Reliability Assessment Of Heated Rubber Tyre Concrete

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***Abstract*— In this study, effort has been made to determine the reliability of heated rubber tyre concrete. The rubber tyre concrete (RTC) was subjected to single temperature load in accordance with the procedure suggested by ISO 834 using Constant Failure Rate (CFR) method. For this, twenty-seven (27) samples were prepared from each series of mix containing tyre fibers of 10 mm width and length in various proportions namely; 0%, 2.5%, 5.0% and 7.5%, with water cement ratio of 0.55. In the view of variations of test results, this study therefore explores the use of rubber tyre concrete as an additional constituent in the conventional concrete. The results indicated that incorporating rubber tyre to concrete provides a reliability level of safety.**

Keywords—rubber tyre concrete; mix ratio; ISO 834; CFR; reliability; cement ratio; and temperature load.

1.1 Introduction

Gideon (2012), defined 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. Wasiu and Raji (2015) proposed that to begin reliability analysis, the state variables of the problem must be defined. The performance function could be formulated using the state variables which include basic load and resistance parameters.

The statistical parameters (means, variance, standard derivation) of these variables can now be generated or calculated using any acceptable technique.

1.2 Concept of Limit State Function

David (2005) identified the function of concept of a limit state as defining failure in the context of structure reliability analyses. A limit state is the boundary between the desired and the undesired performance of a structure.

Yihua et al., (2018) explained that the mode of failure of a rubber concrete section depends on the amount of the materials used and their corresponding mechanical properties, as well as the geometric configurations of the considered member. According to Bai et al., (2018), safety and serviceability provisions in codes and standards used in existing Structures and damaged structure take the form:

Required strength ≤ Design strength

Deformation due to service loads ≤ Deformation limit

Such reliability analyses are intended to ensure that the structure is safe under extreme loads and remains functional under building loads, especially for the damaged structure. Uncertainties arise from variations in loads and material strength properties and member dimensions with different temperature, after the structure be fired, with the advances in structural reliability probabilistic methods have accompanied the development of limit states Equation as engineering field of endeavor.

Bai et al., (2018), also defined limit state Equation based on the relation between stress S and resistance R, it occurs when exposure to stress exceeds the strength of the design. However, since R and S are established by material performance and member dimension; they are characterized as random variables with corresponding means μ_S and μ_R, σ_s and σ_R. Probability distribution function are $f_S(S)$ and $f_R(S)$ respectively. The reliability is defined in Equation (1) as:

$$R_r = 1 - P_f \quad (1)$$

where R_r = for reliability, Pf= Probability of occurrence

2 Methodology

2.1 Material and Properties: 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. This was used for all the samples for consistency in the comparison. The concrete cube moulds were hooked together to prevent leakage. Lubricant was applied in thin layer to the inner part of the mould for easy demoulding.

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
0	33.70	67.32	134.64	0.00	18.54	0.
2.5	33.70	67.32	131.27	3.37	18.54	0.
5.0	33.70	67.32	127.90	6.74	18.54	0.
7.5	33.70	67.32	124.53	10.11	18.54	0.

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 respectively after been heated (ISO 834 fire curve) at average temperature of 300^0C which were recorded at 30 and 60 minutes respectively. Thereafter, the specimens were left to room temperature to cool down. 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 Compressive Strength Test (BS EN 12390-3, 2002)

Compressive test was carried out in accordance with (BS EN 12390-3, 2002) on the rubber concrete cubes using Manual Testing Machine (MTM) at Civil Engineering Laboratory (University of Ilorin). Compressive strength of concrete is the value of uniaxial compressive stresses reached when concrete fails completely. This was given in terms of the characteristic compressive strength of 100mm sizes cubes tested at 7 and 28 days respectively.

The test was carried out by placing each sample between the two parallel rectangular plates of the machine and subjected to increasing load pressure until failure is observed. The failure was measured in Kilo Newton (kN). The compressive strength was computed using the relationship given in Equation (7).

Compressive strength = $\frac{Load,\ P\ (kN)}{Area,\ A\ (mm^2)}$ (7)

Where:

Size of cube =100mm×100mm×100mm

Area of specimen, A = 10,000mm^2

P = Failure load (kN)

A typical failure mode of the rubber concrete tested for compressive strength is shown in Plate 3.10. The samples were fed into the Manual Testing machine simultaneously. In which the plunger was allowed to have contact with the surface of the specimen and the crushing was finally done.

2.5 Constant Failure Rate

According to Leitch (1988), reliability index using constant failure rate (CFR) model is as given in equation (1-2) and λ is assumed constant with time.

where R(t) = reliability index, λ = constant rate of failure, t = variable time.

The failure rate (λ) is expressed in equation (6)

$$Q_i = \sum_{j=1}^{i} (\sigma_i) \quad (2)$$

$$R_i = \sum \sigma - Q_i \quad (3)$$

$$d_i = \frac{\sigma_i}{R_{i-1}} \quad (4)$$

$$d = \sum \frac{d_i}{n} (2.26)$$

$$\lambda = \frac{1-d}{T} \quad (5)$$

where: σ_i = average strength (N/mm^2)

Q_i = cumulative strength (N/mm^2)

R_i = remaining strength (%)

T = time (years), the expected life span of the concrete, and

d = average concrete strength rate (N/mm^2)

The failure density is expressed with respect to constant rate of failure as:

$$F(t) = \lambda e^{-\lambda t} \quad (6)$$

The reliability of RTC as a function of time (years) was evaluated. Reliability, R(t), of the RTC is defined as the probability that RTC will perform its function over a specified period of time provided that other specified service conditions are met. The strength analysis of the experimental results was carried out by considering a total/cumulative strength of 22N/mm^2.Concrete structure service life as stated by European Standard, EN 1990 is 10 years for temporary structures, 50 years for buildings and other common structures and 100 years for monumental buildings, bridges and other special structures. A service life of 100 years was assumed and that other serviceability conditions are met. The constant rate failure (CFR) method was used in evaluating the reliability index of tyre rubber concrete.

3 Result and Discussion

A reliability evaluation based on the compressive and impact strength of RTC with respect to its service life was carried out. Experimental strength results at different ages were used to obtain the strength rate of RTC, the strength analysis of compressive strength and Impact strength of RTC were computed as shown in Tables 3 and 4 respectively.

3.1 Relationship between Experimental Compressive strength and Impact Strength

The relationship between the Impact (y) and compressive (x) strengths of RTC is presented in Figure (2).

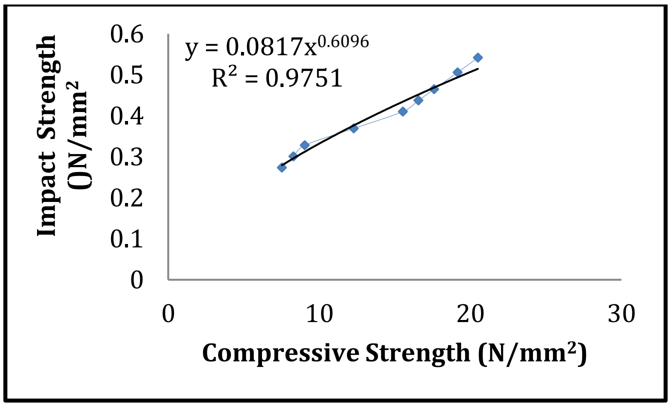

Figure 2: Relationship between Compressive and Impact strength of TRC

Table 3: Strength Analysis of Compressive strength of TRC

S/N	Days	Average Strength (σ_i) (N/mm²)	Cumulative Strength (Q_i) (N/mm²)	Remaining Strength (R_i) (%)	Strength Rate (d_i)
1	7	7.53	7.53	62.66	0.12
2	14	9.04	16.57	53.63	0.14
3	21	15.53	32.10	38.10	0.29
4	28	17.60	49.70	20.50	0.46
5	56	20.50	70.19	0	1
					0.403

The average strength rate, d = 0.4032 (obtained from equation (2.26))

$$\lambda = \frac{1-0.4032}{50} = 0.01193/\text{year} \qquad (7)$$

The average strength rate, $d = \frac{0.33+0.33+0.50+1}{4} = 0.54$

$$\lambda = \frac{1-0.54}{50} = 0.0092\ /\ year \qquad (8)$$

Table 4: Strength Analysis of Impact Strength of TRC

S/N	Days	Average Strength (σ_i) (N/mm²)	Cumulative Strength (Q_i) (N/mm²)	Remaining Strength (R_i) (%)	Strength Rate (d_i)
1	7	0.273529	0.273529	1.745118	0.15674
2	14	0.328235	0.601765	1.416882	0.188088
3	21	0.410294	1.012059	1.006588	0.289575
4	28	0.465	1.477059	0.541588	0.461957
5	56	0.541588	2.018647	-5.9E-08	1
					0.419272

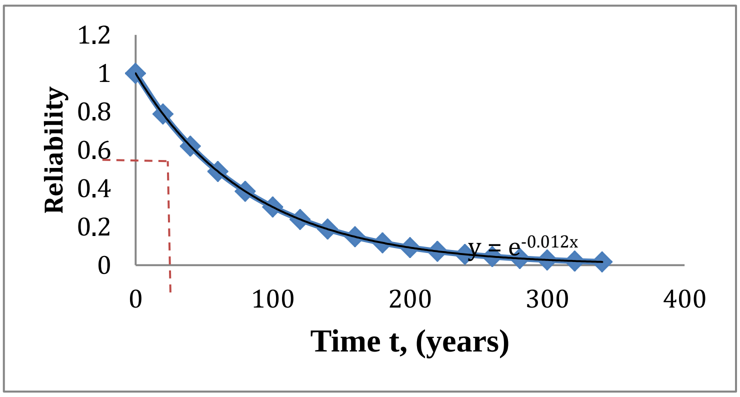

Figure 3: Graph of Reliability of Compressive strength of Tyre Rubber Concrete (RTC)

The Reliability R(t) of rubber tyre concrete means the probability that RTC would be in operation from time 0 to t_1 provided that the operation starts from 0.

$$\text{Reliability, } R(t) = e^{-\lambda t} \qquad (8)$$

Provided that other serviceability conditions are satisfied, a lifespan of 50 years was assumed. Using constant failure rate (RTC), Figure 3 and Table 4 show the evaluated reliability of the compressive strength of RTC at 1:1:2 mix proportion and at water-cement ratio of 0.5

CONCLUSION

Based on this study, in be concluded that:

The compressive and Impact strength reliability at 50 years are 0.61 and 0.62, respectively. These values are greater than 0.5, which implies that RTC is a reliable concrete that can function satisfactorily for 50 years.

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