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The Effect of Aspect Ratio and Volume Fraction on Mechanical Properties of End of Life Tyre Steel Fibre Reinforced Concrete

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Abstract

The utilization of end-of-life tire steel fibers (ELTSFs) to produce greener concrete by reducing the amount of solid waste was investigated in this research. Steel fibers are incorporated into concrete to improve its mechanical and durability properties. This paper reports the effect of fiber length and volume fraction (Vf) of ELTSFs in concrete. The fresh and mechanical properties examined were workability and compressive strength of six mixes of grade 25 (25 N/mm²) with varying fiber lengths of 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, and 60 mm; representing aspect ratios of 10.87, 21.74, 32.61, 43.48, 54.35, and 65.22 respectively. For each fiber length, concrete with five volume fractions (0.5%, 0.75%, 1.0%, 1.5%, and 2.0%) were produced and cured for 3, 7, 14, 21, 28, and 60 days by water immersion. For all resulting concrete, slump value and compressive strength were investigated. The results show that workability decreases with an increase in the fiber length and volume fraction. Concrete with a 10 mm length and a volume fraction of 0.5% produced concrete with the highest slump. The concrete mix with a 60 mm fiber length and a 1.0% volume fraction at 60 days of curing regime gives the optimum compressive strength, enhancing it by 9.85% compared to the reference concrete. The regression model developed for the compressive strength showed a very good relationship between the response and the regressor variables. The coefficient of determination (R^2) is 0.8894, and all the model terms' P-values are less than the alpha value (0.05).

Keywords: *Aspect ratio, Coefficient of determination, End of life tyre steel fibre, Volume fraction, Optimum*

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I. INTRODUCTION

The advancement in automobile technology has led to increase in the number of vehicle unit manufactured. Globally, over 85.4million passenger and commercial vehicle were produced in 2022 [1], thus, propelled the increase in vehicle tyre demand [2], [3] and [4]. The estimate of worldwide tyre production was about 3billion unit annually and about 1.5million tons end as a waste generated or end of life tyres (ELTs) [5] causing serious disposal and environmental problems such as: fires, contamination of soil and ground water, distraction in natural operation of flora and fauna and promote conditions for epidemics [6],[4].

Nigeria is a developing nation with approximately 5.7 million tyre units sold annually and is expected to rising by 3-5% annually [7]. This represent small percentage of tyres used by vehicle owners, as vehicle owners preferred to buy low price tyres imported from Asia pacific (Tukunbo tyres) obtain smuggles illegally in to the country. Lack of reliable data is making it difficult to estimate the number of ELTs in Nigeria. However, hundreds of abandoned stock piles of ELTs are visibly scatted in dump sites posing serious fires hazard and other health related issues. Therefore, an adequate management solutions of ELTs in construction to lower the impact of solid waste is paramount important.

Global warming, climate change which causes environmental degradation and an increasing amount of solid waste presents a great threat to the world [4] that required global attention. However, research efforts in various fields to address these challenges were carried out by many researchers. Resent research effort in the construction industry to utilise solid wastes as construction material has witness favourable development over time. The utilization of both agricultural and industrial solid waste materials as construction materials was reported by many researchers. Baggage and rice waste [8], saw mill waste [9], fly ash [10], blast furnace slag aggregates [11], phosphogypsum [12], demolished building recycled [13], red mud [14], Kraft pulp production residue [15], waste tea [16], etc.

World over, Part of solution to solid waste is to recycled end of life tyres (ELTs). Depending on the nature and the service purpose of the ELTs, the vehicle tyre constituents can

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approximately be 5 to 30% steel, 70% rubber and 15% textiles [17]. However, the used of ELTs for recycling has been mainly for industrial and civil construction applications [18]. In the industry, about 64% of ELTs are used as energy source [19] rubber obtained from ELTs is used in the cement kiln as fuel in the combustion oven [20]. However, steel fibres removed from ELTs usually constitute 6 to 25% by weight and are mostly treated as waste scrap obtain sold to steel mills as scrap [19].

In contrast, developing nations such as Nigeria lack the framework for proper solid waste disposals is cause of concern. Nigerian constitution upholds environmental and natural resources conservation and Nigeria is party to international conservations on environmental protection and resources conservation for sustainable development. Resent commitments by Nigerian government is the signing of conference of parties 26 (COP26) agreement. Regrettably, little attention is received by Nigerian government to impose the Law guiding the solid waste disposal matters in Nigeria. Disposal of ELTs has remained in the traditional way of landfilling, stockpiling and opened burning [21].

Researchers report conflicting experimental results on the effect of inclusion of steel fibre reinforced concrete (SFRC). The result shows inclusion of fibre contribution to the compressive strength from negligible, marginal increases to significant increases [22]. This work studied the effect of incorporating recycled ELTs steel fibre in concrete in regard to the fresh and hardened properties; slump and compressive strengths by varying fibre volume fractions and the aspect ratios.

Steel fibre when incorporated in concrete results in concrete with improved properties such as: resistance to crack propagation, high impact resistance and exceedingly good durability [23]. Number of factors influences the strength properties of SFRC as reported by many researchers, fibre volume fraction and aspect ratio as the most influential factors in the strength performance characteristics of SFRC [24], [25]. Study by [26] used ELT steel fibre extracted by opened burning with constant aspect ratio of 90 and added to concrete at volume fractions of 0.5%, 1.0%, 1.5%, 2.0% and 2.5%. The optimum compressive strength was achieved at Fibre volume fraction of 2.5% inclusion. However, at above 2.0% volume fraction, the mix exhibited balling effect and less workable. In their review paper Oluwaseyi et al., [27] reported it has been generally accepted that the inclusion of fibers reduces the workability of concrete.

[28] carried out laboratory experiment on SFRC concrete cube and cylindrical specimens were designed with SF containing 0% and 0.5% volume fraction of hook end and crimped round SF of 50 , 53.85, 62.50 (copper coated) aspect ratio and admixture for compressive and splitting strengths test. The specimens were then cured for 7 and 28days before testing. The test result shows a slight increase in compressive strength at 28days curing regime and for all fibre type. However, there is a significant increase in splitting strength when compared with the result of the control concrete at the same curing period and fibre type and increases with fibre length. It was concluded that, the split tensile strength of fibre reinforced concrete dependent on length of fibre used. Similarly, [29] reported splitting tensile that splitting strength of ELSFRC increased with increase in the length of fibre and with the increase in the percentage of fibre.

The post-cracking performances of Recycled Fibre Reinforced Concrete were evaluated by [30]. Concrete beam and slab were produced for the evaluation by means of tests on flexural elements and slabs. The effectiveness of the recycled Steel fibers Reinforced concretes (RSFRC) were evaluated in comparison with the experimental data obtained for specimens realized with Industrial Fibre Reinforced Concrete (IFRC). All fresh and hardened proprieties of concrete mixes were experimentally estimated. The post-cracking behaviour of the RSFRC, obtained by flexural tests, was comparable with that of ISFRC. RSFRC specimens showed good energy absorption and good residual strength after cracking.

II. MATERIALS AND METHOD

2.1 MATERIALS

A. *Cement*

Ashaka brand ordinary Portland cement locally available in market was used for the study. The cement properties are presented in Table 1.

TABLE 1: CHEMICAL AND PHYSICAL PROPERTIES OF ASHAKA CEMENT

Chemical properties		
Oxide composition	Weight (%)	Limit specified by [31]
SiO_2	19.68	17 -25
Al_2O_3	6.44	3-8
Fe_2O_3	3.32	0.5-6.0
CaO	60.92	60-67
MgO	0.97	0.1-4.0
SO_3	2.28	1-3
K_2O	0.85	Combined alkalis (K2O+Na2O)
Na_2O	0.12	0.2-1.3
LOI	1.0	1.2
Physical Properties		
Specific gravity	3.15	-
Blaine fineness (m^2/kg)	370	275
Soundness (mm)	2.0	-

B. *Aggregates*

The fine aggregates were source from stream near Yelwan Makaranta Bauchi. The physical properties are indicated in Table 2. The coarse aggregates in the study were sourced from Triacta granite quary site along Bauchi-Dass road Bauchi, Bauchi state Nigeria. The physical properties of the aggregates are also presented in Table 2.

TABLE 2: PHYSICAL PROPERTIES THE AGGREGATES

Aggregate	Coarse	Fine
Property	Value	Value
Specific Gravity	2.66	2.62
Bulk Density(Kg/m^3)	1518	1528
Silt Content	-	4.26
Aggregate Crushing value (%)	14.47	-
Aggregate Impact value (%)	14.95	-

C. Water

Tap water from Bauchi Municipal water supply was used in concrete mix preparation. No test was conducted on the water.

D. Steel fibres

ELTSF used in this research work were extracted manually from end of life tyre using knife and saw. The resulting ELTSF were then cut into the length of 10, 20, 30, 40 and 60mm (representing 10.87, 21.74, 32.61, 43.48, 54.35 and 65.22 aspect ratios respectively). The physical and geometrical properties of the fibre are resented in table 3.

TABLE 3: PHYSICAL PROPERTIES OF ELTSF

Property	Description
Length (mm)	10, 20, 30, 40, 50, and 60
Average Diameter (mm)	0.92
Tensile strength(N/mm^2)	1260
Shape	Cylindrical
Colour	Black

2.2 Methods

2.2.1 *Mix Proportion of concrete*

A grade 25 concrete was produced using ACI 211[32] with water to cement ratio of 0.48**.** In total 31 batches of concrete mix prepared for specimens of 100 mm square cube. The final concrete mix proportions matrix is presented in Table 4.

TABLE 4: MIX PROPORTION FOR CONCRETE PRODUCTION CONTAINING WTSF

Mix ID	Cement (Kg/m^3)	F/A (Kg/m^3)	C/A (Kg/m^3)	Water (Kg/m^3)	WTSF Vf (%)
WTSF	385	663	1170	185	0.00
WTSF	385	663	1170	185	0.5
WTSF	385	663	1170	185	0.75
WTSF	385	663	1170	185	1.0
WTSF	385	663	1170	185	1.5
WTSF	385	663	1170	185	2.0

2.2.2 *Production of Concrete*

In total 558 cubes of length 100 mm X 100 mm X 100 mm were casted for the purpose of compressive strength test. The cube specimens were casted with end of life tyres steel fibers added uniformly and randomly distributed in proportions of 0% (Control), 0.5%, 0.75%, 1.0%, 1.5%, and 2.0% fibre volume fractions at fibre lengths of 10, 20, 30, 40, 50 and 60mm each. The specimens were thoroughly compacted in moulds on table vibrator and were removed from the moulds after 24 hours. Then the specimens were demoulded and cured for 3, 7, 14, 21 and 28 days curing regimes in water tank at room temperature. All specimens were cured and tested at age 3, 7, 14, 21, 28 and 60days. The study followed the procedures of BS1881 part-102:1995[33] and BS EN12390 Part-3:2001[34] for the determination of slump (workability) and compressive strength of End-of-Life Tyre Steel Fibre Reinforced Concrete (ELTSFRC) respectively.

2.2.3 *Model Development*

To statistically understand the behaviour of Slump and Compressive strength for all ELTSFRC concrete, mathematical models were developed. The product of volume fraction and the aspect ratio of fibre known as reinforcement index (Ri) and curing ages (Ca) were used as independent variables. The regression analysis was performed using Minitab 19 statistical software. Backward selection with 0.1 alpha to remove and exclude unimportant variable was conducted for modelling. The Analysis of Variance (ANOVA) form the model is shown in Table 7.

III. Results and Discussions

3.1 *Workability of ELTSFRC*

The results slump values shown in Table 5 below. It can be observed as shown in figure 1 that ELTSFC slump values decreases with increases in fibres volume fraction and aspect ratio. The ranges of the slumps are 25-38, 23-32, 23-30, 20-29 and 20-28mm for fibre volume fractions 0.5, 0.75, 1.0, 1.5 and 2.0 respectively. [35] Stated that the degree of workability varies in the ranges from very low to high. 0-25 very low, 25-50 low, 25-100 medium, and 100-172 high. The slump results from the result it can be seen the slump is within the range of 20 to 45 which fall within the very low and low range. This implying superplasticiser may be needed to improve the workability for easy concrete placement.

The effect of volume fraction and the fibre length is shown in figure 1 below. It can be seen from the figure, the concrete with 60mm fibre length and 2.0 volume fractions shows the lowest workability. This may be attributed to partly by fibre content as more fibre is added and partly by the effect of fibre length which combined and clogged making the concrete poorly workable. The aforementioned above are in agreement with [36] and [37] that the workability of steel fibre reinforced concrete reduces as the percentage of steel fibres increases and further affirmed by other authors [38]. The decrease in the workability of fresh ELTSFC can be seen to be linear and proportional to the percentages of steel fibers added to the mix, although the mix remained workable in nature.

TABLE 5: SLUMP TEST RESULTS

	Slump (mm)					
Volume fraction Vf (%)	0.0	0.5	0.75	1.0	1.5	2.0
10mm	45	38	32	30	29	28
20mm	45	35	31	29	28	28
30mm	45	32	30	27	27	27
40mm	45	30	28	28	26	25
50mm	45	28	26	24	23	21
60mm	45	25	23	23	20	20

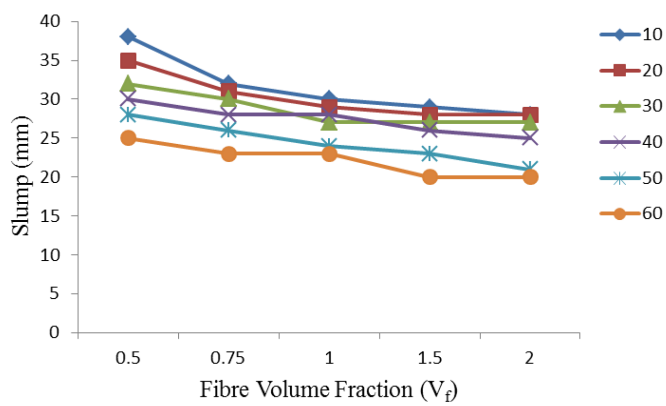

Figure 1: Effect of Fibre Volume Fraction On Slump

3.1.2 Compressive Strength of ELTSFC

Figure 2, 3 and 4 shows the variation of compressive strength of ELTSFC at curing regime of 3, 28 and 60-days, plots of the average compressive strength of ELTSFC and the relation between fibre volume fractions and fibre length. From the plots, it can be deduced that steel addition at fibre volume fraction (V_f) of 0.5, 0.75, 1.0, 1.5 and 2.0% and fibre length 10 to 60mm increases the compressive strength of ELTSFC with increase in curing region. This agrees with findings of other authors [39], [40] analysed ELTSF incorporation into concrete increase the strength and is in agreement with the pattern in this research work. At 28-days curing age and 0.5, 0.75, 1.0, 1.5 and 2.0 volume fraction; fibre length 10 to 60mm, an increase in compressive strength of 0.80-3.16%, 1.05-3.16%, and 2.45-9.85% when compared with control concrete respectively. Previous literatures indicate, inclusion of steel fibre in concrete were found to increase compressive strength from: negligible [41], [42], marginal [43], [44] and to significant increases [45], [46], [47] and [22]. However, beyond 1.0% fibre volume fraction addition, a decreasing trend in compressive strength at all fibre length was observed at all curing ages. At 1.5 and 2.0% fibre volume fraction addition and fibre length 10 to 60mm, an increase in compressive strength 2.24-4.45% and 1.60-4.21% were recorded when compared with control concrete. Similar trends were observed in all the curing ages.

The regression model of ELSFRC Compressive strength with fibre reinforcement index (Ri) and curing age (Ca) as predictor variables is given by equation (1).

$$Fc = 0.7463\ Ca + 28.18\ Ri - 0.7125\ Ca*Ri \quad (1)$$

Where Ca and Ri are curing age and fibre reinforcement index respectively, while F_c is the compressive strength.

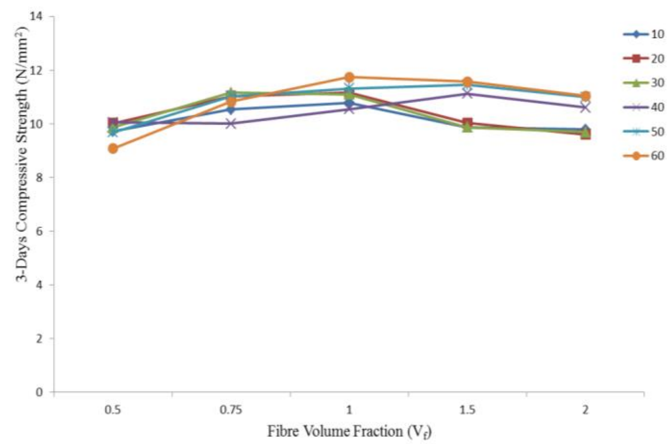

Figure 2: the effect of volume fraction on 3days compressive strength

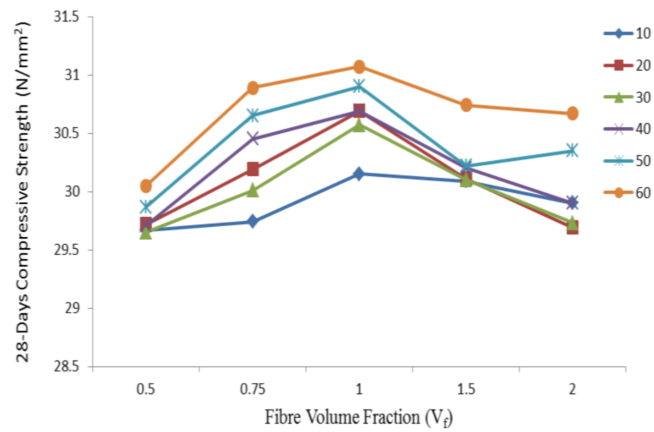

Figure 3: the effect of volume fraction on 28days compressive strength

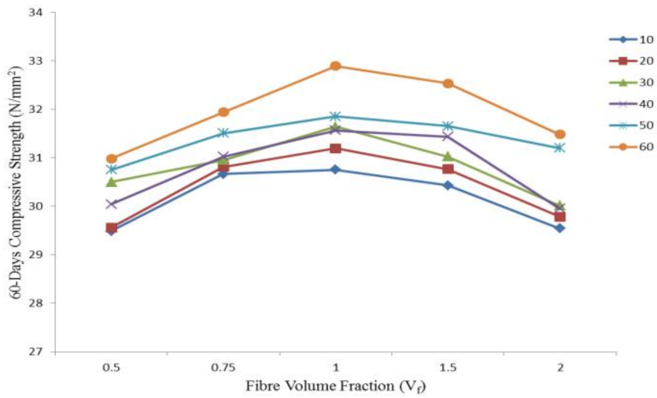

Figure 4: The effect of volume fraction on 60-days compressive strength

The P-values is a measure of the probability that the true coefficient is zero. From the table 6, the p-values of the terms individual Ca, Ri and the interaction Ca*Ri are all highly significant (P-values < 0.05) and thus are useful predictors of the regression model. It can be said that with the entire predictor variable significantly influences the response Compressive strength. The coefficient of determination (R^2) of the Model is 0.8894 (R^2=88.94%). This implies that 88.94% of variation in the compressive strength of ELTSFRC can be explained by the regression model with Ca and Ri as variables. From Table 3 the variance inflation factor (VIF) for all the coefficients are < 5 this shows a perfect correlation and the generated Model is highly significant [22]. However, the index (VIF) quantifies the severity of multicollinearity in least squares regression analysis, since it measures how much the variance of an estimated regression coefficient is increased because of multicollinearity while the basic ANOVA are shown in Table 7.

Normal probability check shows a normal distribution as distribution of residuals are aligned closely to the straight line hence normality is satisfied [48] since no sign of non-normality or skewness was observed. Further check on Residuals vs fitted values was made as shown in Figure 6 and 7. The plot shows no constant variance, missing terms or influential point exists [49].

TABLE 6: REGRESSION ANALYSIS FOR ELTSF COMPRESSIVE STRENGTH

Predictors	Coef.	SE Coef.	T-Value	P-Value	VIF	Significant
Ca	0.7463	0.0381	19.58	0.000	3.00	Significant
Ri	28.18	1.82	15.51	0.000	2.38	Significant
Ca*Ri	-0.7125	0.0847	-8.42	0.000	4.38	Significant

TABLE 7: BASIC ANOVA FOR COMPRESSIVE STRENGTH

Source	DF	Sum SS	Contribution	Adj SS	Adj MS	F-Value	P-Valu
Regression	3	105244	88.94%	105244	35081.3	474.62	0.000
Ca	1	87461	73.91%	28337	28336.9	383.37	0.000
Ri	1	12547	10.60%	17773	17773.1	240.45	0.000
Ca*Ri	1	5236	4.42%	5236	5235.6	70.83	0.000
Error	177	13083	11.06%	13083	73.9		
Lack-of-Fit	117	13044	11.02%	13044	111.5	173.34	0.000
Pure Error	60	39	0.03%	39	0.6		
Total	180	118327	100.00%				

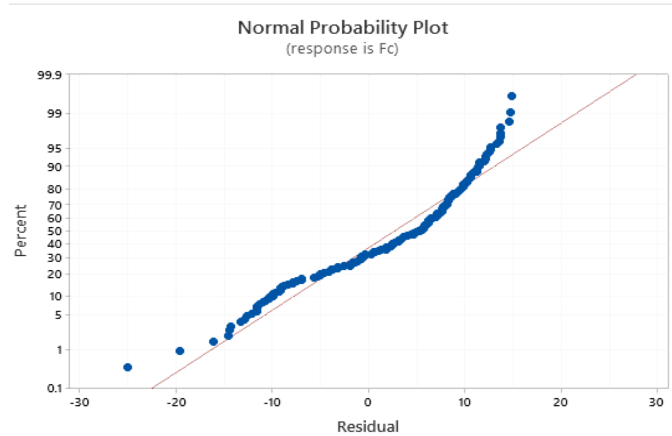

Figure 5: Normal Probability Plot for Compressive strength of WTSF concrete

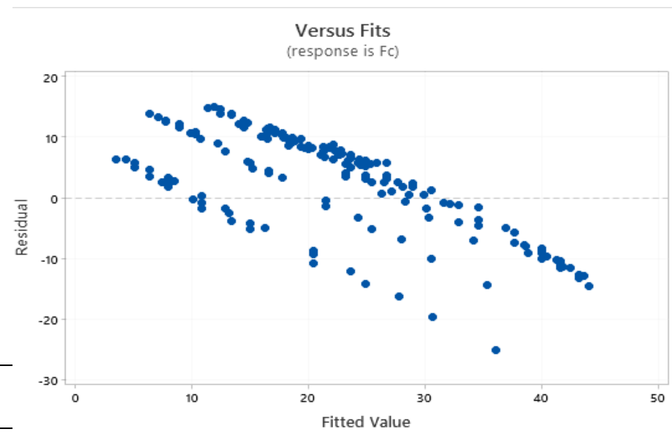

Figure 6: Plot of Residual Vs fitted WTSF Compressive strength (F)

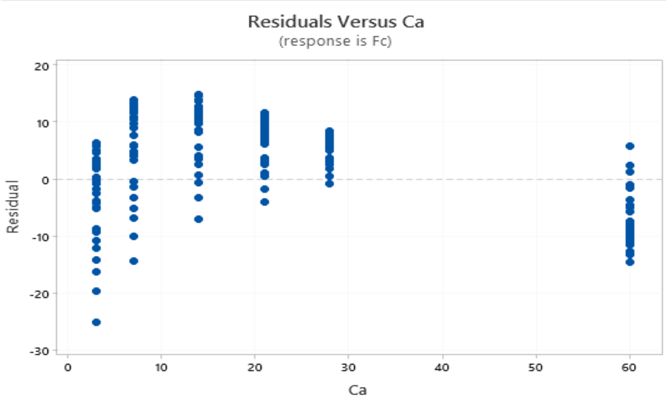

Figure 7: Plot of Residual Vs Curing age

IV. CONCLUSION

Base on the study conducted, the following conclusions can be made:

1. The raw materials used for concrete production meets the standard specifications for concrete production.
2. The workability decreased with increase in fibre length and volume fraction. Concrete containing 10mm length and 0.5% gives the optimum slump.
3. The compressive strength shows an increasing trend for all fibre length and volume fraction up to 1.0%. Beyond 1.0%, volume fraction decreases show a decreasing tread. Concrete containing 60mm length and 1.0% volume fraction is the optimum combination that produced 9.87% increase in compressive strength at 60 days curing age.
4. Based on the experimental results, ELTSFC has the potential to be applied in the development of dams, bridges, roads, industrial flooring, retaining walls, and underground structures etc.
5. The developed model is statistically significant and can explain the compressive strength 88.94% variability in ELTSFRC.
6. The manual method of ELTSF is labour intensive, time consuming, inefficient method and risk in using sharp tool. Therefore, mechanical means of ELTSF extraction is highly recommended thus will provide efficiency and safety.

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