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Investigation of carbon and acrylic fibre-reinforced mortars

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Abstract. This paper presents an experimental study on the compressive, flexure, toughness and abrasion behaviours of acrylic and carbon fibre-reinforced mortars. The mechanical and physical properties of seven different composite mortars samples containing different amounts of textile fibres were compared with reference samples prepared with standard sand, cement and water. The characteristic properties of the mortars were improved by adding fibre. However, this improvement is directly related to the type and length of fibre used for reinforcing the concrete structure. Mortars containing both carbon and acrylic fibre had more compressive strength. In particular, mortars containing acrylic and carbon had 32% higher compression strength than control mortars. Sample AC1 produced with both carbon filaments and acrylic fibres has the highest compressive strength. The brittle property of mortars can be improved by reinforcing it with carbon filaments or acrylic fibres. The toughness of specimens depending on both the fibre type and the length of fibres were observed.

1. Introduction

Mortar is a construction material with a low shrinkage resistance. There is a non-linear relationship between the stress and strain values of a mortars material *l*. In other words, permanent deformations are observed for a while after applied loads have been removed, and then the material returns to its original form slowly. Tensile, compressive and flexural forces are applied to a concrete slab when a tire is passing over it. These forces disappear by changing their directions after the contact between the tire and road ends. These force variations are consistently repeated on a concrete road in the case of heavy traffic loads, and these variations should be kept under the value of the fatigue strength of the concrete road. In contrast, concrete expands and shrinks depending on the temperature changes, such as other materials. In addition to this, the upper and lower surfaces of coverings should be able to withstand substantial forces, such as bending and flexural forces, due to daily or seasonal temperature and humidity differences [1,2].

Fibres added to plain mortars improve its mechanical properties such as fracture toughness, ductility and crack-width control. This technique has been used in the construction of concrete pavement and slabs on the ground for almost 50 years. By reinforcing a construction material with textile fibre, it is possible to improve the cracking performance of concrete pavement, reduce the required slab thickness,

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and increase the allowable joint spacing. Based on experience, engineers have traditionally implemented the design enhancements provided by fibres. The mechanical improvement gained by adding fibres to the mortars, such as toughness, has not been reflected in current structural design codes for concrete pavements. Due to the lack of a standard thickness design approach and accompanying cost-benefit analysis, there has been limited adoption of fibres in rigid pavement applications [3-10]. The performance of steel fibre-reinforced concrete pavements for airfields has been investigated. It was concluded that 1-2% volume fractions of steel fibre caused a 35-70% increase in the flexural strength of concrete, and improved the ultimate capacity of the slab [11,12].

In this study, acrylic and carbon fibre-reinforced mortars were produced, and their compressive strength, flexure resistance, toughness, water permeability performance and abrasion loss values were compared with each other and with a 100% mortars sample.

2. Materaila and methods

2.1. Materials

Fine aggregate was obtained by sieving river sand, and the particle sizes of sieved aggregate were between 4 mm and 60 μ. The amount of water affects all of the characteristic properties of fresh and hardened concrete. To improve the rigid structure of the concrete, 800 carbon filament (12 K), 2.5 dtex acrylic filament and 2.5 dtex acrylic fibre that was 6 mm long, were supplied. These filaments were cut into 1 cm and 15 cm long fibres. These fibres were added to the mortars in the amounts of 0.25%, 0.5% and 1% by weight (Figure 1).

2.2. Methods

Seven different samples were separately produced by adding different amounts of fibres or filaments to mortars mixtures containing 1350 g river sand, 450 g cement and 225 cm^3 water. Moreover, a reference sample was prepared to compare the mechanical and physical properties of these 7 composites. They were shaped with 4 cm $\times$ 4 cm $\times$ 16 cm moulds during a 24-hour period. The moulding process was performed in 3 steps by skewing samples 25 times at the end of each step according to the standards. All samples were cured for 60 days. Samples and their contents are given in Table 1. The R (reference) samples were made with 1350 g of sand, 450 g of cement, and 225 cm^3 of water. C1 and C2 were made with chopped carbon filament, and C3 was made with 4 chopped filaments in each sequence of 3 lines. A1 was made with acrylic fibre, and A2 was made with dtex acrylic tow chopped acrylic filament. AC1 was made with acrylic fibre + 4 carbon filaments 15 cm long in each sequence of 3 lines, and AC2 was made with chopped carbon filament + acrylic fibre.

Figure 1. Fibres, filaments, cement, aggregate and water.

The compressive and flexure strength, toughness, abrasion resistance and water permeability tests were

Table 1. Abbreviations of produced samples and their contents.

Samples	Fiber type						
	Carbon				Acrylic		
	Amount (g)	*K*	Tex	Length (mm)	Amount (g)	dtex	Length (mm)
C1	5,1	12	804	10	-	-	-
C2	10,125	12	800	10	-	-	-
C3	10,125	12	800	150	-	-	-
A1	-	-	-	-	20.25	2,5	60
A2	-	-	-	-	20.25	2,5	10
AC1	10,125	12	800	10	10,125	2.5	15
AC2	10,125	12	804	10	10,125	2.5	60

Note: Dtex is known as a thickness measurement for the synthetic based yarns (10 dtex=1 tex) applied to all samples, and the water permeability and toughness values of the samples were measured. Six specimens with dimensions 40 mm × 40 mm × 40 mm, obtained from the specimens used in the flexural strength tests, were tested under the same laboratory conditions as those applied in the flexural strength test.

2.2.1. Compressive strength

In this experiment, a uniaxial compressive resistance testing device with a 3000 kN load capacity was used to measure the compressive strengths of the samples (Figure 2). The compressive strength values of 8 different samples cured for 60 days are illustrated in Figure 3.

2.2.2. Flexure strength

Samples were tested with the three-point bending test device shown in Figure 4, and the test results are given in Figure 5.

Figure 2. Compressive strength test machine.

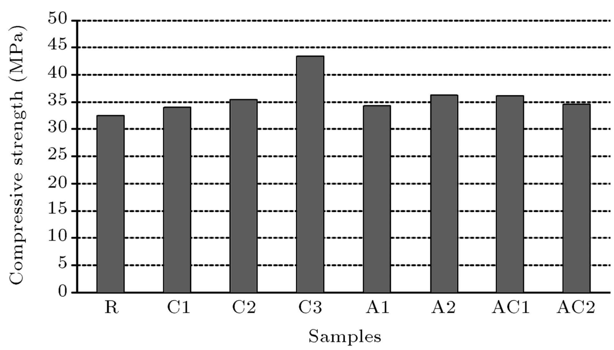

Figure 3. Compressive strength of samples.

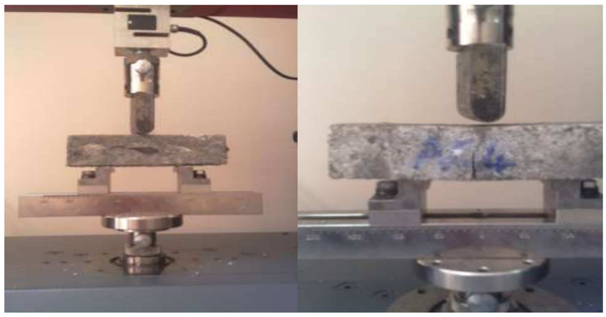

Figure 4. Three-point bending test.

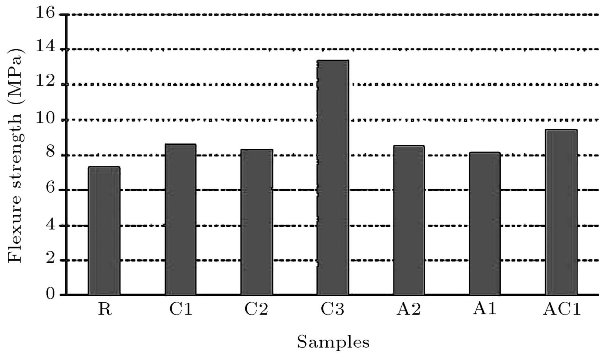

Figure 5. Flexure strength of samples.

2.2.3. Toughness values

Toughness is the amount of energy consumed during plastic deformation until the material breaks. It is also related to the strength and ductility of the material. Therefore, it is very important for construction materials. The ductility of a material is provided by the textile fibres present in [13-15]. The bending strengths of hardened plastic concrete specimens were measured with a three-point bending test device (Figure 4). The toughness of the samples was calculated depending on the stress-strain curve. The toughness values of the samples were given in Figure 6.

2.2.4. Abrasion values of concretes

Abrasion is a significant durability problem, especially in mass concrete with wide surfaces, concrete pavement and dams [16-18]. To measure abrasion resistance, 71 cm × 71 cm × 71 cm samples were produced and then

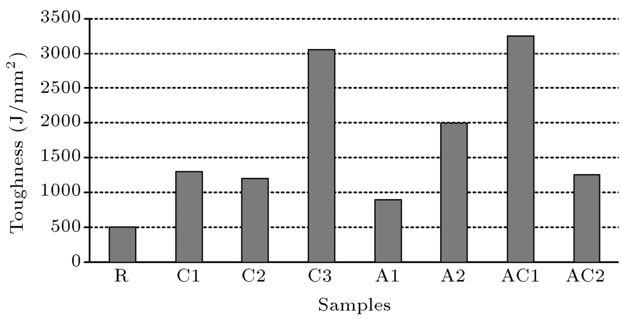

Figure 6. Toughness values of mortars.

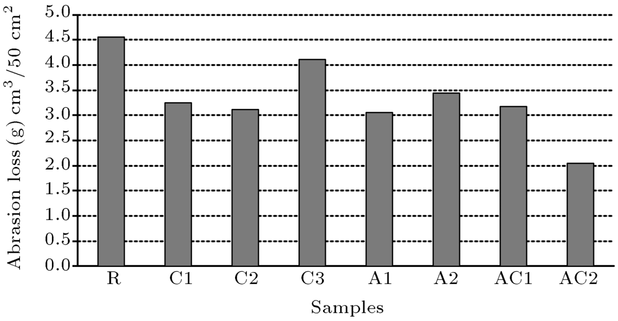

Figure 7. Abrasion resistance of samples.

cured for 90 days. The obtained test results are shown in Figure 7.

These results were determined according to the formula given below [19]:

$$WL = (h_1 - h_2) \times 50/A, \quad (1)$$

where:

WL : Weight loss,

h_1 : Sample volume before the abrasion test (cm^3),

h_2 : Sample volume after the abrasion test (cm^3),

A : Abrasion surface area of the sample.

2.2.5. Permeability

The water permeability values of the samples were obtained by considering the Darcy Laws. This test was applied to cylindrical samples cured for 7, 28 and 90 days. It was performed according to the TS 3455 standard. The test results were recorded by measuring the amount of water passing through the samples and the depth of water. The permeability test results are shown in Figure 8.

3. Results

3.1. Compressive strength

The minimum compressive strength required by the Turkish standard for mortar is 15-20 N/mm^2. However, the values for the fibre-reinforced mortars tested in the present study are much higher, namely, 34.0-52.2 N/mm^2. In practical terms, this means that by using fibre-reinforced concrete, the thickness of the outer load-bearing walls can be reduced substantially.

Considering the average compressive strength, the compressive strength of group C specimens was found to be 21% higher than that of group A specimens and 32% higher than that of the reference specimens. In contrast, considering the average compressive strength, the compressive strength of group C specimens was found to be 14% higher than that of reference specimens. The C3 samples produced with both carbon filaments had the highest compressive strength value. The compressive strength of samples could be decreased by shortening the fibre length. It was noticed that the compressive strength values of mortars containing carbon filaments were also higher than those of the other samples.

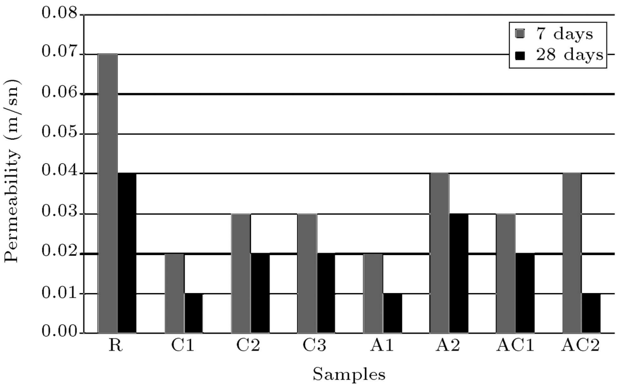

Figure 8. Water permeability values of samples.

3.2. Flexure strength

The flexure strengths of fibre-reinforced mortars were generally higher than that of the reference sample. According to the obtained test results, the flexure strength of the reference sample was determined to be 7.30 MPa, whereas sample C3 had the highest flexure strength. In other words, the flexure strength was improved by increasing the length and amount of acrylic and carbon fibre used in the concrete. Both carbon and acrylic fibres improve the flexibility of mortars and increase the toughness. Mortar containing acrylic has a higher toughness. The toughness of the specimens depends not only on the fibre type but also on the fibre length.

The flexure strengths of group C specimens were found to be 27% higher than those of group A specimens and 32% higher than those of the reference specimens. In contrast, the flexure strengths of group C specimens were found to be 28% higher than those of the reference specimens.

3.3. Abrasion resistance

The highest abrasion loss was observed in the reference sample. In contrast, the abrasion losses of carbon fibre-reinforced samples were higher than those of composite mortars containing acrylic fibres. The abrasion rates of concretes are directly related to the fibre type and quantity. It was observed that the abrasion resistance of all samples was obtained under the value determined in the TS EN 1338 standard.

3.4. Permeability

The water permeability rate of mortars is directly related with the fibre type and length. However, all specimens have lower absorption rates than those of reference mortars.

It can be observed from Figure 6 that in terms of the water absorption of the mortars, specimens with acrylic fibre had a considerably lower value than other specimens. Reference specimens show considerably higher percentages of water absorption. Water absorption correlated well with the abrasion value of mortars [20].

Considering the average water permeability at 7 days, the water permeability of group A specimens was found to be 74% lower than that of group C specimens and 90% lower than that of reference specimens. In contrast, the water permeability of group C specimens was found to be 63% lower than that of reference specimens. Considering the average water permeability at 28 days, the water permeability of group A specimens was found to be 66% lower than that of group C specimens and 87% lower than that of reference specimens. In contrast, the water permeability of group C specimens was found to be 60% lower than that of reference specimens. Both AC1 and AC2 samples produced with both carbon filaments and acrylic fibres had water permeability values lower than the reference but higher than the A specimens.

4. Conclusion

Based on the investigation reported in this paper, the following conclusions can be drawn:

1. Concrete samples containing textile fibres have better mechanical and physical properties. The characteristic properties of concrete are improved by adding fibre. However, this improvement is directly related to the type and length of fibres used for reinforcing the concrete structure.
2. Concretes containing both carbon fibre had more compressive strength. In particular, mortars with acrylic and carbon have 32% higher compression strength than the reference concrete.
3. Sample C3 produced with both carbon filaments has the highest compressive strength.
4. The water permeability values of acrylic fibre-reinforced samples are generally lower than those of carbon fibre-reinforced concretes and the reference sample.
5. The brittle property of concrete can be improved by reinforcing it with carbon filaments or acrylic fibres. The toughness of specimens depends on both the fibre type and the length of the fibres.

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Biographies

Hanifi Binici received his Engineering Degree in Civil Engineering from the University of Cukurova, Adana, in 1989 and PhD degree in Engineering Science from the University of Cukurova, Turkey, in 2002. He is currently Associate Professor in the Department of Civil Engineering, Kahramanmras, Sutcu Imam University, Turkey, where he is serving as Director of the High School of Elbistan. His research and teaching activities have focused on the issues of materials and design. His research interests are in the general area of materials and durability of concrete, especially mineral admixtures and microstructures, including cement, concrete, etc. He has published over 250 research articles on related subjects, including cement, concretes and mud brick. He is currently serving as a Co-editor of journal of the Kahramanmaras Sutcu Imam University Journal of Engineering Sciences.

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