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Abrasion resistance and fracture energy of concretes with basalt fiber

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HIGHLIGHTS

- Abrasion resistance and fracture energy of basalt fiber concrete are investigated.
- Flexural strength and fracture energy improved with basalt fiber addition.
- The increase in fiber content and length contributed to resistance to abrasion.
- Abrasive wear of concrete with basalt fiber can be predicted.

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ABSTRACT

In this paper, the effect of basalt fiber (BF) on physical and mechanical properties of concretes is reported. High strength and normal strength concretes were cast by adjusting water to cement ratios as 0.45 and 0.60 and a total of ten mixtures were prepared by incorporating different amounts and sizes of BF into those concretes. Test results showed that an improved flexural strength, fracture energy and abrasion resistance can be obtained by using BF even at low contents. However inclusion of BF in concrete resulted in a decrease in the compressive strength. A quite strong relationship was established between abrasive wear and void content and flexural strength of concretes.

1. Introduction

The use of fibers has a long history going back at least 3500 years. In more recent times, different types of fibers such as asbestos, cellulose, steel, polypropylene and glass have been used to reinforce cement products [1]. Introduction of fibers in concrete can help to improve the rheology, plastic cracking characteristics, the tensile or flexural strength, the impact strength and toughness and to control cracking and the mode of failure by means of post-cracking ductility and to improve durability [1–3].

Basalt is a volcanic igneous rock which performs well in terms of strength, temperature range, and durability [4]. Basalt fibers (BF) are obtained from basalt rocks through melting process. The basalt rocks can be so finely divided into small particles that it becomes possible to produce into a form of fibers. In addition, the BFs do not contain any other additives, which make additional advantage in cost. It is known that the BFs have better tensile strength than the E-glass fibers, greater failure strain than the carbon fibers as well as good resistance to chemical attack, impact load and fire with less poisonous fumes [5]. These features, combined with its lower cost, could make basalt a suitable replacement for steel, glass, and carbon fibers in many applications [4]. However, previous studies on the use of BFs in concrete are limited; there are only a few papers available in the literature [4–8]. Therefore further experimental studies should be conducted on the use of BF in cement based composites to characterize its effects on physical and mechanical properties of composites.

The use of fibers provides a reduction in abrasive wear of concrete which is reported to be affected by several parameters such as aggregate properties, mixture proportions, concrete strength, type and quantity of cement, the use of supplementary cementitious materials, addition of fibers, curing conditions and time, environmental conditions, surface treatment, water to cementitious materials ratio, workability and air entrainment [9–15]. Among these parameters compressive strength is generally reported as the most important factor that influences the abrasion resistance of concrete [9–14]. Atiş [16] reported that the increase in compressive strength and a decrease in porosity resulted in a decrease in the abrasion of fly ash concrete.

The use of fibers may also considerably increase the toughness and energy absorption capacity of cement based materials [17].

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Ding et al. [18] reported that the addition of steel and polypropylene (PP) fibers aids in converting the brittle properties of concrete into a ductile material with an increased flexural toughness. However they observed no significant trend of improving compressive and flexural strength. Nataraja et al. [19] investigated the effect of two steel fibers with different lengths and aspect ratios on toughness characterization of concrete and found that flexural toughness increased as the fiber volume fraction is increased for a given aspect ratio of the fibers. The increase was also observed as the aspect ratio is increased, for a given volume fraction. Dias and Thaumaturgo [6] found that the addition of 1.0% BF by volume resulted in 26.4% and 12% reductions in the compressive and splitting tensile strengths of the concrete, respectively. They also mentioned that concretes with lower fiber content (0.5% by volume) presented negligible changes in the compressive and splitting tensile strength relative to concrete without fibers.

Although several types of fibers have been used in concrete, however there is only a limited study reported in the literature on the use of BF in concrete. In this study, therefore, it is aimed to evaluate the effects of admixed BF content (2 and 4 kg/m^3) and length (12 and 24 mm) on the fresh and hardened properties of normal strength and high strength concretes produced with 0.60 and 0.45 water to cement (w/c) ratio respectively. This objective is supported by various tests such as workability, water absorption, void content, abrasion resistance, compressive strength, flexural strength and fracture energy. Test results were also evaluated in developing mathematical equations to predict abrasion resistance of concretes with BF.

2. Experimental study

2.1. Materials and mix proportions

The materials used in this research include limestone coarse aggregate with a particle density of 2.71 kg/dm^3, natural river sand with a particle density of 2.58 kg/dm^3, crushed limestone sand with a particle density of 2.64 kg/dm^3, cement, chemical admixture and BF. Maximum particle size of the coarse aggregate, natural river sand and limestone sand was 11.2 mm, 2 mm and 4 mm respectively.

The type of cement used in all concrete series was CEM I 42.5R and its properties are presented in Table 1. A *modified polycarboxylate polymer* based superplasticizer was also used at varying contents to produce concretes with a slump in the range of 13 ± 3 cm.

BF with a density of 2.8 g/cm^3 and a length of 12 and 24 mm was used throughout the study at varying contents. Physical and mechanical properties of BF, provided by the manufacturer, are presented in Table 2.

As summarized in Table 3, a total of 10 mixtures were prepared with constant cement content of 350 kg/m^3 and two different w/c ratios of 0.45 and 0.6. For each w/c ratios BF was added at two different contents of 2 and 4 kg/m^3 and lengths of 12 and 24 mm. In Table 3, R45 and R60 represents the reference concretes with w/c ratios of 0.45 and 0.60 respectively. The other mixtures were coded in the form of FXX/YY/Z; in which "F" represents BF addition, "XX", "YY" and "Z" represents the fiber length, w/c ratio and fiber content respectively. Mixing was performed in a 45 l capacity pan mixer with a vertical rotation axis and fresh concrete properties were determined immediately after the mixing and listed in Table 3.

Table 1
Chemical, physical and mechanical properties of cement.

Chemical properties (%)		Physical properties	
Insoluble residue	0.57	Specific gravity	3.15
SiO_2	19.75	Setting time (start, min)	170
Al_2O_3	4.28	Setting time (end, min)	210
Fe_2O_3	3.48	Volume expansion (mm)	1
CaO	64.31	Specific surface (cm^2/g)	3591
MgO	1.14		
SO_3	2.70		
$Na_2O + 0.658K_2O$	0.67	Compressive strength	
Cl^-	0.0087	28 days (MPa)	50.0
Loss of ignition	2.57		
CaO (free)	1.29		

2.2. Sample preparation and testing procedure

In order to determine the effect of BF addition on compressive strength and abrasion resistance, cube specimens with dimensions of 100 mm and 71 mm were cast respectively. Additionally, density, water absorption and void content were determined on 100 mm cube specimens. Furthermore, 20 notched beams (2 for each mixture) with dimensions of 70 × 70 × 285 mm and with a notch depth and thickness of 30 mm and 3 mm were tested by three-point loading to determine the flexural strength and fracture energy, as illustrated in Fig. 1. Before performing hardened concrete tests at 28 days, all specimens were cured in water at 20 ± 2 °C.

Compressive strength was determined on three 100 mm cubic specimens for each mixture according to EN 12390-3 [20].

Böhme test (EN 1338) [21] was used for assessing the abrasion resistance of concretes. Test was performed on three specimens for each mixture. The specimens were initially dried to constant mass at a temperature of 105 ± 5 °C. Specimens were then placed on the test track of a 750 mm diameter rotating disc on which a 20 g of standard abrasive (artificial corundum) is poured. Prior to testing, the density of the specimens (ρ_R) was determined by measurements, to the nearest 0.1 mm, and by weighing, to the nearest 0.1 g. The specimens were then subjected to grinding for 22 revolutions under a constant load of 294 ± 3 N and 30 rev/min rotation speed. The specimens were tested for 16 cycles, each consisting of 22 revolutions. The abrasive wear was calculated after 16 cycles by determining the loss in specimen volume by the following equation.

$$\Delta V = \Delta m / \rho_R \quad (1)$$

where ΔV (mm^3/50 cm^2) is the loss in volume after 16 cycles; Δm (g) is the loss in mass after 16 cycles and ρ_R (g/mm^3) is the density of the specimen. During the test, the loss in mass measurements was also taken for each specimen after 4, 8 and 12 cycles to quantify the abrasive wear at these cycles.

Notched specimens were used for determining flexural strength and fracture energy of concrete mixes. The notches were formed using a diamond saw 1 day before the flexural test. The deflection, evaluated in the proximity of the notch on the lower side of the sample, was measured using a linear variable displacement transducer (LVDT). The load was applied using a closed-loop testing machine (Instron 5500R) at a rate of 0.1 mm/min. Load and deflection values were recorded continuously for the duration of the test and data collection was continued until the load on samples reduced to about 100 N. Thus, load versus deflection curves were obtained for each specimen. The fracture energy (G_F) was determined by using the following formula given by RILEM 50-FMC Technical Committee [22].

$$G_F = (W_0 + mg\delta)/[b * (d - a)] \quad (2)$$

where W_0 represents the area under the load-deformation curve, m is the weight, δ is the maximum deformation, b is the thickness, d is the height, a is the notch depth of the specimens and g is the acceleration due to gravity.

Physical properties of concretes such as density, water absorption and void content were determined on 2 specimens for each mixture according to ASTM C 642 [23].

3. Results and discussion

3.1. Workability

Slump values of the concrete mixes are presented in Table 3. In order to provide a target slump of 13 ± 3 cm, superplasticizer was used at varying contents. The fibers, generally, are known to deteriorate the workability of concrete. This effect is characteristic of all fibers and partly results from the consumption of a fraction of mixing water and cement paste for coating the surface area of the fibers [6]. Due to larger surface area than aggregates, fibers need to adsorb a lot of cement paste to wrap around, which increases the viscosity of the mixture [24]. In this study, generally, fiber addition increased the superplasticizer quantity and increase in fiber content caused further superplasticizer requirement to obtain the target slump. Doubling the fiber length caused even higher demand for superplasticizer content as can be seen in Table 3. Although not observed in this study, it should be noted that higher amount of admixture might retard the time of set of concrete [25] and might also cause excessive slump which in turn might cause segregation problems.