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Structural Models for the Prediction of Compressive Strength of Coconut Fibre-reinforced Concrete

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Abstract- ***The quality of concrete used in any construction work is a function of its compressive strength. In this paper, structural models are formulated to predict the compressive strength of coconut fibre-reinforced concrete mix 1:2:4 at water-cement ratios of 0.55 and 0.60 using three-dimensional elasticity equations. The results obtained using the formulated models were compared with the measured values and were found to be very close (correlation coefficient = 0.9011). For both the measured and predicted values, the compressive strength of concrete mix (1:2:4) were found to decrease as the coconut fibre contents increased.***

Keyboard: structural models, compressive strength, coconut fibre, three-dimensional elasticity equations, fibre contents.

I. INTRODUCTION

Concrete is the most widely used structural material in the world. Its importance and usage in the modern society cannot be overlooked. Concrete is obtained by mixing cementitious materials, water and aggregates in required proportion. The mixture when placed in forms and allowed to cure hardens into a rock-like mass known as concrete. Advances in concrete technology have brought about various measures of improving the properties and qualities of concrete. One of such measures is by using additive. Additives are materials which are often added to concrete to make concrete mixture more economical and increase strength or influence other concrete properties [1-4]. Fibres used in concrete are either artificial or natural. Examples of artificial fibres, glass fibres, steel fibres etc. Examples of natural fibres are coconut fibres palm-nut fibres, akwara fibres, coir fibres etc. These fibres when used in concrete improves flexural toughness, ductility, crack resistance and splitting tensile strength. Although these fibres are being used as reinforcements in concrete, they have limited usage because there are no well-established equations to predict their behaviour and properties [5-10]. Projects where concrete is being used as a structural material are hardly achievable by both urban and rural dwellers because of increasing cost of conventions reinforcement as one of the construction materials. Consequently, any material that can replace conventional reinforcements in concrete production will go along way to making concrete production cost-effective [11]. In this paper, a mathematical model is formulated to predict the compressive strength of coconut fibre-reinforced concrete using three-dimensional elasticity equations. The formulated models are simple, straight-forward and not mathematically cumbersome.

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II. MODEL DERIVATION

Consider a coconut fibre-reinforced concrete cube loaded in compression as shown in figure 1. The 3-dimensional elasticity equations in Cartesian coordinate representing the deformation in the 3 coordinate axes are given by:

$$\varepsilon_x = \frac{1}{E}\left[\sigma_x - v\left(\sigma_y + \sigma_z\right)\right] \quad (1)$$

$$\varepsilon_y = \frac{1}{E}\left[\sigma_y - v\left(\sigma_z + \sigma_x\right)\right] \quad (2)$$

$$\varepsilon_z = \frac{1}{E}\left[\sigma_z - v\left(\sigma_x + \sigma_y\right)\right] \quad (3)$$

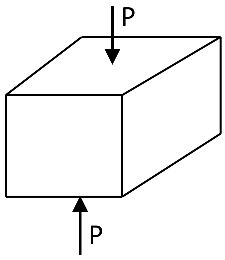

Figure 1: A coconut fibre-reinforced concrete cube under compressive loading.

Addition of equations (1), (2) and (3) gives:

$$\varepsilon_x + \varepsilon_y + \varepsilon_z = \frac{1-2v}{E}\left(\sigma_x + \sigma_y + \sigma_z\right) \quad (4)$$

Where:

$\varepsilon_x + \varepsilon_y + \varepsilon_z =$ volumetric strain.

Average strain and stress are given by equations (5) and (6) respectively as:

$$\varepsilon_{av} = \frac{1}{3}\left(\varepsilon_x + \varepsilon_y + \varepsilon_z\right) \quad (5)$$

$$\sigma_{av} = \frac{1}{3}\left(\sigma_x + \sigma_y + \sigma_z\right) \quad (6)$$

From equations (5) and (6), we have:

$$\varepsilon_x + \varepsilon_y + \varepsilon_z = 3\varepsilon_{av} \quad (7)$$

and

$$\sigma_x + \sigma_y + \sigma_z = 3\sigma_{av} \quad (8)$$

Using equations (7) and (8), equation (4) now transforms to:

$$\sigma_{av} = \frac{E.\ \varepsilon_{av}}{1-2v} \quad (9)$$

Where: $\upsilon =$ poisson ratio of concrete = 0.3 [9]

Equation (9) shows that average stress is proportional to average deformation.

Using equations (5) and (9), we have:

$$3\sigma_{av} = \Delta \quad (10)$$

Where:

$$\Delta = \varepsilon_x + \varepsilon_y + \varepsilon_z \quad (11)$$

Equation (11) represents average deformation in the three coordinate axes.

Using equation (9),

$$\sigma_{av} = \frac{E\,\Delta.}{3(1-2v)} \quad (12)$$

From strength of materials,

$$\Delta = \frac{e}{l_o} \quad (13)$$

Where:

$e,\ l_o =$ change in length and original length respectively.

From Hooke's law,

$$e = \frac{Pl_o}{AE} \quad (14)$$

Substituting for e in equation (13) now transforms equation (13) to:

$$\Delta = \frac{P}{AE} \quad (15)$$

Substituting for Δ in equation (12) transforms equation (12) to:

$$\sigma_{av} = \frac{P}{3(1-2v)A} \quad (16)$$

Where:

P, A = Compressive load and cross-sectional area of coconut-fibre reinforced concrete cube respectively.

$$A = bd \quad (17)$$

Using equation (17), equation (16) becomes:

$$\sigma_{av} = \frac{P}{3bd(1-2v)} \quad (18)$$

The failure load P concrete in compression is assumed to decrease with increase in the volume fraction of coconut fibre.

The equation that describes the effect of the fibre on the compressive strength property can be given by:

$$P = P - \lambda_f P = P(1-\lambda_f) \quad (19)$$

Using equation (19), equation (18) now transforms to:

$$\sigma_{av} = \frac{P(1-\lambda_f)}{3bd(1-2v)} \quad (20)$$

Where:

λ_f = volume fraction of coconut fibres in the composite.

υ = poisson's ratio for concrete.

From equation (20), $\sigma_{av} =$ compressive strength of coconut fibre – reinforced concrete. Equation (20) now transforms to:

$$\sigma_c = {P(1-\lambda_f)}\Big/{3bd(1-2v)}$$

III. RESULTS AND DISCUSSIONS

The result of the compressive strength obtained from the structural models are compared with those obtained experimentally at ages 7-14 and 28days as can be seen in figures 1-6. From Tables 1-6, it can be seen that the model results compared favourably with those of the experimental values. The correlation coefficient values were high (0.94 – 0.968). F-statistic test was also conducted and the result showed that both the experimental and model results have equal variance showing good reliability of the proposed structural models. From the Tables, it can also be seen that the compressive strength decreased with increase in the volume percentage of coconut fibre. This trend may be due to the fact that coconut fibres act as a filler under compressive loading. This leads to the formation of voids or points of local discontinuities in the composite resulting in decrease in strength. The disparity between the experimental and model results may be attributed to errors in the model formulation and imperfections in the measuring instruments.

IV. CONCLUSION

The compressive strength values at water-cement ratios of 0.55 and 0.60 for a concrete mix of 1:2:4 based on 3-dimensional elasticity equations are compared with the measured or experimental values. The results of the formulated model and the experimental values are found to be sufficiently close and the compressive strength decreased with increase in the volume percentage of coconut fibres showing the effectiveness of the models in the prediction of strength properties of coconut fibre reinforced concrete.

Table 1: Compressive strength (σ_c) of concrete mix 1:2:4 at water-cement ratio of 0.55 at age 7 [10]

S/N	λ_f (%)	Compressive strength	
		Expt	Model Result
1	0	14.31	13.5
2	0.5	13.10	12.4
3	1.0	12.00	11.35
4	1.5	8.64	8.20
5	2.0	6.35	5.78
6	2.5	3.15	2.98

Table 2: Compressive strength (σ_c) of 1:2:4 concrete mix at age 14: water-cement ratio = 0.55 [10]

S/N	λ_f (%)	σ_c (N/mm^2)	
		Expt	Model Result
1	0	24.12	23.7
2	0.5	23.05	22.3
3	1.0	20.81	20.2
4	1.5	15.65	15.00
5	2.0	7.68	7.3
6	2.5	4.00	3.4

Table 3: Compressive strength (σ_c) of 1:2:4 concrete mix at age 28: water-cement ratio = 0.55 [10]

S/N	λ_f (%)	σ_c (N/mm^2)	
		Expt	Model Result
1	0	29.50	28.4
2	0.5	26.91	26.5

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3	1.0	23.11	22.3
4	1.5	20.55	20.0
5	2.0	17.14	16.6
6	2.5	8.06	7.2

Table 4: Compressive strength (σ_c) of 1:2:4 concrete mix at age 7: water-cement ratio = 0.60 [10]

S/N	λ_f (%)	σ_c (N/mm^2)	
		Expt	**Model Result**
1	0	18.5	17.8
2	0.5	15.24	14.7
3	1.0	13.98	13.2
4	1.5	11.56	10.9
5	2.0	8.21	7.5
6	2.5	4.21	3.6

Table 5: Compressive strength (σ_c) of 1:2:4 concrete mix at age 14: water-cement ratio = 0.60 [10]

S/N	λ_f (%)	σ_c (N/mm^2)	
		Expt	**Model Result**
1	0	20.02	19.2
2	0.5	16.98	16.2
3	1.0	14.42	13.9
4	1.5	11.01	11.7
5	2.0	10.51	9.4
6	2.5	5.8	5.1

Table 6: Compressive strength (σ_c) of concrete mix 1:2:4 at age 28: water-cement ratio = 0.60 [10]

S/N	λ_f (%)	σ_c (N/mm^2)	
		Expt	**Model Result**
1	0	23.99	23.3
2	0.5	21.21	20.6
3	1.0	17.12	16.5
4	1.5	14.51	13.8
5	2.0	12.02	11.2
6	2.5	7.12	6.3

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