International Journal of Civil Engineering and Technology (IJCIET)
Volume 9, Issue 9, September 2018, pp. 1129–1137, Article ID: IJCIET_09_09_109
Available online at http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=9
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

SPLITTING TENSILE STRENGTH ASSESSMENT OF LIGHTWEIGHT FOAMED CONCRETE REINFORCED WITH WASTE TYRE STEEL FIBRES

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ABSTRACT

This study evaluates the splitting tensile strength of lightweight foamed concrete (LWFC) reinforced with steel fibres from waste tyres. The volume fractions of the steel fibres used were 0%, 0.2%, 0.4%, *and* 0.6% *by total volume of concrete. Mix ratio of 1:2.25 (cement: sand) was used with 0.5 water/cement ratio. The splitting tensile strength decreases as the steel fibres increases from 0% to 0.4%. It became higher for 0.6% steel fibre content which had splitting tensile strength of* $0.66\ N/mm^2$, $1.08\ N/mm^2$ *and* $1.46\ N/mm^2$ *at 7, 14 and 28 days respectively. The results of the LWFC mixes showed a decrease in the splitting tensile strength for the specimens as the steel fibre content increased till it became adequate at which point the splitting tensile strength increased. These results are then checked with the Scanning Electron Micrographs (SEM) of the samples with different percentage of steel fibre content.*

Keywords: Lightweight Foamed Concrete, Splitting Tensile Strength, Cement, Steel Fibre, Waste Tyre.

Cite this Article: Atoyebi Olumoyewa D, Odeyemi Samson O, Bello Sefiu A and Ogbeifun Cephas O, Splitting Tensile Strength Assessment of Lightweight Foamed Concrete Reinforced with Waste Tyre Steel Fibre, International Journal of Civil Engineering and Technology, 9(9), 2018, pp. 1129–1137.

http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=9&IType=9

1. INTRODUCTION

Concrete is known as a common material which is used daily in the construction world, its use spans from the most menial work or element to mega building and structures. The mixture of fine and coarse aggregates with cement as binder and water produces concrete and some of its characteristics are; good workability, resistant to freezing, chemical resistant, wear resistant, low permeability, and economy [1]. The removal of coarse aggregate from the mix and addition of pre-formed foam gives a type of concrete known as foamed concrete; the pre-formed foam is a mixture of either a synthetic or protein based foaming agent, water and air [2]. Lightweight concrete (LWC) is a type of concrete which has entrapped air in small bubbles within the cement mix, these bubbles of air are induced either through mechanical or chemical methods. Another name for LWC is foamed concrete. Some of the general properties of LWC are high modulus of elasticity, good freeze/thaw resistance, high strength to weight ratio, low water absorption, low coefficient of permeability, thermal insulating properties, low shrinkage and fire resistance. It also has high workability, reduced self-weight, minimum aggregate use, controlled low strength, and very good thermal insulation properties [3]. Concrete is known for its compression ability and poor response to tension and with its brittle nature; it can't resist direct tension due to applied load except with the inclusion of metals as reinforcements.

LWC is a versatile material that has created a great interest and in recent years, its use in construction projects is of a very high demand, despite its known use dated back to 2000 years. LWC is a concrete which by one means or another has been made lighter than conventional (normal weight aggregate) concrete [4]. Lightweight foamed concrete (LWFC) consists of paste from Portland cement known as mortal with air introduced into it in small bubbles to form a pore structure [5]. Numerous researches as been done on LWFC, the effect of size and shape specimen on the compressive strength of LWFC reinforced with glass fibres was investigated by Hamad A. J. [6] and a study on the preparation and properties of high-porosity foamed concretes based on ordinary Portland cement was done by Jun et al [7]. Many other researchers also worked on foamed concrete [8,9,18–20,10–17]. Some of its application includes blocks building and partition panels with load bearing walls, Floor Screed, Roof Insulation, Road sub-base, fuel storage tank works, sewers, pipe lines, culverts and shafts, Trench re-instatement, Insulating sub-screeds, filling of arches in bridges and viaducts [14]. Metals are used as enhancements to concrete and this helps to improve some mechanical properties like its flexural strength[21,22], toughness, fracture energy, impact resistance and ductility. The concrete therefore, develops cracks while under tension. Thus, determining the point and the load value which causes crack in the concrete members is of much importance. This research work is conducted to evaluate the splitting tensile strength of lightweight foamed concrete reinforced with steel fibres from waste tyres.

According to International Organization of Motor Vehicle Manufacturers as reported by [23], more than 90 million motor vehicles (including passenger cars, trucks, and buses) were produced in 2014 and this amount is expected to increase in the coming years. The total number of the vehicles on roads is estimated at approximately 1.2 billion by the same organization. Considering that each vehicle has at least four tyres, it can be calculated that more than 4.8 billion tyres are in use today. Due to the continuous production of vehicles, it may also be assumed approximately 4 billion used tyres are generated each year [24]. There is a possibility of recycling these used tyres through coating, regrooving or even direct use as second hand tyres but there will always be an end-of-life period for every tyre where they are turned to scraps. Waste tyres can be classified with respect to their shape and sizes as Chipped tyre, shredded tyre, slit tyre, whole tyre, ground tyre or crumb tyre [25]. Considering the increasing trend of vehicle production, a high amount of scrap tyres turning to wastes emanates and method of disposing becomes very hard and expensive hence giving rise to environmental issues through land filling or stockpiling thus, threatening human health and the environment. Managing this high amount of waste is a great concern across the globe [26,27]. Researchers are beginning to look into the possibility of using waste tyres in construction [25,28–31] but there is been little or no research in the reuse of steel fibres in the waste tyre. In this study, steel fibres from waste tyres are added to LWFC in different ratios for the purpose of studying the effect of tyre metal strips on the splitting tensile strength of the concrete. The steel in tyres is high quality, it consist of thick twisted strands known as bead wire and can be separated mechanically from the tyre by “debeading” or during the shredding or powder production process along with the other steel. The addition of tyre steel strands gives the wastes an ecological value and it puts an end to unnecessary costs of disposal, natural resources depletion and environmental problems [32]. LWFC has a structural strength with low density and high workability; it is used in present day concrete technology and extensively in the high-rise buildings constructions and long-span concrete structures among others [6].

2. MATERIALS AND METHODS

The materials for this research are cement, fine aggregate (sand), foam agent (aluminum powder) and steel fibres from waste tyres. The separated steel wire in normal mechanical processing is usually contaminated with up to 20% rubber material: this has an adverse effect on the steel recycling. To achieve 100% steel wires with zero inclusion of rubber, waste tyres were burnt to extract the pure steel strands as shown in fig. 1 and the steel fibres were cut into irregular straight pieces of approximately 20mm length and a range of 0.18mm-0.23mm diameter.

Figure 1 Extracted steel fibres from waste tyre.

The mix proportion by volume that was used in this study is 1 : 2.25 cement: sand respectively [33]. Water cement ratio was 0.5 while the foam agent was 0.4% of the weight of the mixture. Different volume fractions of steel fibres from waste tyres were used

$(0\%, 0.2\%, 0.4\%\ and\ 0.6\%)$. The specimen shape to be used is the cylinder shape with size of the cylinder specimen to be $150mm\ diameter\ x\ 300mm\ long$. Three specimens were cast each for the different percentages of steel fibres to be tested after 7 days, 14 days and 28 days giving a total of 36 cylinders. A dry mix of the cement, sand, gas-forming agent and the steel fibres was evenly prepared before adding water to prepare the mortar. The proportions at which steel fibres were added to the mix (lightweight foamed concrete) are as shown in table 1.

Table 1 Concrete mix designs and proportions

SAMPLE	Cement (kg)	Sand (kg)	Water (litres)	Foam Agent (0.4%)	Steel Fibre (g)	Water-cement ratio
Sample 1 (0%)	21.15	52.83	10.58	295.92	0	0.5
Sample 2 (0.2%)	21.15	52.83	10.58	295.92	147.96	0.5
Sample 3 (0.4%)	21.15	52.83	10.58	295.92	295.92	0.5
Sample 4 (0.6%)	21.15	52.83	10.58	295.92	443.88	0.5

The total mixing time to achieve an even mix was about 6 minutes. It was ensured that the steel fibres were uniformly spread in the mix to prevent segregation. After that, the mix was poured into the mould, filling three-quarters of its volume. The test specimens were cast in one layer and compacted through vibration for 10 seconds just to make the concrete level. Mixture then expands to fill mould in about 30 minutes, thus, lightweight foamed concrete is obtained. Three cylinders were cast for splitting tensile strength at age 7, 14 and 28 days for each mix. After 24 hours, the specimens were demoulded and cured in water with a controlled temperature of $23^0C \pm 2^0C$ according to [34]. The specimen was tested according to [35] to determine the splitting tensile strength for each mix and size at age 7, 14 and 28 days.

Splitting tensile Strength test method was carried out on the cylindrical concrete specimens according to [36]. The specimens are subjected to a diametral compressive force which puts the plane containing the applied load under tensile stresses and the surrounding area of the applied load under compressive stresses. The maximum load sustained by the specimen is divided by appropriate geometrical factors to obtain the splitting tensile strength as given in equation 1 below.

$$T = {}^{2P}/_{\pi l d} \quad (1)$$

Where:

T = splitting tensile strength, psi [N/mm^2]

P = maximum applied load (N)

l = length (mm)

d = diameter (mm).

3. RESULTS AND DISCUSSION

3.1. Splitting Tensile Strength Test Result: The average value of the splitting tensile strength test on the three specimen for each mix design is as given below in Table 2.

Table 2 Mean values for the splitting tensile strength test

Steel fibre (%)	Splitting Tensile Strength (N/mm^2)		
	7 days	14 days	28 days
0	0.85	1.06	1.28
0.2	0.74	0.97	1.08
0.4	0.4	0.45	0.49
0.6	0.66	1.08	1.46

The splitting tensile strength of all the LWFC increased with age but decreased with addition of steel fibres up to 0.4% till the fibre became adequate as seen for 0.6% steel fibre addition where the splitting tensile strength increased consequently. The tensile strength of the control cylinder is found to be 1.28 N/mm^2 and decrease until 1.08 N/mm^2 at 0.2% and 0.49 N/mm^2 at 0.4%. However, the strength increased back at 0.6% for 1.46 N/mm. This shows that the steel fibre content has effect on the splitting tensile strength, the splitting tensile strength only increases when there is adequate reinforcement, inadequate amount of steel fibres negatively affects the binding of the concrete instead of aiding it. This is due to the reduction in the porosity of LWFC and an enhancement in mechanical bond strength when adequate reinforcement is added.

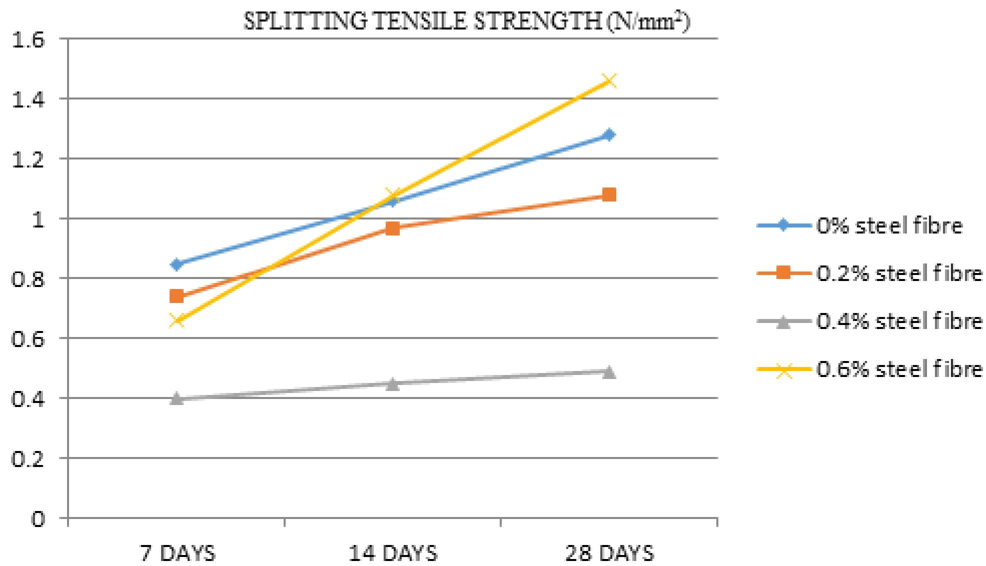

Figure 2 Variation of values of splitting tensile strength at different curing ages for lightweight foamed concrete

3.2. Scanning Electron Microscopy (SEM)

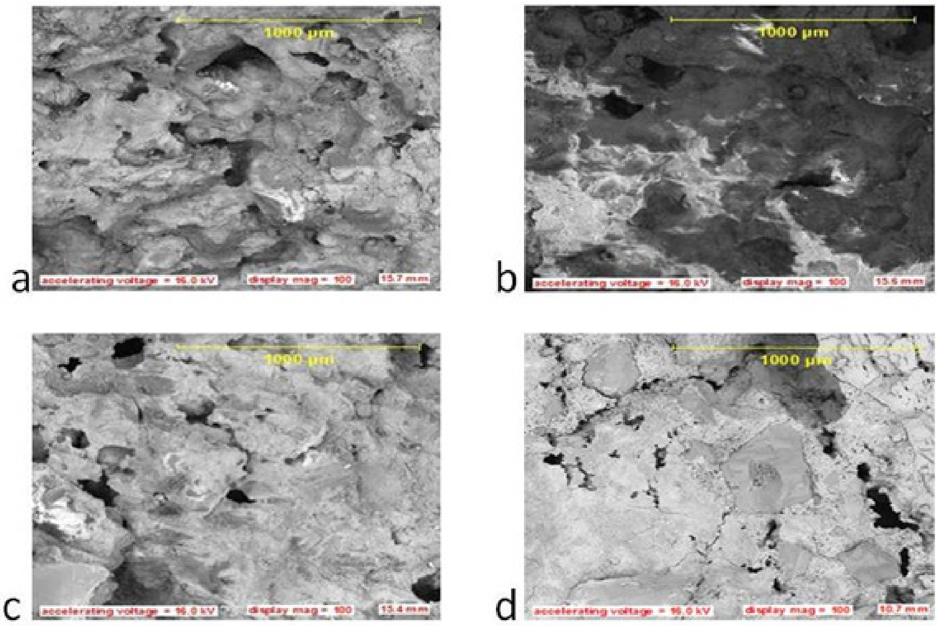

Figure 3 SEM micrographs of self-compacted concretes containing (a) 0 % (b) 0.2% (c) 0.4 % (d) 0.6% iron fibres

Figure 3(a) presents the semi crystalline ceramic rigid structure developed from chemical interaction of cement, sand and foaming agent (aluminum powder) when water was added to their mix. The process taking place is the hydration of cement which initially, gypsum reacted with aluminate (C_3A or C_4AF) or aluminate and silicate (C_3S and C_2S) to produce hydrated cement paste which bonded aggregate and admixture particles together and form an infusible hard structure as shown in Figure 3(a). Layers of irregular solid structures which have been fused and interlocked into one another are discernible in Figure 3(a). The structure belongs to silicate hydrate (C-S-H) produced from interaction of C_3A or C_2A with water. Interstitial within the irregular silicate hydrate layers is the prismatic material which appears in forms of flat hexagonal or cubic plates. The heat generated within the mix has tendency to vapourize water and un-escaped vapour during casting may be trapped with the mix and lead to voids formation.

Presence of the voids causes region of discontinuity within the LWFC and impair the mechanical properties of the developed LWFC structure due to reduction in material densification. When iron fibres were added to the mix, the developed LWFC structure appeared different. Steel fibres addition may enhance or impair the mechanical properties of the LWFC depending on adhesion of the steel fibres with the matrix. Based on the voids seen in Figure 3a-d, it can be inferred that steel fibres addition and steel fibres contents of LWFC have no defined relationship with the porosities of the developed LWFC. Connecting the microstructures of the LWFC in Figure 3 with the splitting tensile strength, at 7 days of curing, the tensile strength of the LWFC has negative variation with steel fibres contents. This indicates a poor adhesion of the iron fibre with ceramic silicate hydrate matrix. Since Ca, O, Si, Al and Fe are basic elements of cements, interaction of cementitious Fe powders may prevent good steel fibre adhesion to the matrix. As the hydration and curing period increases, there is an improvement in the tensile strength of the LWFC. This justifies structural modification each of the LWFCs due to progressive hydration of C_3S and C_2S and curing of the LWFCs. Surprisingly, 0.6% steel fibre LWFC possesses ultimate splitting tensile strength after prolonged curing days. This may be attributed to oxidation of Fe fibres to Fe oxides or hydrated oxides, ceramic materials which have better tendency to adhere to ceramic silicate matrix and enhance the stiffening tendency of the LWFC under loading.

4. CONCLUSION

Based on the findings from this study, the following conclusions are drawn;

- Very little amount of steel fibre in the LWFC reduces the strength of the concrete as it causes irregularities instead of reinforcing it.
- When adequate reinforcement is added to the LWFC, it increases the mechanical strength of the concrete and causes regular bonding thus, increasing the splitting tensile strength of the concrete. When the reinforcement is inadequate, it acts as obstruction to the mechanical bond of the concrete therefore; reinforcement has to be adequate to allow for proper bonding.
- Poor steel fibre adhesion could be attributed to the size of the steel fibre itself. A further research is necessary to reduce and vary the size of the iron fibres, iron particles inclusive. The length of steel fibres can be increased in subsequent studies to check its effect on the LWFC. Subsequent studies should be carried out on LWFC with increased steel fibre content in order to follow-up on the Splitting Tensile Strength values.

5. ACKNOWLEDGEMENTS

The authors thank the management of Landmark University for the opportunity and the facilities provided to carry out this research.

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