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Effects of few layers graphene addition, aggregate size, and water acidity on the compressive strength and morphology of cellular lightweight concrete

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Abstract. Cellular Lightweight Concrete (CLC) with the addition of Few Layers Graphene (FLG) has been fabricated and characterized for canal blocks application. The CLC-FLG composite was made by mixing fine agregate (sand), cement, fly ash, water, and FLG. The compressive strength properties of the composite was tested using a digital compressive strength test to determine the effects of FLG addition, sand size gradations, and environmental acidity on the compressive strength of the composite. Meanwhile, the composite morphology was examined using Scanning Electron Microscopy (SEM). The increase in FLG content and concentrations increased the compressive strength. The highest compressive strength was shown by the composite with the highest FLG addition (15%) and without sand size gradation, namely 5.19 Mpa or there was an increase of 15.6% compared to CLC without the addition of FLG. The level of water acidity relatively did not affected the compressive strength of CLC-FLG composite. Morphological analysis showed that the addition of FLG resulted in a denser structure and reduced porosity of CLC. The CLC-FLG composite can be used as canal blocks materials for peatland restoration.

1 Introduction

Forest and peatland fires are common in Indonesia [1]. It is not uncommon for an atmosphere of smog to persist for a long time, even after the fire has been contained. This can lead to various problems and respiratory diseases in society [2]. The prolonged duration of the haze disaster is often caused by peatland fires, which emit thick smoke even when there are no visible embers above the ground. Conventional methods of direct water sprinkling are not an adequate solution for extinguishing embers in peatlands. Integrative solutions must be taken, starting with protecting the peatland ecosystem and maintaining water balance [3].

The balance of water in peatlands has recently been quite disturbed by the widespread construction of water canals (canal blocks) for the purpose of converting peatlands into oil palm plantations or other purposes, both carried out by the community and by private parties [4]. The creation of these canals or waterways triggers severe drought in peatlands, and peat is easily flammable during the dry season [5]. One of the efforts to maintain water balance in peatlands that is being promoted by the government is the construction of canal blocks to prevent water from flowing quickly downstream [6]. Usually, the material that is widely used by the community to make canal blockings is wood. However, the use of wood materials can accelerate the rate of deforestation, and when viewed from its durability for long-term use, it is not effective. Therefore, a material that is stronger, has high durability, and is environmentally friendly is needed for long-term (permanent) use [7].

Concrete is the right material solution as a material used for canal blocking because it has the advantage of being able to withstand high pressure and can be used for a long time [8]. Even so, traditional concrete has a density that cannot be tolerated for application in peatlands, which are actually critical or sub-optimal lands. Lightweight concrete is thought to be one solution. Cellular Lightweight Concrete (CLC) is a type of concrete with a lower density because it has a porous structure made by adding thick foam into the sand-cement paste mixture, resulting in a low density ranging from 500-1600 kg/m^3 [9]. In addition to lower density, other properties of CLC include fire resistance, earthquake resistance, termite resistance, and good thermal insulation. The lower values of mass density and elastic modulus of CLC tend to reduce inertial forces on buildings due to seismic movements, making the application of lightweight concrete suitable for earthquake-prone areas [10]**.** As a logical consequence of the porous structure in CLC, it causes CLC to have lower strength than conventional concrete. In order to be used as a peatland canal blocking material, the mechanical strength of CLC needs to be increased by adding reinforcing additives without increasing its weight. The use of graphene fulfills this criterion. Graphene is a carbon-based 2D nanomaterial that has

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*Corresponding author: amun.amri@eng.unri.ac.id extraordinary strength but is extremely light and flexible [11].

This research studied the effect of the addition of Few Layers Graphene (FLG) additives, the gradation of sand aggregate size, and the level of environmental acidity (simulated peat water) on the compressive strength and morphology of CLC. CLC with the addition of FLG additives is proven to have higher compressive strength and good acid resistance when immersed in peat water. The morphological test results showed that the addition of FLG could fill the pores in the CLC matrix, which strengthens the composite.

2 Experimental

2.1 Sampel preparation

The materials used in this study were Portland cement, sand as a fine aggregate, water as a solvent, fly ash, FLG synthesized using the Turbulence Assisted-Shear Exfoliation (TASE) method [12] and foaming agent (Sodium Lauryl Sulphate or SLS) as a foaming agent.

Making CLC-FLG was done by mixing the ingredients to be used, starting with preparing the foaming liquid. The foaming liquid was prepared by dissolving the foaming agent in water, with the ratio of foaming agent to water being 1:20. Furthermore, the foaming fluid was connected to the foam generator to produce the desired foam. The process of mixing raw materials was carried out with a weight ratio (% w/w) of sand: cement: water: fly ash of 2:1:0.5:0.05 with different sand size gradations (passing 80 mesh, 80<x<40 mesh, and mixed (without gradation)) and continued with the addition of graphene (0%, 5%, 10%, and 15%). Then, proceed with the addition of the foam to obtain a wet density of 1.5 Kg/L. After that, stirring was done evenly until the dough became a paste. The mixing process was carried out using a hand mixer. After finishing mixing and stirring until evenly distributed, the paste was then poured into cube-shaped molds with a size of (10 cm x 10 cm x 10 cm). The paste was compacted so that it fills the entire mold. After it was poured, the paste was dried at room temperature until it hardened.

After CLC-FLG hardened, it was released from the mold. Then, the CLC-FLG samples were left at room temperature until the testing time, which was 14 days for testing the CLC-FLG produced. The tests carried out were a compressive strength test, acid resistance test, and morphological analysis.

2.2 Characterizations

The CLC-FLG characteristic test consisted of 3 tests, including the mechanical properties test which consisted of a compressive strength test following the ASTM standard 2012 using a digital compressive strength test, an acid resistance test carried out using peat water regulated by pH (3, 5, and 7) with the addition of sulfuric acid (H2SO4), and morphological tests using Scanning Electron Microscopy (SEM) JEOL JSM-6510LA.

3 Result and disscusion

3.1 Compresive strenght analysis

Fig. 1 shows a graph of the relationship between the variation of sand size gradations and the percent addition of FLG to the compressive strength of the CLC-FLG composite at 14 days of age. From the figure, it can be seen that in general, the addition of FLG into CLC affects the compressive strength value of the composite, where the higher the FLG number, the compressive strength value increases. The highest compressive strength was shown by the sample with the highest FLG addition (15%), which was 5.19 MPa, so that it was able to increase the compressive strength by 24.46% of the compressive strength value of the second-highest sample on the 40-mesh sand size gradation variation with the same percent addition of FLG.

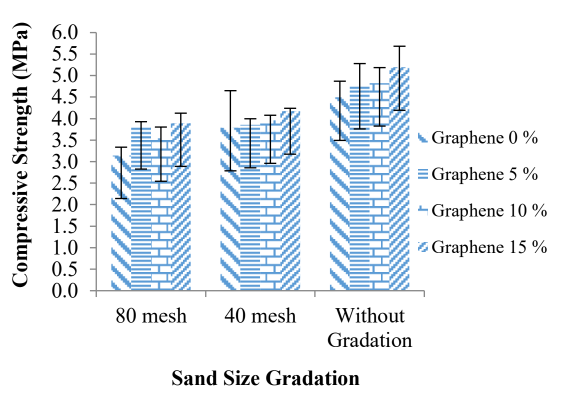

Fig. 1. Graph of correlation between variation of FLG addition and gradation of sand size to CLC compressive strength at 14 days of age.

The addition of FLG into the CLC matrix can increase the compressive strength and reduce porosity. This is because the nanometer-sized FLG material fills the pores formed in the concrete matrix, so that graphene contributes to the formation of a denser structure. When mixed with cement, it forms a compact and homogeneous structure [13], [14]. In addition, graphene, which has a large surface area, will form stronger intermolecular bonds at the interface of the components involved, so it can accelerate the cement hydration process [15]. The results of this study are supported by a lightweight brick-graphene composite study conducted by [16]. When graphene is added to the lightweight brick matrix, it will coat the surface of the particles in the composite. Graphene sheets will tightly envelop the particles in the lightweight brick matrix, so that the CH_3 groups on the graphene edge structure will be secondary bonded with the O groups of the lightweight brick matrix, both O groups in Si-O-Al or O groups in Si-O-Si [17]. Therefore, the addition of graphene in the matrix can indirectly improve the mechanical properties of lightweight bricks.

In addition to the percent addition of FLG, in this study, the gradation of sand size also affected the compressive strength value of CLC. Based on Fig. 1, it can be seen that the compressive strength of CLC has increased as the sand size gradation has decreased. The smaller the sand size gradation, the smaller the sand particle size. Where in this study the greater the gradation of sand size, the compressive strength value increased. The increase in the value of the compressive strength of concrete, where by decreasing the sand size gradation from 80 mesh (sample size gradation A) to 40 mesh (sample size gradation B) has increased by 7.198%. The results of the highest compressive strength values were obtained with samples without gradation (sand size gradation C), which experienced an increase in compressive strength of 24.46%.

The high compressive strength of CLC with the use of C sand size gradations is due to the use of ungraded sand, which will form a denser matrix because almost all the spaces/pores in the CLC are filled. This is because ungraded sand has non-uniform particle sizes, some are large and some are small, so that these small particles can fill the space in the non-uniform pile of sand particles resulting in a denser CLC. The results of this study are supported by Karaguler and Yatagan [18], which explains that the larger aggregate size is able to resist crack development.

Haque et al. [19] said that the compressive strength of aggregate is closely related to aggregate gradation and aggregate size. If the size of the aggregate in the concrete increases, the surface area will decrease. Then the amount of material used per unit surface area will increase, thus increasing the compressive strength of the resulting concrete. Based on the results of the compressive strength test conducted in this study, it can be concluded that by adding graphene and varying the resulting sand gradations, it can meet the minimum specifications for lightweight brick compressive strength. Based on ASTM C 869-91 for lightweight bricks, the average minimum compressive strength that must be met is 1.4 MPa.

3.2 Acid resistance testing

In Fig. 2, you can see a graph of the acid resistance testing of the CLC-FLG composite against compressive strength in peat water with a pH of 3, 5, and 7. It can be seen that CLC with the addition of 15% FLG always has higher acid resistance than without the use of FLG. This can be seen in Fig. 2, where the compressive strength of CLC with the addition of FLG is higher at each peat water pH compared to CLC without the addition of FLG.

This higher acid resistance is due to the addition of graphene to CLC, which has a significant effect on CLC properties such as flexural tensile strength, elastic modulus, and thermal stability [20]. Besides, the graphene sheet is in contact with the matrix resulting in a stronger connection between the graphene and the matrix [21]. This is supported by research results from Yang et al. [22], where the addition of Graphene Nanoplatelets (GNP) has a significant effect on cement mortar in acidic conditions. This is because GNP is able to accelerate the cement hydration process and improve the pore structure in the cement mortar, thereby increasing the corrosion resistance and compressive strength of the cement mortar.

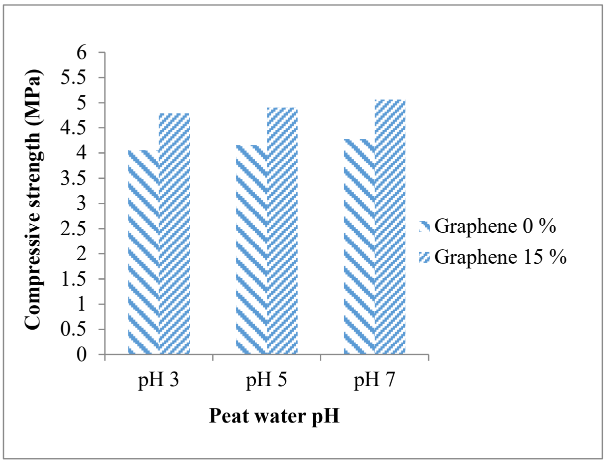

Fig. 2. Compressive strength test of the CLC-FLG composite at various pH and FLG composites.

From Fig. 2, it can be observed that the acidity level of peat water has an impact on the compressive strength of CLC, with lower pH (more acidic) peat water resulting in lower compressive strength of CLC, although not a significant difference. The highest compressive strength was found in CLC samples with an addition of 15% FLG at a pH of 7 peat water, with a value of 5.06 MPa. It can be seen that CLC with the addition of FLG can increase the compressive strength in acidic conditions by an average of 18% compared to the compressive strength of CLC without the addition of FLG. This is because one of the factors that affect the durability of concrete is the level of acidity. Sulfuric acid attacks the bonds of the concrete structure, starting from the edge of the concrete surface to the inside, weakening the bonds between particles in the concrete. CLC in peat water immersion tends to increase porosity and concrete permeability [16].

3.3 Morphology analysis

Fig. 3 shows a comparison of the morphological structures of CLC without the use of FLG and with the use of 15% FLG at magnifications of 100, 2,500, 5,000 and 10,000 times. It can be seen that the addition of 15% FLG into the CLC results in an increase in solid content and a decrease in the porosity of the CLC's morphological structure. This is because graphene, with its unique two-dimensional morphology, can fill empty cavities in the matrix, thereby improving the mechanical properties of concrete [23]. This theory is supported by the results of the compressive strength test, where an increase in the number of FLG additions leads to an increase in the compressive strength value. The results of this study are consistent with research conducted by [24], in his research mentioned, graphene which has a large specific surface area and superior mechanical properties of graphene will improve the mechanical properties of CLC and when graphene is added to the matrix, graphene can act as a composite wrapper.

Fig. 4 shows the morphological structure of CLC using sand size gradations of variations B (40 mesh) and C (ungraded mixture). The use of variation C (ungraded mixture) has an effect on the matrix and porosity of the morphological structure of the CLC. This is obtained because the use of ungraded sand minimizes voids/empty space, resulting in a denser CLC. The SEM results were then analyzed using the ImageJ 1.8 application to see the distribution of pores (qualitatively) formed in the CLC. The results of the analysis using ImageJ can be seen in Fig. 5.

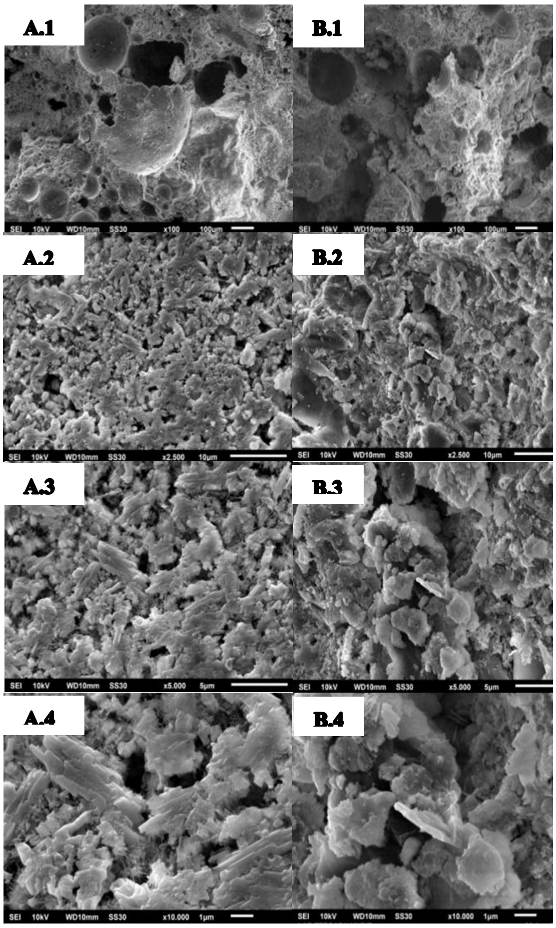

Fig. 3. CLC SEM analysis results (A.1) 0% FLG and (B.1) 15% FLG with 100 x magnification, (A.2) 0% FLG and (B.2) 15% FLG with 2,500 x magnification, (A.3) 0% FLG and (B.3) 15% FLG with 5,000 x magnification and (A.4) 0% FLG and (B.4) 15% FLG with 10,000 x magnification.

Based on Fig. 5 (a) and (b), it can be seen that, in general, there are differences in CLC with the addition of FLG and without the addition of graphene. The CLC structure without the addition of FLG appears to have more large pores compared to the CLC with the addition of FLG. With the large pore size produced, it is easy for cracks to occur in the concrete, resulting in a low compressive strength value [25]. To determine the percentage of porosity in CLC, the origin application is used. The results of the analysis of the percentage of porosity are shown in Fig. 6.

Based on the results of the analysis using the origin application, the highest porosity percentage was found in the 0% graphene sample without sand size grading, namely 59.5%, while the lowest porosity percentage was obtained in the CLC sample with the addition of 15% FLG without gradation, namely 48.05%. This is consistent with the results of this study, where the higher the compressive strength value, the lower the porosity value. Because with a low porosity percentage, the concrete that is formed is denser.

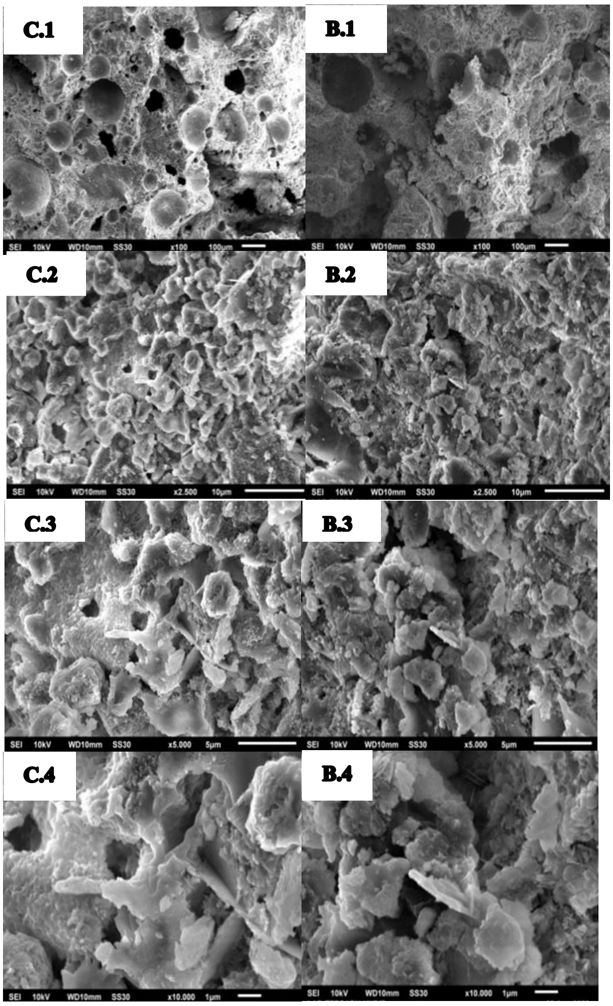

Fig. 4. CLC SEM analysis results CLC SEM analysis results (C.1) 40 mesh sand size gradation and (B.1) without sand size gradation with 100 x magnification, (C.2) 40 mesh sand size gradation and (B. 2) no sand size gradation with 2,500 x magnification, (C.3) 40 mesh sand size gradation and (B.3) no sand size gradation with 5,000 x magnification and (C.4) 40 mesh sand size gradation and (B.4) without sand size gradation with 10,000x magnification.

4 Conclusion

In this study, CLC with the addition of FLG added and sand size gradations has been successfully fabricated and characterized. The increase of FLG content increased the compressive strength of CLC, while the decrease in sand agregate size decreased the porosity of CLC. The highest compressive strength was shown by the composite with the highest FLG addition (15%) and without sand size gradation namely 5,19 Mpa or there was an increase of 15,6% compared to CLC without the addition of FLG. The level of water acidity relatively did not affect the compressive strength of CLC-FLG composite. Morphological analysis showed that the addition of FLG resulted in a denser structure and reduced porosity of CLC, because FLG filled the pores in CLC.

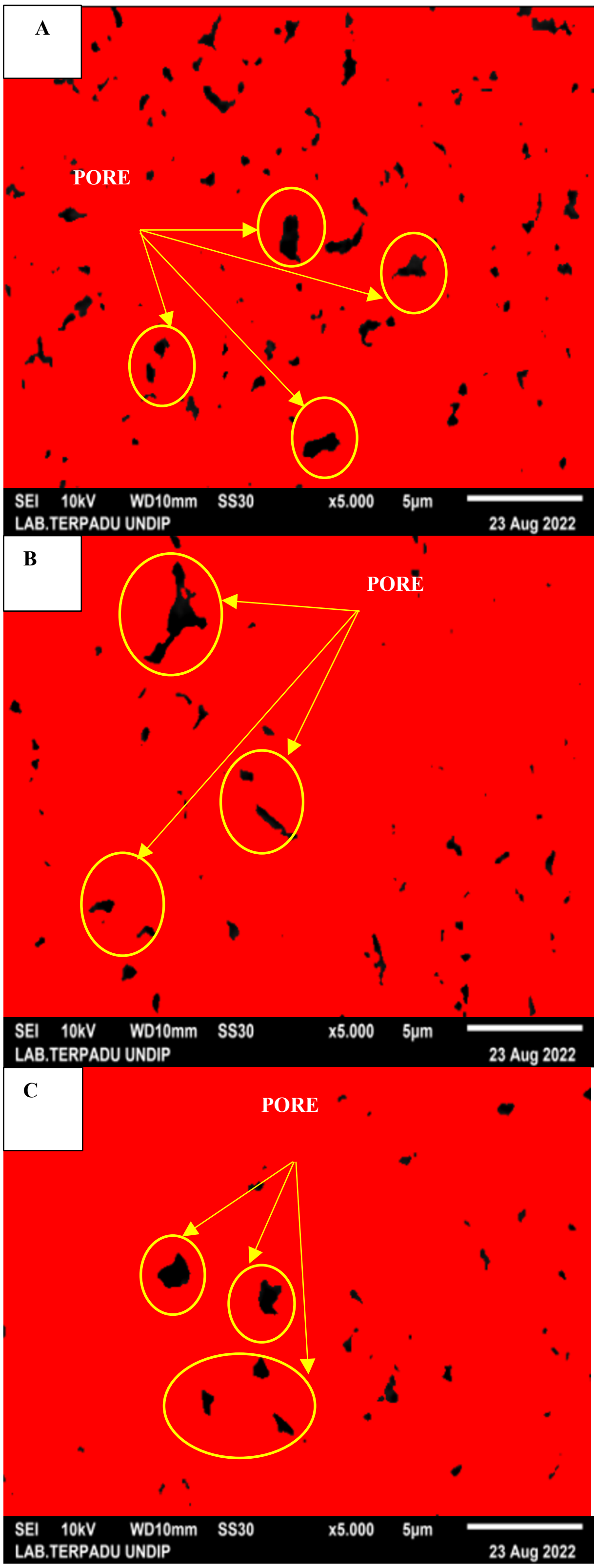

Fig. 5. Results of SEM analysis using Image J (a) 0% FLG without gradation (b) 15% FLG without gradation and (c) 15% FLG with 40 mesh size gradation with 5000 x magnification.

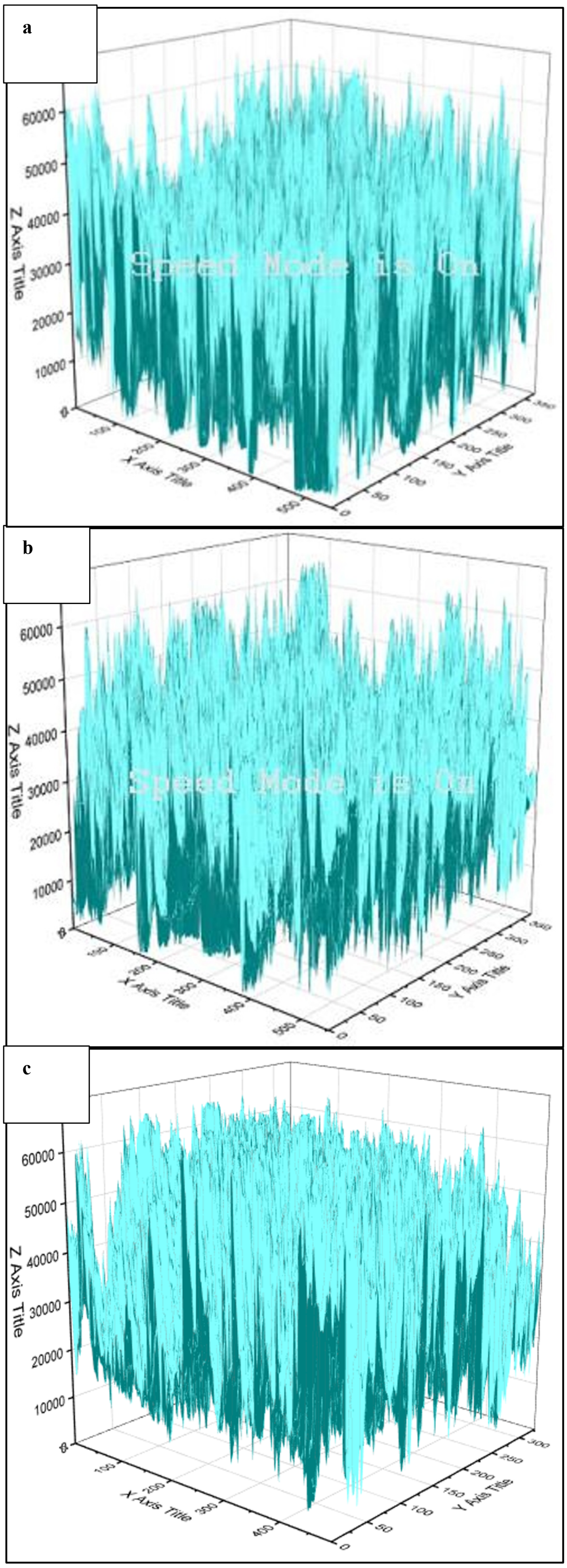

Fig. 6. Results of 3D morphological visualization of CLC using Origin Application (a) 0% graphene without gradation (b) 15% graphene without gradation and (c) 15% graphene with gradation 40 mesh size with 5000 x magnification.

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