

Article

# Compressive Behaviour of Coconut Fibre (*Cocos nucifera*) Reinforced Concrete at Elevated Temperatures

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**Abstract:** Fire outbreaks in buildings have been a major concern in the world today. The integrity of concrete is usually questioned due to the fact that after these fire outbreaks the strength of the concrete is reduced considerably. Various methods have been adopted to improve the fire resistance property of concrete. This study focused on the use of coconut fibre to achieve this feat. In this study, varying percentages of treated and untreated coconut fibres were incorporated into concrete and the compressive strength was tested for both before heating and after heating. The percentages of replacement were 0.25, 0.5, 0.75 and 1% fibre content by weight of cement. Concrete cubes that had 0% fibre served as control specimens. After subjecting these concrete cubes to 250 °C and 150 °C for a period of 2 h, the compressive strength increased when compared to the control. The compressive strength increased up to 0.5% replacement by 3.88%. Beyond 0.5% fibre, the compressive strength reduced. Concrete having coconut fibre that had been treated with water also exhibited the highest compressive strength of 28.71 N/mm<sup>2</sup>. It is concluded that coconut fibres are a great material in improving the strength of concrete, even after it was exposed to a certain degree of elevated temperature.

**Keywords:** coconut fibre; concrete; compressive strength; reinforced concrete; thermal

## 1. Introduction

Concrete is the most utilized material in the construction industry. Concrete is said to be good in compression but has low tensile strength, and that is why it is usually reinforced with steel [1]. Lau and Anson [2] studied the effect of high temperature on high-performance steel fibre reinforced concrete (SFRC) with heating temperatures ranging between 105 °C and 1200 °C. It was reported that at temperatures below 400 °C the loss in compressive strength was relatively small, and a further increase in temperature above 400 °C leads to a further decrease in compressive strength. Greater compressive strength loss was also observed in high performance concrete (HPC) compared to normal strength concrete (NSC) at temperature above 600 °C. It was concluded that at 1% steel fibres an improvement in crack and fire resistance were noticed. It was also observed that SFRC performs better than non-SFRC in mechanical strength for temperature below 1000 °C. Shrinkar et al. [3] conducted the experiment on the effect of elevated temperature on the flexural and compressive strength of fibre reinforced concrete and found that the strength increased up to 100 °C and decreased gradually as temperature increased beyond 100 °C. In another study, Ashfaque and Samiullah [4] examined the steel fibre's effect on the compressive and flexural strength of concrete and concluded that the highest compressive and flexural strengths were achieved with the addition of 3% steel fibres. Abass et al. [5] studied the physical and

mechanical properties of sisal fibre reinforced concrete. The fibres were added in varying percentages of 0.5%, 1.0%, 1.5% and 2.0% by weight of cement. The computed modulus of elasticity of sisal fibre reinforced concrete was compared with predicted values in some available design codes and it was reported that the sisal fibre can enhance Young's modulus and split tensile of concrete, but cannot improve some physical and mechanical properties of concrete such as water absorption, workability and compressive strength. Sina and Nima [6] examined the effects of cement–polymer interface properties on the mechanical response of fibre reinforced cement composites. The combination of experimental and molecular dynamics (MD) techniques was used to examine the nanostructure of fibre cement interfaces, while the microstructural analyses, such scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) analyses, were used to obtain a better understanding of the C–S–H fibre (in cement chemistry notation, C = CaO, S = SiO<sub>2</sub> and H = H<sub>2</sub>O). It was discovered that the increase in the adhesion energies between the fibres and cement is a function of the fibre polarity. Faezeh and Nima [7] studied the nanostructural characteristics and interfacial properties of polymer fibres in the cement matrix and reported that the functional group in the macromolecule polymer structure affects the adhesion energy by changing the calcium–silicate–hydrate (C–S–H) at the interface and by absorbing additional positive ions in the C–S–H structure. Novak and Kohoutkova [8] examined the synthetic fibre reinforced concrete exposed to elevated temperature and concluded that synthetic fibres increase concrete spalling, which leads to improvement in the mechanical properties of the concrete produced. Coconut fibres are agricultural wastes [9–14]. These wastes can be used to either substitute some materials in the construction industry, such as soil and embankment stabilization, steel, cement (fibre reinforced cement) and river sand (coconut coir path as partial replacement of river sand), or can be used as an alternative material. The fibres of coconut are derived from the outer shell of coconut. It is commonly referred to as COIR. Its scientific name is called *Cocos nucifera* and it belongs to the plant family known as Arecaceae [15–17]. There are four types of coconut fibre namely: bristle coil, buffering coil, brown fibres and white fibres [18]. The brown fibre is derived from mature coconut, which is usually very strong, thick and is of high abrasion resistance, making it the most preferred and most-used fibre [18]. The white fibre, on the other hand, is obtained from immature coconut and it is usually not as strong as the brown fibre. The fibre has high lignin substance and low cellulose content, which renders the fibres versatile, solid and strong [19]. Coconut fibres can either be treated or untreated. It can be treated either by soaking the fibres in hot water or in chemical solutions [20–23]. Mulinari et al. [24] stated that treated natural fibres, when it is incorporated into concrete by the compression moulding method with a 10% fibre weight, results in the concrete having a very high tensile strength when compared with composites that have untreated fibres incorporated in it using tensile and fatigue tests. The increase in strength of the treated fibres was as a result of the removal of lignin, pectin, wax and hemicellulose on the fibre surface, leading to the elimination of parenchyma cells, which increases the contact area of the exposition of fibrils and globular marks; consequently, leading to the roughness of the fibres that increase the adhesion between the matrix and the fibres. The effect of both treated and untreated coconut fibres on the thermal property of concrete was considered in this current study. Coconut fibres are low-cost, light, durable and environmentally sustainable. It should be noted that coconut fibres have low thermal conductivity while being tough and stiff, and at the same time, increasing the tensile, flexural and compressive strengths of concrete [25]. According to statistics, fire outbreaks have been of high occurrence in our society, posing a lot of risk to human lives and properties at large [25–27]. Imhaz et al. [28] evaluated the influence of fibre length on the polypropylene (PP) fibre reinforced cement concrete. Three PP fibres at a varying percentage of 0.2%, 0.25% and 0.3% content by weight were examined. The compressive and flexural strengths of concrete were determined as well, and it was observed that an increase in the size of fibres decreased the compressive strength of concrete. It was concluded that the length of fibre has a significant effect on the flexural and compressive strength of concrete.

This study is motivated by the rate at which structures are inundated by a fire, which has turned into an issue of worry in Nigeria and the world at large. Coconut fibres are a form of solid waste and, therefore, the use of these fibres in concrete prompts a compelling strong waste administration technique. This current study focused on the fire resisting property of coconut fibre reinforced concrete as compared to plain concrete at varying temperatures. This study explored the effects both treated and untreated coconut fibre have on the thermal property of concrete. It also focused on the use of coconut fibres to improve the fire resistance of concrete. The main objectives were to investigate the effect of treated and untreated coconut fibres on the compressive strength of concrete and to determine the effect of exposure to high temperatures up to 250 °C on treated and untreated coconut fibre reinforced concrete.

## 2. Materials and Methods

Materials used for this study are coconut fibres, cement, water, fine and coarse aggregates. Coconut husks were obtained from the Seme border, Nigeria. The Seme border has a latitude of 6°22'32.99'' N and a longitude of 2°43'11.99'' E. The fibres had to be extracted from the husk before it could be used for the purpose for which it was bought. Fibres were chopped with scissors maintaining the length of 15 to 35 mm with diameter ranging from less than 0.004 mm to 0.2 mm and oven dried to remove water content. Part of the fibres were extracted from the husk without treating it in water or sodium hydroxide (NaOH) solution, while the remaining husks were soaked in either water or 1% concentration of NaOH, this is called the treatment of the fibres. The ones that were soaked in water and sodium hydroxide were easier to extract. The purpose of treating the fibres in water is to increase the bond between the cement and the fibres and also to eliminate the lignin from the surface of the fibre [29]. The fibres were washed in water three times as specified in Reference [29], and a comb was used to brush out the remaining pith and oven dried at a temperature of 110 °C. The extraction processes are shown in Figure 1a,b. Dangote Portland cement of grade 42.5 N was used for the purpose of this study in line with ASTM C150 [30]. Aggregates of sizes  $\frac{3}{4}$  inch, which is approximately 19 mm, and  $\frac{1}{4}$  inch, which is approximately 12.5 mm and lower, were combined in the mix. River sand obtained from the Ogun River, Ogun State, Nigeria, was adopted for the study. Potable water obtained from Covenant University, Ota, Ogun State was employed for use in this study. The water was used to mix the cement, sand and aggregates; it was also used to cure the cast cubes. Batching of materials was done by weight, using an electronic weighing scale that measures accurately to 0.01 kg. The mix ratio of 1:3:4 was observed as the most suitable mix as it was more workable and it has less segregation. So, 1:3:4 was adopted for the mix design. In preparing the concrete specimens, sand and cement were mixed properly in the mixing machine, followed by granite and addition of fibres. It is important to note that the coconut fibres were added at varying percentages for different batches to the mix. Slump and compacting factor tests were carried out on fresh concrete as shown in Figure 2a to ascertain the workability and the ease of flow of concrete mix adopted in line with ASTM C172/C172M [31]. After the concrete has been demoulded, the specimens were placed in the curing tank for 7, 14, 21 and 28 days in line with ASTM C31 [32]. Compressive strength and fire resistance tests were carried out on hardened concrete in line with ASTM C39 and BS 476: Part 20 [33,34]. The compressive strength of the specimens was determined with the use of the compressive strength testing machine with model number YES-2000 and 2000 kN in maximum capacity as shown in Figure 2b. Concrete cubes of 150 mm that have been cured for 7, 14, 21, and 28 days are subjected to compressive load while for fire resistance the concrete cubes of 150 mm were placed in the oven after it was cured for specified days. The temperatures in the oven were varied at 150 °C and 250 °C, for two hours. After the specimen had undergone the heating process at various degrees Celsius, they were tested for their compressive strength. The values obtained here were compared to those that did not undergo heating.



Figure 1. (a) Coconut fibres soaked in water. (b) Coconut fibres after being extracted from the husk.



Figure 2. (a) Slump experiment. (b) Concrete fibres after being extracted the husk.

### 3. Results and Discussion

#### 3.1. Test on Fresh Concrete

A slump test was carried out to determine the ease of flow of concrete. All the values obtained from the slump test fell within the range of true slump (50 mm–100 mm) as shown in Figure 3. This implied that the concrete mix used in this study is workable, and only a true slump is of use in the construction industry. Table 1 shows the slump range according to the ASTM C172/C172M [31] standard. From the results obtained it was observed that the increase in fibre content beyond 0.5% decreased the workability. The workability obtained from the study is medium and the slump is a true slump.

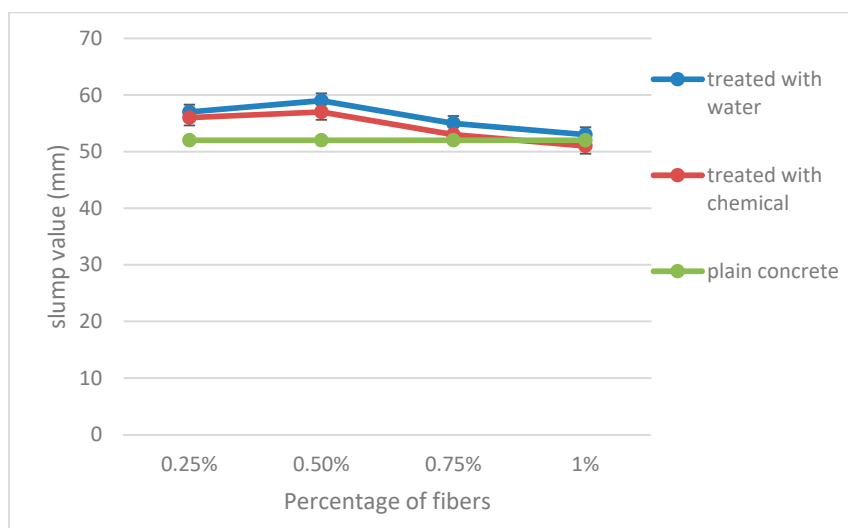


Figure 3. Graph showing differences in slump values.

**Table 1.** Concrete slump range.

Workability	Slump (mm)
Very low	0–25
Low	25–50
Medium	50–100
High	100–175

### 3.2. Tests on Hardened Concrete

The compressive strength of the control experiment was compared with that of concrete that had a varying percent of the fibre. The results are shown in Figure 4. Figure 4 shows the results obtained from the compressive test when 0.25% fibre was incorporated in concrete. From the result, it was discovered that coconut fibre increased the compressive strength of concrete. The highest result was obtained from the treated coconut fibres, i.e., treated with water (25.59 N/mm<sup>2</sup>) followed by treating with chemicals (25.19 N/mm<sup>2</sup>). It can also be seen that the compressive strength of the control specimen and concrete with untreated fibre were not so far apart.

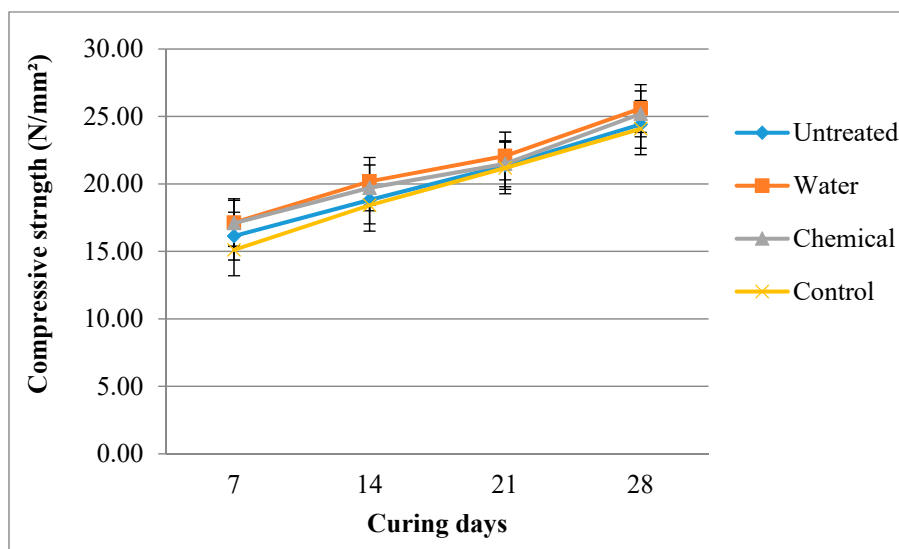
**Figure 4.** Bar chart showing variations in compressive strength at 0.25% fibre.

Figure 5 shows the results obtained from the compressive test when 0.5% fibre was incorporated in concrete. The result shows that coconut fibre increased the compressive strength of concrete. The highest result was achieved from the treated coconut fibres, i.e., treated with water (28.71 N/mm<sup>2</sup>) followed by treating with chemicals (27.61 N/mm<sup>2</sup>). It can also be seen that the compressive strength of the control specimen and concrete with untreated fibre were not so far apart. The results obtained from 0.5% fibre content was higher than that of 0.25%. In the whole analysis, a 0.5% fibre content exhibited higher strength. Figure 6 shows the results obtained from the compressive test when 0.75% fibre was incorporated in concrete. Due to the results achieved here, it is safe to say that beyond 0.5% fibre content, coconut fibre causes a reduction in strength of concrete. It was also observed that treated fibres gave a higher strength than untreated fibres. Coconut fibre will only increase the strength of concrete at certain percentages. Figure 7 shows the results obtained from the compressive test when 1% fibre was incorporated in concrete. The results obtained at 1% was lower than that of 0.75%. Beyond 0.5%, the higher the fibre content, the lower the strength.

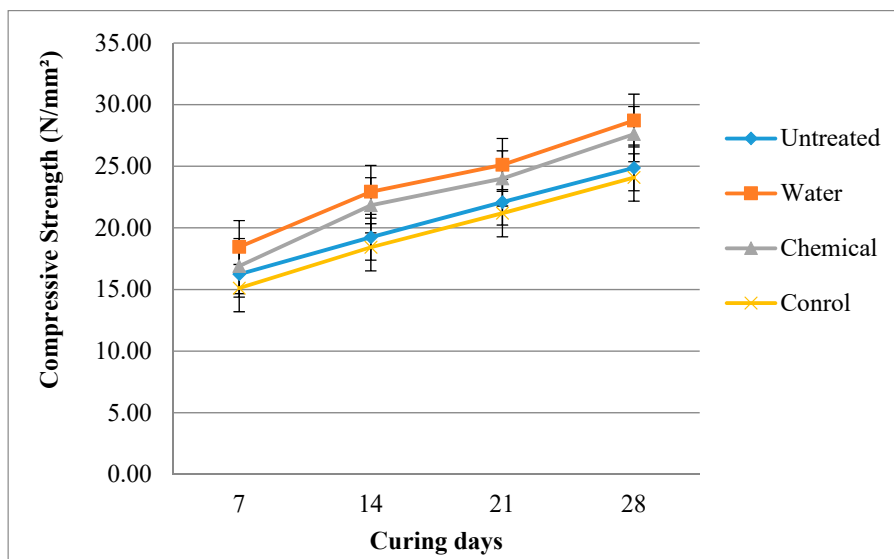


Figure 5. Line graph showing variations in compressive strength at 0.5% fibre.

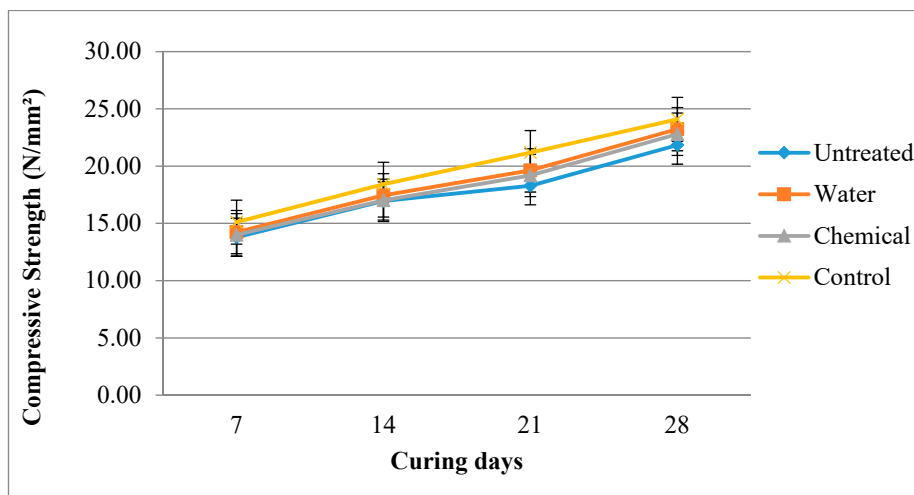


Figure 6. Bar chart showing variations in compressive strength at 0.75% fibre.

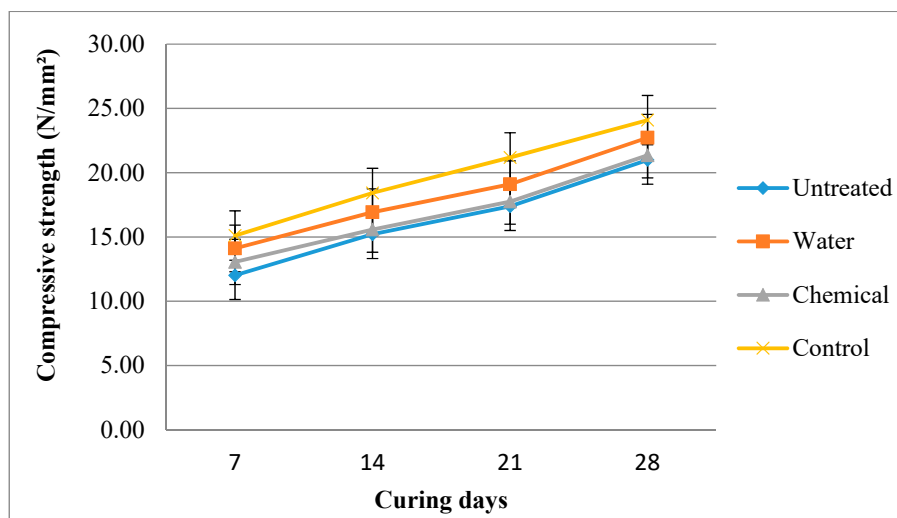


Figure 7. Line graph showing variations in compressive strength at 1% fibre.

Generally, it can be seen that the addition of coconut fibre increased the compressive strength to a large extent. The 0.5% fibre sample exhibited the highest compressive strength values. Beyond 0.5%, the addition of fibre decreased the compressive strength of concrete. A 1% fibre content gave a very low compressive strength when compared to the control experiment. It can be said that the treatment of fibre also improved the strength, especially fibres that were treated with water. Fibres that were treated with water gave higher strength followed by those treated with sodium hydroxide because the lignin, hemicellulose, pectin and wax, together with parenchyma cells—which increase the contact area of exposition of fibres—has been removed, and as a result led to the adhesion of fibres and the matrix [23].

### 3.3. Fire Resistance Test

The variation in the compressive strength when the concrete cubes containing different percentages of fibre were subjected to heat was compared to the control specimens, which had no fibre in it but was also heated at varying temperatures for 2 h. When heat was applied at 150 °C there was an obvious reduction in the residual strength of the concrete. When the intensity of the heat was increased to 250 °C the strength reduced further. Figure 8 shows the results obtained from the compressive test when 0.25% fibre was incorporated in concrete that was heated at 150 °C. According to this result, it is seen that coconut fibre increased the compressive strength of concrete. The highest result was obtained from the treated coconut fibres, i.e., the one treated with water (25.16 N/mm<sup>2</sup>) followed by treating with a 1% concentration of NaOH (23.27 N/mm<sup>2</sup>). It can also be seen that the compressive strength of the control specimen (22.70 N/mm<sup>2</sup>) and concrete with untreated fibre (22.93 N/mm<sup>2</sup>) were not so far apart.

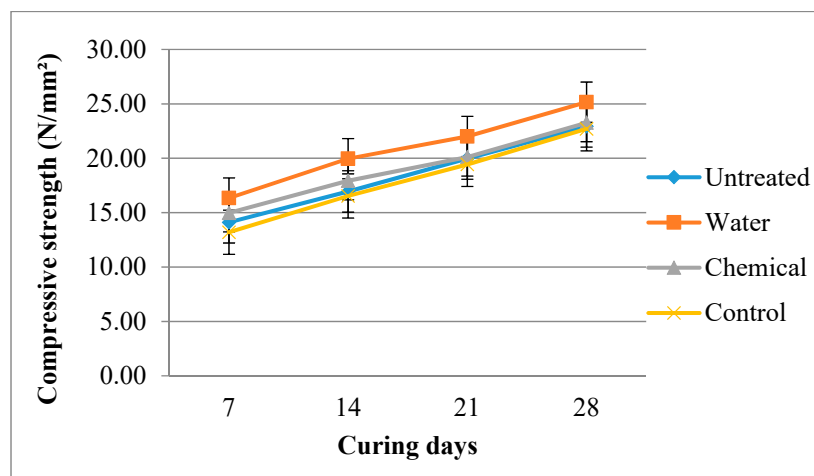


Figure 8. Bar chart showing variations in compressive strength at 0.25% fibre, 150 °C.

Figure 9 shows the results obtained from the compressive test when 0.25% fibre was incorporated in concrete that was heated at 250 °C. From the result obtained it is seen that coconut fibre increased the compressive strength of concrete. The highest result was obtained from the treated coconut fibres, i.e., fibre treated with water (23.54 N/mm<sup>2</sup>) followed by fibres treated with chemicals (21.39 N/mm<sup>2</sup>). It can also be seen that the compressive strength of the control specimen (19.76 N/mm<sup>2</sup>) and concrete with untreated fibre (21.12 N/mm<sup>2</sup>) were not so far apart. The compressive strength values obtained here are lower than that of 150 °C and this is due to an increase in the intensity of heat.

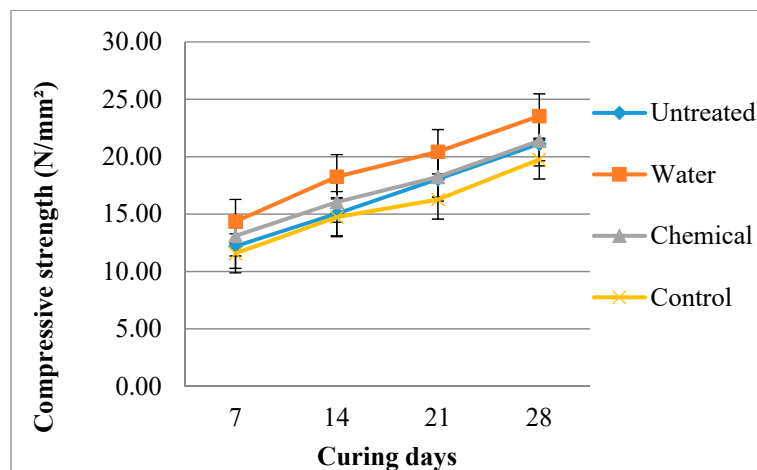


Figure 9. Line graph showing variation in compressive strength at 0.25% fibre, at 250 °C.

Figure 10 shows the results obtained from the compressive test when 0.5% fibre was incorporated in concrete that was heated at 150 °C. From the result, it was observed that coconut fibre increased the compressive strength of concrete. The highest result was obtained from the treated coconut fibres, i.e., treated with water (26.30 N/mm<sup>2</sup>) followed by treating with chemicals (24.07 N/mm<sup>2</sup>). It can also be seen that the compressive strength of the control specimen and concrete with untreated fibre were not so far apart. The residual strength valued obtained are higher when compared to the values of 0.25% fibre at 150 °C.

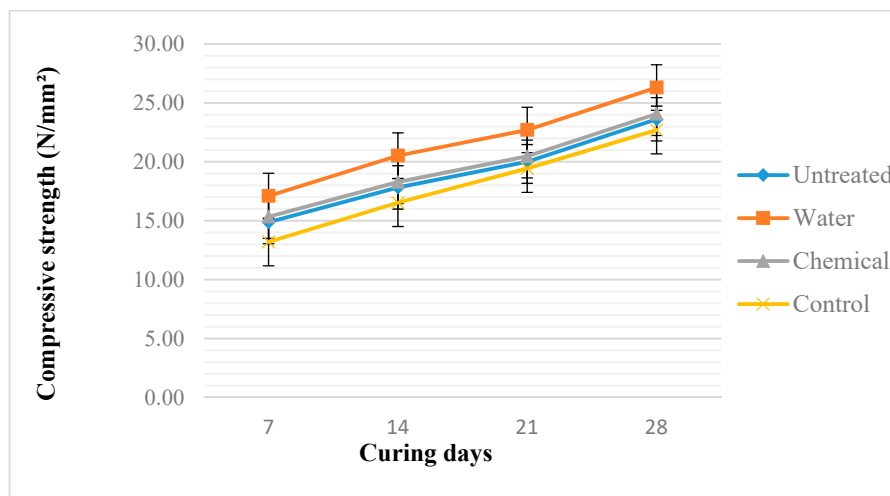


Figure 10. Bar chart showing variations in compressive strength at 0.5% fibre at 150 °C.

Figure 11 shows the results obtained from the compressive test when 0.5% fibre was incorporated in concrete that was heated at 250 °C. From the result obtained, it is seen that coconut fibre increased the compressive strength of concrete. Although the values were reduced compared to those heated at a lower temperature. At 0.75% fibre (150 °C), the control specimen exhibited a higher strength compared to the coconut fibre reinforced as shown in Figure 12. The Figure 13 shows the results of compressive strength of concrete obtained from 0.75% fibre heated at 250 °C and the control specimen had higher results. Beyond 0.5%, it is advised that coconut fibres should not be used because it leads to a reduction in the compressive strength. Figures 14 and 15 show that 1% fibre gave a very low strength when compared to the control experiment. The results obtained are even lower than that of 0.75% at 150 and 250 °C, respectively. Coconut fibre has no effect on the results obtained.



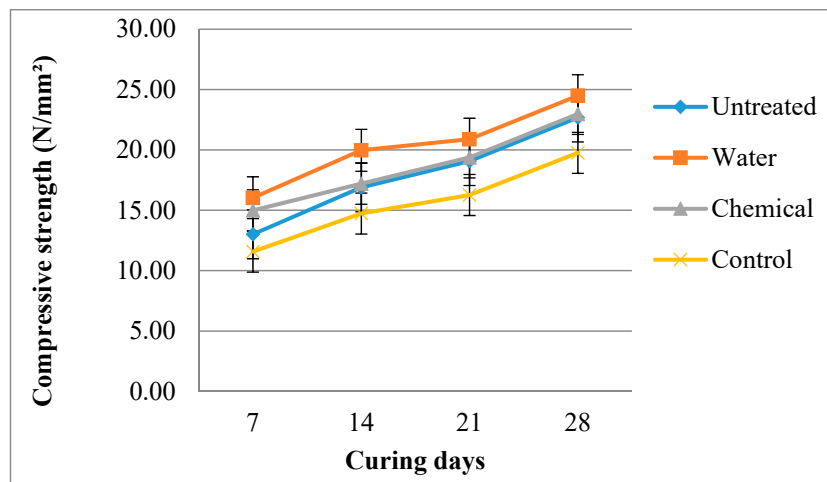


Figure 11. Line graph showing variation in compressive strength at 0.5% fibre at 250 °C.

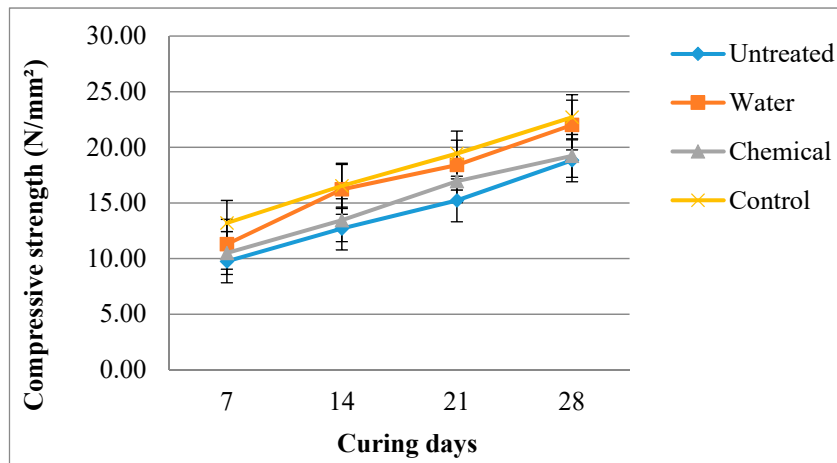


Figure 12. Line graph showing variation in compressive strength at 0.75% fibre at 150 °C.

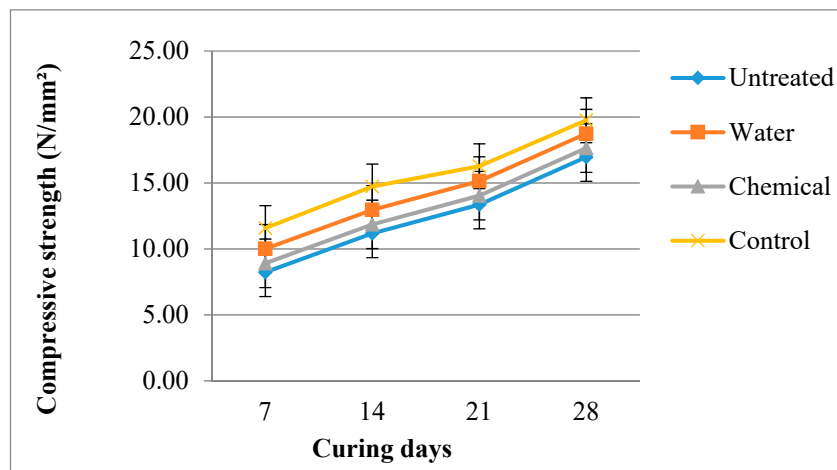


Figure 13. Bar chart showing variations in compressive strength at 0.75% fibre at 250 °C.

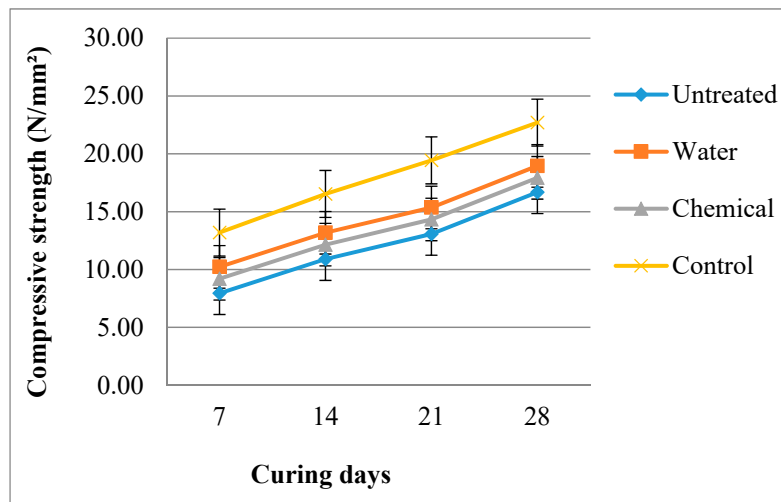


Figure 14. Line graph showing variation in compressive strength at 1% fibre at 150 °C.

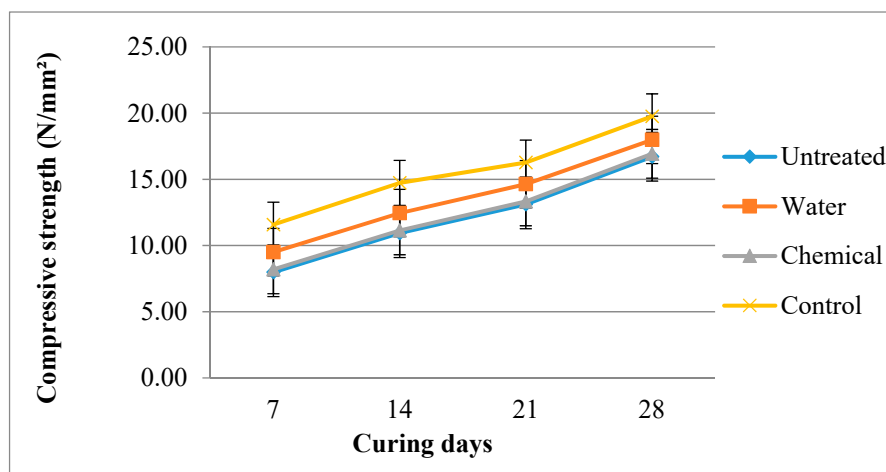


Figure 15. Bar chart showing variations in compressive strength at 1% fibre at 250 °C.

Generally, heat affected the compressive strength of plain concrete to some extent, but when the values obtained from this study were compared to that of coconut fibre reinforced concrete that had been subjected to the same amount of heat, coconut fibre reinforced concrete displayed a higher strength up to 0.5% fibre content. Beyond this percentage, there was a decrease in strength. The reason for this phenomenon is related to bond strength and the matrix strength between the coconut fibre and the concrete. This is also in line with the finding of Mahyduddin et al. [35], reporting that the incorporation of coconut fibre in concrete increase the compressive and flexural strength of concrete. This indicates that coconut fibre is efficient as long as the right amount is utilized. The highest strength was obtained at 0.5% fibre content. After the cubes were crushed the coconut fibres were seen to hold the concrete together. This is a good explanation of the role coconut fibres play when incorporated into concrete. The presence of coconut fibre gives concrete a great ductility, thereby preventing fragile collapse.

#### 4. Conclusions

From tests carried out the following conclusions were made:

- (1) The lowest slump value was recorded at 0.5% coconut fibre, indicating lower workability.
- (2) All slump values signified a medium workability, which is also acceptable.
- (3) When the concrete cubes were subjected to higher temperatures, the strength reduced.

- (4) Untreated coconut fibres exhibited higher compressive strength when compared to the control experiment and the water- and chemically treated fibres.
- (5) When the compressive strength of plain concrete that had been subjected to varying temperatures was compared with that of coconut fibre reinforced concrete (CFRC) that had been subjected to the same amount of temperature, the compressive strength of coconut fibre reinforced concrete increased significantly.
- (6) There was an increase in strength up to 0.5% fibre. Beyond 0.5% fibre, there was a decrease in strength.
- (7) The presence of coconut fibre gives concrete a great ductility, thereby preventing fragile collapse.

The addition of coconut fibre to concrete not only improves the strength of the concrete but is also fire resistant in the sense that even after the cubes were heated, it still had a higher compressive strength than when compared to the control specimen. Not only does it improve strength, it is also cost effective when used adequately in construction.

**Author Contributions:** G.B., conception, analysis, interpretation of data, critical reviewing and final approval of the version submitted; B.N., critical reviewing and final approval of the version to be submitted; O.A., design, acquisition, analysis and drafting of the article; O.M., critical reviewing; D.A., critical reviewing and final approval of the version to be submitted; K.J.; data curation and investigation. All authors have read and agreed to the published version of the manuscript.

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