Performance evaluation of the mechanical and durability properties of concrete reinforced with hybridized fibers

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Abstract. The hybridization of two different elements is done for synergy and better performance. This study investigates the effects of combining bamboo, steel, and carpet fibers, as reinforcement in concrete. The steel and carpet fibers were obtained from discarded tires, and carpets, respectively. The addition of fibers to the mixes was kept constant at 2% of the concrete volume. The first category concrete mix contained a hybrid of steel and carpet fibers at a fraction of 1.75% and 0.25%, respectively, the second category combined steel and bamboo fibers at a fraction of 1% - 1%. The third category contained only steel fibers at a 2% volumetric fraction. The mechanical property of the concrete was evaluated through compressive and flexural strengths, while the durability was examined through water absorption and the acid attack. The compressive strength results obtained for the three categories of fiber reinforced concrete ranged between 7.2 and 12.8 N/mm², with the third category performing better. Also, the flexural strength results ranged between 5.37 and 7.47 N/mm² with the first category having the best results. The second category showed the least water absorption capacity, and the concrete reinforced with only steel fibers showed the best acid attack resistance. The results also confirmed that short discontinuous fibers are suitable strength and durability enhancers in producing durable eco-friendly concrete.

Keywords: steel fiber reinforced concrete; steel fibers; bamboo fibers, carpet fibers

1. Introduction

The introduction of short discontinuous fibers in concrete is referred to as fiber reinforced concrete. Typically, fibers have been found suitable for enhancing the performance of concrete [1]. In this regard, quite several fibers have been incorporated into the concrete mix, and these fibers range from natural to industrially manufactured fibers [2]. The process of combining two or more fibers in concrete is referred to as hybridization. In hybridization, the performance of the composite material named concrete is improved with benefits from each of the individual fibers added to the concrete mix. The advantage of incorporating these fibers into concrete includes enhanced tensile strength, ductility, toughness, and durability [3]. Natural occurring fibers such as bamboo fibers are usually obtained at little or no cost, while the industrially manufactured fibers increase the cost of producing concrete. The addition of 1% of steel fibers content approximately doubles the material costs of concrete [4]. Most developing countries, such as Nigeria, lack the presence of viable steel manufacturing industries to meet the demand for steel fibers if the material were to be incorporated into the concrete mix. Steel fibers waste tires are now being...
considered as an alternative source of steel fiber for use in concrete. Due to the high volume of waste tire generated annually, they are readily available, and a few pieces of research have also been carried out in this area [5], [6], [7], [8] and [9].

It is estimated that 259 million tires are discarded annually across Nigeria [9], and it is expected that this number will increase, considering the ever-growing population and rising interest in personal mobility. Furthermore, most of the populace depends on used tires, also known as ‘Tokunbo Tires,’ as a replacement for worn-out tires. This, coupled with the deplorable states of most Nigeria roads, causes these tires to wear quickly and, in turn, increases the rate at which waste tires are generated. Tires are made of elastomers (synthetic rubber and natural rubber), fillers (carbon black and silica), reinforcing metals (wires and bead wires), plasticizers (resins and oils), textile reinforcement (rayon, aramid, nylon, and polyester) and chemical (sulfur) [10]. It is most effective to make use of the metal reinforcement derived from tires as fibers to reinforce concrete, while other materials from tires can be used for other purposes such as making surfaces and into chips for use as solid fuel, considering the cost of purchasing steel fibers, the amount of landfill space occupied by waste tires and the eventual environmental pollution or hazard that results from its disposal [11].

A carpet is a form of polypropylene fiber that has a tensile strength of 40-60N/mm² [12]. Carpets are made of polyvinyl chloride (or vinyl) resin, plasticizer (high molecular solvents), pigment and trace stabilizers, and a carrier sheet or backing. Due to the low standard of living of Nigerians, carpets seem the cheapest flooring material, and depending on the maintenance and usage, carpets last for an average of 3-5 years before ending up as waste. This waste carpet comprises different polymeric materials, which makes it suitable for use as fiber in concrete. Waste carpets are relatively readily available, and fibers obtained from shredding these carpets are flexible with high resistance to corrosion, judging by the presence of polyvinyl chloride (or vinyl) resin. This provides another avenue to reuse this carpet and also to reduce the problems associated with its disposal. Since the material is non-biodegradable, it seldom decays, except by burning. This releases pollutants that are hazardous to the environment, especially in the case of open burning as often practiced in the country.

Bamboo fibers, as mentioned earlier, are natural fibers that are environmentally friendly and have an excellent mechanical property that makes them a material of choice in reinforcing concrete. The bamboo fibers can be used in place of the non-degradable synthetic fibers, which are capable of emitting poisonous gases into the atmosphere. The bamboo fibers have tensile strength ranging between 150 and 810MPa, which makes it suitable for use as conventional fiber [13]. The bamboo plant is readily available in most parts of Nigeria due to its fast-growing nature, and it has a growth rate of 3 cm per hour. Besides, bamboo has been found useful for a variety of applications in the construction industry ranging from making of scaffolding, bridges, walls, partitions, roofing, and houses [14].

A study of the mechanical behavior of concrete reinforced with different types of fibers such as polypropylene, glass, and steel at different volumetric fractions ranging between 0.5 and 2% was conducted. The results showed that the compressive strength generally increased with an increase in fiber volumetric fraction [14]. Another investigation into the mechanical properties of hybrid steel polypropylene (ST-PP) Fiber Reinforced Concrete (FRC) at a low fiber volume fraction of 0.5% shows that the hybrid fibers can enhance composite performance when compared to FRC [15]. The mechanical properties of different mixes incorporating various volumetric fractions of ST and PP fibers in hybrid form were also investigated. The results indicate that a hybrid fiber system can lead to similar significant improvements that can also be achieved with the mono fiber system at higher fiber content [16]. Moreover, a study of the mechanical properties and water permeability of fiber reinforced concrete containing hybrid steel- polyvinyl alcohol (ST-PVA) incorporating both macro and micro-fibers showed that the hybridization of macro and micro-fibers in mortar significantly improved the resistance to water permeation. And it also enhanced the mechanical properties of the concrete [17].
The use of short discontinuous fibers as a means for reinforcing concrete for improved performance has been known for several years. These short discontinuous fibers are either used solely or in combination with other industrially manufactured fibers. From the environmental viewpoint, the study examines the potentials of recycling waste materials as a source of fiber for reinforcing concrete. The steel fibers extracted from waste tires, as well as polypropylene fibers extracted from waste carpet, provides an opportunity to reduce the problems associated with waste generation and handling. Besides, the study examines the performance of hybrid short discontinuous fibers obtained from waste and natural means on the mechanical and durability properties of concrete. To this end, the combinations of metallic and natural fibers, as well as metallic and polypropylene fibers, were considered.

2. Materials, Methods, and Testing

2.1. Material

- **Cement**
  The cement used was Ordinary Portland Cement of grade 32.5, with a consistency of 27%. It had an initial setting time of 30mins and a final setting time of 450mins. It was purchased from Ado Ekiti local market. The cement properties conformed to British Standard for Portland Cement [18].

- **Steel fibers**
  The steel fibers were obtained from waste tires by manually shredding, after which they were cut to a length of 30 mm using the cutting disc. The addition of fibers to the concrete mixes was kept constant at a volumetric fraction of 2% of the concrete volume. Three different categories of the concrete mix were considered in the study. The first category contained a combination of steel and carpet fibers at a volumetric fraction of 1.75% and 0.25%, respectively, while the second category of the concrete mix contained a combination of steel and bamboo fibers at a volumetric fraction of 1% - 1% respectively. Lastly, the third category contained only steel fibers at 2% volumetric fraction.

- **Carpet fibers**
  Waste carpets were taken from dumpsites located at the Satellite Area of Ekiti State University (EKSU) campus. The shredding of the waste carpet into fibers of length 18mm was done using blade and scissors.

- **Bamboo fibers**
  Bamboo trees are located at the Satellite Area of EKSU. Selected trees were cut, after which they were allowed to dry under ambient temperature for weeks. After drying, they were cut into pieces at the sawmill before being shredded into small sizes and length of 30 mm.

- **Superplasticizer**
  Superplasticizer was added at 1.5% by weight of cement to improved workability.

- **Silica sand**
  Silica sand was obtained from Laguna Beach in Lagos state and transported in sacks bags to Ado Ekiti. It was sun-dried and made fine. The silica sand was used as filler in the matrix. A constant proportion of 10% by weight of cement was used.

- **Aggregates**
  The fine and coarse aggregates used are stone dust and granite, respectively. The stone dust passed through sieve 4.75mm while passed through sieve size 20mm.

- **Water**
  Potable water was used.
2.2. Methods

The fine, coarse aggregates, filler, cement, superplasticizer, and fibers were weighed using a weighing balance. The casting was done in segments to accommodate the different types of fiber combinations, as presented in Table 1. In the sequence of mixing, cement was mix with 10% by weight of silica sand before the addition of the fine aggregate and coarse aggregate. A constant water-cement ratio of 0.42 was used, and the mixing time was between 3-5mins. The freshly prepared concrete was placed in appropriate molds and compacted in 3 layers.

After 24 hours of casting, the concrete cubes and beams were removed from their respective molds. The weight of each specimen was taken before the concrete cubes and beams were submerged in water for curing. The workability of the concrete containing steel-polymer hybridized fiber matrix had better workability when compared to the steel-bamboo hybridized fiber matrix despite the presence of superplasticizer. This was attributed to the water-absorbing nature of the bamboo fiber. Besides, concrete specimens containing only steel fiber required more setting time for adequate bonding than their hybridized counterpart.

### Table 1. Details of concrete mix.

| Samples | Cement (kg) | Silica sand (kg) | Water (kg) | SP (kg) | Stone dust (kg) | Granite (kg) | Steel fiber (kg) | Carpet fiber (kg) | Bamboo fiber (kg) |
|---------|-------------|-----------------|------------|---------|-----------------|--------------|-----------------|-----------------|-----------------|
| C       | 3.66        | 0.37            | 1.54       | 0.06    | 4.77            | 14.28        | 0.32            | 0.11            | ---             |
| B       | 3.66        | 0.37            | 1.54       | 0.06    | 4.77            | 14.28        | 0.22            | ---             | 0.07            |
| S       | 3.66        | 0.37            | 1.54       | 0.06    | 4.77            | 14.28        | 0.43            | ---             | ---             |

C = Concrete cubes hybridized with steel and carpet fiber at 1.75%-0.25%, respectively.
B = Concrete cubes hybridized with steel and bamboo fiber at 1%-1%, respectively.
S = Concrete cubes reinforced with 2% steel fiber.

2.3. Testing

The performance of the hybridized fiber specimens in comparison with the control specimen was done using compressive strength test, flexural strength test, sorptivity test, and susceptibility to acid attack. The compressive strength test was carried at 28 days using the 100 mm cubes, and the average maximum crushing load divided by the area was used to obtain the compressive strength values. The third point bending test with beam size 400 mm by 100 mm by 100 mm was used to determine the flexural behavior of the test specimen. The sorptivity test was done to ensure water penetration resistance. Cubes of 100 mm sizes were coated at the four edges to ensure unidirectional absorption, and after that, the test specimen was dried before being exposed to 10± mm of water. The test specimens were removed from the water and dried with a towel before weighting at time intervals of 15 min, 30 min; 1h, 1.5h, 3 h, 5 h, 8 h, 24 h, 72 h, 96 h, 120 h, 144 h, and 168 h. The test specimens were submerged in water immediately after their weights were taken. The susceptibility to acid attack was done using 100 mm cubes, and the acidic water contained 3% concentrated on hydrochloric acid. Test specimens were in the acidic concentration for 90 and 120 days before testing.

3. Results and Discussions

3.1. Compressive Strength

The compressive strength at twenty-eight (28) days for steel-bamboo fibers (B1 - B3) and steel-carpet fibers (C1 - C3) was compared with concrete reinforced with only steel fibers (S1 - S3) as presented in Table 2. Obviously, the strength values of specimens reinforced with steel-bamboo fibers performed better than the control specimens. Besides, the control specimen showed better behavior than specimens
reinforced with steel-carpet fibers. From these results, it can be inferred that the synergy between steel and bamboo was better than that between steel and carpet, which demonstrates the positive effect of hybridization on the performance of concrete. The percentage combination of steel-bamboo fibers was equal; that is 1% each. From this result, it could be inferred that increasing the percentage of the steel fiber beyond 1% may not be necessary because a more significant proportion of the steel fiber, as observed with the control specimen (2%), does not translate to an increase in compressive strength. This assertion is supported by previous research [19]. It has been previously observed that there is a reduction in compressive strength of steel fiber reinforced concrete when the percentage of fiber is increased above 1% [20]. It has also been reported that the maximum increase in compressive strength of concrete reinforced with bamboo fibers is at 1% [21]. Therefore, by combining the optimum steel fibers and bamboo fibers can enhance the compressive strength property of the concrete.

### Table 2. Compressive strength of cubes at 28 days.

| Sample Number | Mass before immersion (kg) | Mass after immersion (kg) | Volume of cube (m³) | Density of cube (Kg/m³) | Crushing load (KN) | Area of cube (mm²) | Compressive strength (N/mm²) | Average Compressive strength (N/mm²) |
|---------------|----------------------------|---------------------------|---------------------|------------------------|-------------------|-------------------|-----------------------------|-----------------------------------|
| B1            | 2.44                       | 2.50                      | 0.001               | 2500                   | 140.4             | 10000             | 14.04                       | 12.8                              |
| B2            | 2.56                       | 2.62                      | 2620                | 130.4                  |                   |                   |                             |                                    |
| B3            | 2.48                       | 2.54                      | 2540                | 113.3                  |                   |                   |                             |                                    |
| C1            | 2.36                       | 2.46                      | 0.001               | 2460                   | 60.2              | 10000             | 6.02                        | 7.21                              |
| C2            | 2.48                       | 2.56                      | 2560                | 87.0                   |                   |                   |                             |                                    |
| C3            | 2.60                       | 2.68                      | 2680                | 69.1                   |                   |                   |                             |                                    |
| S1            | 2.66                       | 2.72                      | 0.001               | 2720                   | 85.1              | 10000             | 8.51                        | 8.00                              |
| S2            | 2.56                       | 2.62                      | 2620                | 78.7                   |                   |                   |                             |                                    |
| S3            | 2.52                       | 2.58                      | 2580                | 76.2                   |                   |                   |                             |                                    |

3.2. **Flexural Strength**

The flexural behavior of the three categories of fiber reinforced concrete considered in the study are presented in Table 3. From this table, it was observed that concrete reinforced with hybrid steel–carpet fibers had the best flexural strength, which is an improvement on the steel fiber reinforced concrete. However, concrete reinforced with hybrid steel–bamboo fibers had the least strength when compared with the others. The enhanced performance may be attributed to the malleable nature of both the steel and carpet fibers since the bamboo fiber is stiffer. Carpet fiber is usually flexible, and this has appeared to affect the bending strength of the hybrid fiber reinforced concrete. Also, the carpet fibers being of a shorter length acted as the micro-fiber to take care of mini-cracks, thereby improving the ductility of the concrete. A previous study on the flexural strength of concrete reinforced with industrial manufactured steel fiber at 1.5% volumetric fraction of concrete gave flexural Strength values less than 8 N/mm² at 28 days [22]. The result is similar to that achieved in this study with the hybrid steel-carpet fibers. The advantage presented here is that both hybrid fibers obtained from waste products can be used to positively enhance the flexural behavior of fiber reinforced concrete, which promotes sustainability in the construction industry. Since both waste products are non-biodegradable, their recycling provides an avenue for reducing the environmental challenges associated with its generation and handling.
Table 3. Flexural strength of beams at 28 days.

| SAMPLE NO | Mass before immersion (kg) | Mass after immersion (kg) | Depth and width of specimen (mm) | Length (mm) | Maximum load (KN) | Position of fracture “a” (mm) | Flexural strength (N/mm²) | Average Flexural strength (N/mm²) |
|-----------|-----------------------------|----------------------------|---------------------------------|-------------|-------------------|-------------------------------|--------------------------|----------------------------------|
| B1        | 10.78                       | 10.84                      | 100x100                         | 400         | 11.0              | 13.9                          | 4.95                     | 5.37                             |
| B2        | 10.94                       | 11.00                      |                                 |             | 14.0              | 14.0                          | 6.30                     |                                  |
| B3        | 10.34                       | 10.40                      |                                 |             | 10.8              | 12.8                          | 4.86                     |                                  |
| C1        | 11.06                       | 11.14                      | 100x100                         | 400         | 16.8              | 12.7                          | 7.56                     | 7.47                             |
| C2        | 11.07                       | 11.16                      |                                 |             | 16.9              | 14.5                          | 7.61                     |                                  |
| C3        | 11.58                       | 11.66                      |                                 |             | 16.1              | 14.4                          | 7.25                     |                                  |
| S1        | 11.08                       | 11.14                      | 100x100                         | 400         | 15.0              | 14.1                          | 6.75                     | 6.03                             |
| S2        | 11.84                       | 11.90                      |                                 |             | 12.0              | 13.0                          | 5.40                     |                                  |
| S3        | 11.32                       | 11.38                      |                                 |             | 13.2              | 10.8                          | 5.94                     |                                  |

3.3. Water absorption property

The water absorption property of the three categories of fiber reinforced concrete considered in the study is graphically presented in Figure 1. From this graph, it was generally observed that all fiber reinforced concrete attained optimum water absorption at 5 hours, after which a decline in the rate of absorption was observed. More specifically, it was noted that the hybrid steel - bamboo fiber reinforced concrete had better resistivity to water penetration than the hybrid steel – carpet fiber reinforced concrete as well as the steel fiber reinforced concrete. It has been observed that the nature of the concrete pore structure determines the durability of the concrete [23]. Concrete with a more open pore structure is likely to be susceptible to degradation resulting from infiltrating substances. These substances, which may be gases and/or liquids, can penetrate the concrete from the surrounding environment, resulting in physical and chemical reactions within its internal structure, probably leading to irreparable damage [24]. The Water absorption test has also demonstrated the positive effect of hybridization in fiber reinforced concrete since there is a linear relationship between water absorption and porosity of concrete [25]. The ability of hybrid steel - bamboo fiber to outperform steel – carpet fiber may be attributed to the low volumetric fraction of the carpet fiber considered in the study. The results of the study have also indicated that concrete reinforced with only steel fibers or high volumetric fractions of steel fiber is likely to absorb more water.
3.4. Susceptibility to acid attack

The compressive strength determined after 90 days of submerging the cubes into water containing hydrochloric acid is presented in Table 4. A general trend of an increase in compressive strength for all categories of fiber reinforced concrete was observed when compared to the strength values obtained at 28 days. This is expected with increased curing age. Figure 2 shows the compressive strength values obtained at 28, 90, and 120 days. Furthermore, it was observed that the control specimens reinforced with only steel fiber performed better than their hybrid counterpart. However, the hybrid steel-carpet fiber reinforced concrete was most affected by the acid solution, while the hybrid steel-bamboo fiber reinforced concrete had relatively good strength. The increase in strength of the specimens reinforced with steel fibers as well as hybrid steel-bamboo fiber implies that the acidic solution only had a deteriorating effect on the aesthetic. This is because the cubes were observed to have rusty stains on them, and not much impact on the mechanical properties. It may also be attributed to the concentration of the acid solution, which may not be toxic enough to have a significant effect on the concrete.

The strength gained for steel-carpet fiber reinforced concrete was considered low, which may be due to the carpet fibers being adversely affected by the acid solution. This could have weakened the bond within the concrete matrix. It explains the reason why the steel-carpet fiber reinforced concrete gained weight due to more penetration of the acid solution when compared with their hybrid counterpart. A similar trend as above, was observed at 120 days of curing in acid solution, as presented in table 5. However, the compressive strength was observed to decrease slightly for all types of fiber-reinforced concrete investigated. The percentage decreases in compressive strength from 90-120 days are 2.1%, 0.8%, and 5.8% for steel, hybrid steel-bamboo, and hybrid steel-carpet fiber reinforced concrete, respectively. This implies that as the curing day increased from 90 to 120, the acid concentration began to have an effect on the strength of fiber-reinforced concrete. It could be inferred that concrete reinforced with only steel fiber had better resistance to acid attack than the others. In general, the concrete environment is highly alkaline in nature, with a pH between 12 and 13. This alkaline nature results in the formation of insoluble oxide film on the surface of steel fibers. However, this may sometimes be destroyed by the formation of weak carbonic acid resulting from the reaction between atmospheric carbon
dioxide and water. In conclusion, it has been found that corrosion of the steel fibers is usually confined to the skin of the concrete while the interior fibers enjoy the protective cover of the alkaline environment [4].

Table 4. Compressive strength of cubes after 90days of acid attack.

| SAMPLE NO | Mass before immersion (kg) | Mass after immersion (kg) | Volume of cube (m³) | Density of cube (Kg/m³) | Crushing load (KN) | Area of cube (mm²) | Compressive strength (N/mm²) | Average Compressive strength (N/mm²) |
|-----------|---------------------------|---------------------------|---------------------|-------------------------|--------------------|--------------------|-----------------------------|-----------------------------------|
| B7        | 2.50                      | 2.52                      | 0.001               | 2520                    | 181.40             | 10000              | 18.14                       | 18.90                             |
| B8        | 2.56                      | 2.58                      |                     | 2600                    | 196.80             |                    | 19.68                       |                                   |
| B10       | 2.54                      | 2.58                      |                     | 2580                    | 188.70             |                    | 18.87                       |                                   |
| C7        | 2.44                      | 2.52                      | 0.001               | 2500                    | 138.07             | 10000              | 13.81                       | 13.61                             |
| C8        | 2.54                      | 2.60                      |                     | 2580                    | 129.76             |                    | 12.98                       |                                   |
| C10       | 2.46                      | 2.52                      |                     | 2500                    | 140.48             |                    | 14.05                       |                                   |
| S7        | 2.56                      | 2.58                      | 0.001               | 2580                    | 279.80             | 10000              | 27.98                       | 27.30                             |
| S8        | 2.74                      | 2.72                      |                     | 2720                    | 268.20             |                    | 26.82                       |                                   |
| S9        | 2.68                      | 2.66                      |                     | 2660                    | 271.10             |                    | 27.11                       |                                   |

Table 5. Compressive strength of cubes after 120days of acid attack.

| SAMPLE NO | Mass before immersion (kg) | Mass after immersion (kg) | Volume of cube (m³) | Density of cube (Kg/m³) | Crushing load (KN) | Area of cube (mm²) | Compressive strength (N/mm²) | Average Compressive strength (N/mm²) |
|-----------|---------------------------|---------------------------|---------------------|-------------------------|--------------------|--------------------|-----------------------------|-----------------------------------|
| B4        | 2.46                      | 2.50                      | 0.001               | 2500                    | 180.01             | 10000              | 18.01                       | 17.80                             |
| B5        | 2.60                      | 2.64                      |                     | 2640                    | 178.00             |                    | 17.80                       |                                   |
| B6        | 2.28                      | 2.32                      |                     | 2320                    | 175.90             |                    | 17.59                       |                                   |
| C4        | 2.36                      | 2.42                      | 0.001               | 2420                    | 128.10             | 10000              | 12.81                       | 13.50                             |
| C5        | 2.56                      | 2.62                      |                     | 2620                    | 135.80             |                    | 13.58                       |                                   |
| C6        | 2.66                      | 2.72                      |                     | 2320                    | 141.12             |                    | 14.12                       |                                   |
| S4        | 2.64                      | 2.66                      | 0.001               | 2660                    | 258.00             | 10000              | 25.80                       | 26.72                             |
| S5        | 2.46                      | 2.48                      |                     | 2480                    | 274.00             |                    | 27.40                       |                                   |
| S6        | 2.64                      | 2.66                      |                     | 2660                    | 269.60             |                    | 26.96                       |                                   |
4. Conclusion
Hybridization of waste steel fiber reinforced concrete with either natural or synthetic fibers portends a novel way to develop durable eco-friendly concrete that can be used for construction purposes. The following conclusion has been drawn from the study;

i. The combination of 1% steel fiber combined with 1% of bamboo fibers can be used to enhance the compressive strength of concrete.

ii. The combination of steel and carpet fibers can be used to improve the flexural strength of concrete.

iii. The combination of steel - bamboo fibers had better resistivity to water penetration.

iv. Concrete reinforced with only steel fibers can withstand acidic attack when compared to their hybridized counterpart.

References
[1] Ayub T., Shafiq N. and Nuruddin M. 2014 Mechanical Properties of High – Performance Concrete with Basalts Fibers. Fourth International Symposium on Infrastructure Engineering in Developing Countries, 77 pp131-139.
[2] Ayan E., 2004 Parameter Optimization Of Steel Fibre Reinforced High Strength Concrete By Statistical Design And Analysis Of Experiments. Master of Science Thesis. Middle East Technical University, Ankara, Turkey.
[3] Pakravan H., Latifi M. and Jamshidi M 2017 Hybrid Short Fibre Reinforcement System in Concrete: A Review. Construction and Building Materials 142 pp280–294.
[4] Nasir B. 2009 Steel fiber reinforced concrete made with fibers extracted from used tires, Master of Science Thesis, Addis Ababa University, Ethiopia.
[5] Syaidathul A. and Izni S. 2012 Mechanical properties of recycled steel fiber in concrete, technical report, Faculty of Civil Engineering, Universiti Teknologi Malaysia.
[6] Ndayambaje J. 2018 Structural performance and impact resistance of rubberized concrete. Master of Science Thesis, Pan-African University, *Institute for Basic Science, Technology, and Innovation*.

[7] Mastali M., Dalvand A. 2016 Use of silica fume and recycled steel fibers in self-compacting concrete (SCC). *Construction and Building Materials, 125* pp196–209.

[8] Awolusi T, Oke O, Akinkurolere O, and Sojobi A. 2019a Application of response surface methodology: Predicting and optimizing the properties of concrete containing steel fiber extracted from waste tires with limestone powder as filler, *Case Studies in Construction Materials, 10:*e00212.

[9] Awolusi T., Oke, O., Akinkurolere O., and Atoyebi O. 2019b Comparison of response surface methodology and hybrid-training approach of artificial neural network in modeling the properties of concrete containing steel fiber extracted from waste tires, *Cogent Engineering*. https://doi.org/10.1080/23311916.2019.1649852.

[10] Bulei C., Todor M., Heput T, and Kiss I. 2018 Directions for material recovery of used tires and their use in the production of new products intended for the industry of civil construction and pavements. *International Conference on Applied Science*, 294012064.

[11] Scrap Tyre recycling in Nigeria; The Pre- Feasibility Report accessed May 19, 2019. https://foramfera.com/scap_tyre_recycle

[12] Sridhar M. K. C., Hammerd T. B. 2014 Turning Waste to Wealth in Nigeria: An Overview. *Journal of Human Ecology, 46*(2) pp195-203.

[13] Sotayo A., Green S., Turvey G. 2015 Carpet recycling: A review of recycled carpets for structural composites. *Environmental Technology and Innovation, 3* pp97-107.

[14] Shi Hong L., Benlian Z, Qiyun Z. and Xianrong B. 1994 A new kind of super- hybrid composite material for civil use – ramine/ A I Composite, *25*(3) pp225-228.

[15] Simoes T., Costa H., Dias-da-Costa D., Julio E. 2017 Influence of fibers on the mechanical behaviour of fiber-reinforced concrete matrixes *Construction and Building Materials* 137 pp548–556.

[16] Shah A., Sultan M., Jawaid M., Cardona F. and Taib ARA 2016 A review on the tensile properties of bamboo fiber reinforced polymer composites. *Bioresources com, 11*(4) 10654-10676.

[17] Yao W., Li J., and Wu K. 2003 Mechanical properties of hybrid fiber-reinforced concrete at low fibre volume fraction. *Cement and Concrete Research, 33* (1) pp27–30.

[18] Qian C., Stroeven P., 2000 Development of hybrid polypropylene-steel fiber reinforced concrete. *Cement and Concrete Research, 30* (1) pp63–69.

[19] Lawler J., Zampini D. and Shah S. 2005 Microfibre and macro-fiber hybrid fibre reinforced concrete *Journal Materials in Civil Engineering, 17* (5) pp595–604.

[20] Yao W., Li, J. and Wu K. 2003 Mechanical properties of hybrid fibre-reinforced concrete at low fibre volume fraction *Cement and Concrete Research 33* (1) pp27–30.

[21] Brindha M. 2017 Properties of Concrete Reinforced With Bamboo Fibre *International Journal of Innovative Research in Science, Engineering and Technology, 6*(3) pp3809 - 3812.

[22] Shewata P and Kavilkar R. 2014 Study of flexural strength steel fibre-reinforced concrete *International Journal of Recent Development in Engineering and Technology 2*(5) pp13-16.

[23] Khan M. 2003 Isoresponses for strength, permeability, and porosity of high-performance mortar. *Building and environment, 38* pp1051-1056.

[24] Claiss P., Elsayad H. and Shaaban I. 1997 Absorption and sorptivity of cover concrete. *Journal of Materials in Civil Engineering, 9* pp105-110.
[25] Abo-El-Enein S., Ali A., Talkhan F., Abdel-Gawwad H. 2013 Application of microbial biocementation to improve the physico-mechanical properties of cement mortar. *HBRC Journal*. 9 pp36–40.