COMPRESSIVE TEST RESULTS

The compressive strength test for the concrete cubes was carried out on the specimens at the ages of 7, 14, 21, and 28 days. The average compressive strength test results are presented in Figures 5. The plain concrete, which serves as the control sample, gains maximum strength after 28 days. The compressive strengths of all the fiber mix arrangements also increase with age. The result shows that at 7 days, the disperse arrangement has the highest average compressive strength, which is about 50% more than the lamina arrangement that has the lowest value, however, at 14 days, the strength of mesh arrangement equates the disperse. At this point, both of the former arrangements have about 54% increase compressive strength more than the lamina and longitudinal arrangement and about 15% more than the control sample. At 28 days, the longitudinal arrangement increases dramatically to a strength of 25.8 MPa, followed by the disperse 23.1 MPa, while the control sample has an average value higher than the lamina and the mesh arrangement. An increase in curing days causes a relative increase in strength. Figure 6a shows one of the compressive test crushed samples; the loading on the sample here was intentionally extended to see how the Luffa fiber can hold the concrete together. It is seen that the fiber can somewhat hold the aggregates. This may be useful in increasing the performance of spall concrete.

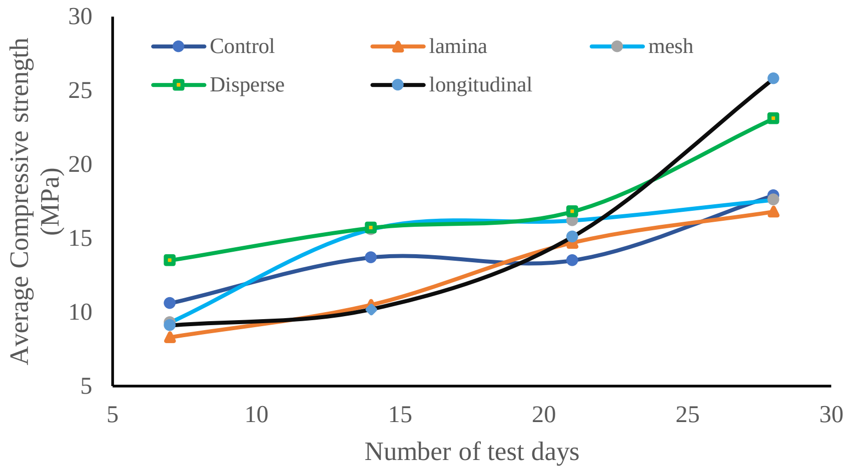

Figure 5. Compressive Strength Results

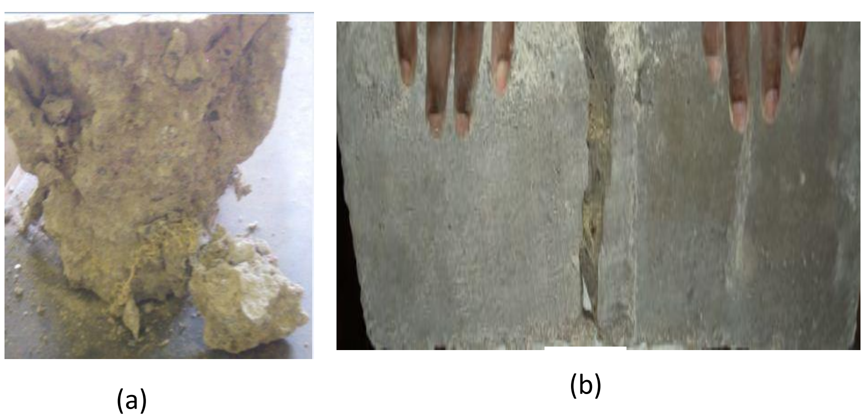

Figure 6. Crushed sample showing the essence of Luffa fiber (a) compressive strength test specimen (b) tensile strength test specimen

Figure 7 shows the flexural strength test results of the control sample and the Luffa fiber layers. The flexural strength test of the specimens was carried out using the three points method at ages 7, 14, 21, and 28 days. The longitudinal arrangement has the highest flexural strength among the arrangements adopted, which stands as 10.2 MPa, then follows by the dispersed 7.7 MPa. In the 14th day test, there was an early increase in the flexural strength of the control sample and the lamina arrangement; however, this does not last long as the 28th-day strength reveals a significant drop in their strength. Conversely, the longitudinal, dispersed, and mesh arrangements gradually gain their strength up to the 28th day. The different arrangement of the fiber clearly shows how the performance of the concrete can be influenced. During the flexural testing, some of the longitudinal and the lamina arranged fibers held the aggregates in place. In Figure 6b, the loading was prolonged to have a clear view of how the fiber held the concrete aggregates in place. To achieve mixes with overall strength, it is possible to use longitudinal arrangement as a mode of reinforcing the concrete matrix for flexural strength purposes.

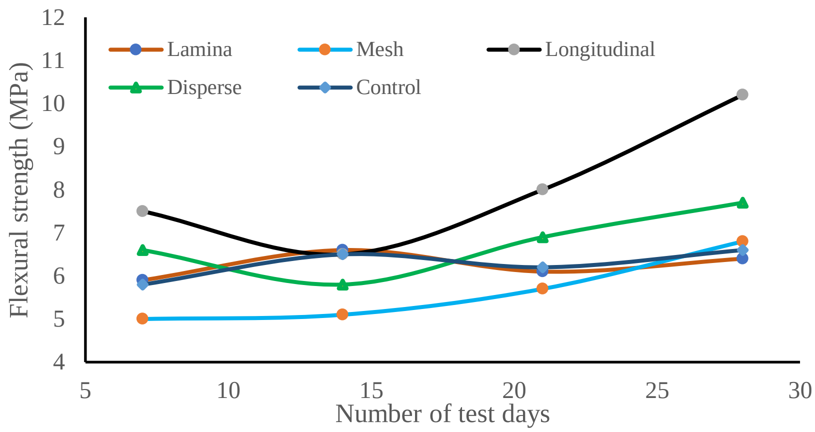

Figure 7. Flexural Strength Results

4. CONCLUSION

Since it is quite common for researchers to use artificial fibers as common means of proving reinforcement in concrete studies, this study, however, investigated the effects of natural material such as luffa aegyptiaca as reinforcement in concrete. Based on the presented experimental results, conclusions are drawn as follows:

Concrete reinforcement with the use of luffa aegyptiaca fiber generally shows an increase in the strength gained with time.

The longitudinal arrangement of luffa aegyptiaca reinforcement in both cube and flexural strength test shows higher strength compared to other forms of arrangement.

The results imply that to achieve mixes with better overall strength compared to plain cement concrete, it is possible to use lamina arrangement as a mode of reinforcing the concrete matrix. The results indicate the longitudinal arrangement can be used for structural concrete reinforcement.

The fiber can be used to correct the spall of concrete, as the experimental results have clearly shown.

Extended studies on the mechanical properties of the Luffa fiber to ascertain its significance as natural fiber in our environment are needed.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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