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A Simplified Constitutive Model to Predict Behaviour of Concrete with Tire Derived Aggregate

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Abstract **-** Due to the worldwide depletion of raw materials required for construction projects, it is becoming clear that alternative and renewable construction materials are needed to reduce the demand for raw materials, such as rubber waste. Sound concerns arise from the side effects of rubber waste on the mechanical properties of Portland Cement Concrete (PCC) mixes. In this research, a simplified constitutive model is proposed to predict the mechanical properties of PCC mixes with Tire Derived Aggregates (TDA) replacing natural aggregate. The model will be used to predict Young's moduli and stress-strain curves for PCC mixes. It was found that the proposed model seems to capture the behaviour of PCC mixes with TDA fairly well, including ultimate stresses, ultimate strains, and the elastic modulus.

Keywords**:** Portland Cement Concrete Mixes, Tire Derived Aggregates, Homogenization, Constitutive Modelling

1. Introduction

There is no doubt that massive, widespread development and urbanization globally and regionally have negatively impacted the environment and increased the rate of depletion of natural resources and increased solid wastes. Typical solid wastes include organics, paper, glass, plastics, metals, wood, rubber tires, etc. However, if properly treated and processed, solid waste can become a sustainable source of useful construction materials.

Researchers have been investigating the utilization of different types of waste as construction materials. The evaluated waste materials included recycled construction materials, plastic waste, glass, rubber tire waste, and steel manufacturing by-products. Molenaar [1] has suggested that the utilization of recycled and waste materials in road construction projects could reduce the carbon footprint, while generating economic and environmental benefits. However, concerns have been raised with regard to the inclusion of waste materials in construction materials, especially in Portland Cement Concrete (PCC) mixes. For example, it has been suggested that reduced bonding associated with the aggregates and cement paste could lead to a reduction in strength.

Many research studies have been conducted on adding rubber tire waste to PCC mixes. Findings have shown that with increased rubber content, PCC preferred mechanical properties decreased, but ductility and material toughness improved [2-5]. Bandarage and Sadeghian [6] reported that incorporating shredded rubber particles to replace fine materials resulted in failure patterns differing from those of a typical PCC mix. On the other hand, some studies showed that PCC mixes with rubber could be incorporated in concrete structural elements, providing sufficient strength and adequate service life [7] and [8], with the added benefit that large amount of plastic energy could be absorbed by rubberized concrete under different loading conditions [9] and [10]. Abu Abdo and El Naggar [11] evaluated utilizing TDA in the construction of rigid pavement. They suggested that using TDA resulted in a reduction of environmental impacts and overall costs and improvement in the flexibility of PCC mixes in rigid pavements and will achieve an eco-friendly and sustainable rigid pavement design.

2. Objective

The main objective of this study was to develop a simplified model to predict Young's moduli and stress-strain curves for concrete mix with TDA replacing natural coarse aggregate.

3. Materials and Lab Tests

A typical PCC mix was used in this study, with a mix design of 25% cement, 10% water, 24% fine aggregates, and 41% coarse aggregates by weight. Waste rubber tires were shredded and cut to particle sizes ranging between 4.75mm to 19.05mm and a bulk density of 557 kg/m^3 to replace natural coarse aggregate. Three cylindrical samples were cast with ϕ150 mm x 300 mm high for each mix condition and then tested using ASTM C469M Standard Test Method for Static Modulus of Elasticity and Poisson's procedure.

4. Analysis and Results

To achieve the goals of this study, three uniaxial constitutive relations were used to simulate the stress-strain diagram of the normal concrete (0% TDA) and TDA concrete (100% TDA):

Desayi and Krishan [12] model:

$$\sigma = \frac{E\varepsilon}{1 + \left(\frac{\varepsilon}{\varepsilon_P}\right)^2} \tag{1}$$

where σ, ε are stress and strain tensors, E is the Young's modulus, ε_P is the strain at peak stress.

Saenz [10] model:

$$\sigma = \frac{E\varepsilon}{1 + \left(\frac{E}{E_p} - 2\right)\left(\frac{\varepsilon}{\varepsilon_P}\right) + \left(\frac{\varepsilon}{\varepsilon_P}\right)^2} \tag{2}$$

where E_p is secant elastic modulus at peak stress.

and simplified proposed model:

$$\sigma = E\varepsilon - aE_p\varepsilon^2 \tag{3}$$

Where a is a material adjustment parameter.

The three models were used to simulate the stress-strain diagram of normal concrete (0% TDA), and plotted in Fig. 1, along with the experimental tests results of normal concrete standard cylinders. The ultimate stress reached about 40 MPa. The values used to plot the models are: $E = 39112\ MPa$, $E_p = 23723\ MPa$, $\varepsilon_P = 0.001801$, and a is found to be equal to 400 in the present case. It was clear that Desayi and Krishan [12] model underestimated the stress-strain diagram, while Saenz [13] model overestimated the test results. On the other hand, the proposed simplified model captured the stress-strain behavior very well because of the use of the adjustment parameter. The discrepancy between the models started to be apparent at stress above about 50% of the ultimate stress.

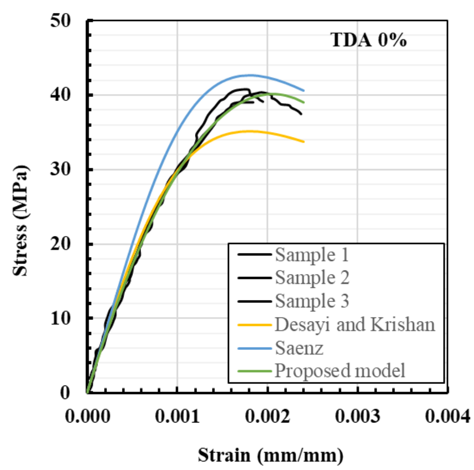

Fig. 1: Stress-Strain Diagram of Normal Concrete (0% TDA)

Fig. 2 shows the experimental results of testing 100% TDA concrete samples, along with the three aforementioned constitutive relationships. The material properties used to plot the models were: $E = 6492\ MPa$, $E_p = 3211\ MPa$, $\varepsilon_P = 0.00263$, and $a = 400$. The discrepancy between the three constitutive models here was less than the case of normal aggregate concrete (0% TDA). The proposed model shows a steeper strain softening after the ultimate stress is reached, when compared with the other two models.

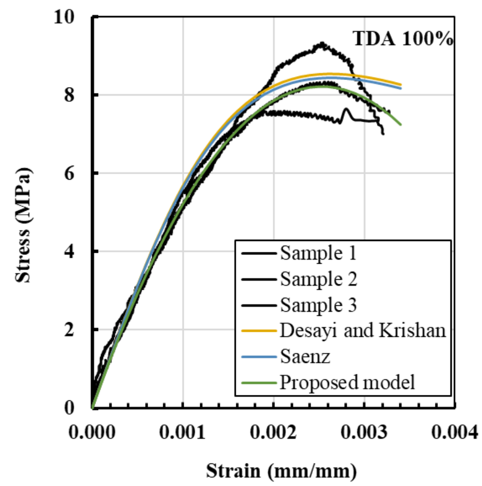

Fig. 2: Stress-Strain Diagram of 100% TDA Concrete

4. Conclusion

A simple model was developed to predict Young's moduli and stress-strain curves for PCC mixes with TDA as a replacement for natural coarse aggregate. The proposed model seems to capture the behaviour of the material fairly well, when compared with other constitutive models. Both ultimate stresses and ultimate strains were well predicted, along with the elastic modulus. It is recommended that more tests be done with different percentages of aggregate replacement in the future.

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