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Static and Dynamic Performance of Two Stage Concrete

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Abstract. Concrete is arguably the most important construction material in the world. In the last decades, it has been reported that infrastructures faced extreme static and dynamic loads which caused structural catastrophic disasters [1]. The increase usage of conventional concrete in engineering industries led to high consumption of mineral resources which caused several environmental damages related to reduction in the rocket layers [2], besides, the economical damages due to the high demand of natural resources materials which rises the cost of construction [3]. Therefore, the utilization of recycled waste rubber (steel wires) in concrete can be a sustainable solution for waste construction developments [4]. Recently, two stage concrete (TSC) (non-traditional concrete) was introduced. Placing of coarse aggregate followed by injecting the cementitious materials among the aggregate layers in the formwork are the basic steps of producing TSC. Evaluating the static and dynamic performance of TSC were the objectives of this study. Cement, aggregates, water, recycled steel wires of rubber tires were utilized in manufacturing TSC specimens. The compressive characteristic and impact resistance of TSC test specimens were evaluated. Results showed that steel wires improved the dynamic behaviour of TSC, while a slight to no effect was observed on its compressive characteristics. This study demonstrates the potential to engineer sustainable TSC mixtures.

Keywords: Two-stage concrete; impact; sustainability

1. Introduction

The dynamic behaviour of concrete is considered one of the most important priorities in infrastructure construction [5]. Due to its brittleness, concrete can be damaged by the impact of sudden heavy loads [6]. Many research work have demonstrated the significant enhancements in the dynamic performance of metallic fibre reinforced concretes [7]. The incorporation of metallic fibres in concrete production also enhances various properties such as; fatigue, toughness, and energy absorption capability [8]. This behaviour is attributed to fibres capability to arrest crack initiation through concrete elements [7, 9]. Furthermore, incorporation of waste rubbers in concrete production have provided very promising characteristics to concrete under static and dynamic loading [10]. Many research work have demonstrated that the rubberized concrete performed efficiently under static and dynamic loading by partial replacement of sand and cement with rubber by up to 20% by volume fraction [11].

Recently, two stage concrete (TSC) was introduced. The TSC can be made by direct injecting of cementitious grout to fill the voids among the aggregate layers in the formwork. A sustainable rubberized TSC can be produced by adding waste truck tire rubber as a partial replacement of sand or aggregate. This can be considered as one of the solutions to reduce time and mineral resources consumption of construction. On the other hand, the ease of gravitational placement of TSC in formworks differs from pumping process in traditional concrete. This can reduce the probability of honeycombing and segregation also [12].

Although, various research work had been conducted in concrete industries especially on the static behaviour of TSC [12, 13]. However, there is lack of information on the impact resistance of TSC. Therefore, the impact resistance of TSC mixtures incorporating randomly dispersed recycled steel wires as fibres was investigated in this study. The study aims to produce a sustainable cheap concrete mixtures with impact resistance, to present novel alternative to conventional concrete.

2. Experiments

2.1 Proportions of Utilized Materials

The TSC mixtures was produced using ordinary portland cement (OPC) Type I with a specific gravity of 371 m^2/kg, in accordance with ASTM C150 standards [14]. Also, traditional sand was utilized. Furthermore, the TSC mixtures was prepared using 20-45 mm recycled steel wires, with 0.2 mm diameter, and different volume fractions of 0%, 0.5%, 1%, and 1.5%. To control the workability, a water reducing admixture (WRA) as per ASTM C494 specifications [15] was added. Table 1 shows the different TSC mixture proportions.

Table 1. Proportions of Utilized Materials.

ID	OPC	Fine sand	w/c	WRA	Recycled steel wires (%V_f)
TSC0	1.00	1.00	0.45	0.0004	0.00
TSC0.5	1.00	1.00	0.45	0.0004	0.50
TSC1	1.00	1.00	0.45	0.0004	1.00
TSC1.5	1.00	1.00	0.45	0.0004	1.50

2.2 Mixture Preparation, Casting and Curing

A cylindrical mold of 150 mm x 300 mm was prepared from each TSC mixture. First, the aggregates were placed at the bottom of the cylinders followed by the distribution of the recycled steel wires, and then, another layer of aggregates as shown in Fig. 1.

Fig. (1) TSC placing technique

A Cement Mixer was used to dry mix cement and fine sand. Thereafter, a homogeneous mixture was achieved by adding the mixing water and WRA gradually to the dry mixture for three minutes. Finally, the cementitious mixture was injected into the formworks. The formworks were removed after 24 hours then left in clean water up to testing age of 28 days.

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2.3 Test Procedures

2.3.1 Compressive strength

Th compressive strength was determined using a 2000 kN compression machine. Three cylindrical speceimens of 150 mm x 300 mm were placed and tested at 28 d following ASTM C39 guidelines [16].

2.3.2 Tensile strength

To evaluate the tensile properties of the different TSC mixtures, three cylindrical specimens of 150 mm x 300 mm were tested at 28 d following ASTM C496 standards [17]. The splitting tensile strength was obtained using Eq. 1:

$$T = \frac{2*P}{\pi*l*d} \qquad \textbf{(Eq. 1)}$$

Where *T* and *P* are the tensile strength and applied load in MPa and Newton, respectively, *l* and *d* are the length and diameter of tested cylinders in mm.

2.3.3 Impact test

Furthermore, impact test was applied on the different TSC specimens at 28 d following the American Concrete Institute (ACI) Committee 544 [18] guidelines as displayed in **Fig. 2**. The impact load was applied on the different TSC specimen in which each hit was able to produce 20.167 J. This is due to the free fall of a 45 N steel weight falls from 457 mm height. The number of drops induced up to visibility of crack propagation (N1), and fracture (N2) were recorded, respectively. The impact energy was evaluated using Eq. 2 as per ASTM D5628 guidelines [19]:

$$I = N_i . h . w . f \qquad \textbf{(Eq. 2)}$$

Where the impact energy in Joule is represented by *I*, the number of hits, the falling height in mm, and the steel hammer mass in kg are represented by *Ni*, *h*, and *w*, respectively, and *f* is a 9.806 x 10^{-3} constant.

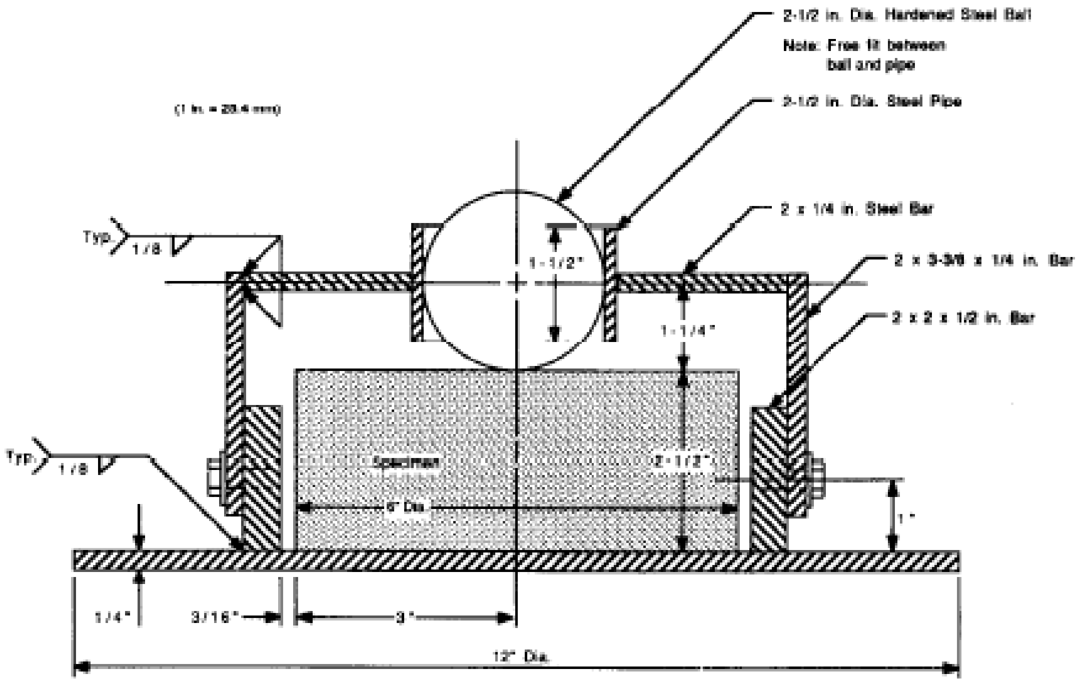

Fig. (2) Test setup of drop weight impact test [18]

3. Results and discussion

3.1 Compressive strength

The compressive strength data was measured at 28 days for the different TSC mixtures. As shown in Fig. 3, the compressive strength of the different TSC specimens varies from 30 to 34 MPa. As expected, the compressive strength generally decreased with increasing fibers content. Incorporating steel fibers in TSC mixtures induced a slight decrease in the compressive strength of TSC. For example, a steel wires addition of 0.5%, 1%, and 1.5% by volume fraction in TSC slightly reduced the compressive behavior by 5.1%, 6%, and 6.4%, respectively, compared to TSC fibreless mixture. This is due to increased porosity accompanied to steel wires addition, which in turn resulted in decreased compressive behavior.

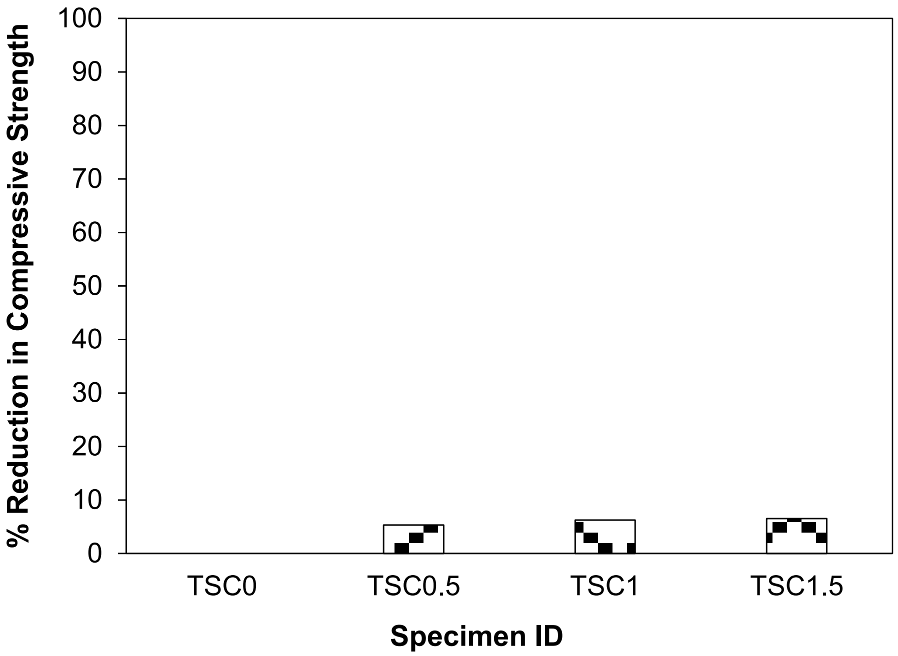

Fig. (3) Compressive behaviour of steel wired TSC specimens

3.2 Splitting tensile strength

Figure 4 shows the variation in splitting tensile strength of TSC specimens at testing age of 28 days. The achieved tensile strength was 3.8 to 6 MPa, depending on fiber content. The tensile behavior of the TSC mixtures was improved owing to incorporation of the steel wires in TSC. For example, the tensile strength of TSC0.5, TSC1, and TSC1.5 specimens increased by about 44.7%, 50.8%, and 60.5%, respectively, relative to the fibreless TSC mixture as shown in Fig. 4. This can be attributed to improved fiber-matrix interfacial bond which improved the overall tensile characteristics.

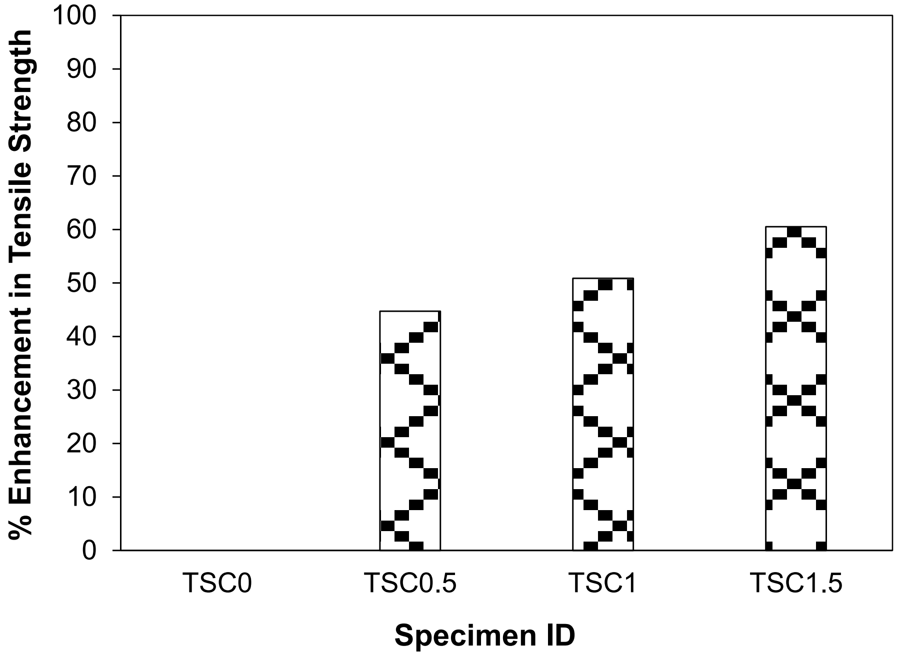

Fig. (4) Splitting tensile characteristics of steel wired TSC specimens

3.3 Impact resistance

The impact resistance of the various TSC mixtures were tested and evaluated under the drop weight impact test [18]. Figure 5 illustrates the impact resistance of TSC mixtures up to first crack and failure. Due to its brittle nature, the fibreless TSC specimen failed after only one drop and split into multiple fragments. Countering that, including recycled steel wires in TSC production significantly increased the sustained impacts by TSC cylinders. The dynamic behavior of recycled steel wired TSC reinforced specimens was approximately 40 times that of fibreless TSC specimens. For example, steel wires addition by 0.5%, 1%, and 1.5% increased the first crack and fracture impact resistance of TSC specimen by up to 3, 4, and 5, and 22, 25, and 40 times that of fibreless TSC specimens, respectively. This is ascribed to the crack arresting capability of steel wires.

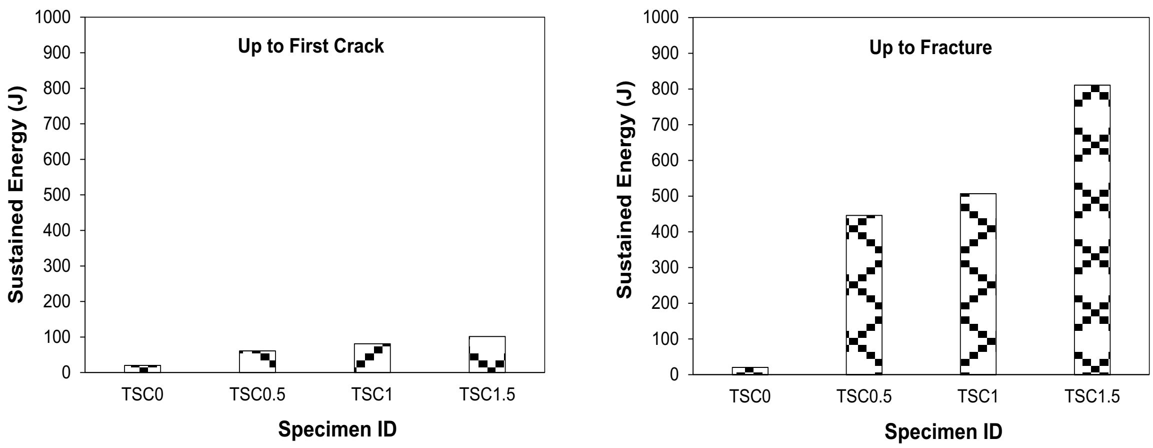

Fig. (5) Dynamic response of recycled steel wired TSC specimens

4. Summary and conclusion

In this study, an experimental investigation was conducted to evaluate the static and dynamic behaviour of two stage recycled steel wired concrete. The main findings are summarized as follows:

- A general reduction in the compressive strength of TSC specimens was observed owing to steel wires addition relative to fibreless TSC mixture.
- The tensile properties of TSC mixtures significantly enhanced owing to incorporation of recycled steel wires in TSC production.
- Among all tested specimens, incorporating 1.5% recycled steel wires in TSC manufacturing acquired superior tensile properties.
- The dynamic performance of TSC mixtures was improved owing to recycled steel wires addition. It was approximately 40 times that of the impact resistance of non-reinforced TSC specimens.
- The static and dynamic behavior of TSC concrete paving the way for further research to produce sustainable cementitious materials.

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