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Research Article

Destructive and non-destructive testing of bronze-waste tire-concrete composites

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ABSTRACT

In this study, the effects of finely-milled bronze and waste tire on the mechanical properties of concrete have been investigated. Approximately 2.5% and 5% by weight for each additive (bronze sawdust and waste tire) were added to dry concrete. The open porosity, density, compressive strength values of cured concrete have been determined. In addition, the Schmidt rebound hammer (SRH) and the ultrasonic pulse velocity (UPV) tests, which are non-destructive test methods, were applied. The microstructure and fracture surfaces of these materials were characterized by scanning electron microscopy (SEM). It was observed that the density of pure concrete was 2.35 g/cm^3 while the density was 2.19 g/cm^3 for a C+5%B+5%T material. Similarly, pure concrete had an almost three times better compressive strength and a two times better SRH value than those of the C+5%B+5%T material. The density and mechanical properties of concrete materials containing bronze and waste tire decreased due to micro crack formations, weak bonding and deep cracks forming especially between the concrete and additives.

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1. Introduction

Concrete is the most widely used construction material around the world. The demand for concrete was rapidly increased as a result of the population growth. This leads to increase the demand for the construction raw materials consist of two or more materials with improved performance and the research on innovative structural designs. The mechanical properties and damage tolerance of brittle material can be improved by using interlocking elements as structural components. The interfaces of the elements also prevent catastrophic crack propagation (Mohammed and Najim, 2020; Javan et al., 2020).

Different types of concrete are needed to meet different engineering environment. And many recent innovations in advanced concrete materials in order to produce concrete with exceptional performance characteristics (Shang et al., 2014).

There are several factors that make cement and cement-reinforced structures unsuitable, such as the poor resistance of the steel reinforcement to deicing salts and marine environments and corrosion in the natural environment. Similarly, poorly-designed concrete structures are unable to withstand natural disasters. As a result, various alternatives to reduce the environmental impact and make the construction industry sustainable and environmentally friendly have been investigated. Traditional fibers, such as steel, glass, carbon, polypropylene, polyvinyl alcohol, and other fibers have also been studied as potential reinforcements. Fibrous reinforcements provide concrete with improved mechanical performance and/or resistance to environmental conditions. The fibers make concrete more flexible and able to withstand stresses (Anandamurthy et al., 2017).

The toughness was greater in concrete where waste was used because the cracks were controlled due to the

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bridging of the fibers, with the waste becoming more ductile. The fiber waste gave better mechanical results than waste used in the form of pieces (Garrick, 2005).

The concrete that was produced at 10-15% by weight of granulated tire/rubber waste material had an approximately 60% better freeze-thaw resistance at 300 cycle performance than that of concrete produced by an admixture of 20-30% waste (Savas et al., 1996).

In this study, the mechanical properties of bronze and waste tire containing concrete were investigated.

2. Materials and Methods

In this study, C30 class ready-dry concrete, finely ground $CuAl_{10}Ni$ bronze sawdust and waste tire were used. Then pure concrete, concrete incorporating 2.5% bronze sawdust and 2.5% waste tire (by wt.), and concrete incorporating 5% bronze sawdust and 5% waste tire (by wt.) were produced in the shape of 5cm³ cubes. After this, all the concrete was cured for 28 days.

Densities and open porosities were determined by the Archimedes principle, according to the ASTM C642 test standard. A compressive test (ASTM C109/C109M), which is a destructive test method, the Schmidt method, which is the most common method used for non-destructive testing of concrete (ASTM C805), and a UPV test, which is another non-destructive test method (ASTM C597), were performed.

3. Results and Discussion

3.1. Physical and mechanical properties

Density, open porosity and strength values of pure concrete and concrete incorporating waste tire and bronze are given in Table 1.

Table 1. Density, open porosity, compressive strength values and SRH and UPV results of bronze-waste tire-concrete composites (C: pure concrete, B: Bronze sawdust, T: waste tire).

Material	Density (g/cm³)	Open porosity (%)	Compressive strength (MPa)	SRH (MPa)	UPV (m/s)
C	2.35	8.78	63.64	53.57	4567
C+2.5%B+2.5%T	2.25	11.22	35.24	40.30	4165
C+5%B+5%T	2.19	11.18	20.47	29.92	3904

According to Table 1, the density values decreased and the amount of open porosities increased. Therefore, the compressive strength values decreased through the incorporation of waste tire and bronze due to weak bonding and deep cracks forming between the tire, concrete and bronze grains, as well as large amounts of micro cracks forming, even though the tire and bronze material were ductile and had a high capacity for absorbing plastic energy under compressive loading (Hernandez et al., 2003; Topcu, 1995; Papakonstantinou et al., 2006; Snelson et al., 2009; Ali et al., 2008). Waste tire grains could absorb some water during curing, tire grains could swell, and then cause micro cracks to form. In addition, ceramic concrete, metal bronze additive and polymer waste tire had different shrinkage behavior, which could also cause cracks to form and a decrease in density and strength values.

Additionally, according to the non-destructive tests results, strength obtained from the SRH method and the speed of the sound wave results (UPV) indicate that the decrease in strength was more significant as the amount of waste tire increased and, consequently, the speed of sound decreased due to the greater amount of porosity. The UPV method is a non-destructive testing method based on measuring the velocity of compression stress waves (P-waves). The ultrasonic pulse velocity depends on the density of the material being tested; the higher the density of the concrete means the higher the pulse velocity (Manish, 2006).

3.2. Microstructural analysis results by SEM

In a microstructure of C+5%B +5%T composite material according to 1000x significance of SEM result (Fig. 1), porosities, micro cracks, and deep cracks due to weak bonding between the concrete matrix, bronze and waste tire additives grains were observed. These defects caused a decrease in strength, SRH and UPV values (Table 1). It was observed that concrete grains (gray color) had a more compacted structure, as seen on the left of the microstructure image (Fig. 1-a) than those of regions where the bronze and waste tire additives were located (as seen on the right of microstructure image).

According to an SEM-mapping analysis, it was observed that additives were non-homogenously distributed in concrete, mainly Ca, Si and Al elements that was contained in the cement phase (gray color grains). The C element that came from waste tire was seen as black. The distributions of Cu, Al, and Ni elements were in the same regions, which indicate that these grains were bronze seen as white (Fig. 1-c-n).

According to the fracture surface images of the concrete materials (Fig. 2), trans-granular (indicated as blue arrow) and inter-granular (indicated as red arrow) fracture types were both seen in pure concrete (Fig. 2-a), while a dominantly trans-granular fracture type was observed in the C+5%B+5%T concrete material (Fig. 2-b). This transition of fracture type is thought to be the reason for the decrease in mechanical properties.

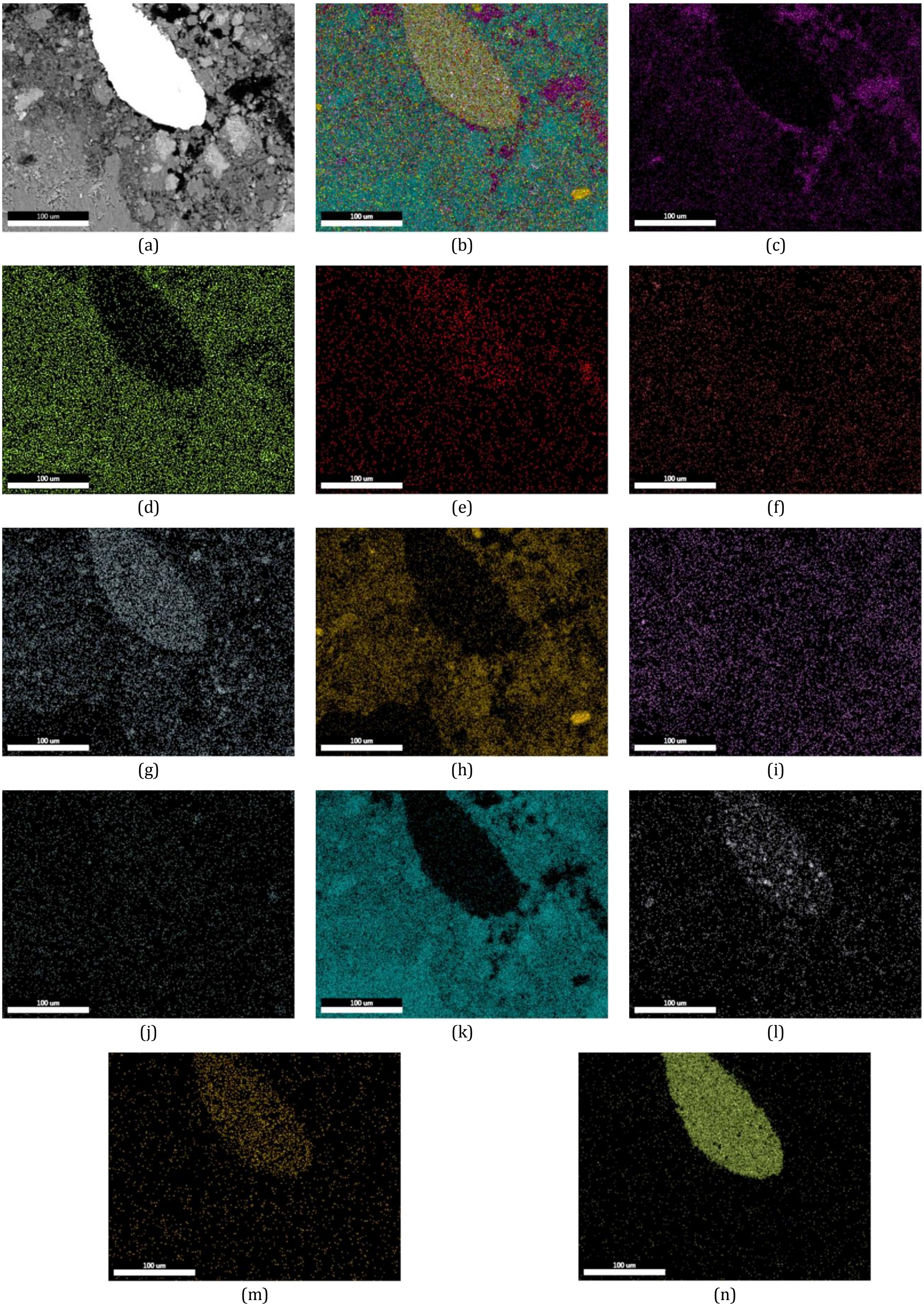

Fig. 1. 1000X-SEM back scattered electron image:
a) Microstructure; b) Colored microstructure of C+5%B+5%T composite and distribution of elements;
c) C; d) O; e) Na; f) Mg; g) Al; h) Si; i) S; j) K; k) Ca; l) Fe; m) Ni; n) Cu.

(a)

(b)

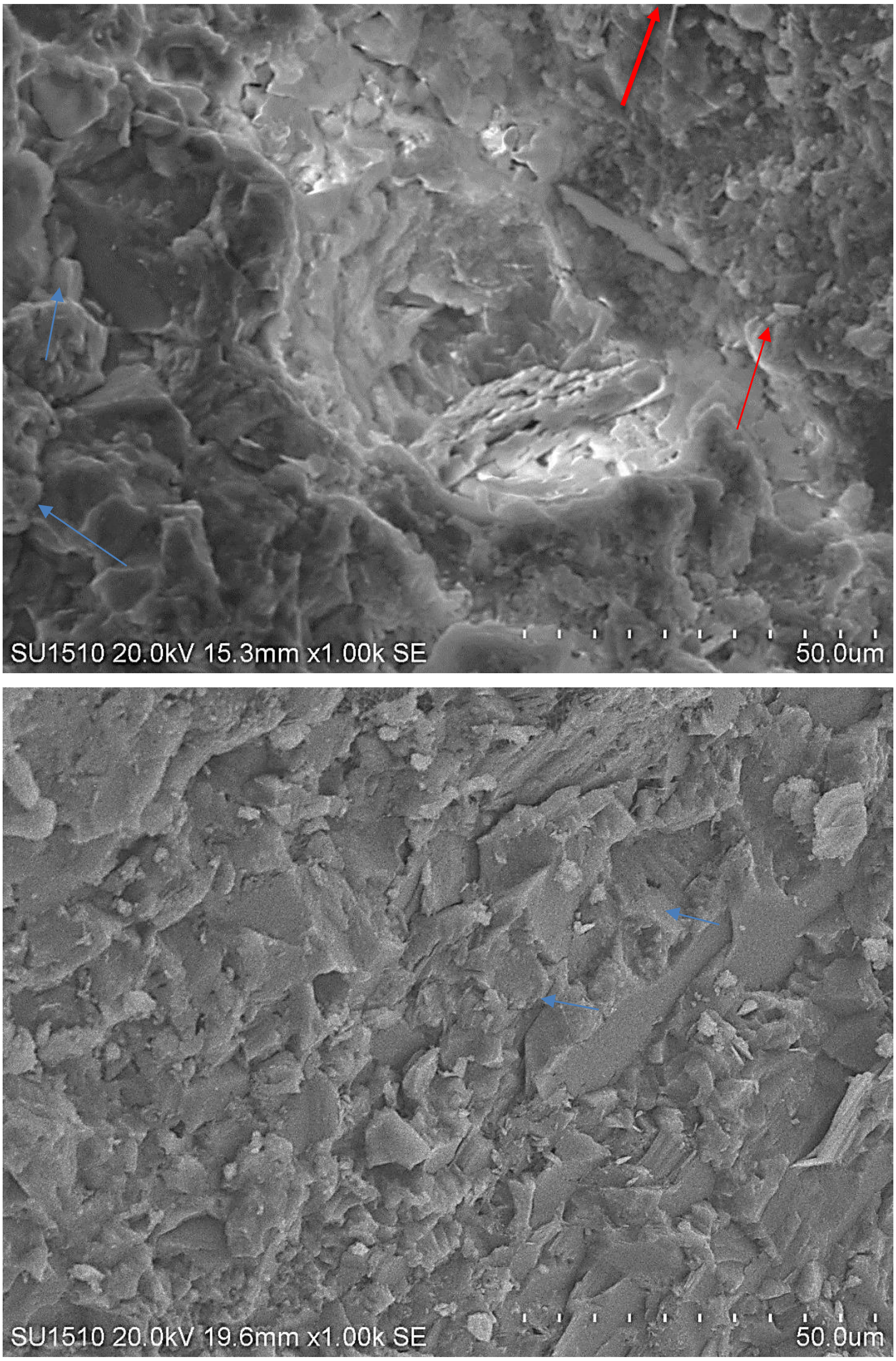

Fig. 2. Fracture surface images of a) C and b) C+5%B+5%T composite materials.

4. Conclusions

Concrete, incorporating bronze and especially waste tire, has lower density and compressive strength, SRH and UPV values than pure concrete due to weak bonding between the tire, concrete and bronze grains.

Transition from trans-granular fracture type to inter-granular fracture type is effective in an increase of mechanical properties.

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