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EFFECTS OF SYNTHETIC HAIR FIBRE ON THE STRENGTH AND MICROSTRUCTURAL PROPERTIES OF CONCRETE

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Abstract: As the use of synthetic hair fibre (SHF) is increasing globally, the rate of hair fibre waste generated is also quite high thereby resulting into environmental pollution. In this study, the effect of SHF waste on the strength and microstructural properties of concrete was investigated. SHF concrete containing the mixture of different percentages of SHF (1, 2, 3 and 4% by weight of cement) were cast using 1:2:4 concrete mix ratio and cured for maximum of 28days to determine the compressive, split tensile and flexural strengths. Scanning Electron Microscopic test was used to examine the micro structural features of SHF concrete. Findings from the study showed that compressive, split tensile and flexural strengths of the concrete reached the optimum value at 2% SHF addition. The SEM test result for the micro structural features of SHF concrete shows reduction in cracks as 2% SHF content. The study therefore revealed that SHF addition to concrete improved the strength and microstructural properties of the concrete. Two (2%) inclusion of the synthetic hair fibre by weight of cement is hereby recommended for the enhancement of the concrete properties.
Keywords: synthetic hair fibre waste; compressive strength; flexural strength; split tensile; microstructural feature

INTRODUCTION

Hairs are considered as waste materials in many parts of the world and it is found in municipal waste streams causing serious environmental problems. They are alternate non–degradable matter that are available in abundance at a little or no cost, and can be used as fibre materials in concrete as a result of its high strength in tension which is equal to that of a copper wire with similar diameter (Ganiron, 2014; Adedokun *et al*., 2016).

Due to non–biodegradable nature of the hair, they can only be disposed of in an economical way by consigning them to landfill and as such they are relatively environmentally unfriendly (Li, 1998; Ganiron, 2014). There is need to effectively utilize these hair fibres in an economical and environmentally friendly ways, and one of such ways is to incorporate them into the concrete as admixtures. In addition, it is very obvious that concrete is weak in tension and hence some measures must be adopted to overcome this deficiency. A way of overcoming this is by introducing hair fibre, which is strong in tension and readily available in large quantity, into the concrete. They are mainly utilized as fibre reinforcing materials in concrete to examine its impacts on the strength properties and cracking control; in order to reduce concrete production cost and to minimize ecological issues created by hair decomposition (Popescu and Hocker, 2007; Jain and Kothari, 2012; Pawar *et al*, 2015). Gupta (2009) through his study on human hair waste concluded that the hair has a large number of uses in many areas ranging from agriculture to medicine to engineering industries. The exceptional properties of human hair such as its unique chemical composition, slow degradation rate, high tensile strength, thermal insulation, elastic recovery, scaly surface, and unique interactions with water and oils, has led to many diverse uses. Utilization of wastes in the concrete production is an environmentally friendly mean of disposing large amounts of materials that would have constituted pollution to land, water and air (Raheem *et al*., 2017a & b; Raheem et al., 2018; Adedokun *et al*., 2021).

Also, there is increase in environmental pollution as a result of the deposition of hair fibre wastes on lands thereby making them unavailable for good purposes. Hence, this made it imperative to use them for other purposes as in construction work. Hair fiber, a fibre deposit/waste with little or no cost, deposited in its millions of tonnes annually around the world is therefore worthy of study. According to Ganiron (2014), hair fibres are very strong in tension and can be used as fibre reinforcing materials in concrete.

Reinforcing concrete with fibres has been said to be a suitable, pragmatic and economic means of overcoming micro-cracks and other concrete deficiencies (Pawar *et al*, 2015; Nila *et al*, 2015). Existing studies (Shakeel *et al*, 2009; Ahmed *et al*, 2011; Ganiron, 2014) are limited to human hair and their impact on CS but this study extended the work of Adedokun *et al*, 2016, which investigated the influence of SHF addition on the concrete strength by examining the strength and microstructural properties of SHF-concrete. Since the usage rate of synthetic hair fibre in Nigeria is increasing, the amount of waste produced due to its usage is quite high resulting to environmental pollution. As salon and manicure centres are springing up in almost every shopping complex in Nigeria, huge waste materials generated from these centres are mostly synthetic hairs.

Hence, this research investigated the impact of these synthetic hair fibres on the workability, strength and microstructural properties of concrete, as a means of reducing waste and improving the strength and microstructural properties of the concrete. This study therefore focused on the reuse of these synthetic hair fibres in concrete production.

MATERIALS AND METHOD

Materials

The materials used for this study are synthetic hair fibre, ordinary Portland cement (OPC), fine and coarse aggregates and water.

- **Synthetic hair fibre** – synthetic hair fibre (SHF) was collected from Awotan dumpsite (Figure 1a). Awotan dump site is one of Government approved refuse waste dump site at Ido Local Government Area in Ibadan, Oyo State, Nigeria. Figure 1b shows the section of SHF deposit at Awotan dumpsite.

(a) Section of SHF at the dumpsite; (b) Dumpsite approach view
Figure 1. Used synthetic hair fibre at Awotan dumpsite, Ibadan, Nigeria

- **Aggregates** – Sharp sand and granite chippings (of 12 mm size), which are fine aggregate and coarse aggregate respectively, was used for the casting of the concrete. The aggregates are in compliance with the requirements of BS 882 (1982), they are clean, free from salt and impurities (including organic matters).
- **Cement** – The cement to be used for this experiment is the Ordinary Portland Cement (OPC) of grade 32.5 N/mm^2. The cement satisfies such properties as fineness, and soundness, which means that the cement meets the specification of the ordinary Portland cement (BS 12, 1996) on the above properties. This cement is readily available and it is the most commonly used in the construction industry.
- **Water** – The water used was obtained from the public water supply at Laboratory of the Ministry of Works, Oyo State Secretariat, Ibadan. The water was relatively clean and free from acids, oils, alkalis, suspended solids, organic matters and soil. The water is potable and therefore suitable for use in casting as required by BS 3148 (1980).

Testing methods

The various tests conducted in this study are the mechanical test on various brands of SHF, tests on fresh (slump and compacting factor) and hardened (compressive, split tensile and flexural strengths) concrete produced by incorporating different combinations of SHF. The used synthetic hair fibres were incorporated into the concrete 1, 2, 3 and 4% by weight of cement.

- **Mechanical test on SHF**

Mechanical tests were carried out on different brands of SHF (Laminar weaveon, Ultra Braid, Besta Braid and the sample from dump site) using Universal testing Machine – Testometric to evaluate elongation at yield, elongation at limit of proportionality, force at yield, force at limit of proportionality, stress at different force application and Young's modulus. The sample length used for the test is 100mm.

- **Tests on fresh concrete**

The slump and compacting factor tests was performed on the fresh concrete mixes containing different percentages of the synthetic hair fibre wastes (1, 2, 3 and 4% by weight of cement). These tests were conducted on different concrete mixes in order to examine the influence of SHF contents on the workability of the fresh concrete in accordance to BS 1881: part 103 (1983).

— **Tests on hardened concrete**

Tests were conducted on various hardened concrete (cube, cylindrical and prism) samples at different percentages of SHF to determine the compressive strength, split tensile strength, flexural strength and microstructural properties of the samples.

- **Compressive strength test** – The compressive strength test was carried out on specimens cubical in shape of size 150 x 150 x 150 mm^3. Fresh concrete mixes were cast and placed into the cubical cast iron mould, and were compacted with the tamping bar on layers. After 24 hours the concrete specimens were removed from the moulds and immediately submerged in clean fresh water. After days (7, 14, 21 and 28 days) of curing the specimens were tested under the load in a compression testing machine.
- **Split tensile strength** – The ASTM test method was used for the determination of the split tensile strength of cylindrical concrete specimens. This method consists of applying a compressive force along the length of a cylindrical specimen. This loading induces tensile stresses on the plane containing the applied load. Tensile failure occurs rather than compressive failure. Plywood strips were used so that the load could be applied uniformly along the length of the cylinder. The maximum load (*P*) at failure was divided by appropriate geometrical factors to obtain the splitting tensile strength (f_{st}) as shown in equation 1.

$$f_{st} = \frac{2P}{\pi l D} \quad (1)$$

where l = height of cylindrical specimen (300 mm) and D = diameter of cylindrical specimen (150 mm)

- **Flexural strength** – Third–point loading method was used in finding out the loading system of flexural tension. Fresh concrete mixes were cast and placed into the cylindrical cast iron mould, and were compacted with the tamping bar on layers. After 24 hours the specimens were removed from the moulds and immediately submerged in clean fresh water. After days (7, 14, 21 and 28 days) of curing the specimens were tested under the load in a compression testing machine. Then the load (*p*) was applied at a constant rate of 400 kg/min. The flexural strength (*F*) was determined as shown in equation 2.

$$\text{Flexural strength, } F = \frac{p l_e}{b d^2} \quad (2)$$

where l_e = effective span of the beam, b = breadth of the beam and d = beam depth

- **Microstructural analysis** – The microstructural properties of the hardened concrete samples containing various percentages of synthetic hair fibre, SHF (1, 2, 3 and 4% by weight of cement) were determined using Scanning Electron Microscopy (SEM). Images of the concrete samples were produced by scanning the surface of sample with a focused beam of electrons. Samples of SHF–Concrete of 0% SHF, 2% SHF and 4% SHF Concrete were investigated using SEM.
- **Statistical analysis** – The experimental results (CS, STS and FS) of the hardened concrete samples containing various percentages of SHF (1, 2, 3 and 4% by weight of cement) were subjected to statistical analysis using 2–way ANOVA without replication. These analyses were conducted to evaluate the statistical significance of SHF and curing days on the strength properties of the SHF–concrete

RESULTS AND DISCUSSION

Mechanical properties of synthetic hair fibre

The results of the mechanical tests conducted on different brands of synthetic hair fibre together with the blend of all the brands (those obtained from the dump site) are presented in Table 1.

Table 1. Mechanical properties of synthetic hair fibre

Synthetic Fibre Type	Elongation (mm)	Stress (N/mm^2)	Young Modulus (N/mm^2)	Strain
Larimar weavon (Black)	19.848	2.971	15.01	0.198
Ultra Braid (Brown)	6.053	1.324	21.70	0.061
Besta Braid (Purple)	31.890	2.937	9.21	0.319
Blend	14.629	4.040	27.67	0.146

From this table, it was observed from the mechanical properties of synthetic hair fibre of different brands and mixture (sample from the dump site) that under the application of force, Ultra braid (brown) gave the lowest elongation and strain values while Besta braid (purple) undergo the highest elongation and strain indicating that Ultra Braid was the toughest and strongest.

Although, Besta braid is quite elastic, it can be stretched beyond 300% of its original length without breaking while Ultra Braid cannot extend beyond 70% of its original length. This implies that Besta braid is highly ductile, while Ultra Braid has low ductivity. Moreover, it was found that the Young Modulus of the Blend (that is, the mixture from dump site) was the highest.

Hence, the usage of the SHF from the dump site is worthwhile as it will combine all the characteristics of the Synthetic Hair Fibre brands, and its application will reduce its rate of dumping and accumulation at the dump site, thereby minimizing the environmental pollution and ecological issues associated SHF usage in the surrounding.

Workability of fresh concrete

Workability of the fresh synthetic hair fibre concrete was investigated using slump and compacting factor tests as shown in Table 2. For slump tests, the results showed that the slump value increased from 19 to 38 mm as the percentage of the hair fibre content increased from 1 to 4%, respectively. However, the slump value for the control sample (0% synthetic hair fibre) was 18 mm. This shows that addition of SHF increased the slump of the concrete.

The concrete became more workable as the percentage of SHF increased. That is, the higher the slump, the higher the workability. This could be attributed to presence of the oil in the used synthetic hair fibre. Similarly, the results of the compacting factor increased from 0.846 for 0% SHF concrete mix to 0.968 for 4% SHF mix. This also showed that compacting factor increased with increasing SHF content, indicating an increase in workability of the concrete with the addition of Synthetic hair fibre.

Table 2: Effects of the used synthetic hair fibre on workability (slump and compacting factor) of the concrete

Tests	Percentage of SHF (%)				
	0	1	2	3	4
Slump	18.0	19.0	20.0	25.0	26.0
Compacting factor	0.846	0.852	0.880	0.862	0.899

Compressive strength

Figure 2 presents the influence of synthetic hair fibre (SHF) and curing age on the compressive strength of concrete. The compressive strength for concrete samples containing 1% SHF showed higher values at 7 and 14 curing days than the control concrete samples (0% SHF) but were lower than the control at 21 and 28 curing days. For 2% SHF addition, compressive strengths were significantly higher than those of the control and 1% SHF samples at each of the curing periods. However, the values of the compressive strength for concrete samples containing 3% and 4% SHF were lower than those of the control and 2% SHF samples. This is an indication that the optimum value of the compressive strength is reached at 2% SHF addition.

This finding is also in agreement with the conclusion of the previous studies by Adedokun *et al.* (2016), while Jain and Kothain (2012) and Sreevani and Ajitha (2017) reported the optimum compressive strength at 1.5% addition of human hair, even though these studies did not test the impact of human hair on concrete beyond 1.5% (by weight of cement). In addition, the compressive strength of 29.28N/mm² obtained for sample with 2% SHF content (by weight of cement) satisfied the minimum compressive strength of 26 N/mm² at 28 days recommended by NIS 439 (2000).

For different curing ages, the results showed that the compressive strength increased as the curing period increased. These results clearly showed that 2% addition of synthetic hair fibre to concrete would not only lead to enhancement in compressive strength but also can lead to a very significant reduction in the environmental pollution and ecological issues resulting from the accumulation of synthetic hair fibre in the surrounding.

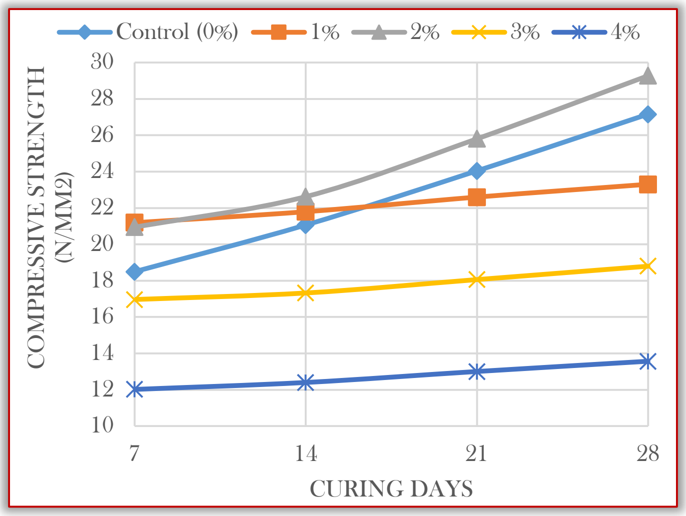

Figure 2. Influence of synthetic hair fibre and curing days on compressive strength of concrete

Table 3 presents the results of the statistical test carried out on the impact of SHF and curing days on the CS of the SHF–concrete using ANOVA at 5% level of significance. From the Table, the p–values are 1.19e–6 and 0.005282 for the SHF and curing day, respectively.

Table 3: Impact of SHF and curing days on CS of concrete

Source of variation	Sum of squares	Degree of freedom	Mean square	*Fcal*	*P–value*	*Fcrit*	Remark
SHF	382.9229	4	95.730	36.84	1.19E–06	3.259	Significant
Curing day	55.5005	3	18.500	7.119	0.005282	3.490	Significant
Error	31.181	12	2.598				
Total	469.6049	19					

The p–value for the SHF is much lower than the adopted 0.05 level of significance. Whereas, for curing day, the value is approximately equal to the adopted level of significance.

In addition, the variance ratio after treatment, Fcal, is 36.84132 (greater than the stipulated ratio of variance, Fcrit of 3.259167) and 7.119663 (>Fcrit of 3.490295).

These two conditions clearly showed that both the SHF and curing day have a statistically significant impact on the CS of concrete, however, the influence of the SHF is much more significant than that of the curing day.

Split tensile strength

The impact of the synthetic hair fibre and curing age on the split tensile strength of the concrete is presented in Figure 3. The split tensile strength for concrete samples containing 1% SHF were higher at 7 and 14 curing days as compared to those of the control concrete samples but were lower than the control at 21 and 28 curing days.

For 2% SHF addition, the tensile strengths were much higher than those of the control and 1% SHF samples at each of the curing periods. However, the values of the tensile strength for concrete samples containing 3% and 4% SHF were lower than those of the control and 2% SHF samples, and this showed the optimum value of the split tensile strength at 2% SHF addition. For different curing ages, the results showed that the split tensile strength increased as the curing period increased.

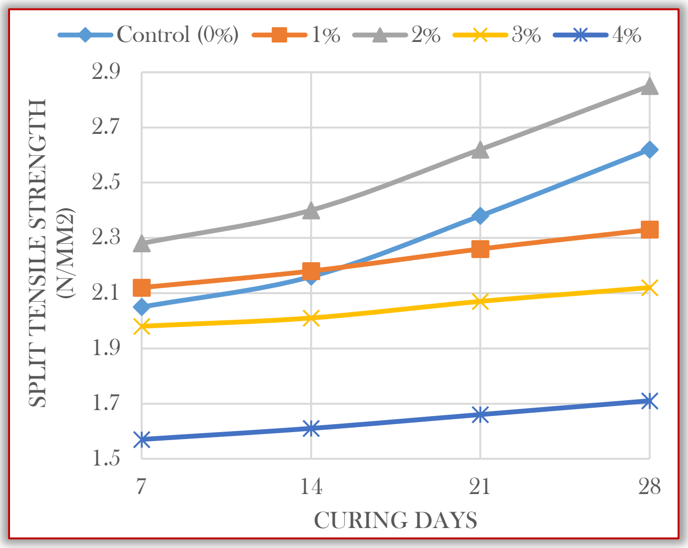

Figure 3. Influence of synthetic hair fibre and curing days on split tensile strength of concrete

Table 4: Impact of SHF and curing days on STS of concrete

Source of variation	Sum of squares	Degree of freedom	Mean square	Fcal	P–value	Fcrit	Remark
SHF	1.809	4	0.4523	45.499	3.71E–07	3.259	Significant
Curing day	0.309	3	0.1031	10.370	0.00119	3.490	Significant
Error	0.119	12	0.0099				
Total	2.237	19					

Table 4 shows the results of the statistical test conducted on the STS of the SHF–concrete to evaluate the impact of SHF and curing day on the STS of SHF–concrete using ANOVA at a 5% level of significance.

The findings from the statistical analysis revealed that the SHF (p–value = 3.71E–07 < 0.05) and curing day (p–value = 0.00119 < 0.05) have statistically significant effects on the STS of the SHF–concrete. However, the lower p–value (3.71E–07) of the SHF than that of curing day (0.00119) is an indication of the greater impact of SHF on STS compared to that curing age.

Flexural strength

Figure 4 shows the influence of the synthetic hair fibre and days of curing on the flexural strength of the SHF concrete. Results from the figure showed higher values of the flexural strength for 1% and 2% SHF concrete samples than those of the control sample (conventional concrete) at all the curing ages, meanwhile the flexural strength for 3% SHF concrete were quite similar to those of the conventional concrete. However, the flexural strength obtained for 4% SHF concrete samples were lower than those of the control samples. Similar to the results of compressive and split tensile strengths, the optimum value of the flexural strength is observed at 2% SHF addition. This finding is also in line with those of Adedokun *et al*. (2016). For different curing ages, the results showed that the compressive strength increased as the curing period increased.

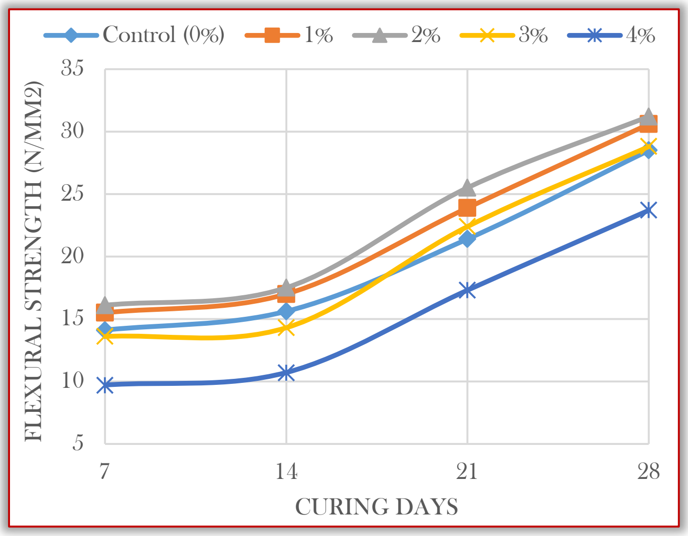

Figure 4. Influence of synthetic hair fibre and curing days on flexural strength of concrete

Table 5 displays the results of the statistical test carried out on the impact of SHF and curing days on the FS of the SHF–concrete using ANOVA at 5% level of significance. The results from the Table that the p–values for SHF and curing day are 7.12E–10 and 1.07E–14, respectively. The p–values are significantly lower than the adopted 0.05 level of significance. However, unlike the trends observed in CS and STS, the p–value for curing age in FS is lower than that of the SHF, indicating much more influence of curing age on FS than the SHF.

In addition, the Fcal = 135.4133 (>Fcrit = 3.259167) for SHF and Fcal = 1015.913 (> Fcrit = 3.490295) for curing day also confirm that both the SHF and curing day have a significant impact on the FS but the influence of curing day is more significant compared to SHF. Generally, these results clearly showed that both SHF and curing day have a statistically significant impact on the strength properties of the concrete.

Table 5: Impact of SHF and curing days on FS of concrete

Source of variation	Sum of squares	Degree of freedom	Mean square	Fcal	P–value	Fcrit	Remark
SHF	1.251	4	0.312	135.413	7.12E–10	3.259	Significant
Curing day	7.042	3	2.347	1015.913	1.07E–14	3.490	Significant
Error	0.02773	12	0.0023				
Total	8.32222	19					

Microstructural properties

Based on the trend of the results, scanning electron microscopies were conducted for the control sample (without SHF), samples with 2% SHF (optimum result) and 4% SHF (lowest result). From the scanning electron micrograph of concrete without or with hair fibre, the yellow dimension line at the top indicates current ruler size depending on the magnification factor. While the red dimension value represent the field of view which is the magnification.

Figure 5 shows the scanning electron micrograph of concrete with 0% addition Synthetic Hair (control sample). From Figure 5 it was observed from the micro graph that micro cracks were present within the concrete composition. This implied that series of infiltration through the cracks can cause weakness in between the concrete elements with time.

Furthermore, figure 6 presents the result of the scanning electron micrograph of concrete containing 2% Synthetic hair fibre addition.

The micrographs shown in Figure 6 revealed the concrete with 2% synthetic hair fibre where the fibre content was more than 1% by weight of cement. In the figure, the SHF added was found to anchor more concrete components (i.e the fine and coarse aggregates) and this could enhance more strength/bond within the concrete components unlike the sample with no SHF and therefore bridging the micro cracks, delaying crack formation and propagation. In other words, the presence of more synthetic hair fibre enhanced the bonding effect of the concrete elements, and therefore making the infinitesimal or micro cracks to be more strongly bonded.

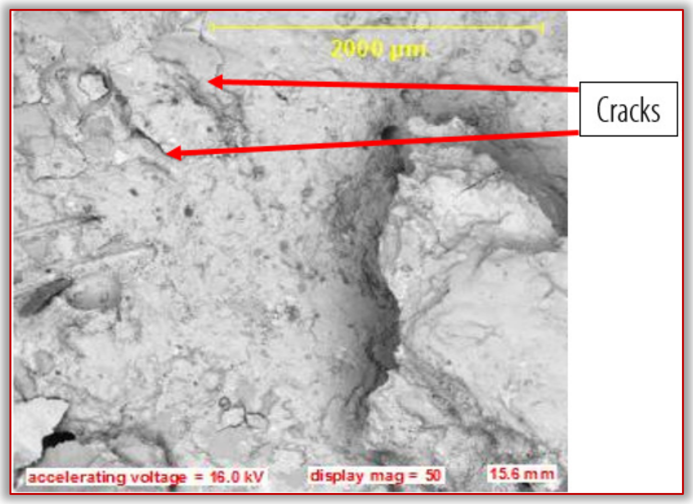

Figure 5: SEM micrograph of concrete with 0% addition of SHF

Figure 6: SEM micrograph of concrete with 2% addition of SHF

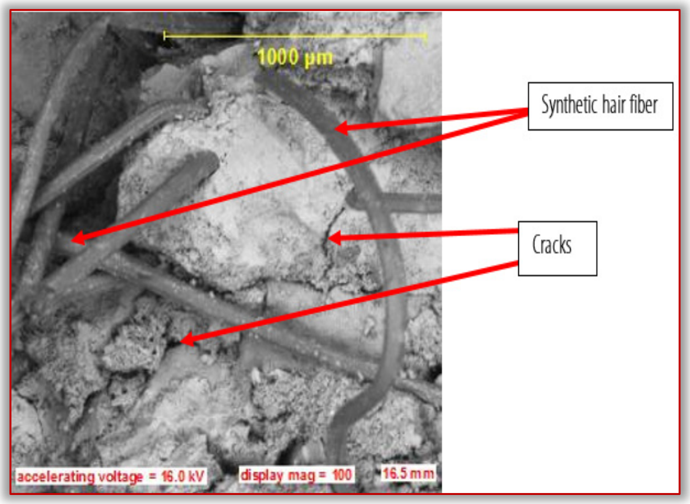

Figure 7: SEM micrograph of concrete with 4% addition of SHF

The image in Figure 7 shows the scanning electron micrograph of concrete containing 4% Synthetic hair fibre addition.

The micrographs indicate concrete containing large volume of the synthetic hair fibres which are not homogenously mixed with the concrete elements. In other words, the components were observed to be too rowdy and larger proportions of the SHF were separated from the other concrete components. This could therefore lead to the formation of a very weak bonding within the concrete components, resulting into decreased concrete properties.

CONCLUSIONS

Based on the results of the study which investigated the impacts of synthetic hair fibre (SHF) on the strength and microstructural properties of concrete, the followings conclusions were drawn.

— The results of the investigation showed that synthetic hair fibre had significant effects on workability, strength and microstructural properties of concrete.
— The slump value of the concrete increased from 19 to 38 mm while the compacting factor value increased from 0.846 to 0.968 as the synthetic hair fibre increased from 0 to 4%, respectively. The two tests indicated that the concrete became more workable as the quantity of synthetic hair fibre in the concrete increased.
— The investigation further revealed that the addition of SHF caused increment in the strength properties of the concrete. The compressive strength, tensile strength and the flexural strength increased with increased synthetic hair fibre (SHF) content from 0 to 2% but decreased beyond this value. This implied that the optimum compressive, split tensile and flexural strength in concrete were achieved with 2% addition of SHF.
— The Scanning Electron microscope test revealed that the addition of the SHF contents in the concrete will reduce the permeability of concrete and thus reduce bleeding of water. It will also control cracking due to both plastic shrinkage and drying shrinkage and moreover, the fineness of the fibres allows them to reinforce the mortar fraction/elements of the concrete thereby controlling crack formation and propagation.
— A 2% addition of synthetic hair fibre (SHF) by weight of cement is therefore recommended generally for improving the workability, compressive strength, tensile strength and flexural strength of concrete. The concrete produced with this fibre can be utilized as light weight concrete with improved strength and durability. Moreover, the usage of SHF with concrete will consequently, reduce the environmental pollution of its deposition effects globally since the blend and other brands investigated behaved generally the same.

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