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ORIGINAL RESEARCH ARTICLE

OPTIMISATION OF COVER THICKNESS IN TYRE-FIBRE CONCRETE UNDER ELEVATED TEMPERATURE

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ABSTRACT

Failure of structural elements after fire outbreak is mostly attributed to spalling action. Spalling of concrete is an occurrence which results to decrease in the cross sectional area of the concrete elements, thus decreases the resistances to fire loads. This study, optimized the concrete cover thickness in tyre fibre concrete (TFC), which was subjected to single temperature load according to ISO 834 using graphical method. Three (3) samples were prepared from each series of mix containing tyre fibers of 10 mm width and varying length viz; 0%, 2.5%, 5.0% and 7.5%, using water cement ratio of 0.55. The samples were produced in 100 x 100 x 100mm cubes and tested for compressive strength. However, the cubes were structural modeled using TEDDS 2.0.01 and STAADPro v8i to under temperature load to determine optimum cover thickness through the deflection mode. The cover thickness for tyre-fibre concrete reduced from 25mm to 17.5mm under the same condition with the conventional concrete mixture. This shows that inclusion of tyre-fibre in concrete increases the fire resistance and reduces the cover thickness. It is recommended that tyre-fibre concrete should be used in our daily construction work for more durability.

1.0 Introduction

Environmental pollution is in existence from the earliest days of life, but now it is a serious issue which poses a threat to human survival Ajello *et al*., (2005a). Ajello et al., (2005b) and Pacheco, (2012) explained that many problems arise in the waste management system, especially for tyres and coals. Growing volumes of used tyres at landfills around the world have created a major environmental problem.

Stergios and Atalia, (2016) considered means of recycling these solid wastes (scrap tyres) or renewed interest in developing alternatives to its disposal in the construction industry is needed to be devised in order to curtail the negative environmental hazards caused by it.

Gideon (2012), Failure of structural elements after fire outbreak is mostly attributed to spalling action. Spalling of concrete is an occurrence which results to decrease in the cross sectional area of the concrete elements, thus decreases the resistances to fire loads. Concrete as a common material used in construction and it competes directly with all other major construction materials such as timber, steel, asphalt, and stone, because of its versatility in applications.

The concrete cover required to protect the reinforcement against corrosion depends on the exposure conditions and the quality of the concrete as placed and cured immediately surrounding the reinforcement. There may be cases where extra precautions are needed beyond those given in order to ensure protection of the reinforcement (BS 8110-1:1997).

Muhammed (2014) said, increasing the concrete cover of structural elements such as beams, columns or slabs in the conventional concrete to prevent the reinforcement's exposure, reduces the effective depths of these elements which may eventually leads to increase in structural member thickness in cases where deflections are not satisfied. For this reason, design for fire resistance has become a necessity. It ensures that the structure has sufficient capacity to support its loads for a period of fire exposure that guarantees safety during the evacuation and fire extinguishing processes.

Robert (2013) explained that modern applications have led to the development and use of new types of concrete (tyre-fibre concrete). The disadvantages caused by increasing concrete cover of structural elements can be avoided by the presence of tyre-fibres in the concrete hence, paving way for effective materials utilization.

Wasiu and Raji (2015) defined optimization of the concrete design as an act of searching for a design for which the sum of the costs of the ingredients is lowest, and satisfying the required performance of concrete, such as workability strength and durability.

Therefore, this study determines the optimum cover thickness needed for a tyre-fibre concrete due to inclusion of tyre-fibre under temperature load.

2.0 Methodology

2.1 Material Used: Ordinary Portland cement (Dangote 3X) of 42.5R grade (BS 12:1991) was used for preparing the concrete mix. The Coarse aggregate (manually crushed) used was granite with maximum nominal size of 20mm and sourced locally from a completed project along Oko- Erin, Ilorin.

The fine aggregate (Sharp sand) used in the concrete mixture was obtained from Gaa Akanbi, Ilorin, Kwara State. The sand was sieved in accordance with BS 933 Part 1 (1997) to remove bigger aggregate sizes and organic impurities. The square tyre-fibres (10mm) used were pre-treated with Sodium Hydroxide solution (NaOH) of 20g/dm^3 before used in order to enhance the adhesion with concrete matrix and increase transfer rate of water and hydration.

2.2 Mixing Proportion: The mix proportion, 1:2:4 (M25 grade) with water cement ratio (w/c) of 0.55 as shown in Table 1 was designed according to BS 5328: part 1. Tyre-fibers were added to the mix in various proportions namely; 0%, 2.5%, 5% and 7.5%, respectively. The maximum of 7.5% was adopted for this study. This was used for all the samples for consistency in the comparison.

Table 1: Mix Design for cube 100 x100 x 100 mm

CRA Content (%)	Cement (kg/m^3)	Sand (kg/m^3)	Granite (kg/m^3)	Coarse Rubber Aggregate (kg/m^3)	Water (kg/m^3)	W/C
0	33.70	67.32	134.64	0.00	18.54	0.55
2.5	33.70	67.32	131.27	3.37	18.54	0.55
5.0	33.70	67.32	127.90	6.74	18.54	0.55
7.5	33.70	67.32	124.53	10.11	18.54	0.55

2.3 Impact Test: Each series of freshly mixed tyre fibre concrete was placed in the cubic moulds of dimension 100 x 100mm for casting the specimens. Twenty four (24) specimens (100 x 100 x100 mm) were cast and cured according to BS 1881: part 111(1983) and tested for impact strength at 7 and 28 days after heating (ISO 834 fire curve) at an average temperature of 300°C) (Figure 1-2) which were recorded at 30 and 60 minutes respectively. Thereafter, the specimens were left at room temperature to cool. The schematic diagram of heat test machine is shown in Figure 1.

Figure 1: Schematic diagram of heat test machine
Source: Geology department, University of Ilorin

2.4 Design Optimization for the Tyre Fibre Concrete

The objective function of the optimization process is to minimize the weight of the fibre concrete weight per unit length, which is to a large extent a function of the concrete cover thickness. The BS8110 is focused on the limit state philosophy and the main aim of the design is to ensure an adequate margin of safety against the ultimate limit state being reached. In the case of vertically loaded (one-sided temperature load) cube, this is obtained by ensuring that the ultimate temperature load (G) does not exceed the design load resistance of the concrete (G_R). The optimization is carried out using graphical method [Wasiu and Raji, 2015].

The optimal design problem formulation is carried out to minimize the weight of the concrete cover subject to stress constraints due to vertical loading (temperature load). Figure 2 shows the cross-section of the concrete cube and the possible applied load. The followings are the notations used in Figure 2.

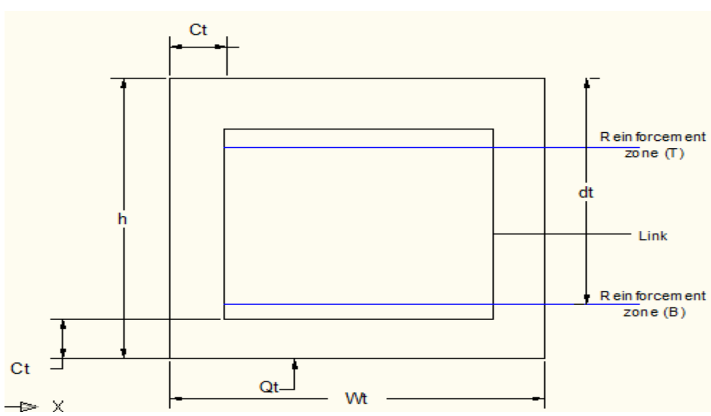

Figure 2: Typical Cross-Section of a Tyre Fibre Concrete Cube with Temperature Load

Where:
h = the height of the cube (100mm)
C_t= Concrete cover thickness (25mm, BS8110)
W_t = Width of the cube (100mm)
b = is the length of the cube (100mm)
Q_t = temperature load on the cube
d_t = effective depth of the cube
$W_r = W_t-2(C_t)$

For tyre fibre concrete cube, stress constraints: at the maximum temperature load of 50 kN per meter length of the cube, the fibre concrete cube weight per unit length is optimized as shwn in Equation 1-10.

W= $Minimize: \ W = \varphi(h, C_t)$ (1) Ajamu and Adedeji, (2013)

$$W = 2\rho_{ct} V_{ct} + \rho_{wr} V_{wr} \quad (2)$$

Where:

ρ_{ct} = density of the concrete cover thickness

ρ_{wr} = density of the concrete below the bottom reinf. - cover thickness

V_{ct} = Volume of the concrete cover per unit length of the cube

V_{wr} = Volume of the concrete remain (minus cover) per unit length of the cube

$$W = (2 \times 23.17 C_t h) + (23.17 \times 2 C_t h) \quad (3)$$

Neglecting the weight of reinforcement ($\emptyset = 12mm$)

$$\therefore W = 92.68 C_t h \quad (4)$$

For the design constraints:

(a) Vertical load due to compression

This is expressed as:

$$\sigma_o - \sigma_{all} \leq 0 \quad (5)$$ Ajamu and Adedeji (2013)

Where σ_{all} = allowable stress (17.6 N/mm^2, from load-deformation test) and σ_o = design stress

$$\sigma_o = \frac{\mu N}{Wtxh} = \frac{1.4N}{4C_t \times h} = \frac{1.4N}{16C_t} \quad (6)$$

Where μ= partial factor of safety, N= design load (kN), allowable load = 198kN (Compressive strength test), Therefore;

$$\frac{1.4N_{vertical\ load}}{16C_t} - \frac{198000}{100 \times 100} \leq 0 \quad (7)$$

$$N_{vertical\ load} - 226.29C_t \leq 0 \quad (8)$$ Ajamu and Adedeji, (2013)

(b) Temperature Load

The rate at which heat is conducted across the specimens of diameter D =100mm is shown in Equation 9.

$$\boldsymbol{Q = K\frac{\pi D^2}{4}\left(\frac{\theta_2 - \theta_1}{d}\right)} \quad (9)$$

Where:

Q = rate of heat conduction (W)

K = thermal conductivity of the material of the specimen (W/mK)

$\theta_2 - \theta_1$ = change in temperature (°C or K) from 30-60 minutes.

For an area of concrete cube of thickness d, the rate of heat conduction per unit area q (W/m^2) of the cube can be expressed as:

$$\boldsymbol{q = K\left(\frac{\theta_2 - \theta_1}{d}\right)} \quad (10)$$

$$\frac{N_{thermal}}{16C_t} - \frac{29.34}{0.10 \text{x}\ 0.10} \leq 0 \quad (11)$$

$$N_{thermal} - 46944C_t \leq 0 \quad (12)$$ Ajamu and Adedeji, (2013)

2.5 Modelling and Simulation

The second aspect involves numerical simulation. Finite element modelling of concrete cube with and without tyre fibre for deflection curve was analysed using TEDDS 2.0.01. The primary objective is to obtain the curve which will be used for optimization computation. This is shown in Figure 3 and 4.

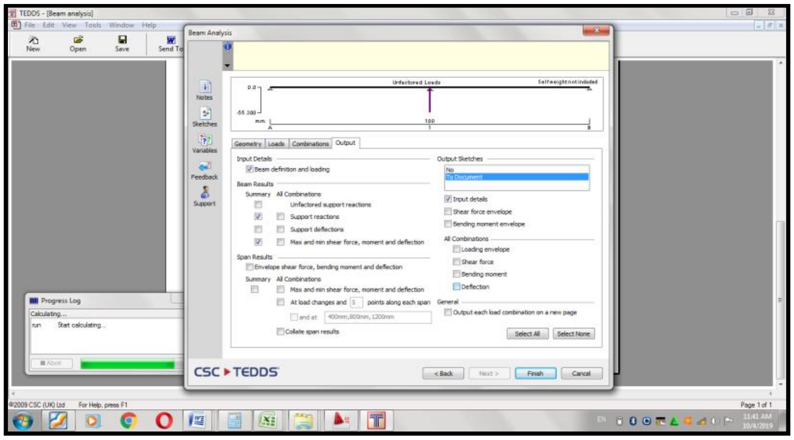

Figure 3: Static Analysis Operation (TEDDS)

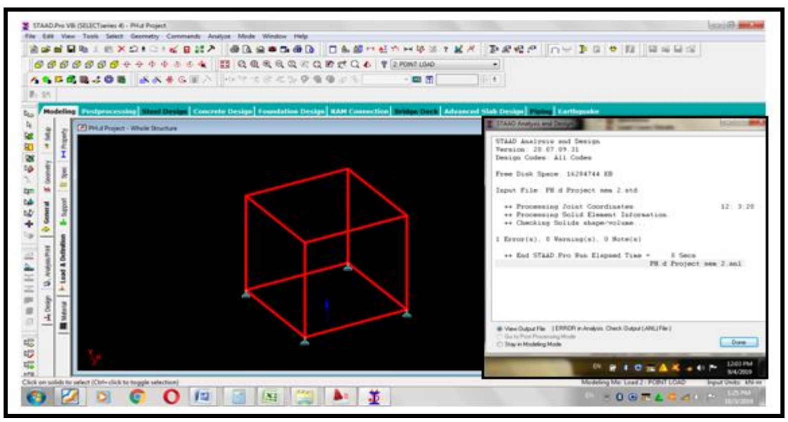

Figure 4: Static Analysis Operation (StaadPro v8i)

3.0 Result and Discussion

Table 2 and 3 show the combined temperature of the concrete (with and without tyre fibre) which was only considered for 0, 30 and 60 minutes respectively. The temperature of the samples increases with increase in time. The temperature in the fibre concrete was slightly lower because there was no free movement of heat within the concrete due to tyre fibre action. However these gains are functions of temperature differences and the time interval between temperature measurements.

Table 2: Temperature (°C) of the Concrete (with and without tyre fibre)

Time (min)	Percentage of tyre fibre replaced			
	0	2.5	5	7.5
0	0	0	0	0
30	619	556	474	600
60	970	914	760	872

Table 3 shows the rate of heat gain at equal time interval for the specimen. The total heat gain per square meter through the concrete (Table 3) in one hour was found to be 2934 J/m^2

(1.63J/s per sq. meter, (Ajamu and Adedeji 2013)) and the allowable thermal load per unit length is given as 29.34N.

Table 3: Evaluation of Rate of Gain of Internal Temperature of the Concrete Cubes

% T	θ_1(°C)	θ_2(°C)	$\theta_2 - \theta_1$(°C)	Gain Rate q(w/m^2)	Time Interval t(s)	Heat Gain/sq.m H(J/m^2)
0	619	975	356	1.78	1800	3204
2.5	556	920	364	1.82	1800	3276
5.0	474	800	326	1.63	1800	2934
7.0	600	893	293	1.47	1800	2637

3.1 Optimization

The loads applied to the specimen increases with increase in cover reinforcement at 5% fibre replacement under a single face temperature load. The deflection observed was approximately linear. Figure 5 shows the graphical representation. The curve intersected at 2.5mm which means the constraints are between 2.5mm and 25mm.

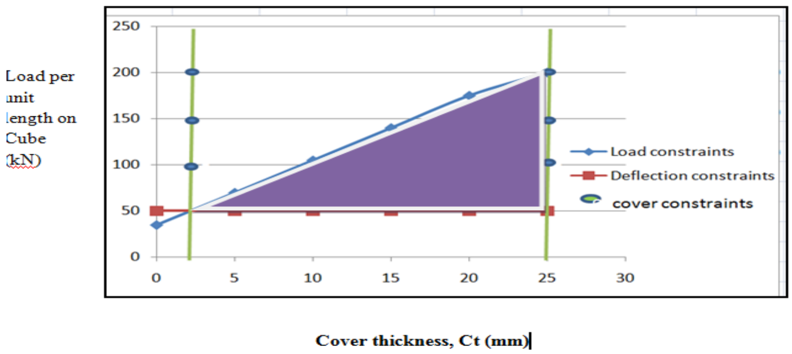

Figure 5: Constraints Optimization

$$C_t = 2.5 + \frac{2}{3} \times (25 - 2.5) = 17.5mm$$

$$N = 50 + \frac{1}{3} \times (200 - 50) = 100kN/mm$$

(The centroid of the "shaded triangle")

(i) The minimum cover thickness:

$$C_t = 17.5mm$$

(ii) The optimal weight per unit length for a cube of 1m is:

$$\therefore W = 92.68C_t h \quad (4.1)$$

$$W = 92.68 \times 17.5 \times 100$$

$$W = 162.19\ kN\ per\ meter$$

That is, 162.19 < 231.7 Ok.

Table 4, 5 and 6 show the cover-load values and average blows on the produced samples. The ratio of the initial to final crack ratio for the sample increases with increase in percentage of tyre-fibre added. This shows that the tyre-fibre has a greater impact on the durability of the concrete.

Table 4: Values for Cover - Load at 5% Fibre Replacement

Cover (mm)	Load (kN)	% Fibre replaced (%)
0	35	5
5	70	5
10	105	5
15	140	5
20	175	5
25	200	5

Table 5: Drop Weight Test Results for Heated and Non Heated Cubes (Average blows)

		N_1/N_2			
Date	Spec. No	$F0\%$	$F2.5\%$	$F5\%$	$F7.5\%$
18/9/19	A	$14/20$	$15/22$	$15/23$	$15/25$
	R	0.70	0.68	0.65	0.60

Table 6: Drop Weight Test Results for Cubes (Average blows)

		N_1/N_2							
Date	Spec. No	$F0\%$		$F2.5\%$		$F5\%$		$F7.5\%$	
		NH	H	NH	H	NH	H	NH	H
18/9/19	A	$16/20$	$15/2$	$17/28$	$18/2$	$15/2$	$16/2$	$16/33$	$19/20$
	R	0.80	0.77	0.62	0.88	0.59	0.76	0.48	0.96

R=ratio, A= Average; F=% of replaced Rubber

4.0 Conclusion

Based on this study, the following conclusions are drawn out.

a. By adding 2.5%, 5.0% and 7.5% volume fraction of tyre-fibre, the energy required causing the visibility of first crack and failure was increased by 8%, 15% and 4% respectively over plain concrete:
b. The results show that 5% volume fraction of tyre fibre considerably increases the impact energy in case of Tyre-Fibre Concrete (TFC) when compared to plain concrete.
c. Inclusion of rubber-tyre in concrete geometry under temperature load reduced the cover thickness by 30%.

The study concluded that the rubber-tyre concrete had maximum resistance to fire and least probability of failure as likened to the conventional concrete. The study recommended that rubber-tyre inclusion in concrete should be preferred for improving its resistance ability to fire.

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