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Use of polymer fibres recovered from waste car timing belts in high performance concrete

Ali Reza Khaloo, Amin Esrafili *, Masoud Kalani, Mohammad Hosein Mobini

Sharif University of Technology, Tehran, Iran

HIGHLIGHTS

- We applied strands recovered from waste car timing belts into HPC.
- Adding waste fibre improved the modulus of rupture and flexural toughness.
- High volume of recycled fibre can cause adverse effects on concrete.
- The experimental results confirmed promising applications of recycled fibre in HPC.

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ABSTRACT

The present paper discusses the possibility of adding recycled polymer fibres to high performance concrete (HPC). Fibres used in this study were recovered from discarded car timing belts. To investigate different characteristics of the concrete specimens several destructive and non-destructive tests, such as compressive strength, modulus of rupture, flexural toughness, ultrasonic velocity and electrical resistance tests were carried out. In addition, slump flow tests were conducted on the fresh concrete.

Experimental results from the study showed that the use of low percentages (up to 0.5%) of waste fibres improved the modulus of rupture and flexural toughness. Based on ultrasonic and electrical resistance test results, an increase in fibre percentage also increased the pore volume and electrical resistance of the fibre reinforced concretes with respect to a control mixture.

1. Introduction

Nowadays sustainable development is a major global concern. Finding new applications for waste material can help us to move toward sustainable development. Re-utilisation of waste material in concrete has positive environmental effects as well as reduces the costs of projects [1]. Despite these positive points, use of waste material in concrete may reduce its mechanical performance.

According to statistics provided by the international organisation of motor vehicle manufacturers, it was estimated that in 2002 over 58 million cars and commercial vehicles were produced worldwide and this number increased to 84 million by 2012. Based on these statistics the number of cars produced increased by 45 percent during those ten years and it is believed that this rising trend will continue in the coming years.

A timing belt is used in most modern cars and must typically be replaced every 60,000 to 100,000 miles. Therefore, a large number of timing belts are discarded annually and as of yet no specific application for these waste belts has been offered. Some of these timing belts are reinforced with polymer strands which improves their behaviour in tension. Timing belt strands are thermoset. Recycling thermoset strands is difficult because it is not possible to heat solid thermoset material and reform it into new shapes. In addition, because of thermoset's very long decomposition period disposing of it in landfills is not recommended.

High performance concrete (HPC) properties have been developed for specific applications. Due to the low water–binder ratio of HPC, superplasticizers must be used to improve the workability of the concrete [2]. High strength and good workability are common characteristics in HPC. Low absorption and high durability are additional reasons to use HPC.

The last three decades have seen a growing interest in the use of fibres in cementitious materials [2,3]. The goal of this study was to find a new application for discarded car timing belts and to improve the characteristics of HPC with waste fibre reinforcement. Several studies have been carried out to examine the use of different types of waste particles in concrete such as PET from waste

* Corresponding author. Tel.: +98 9192111047.
E-mail address: Mr.Esrafili@gmail.com (A. Esrafili).

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bottles and rubber and steel from tires [1,4–12]; but the application of car timing belt strands in concrete is new. In this study, polymer strands of discarded car timing belts were extracted and used instead of conventional fibres in HPC. Tests for compressive strength, modulus of rupture, and flexural toughness were performed in order to determine the mechanical properties of hardened concrete. In addition, ultrasonic and electrical resistance tests were carried out at different concrete ages. Fresh concrete properties were measured by a slump flow diameter test. To consider the effect of length, fibres of two different lengths, 2 and 4 cm, were examined. Fibres were added to concrete in 0.2, 0.5, 1, and 1.5 percentages of the total volume of concrete. A total of eight series of the fibre reinforced concrete with different volume and lengths of fibre were prepared. In addition, a plain mix served as a control mixture.

Fig. 1. Recycled fibres.

2. Material and methods

2.1. Raw materials and specimen preparations

Type II cement conforming to ASTM C150 [13] specifications and with a specific gravity of 3.12 g/cm^3 was used in this study, along with a 10% substitution of silica fume by weight. The chemical compositions of cement and silica fume are shown in Table 1. The coarse aggregates were made up of crushed limestone with a specific gravity of 2.63 g/cm^3 and a maximum size of 16 mm. For the fine aggregate natural river sand having a specific gravity of 2.60 g/cm^3 and a fineness modulus of 3 was used. Both the coarse and fine aggregates met the requirements of ASTM C33 [14].

To improve the workability of the fresh concrete a commercial high performance superplasticizer meeting ASTM C1017 specifications [15] was used. The superplasticizer had a base of poly-carboxylic with a density of 1.12 g/cm^3.

In this study fibres are obtained from polymer strands used in car timing belts. In order to extract the polymer strands, car timing belts were cut into a straight shape. Afterward polymer strands were pulled out by hand. Obtained polymer strands were chopped into 2 and 4 cm lengths; however, due to the curvature of the fibres there were minor variations in their lengths. The cross section of these polymer strands were semi-circular with an average diameter of 0.6 mm. Chemical properties of the fibres were tested at the Zamzam plastic laboratory (Mashhad, Iran) and the Differential Scanning Calorimetry (DSC) test indicated that the fibres were made of polyester with the surface covered with a resin (see Fig. 1).

The fibre reinforced concrete mixtures were designed with the following code: HL-V. The first letter in this code stands for high performance concrete and is followed by a number (L): 2 or 4, which represents the length of fibre in cm. The last letter (V) represents the dosage of the fibre. For example, H2-1.5 represents a high performance concrete reinforced with 2 cm fibres where the fibre volume fraction is 1.5 percent. In addition, H0 represents a control mixture without any fibre. The control mixture (H0) was found in some initial tests to develop into plain concrete with a compressive strength of 70 MPa at the age of 28 days and a slump flow diameter in the range of 40–60 cm.

Table 2 gives the details of the mixture proportions and properties of the fresh concrete. A constant water–binder ratio (W/B) of 0.35 was kept for all mixtures. The amount of superplasticizer needed to keep the slump flow diameter in the range of 40–60 cm was found by trial and error.

Table 1
Chemical analysis of cement and silica fume (values are in percentages).

Chemical analysis	SiO_2	Fe_2O_3	CaO	Al_2O_3	MgO	SO_3	Na_2O_{eq}
Cement	21.4	3.9	62.8	5.4	1.7	2.5	0.6
Silica fume	94.1	1.8	0.4	0.6	0.3	0.1	1.1

2.2. Experiment

For compressive strength tests, concrete cubes of 100 × 100 × 100 mm were cast, and prismatic specimens of 100 × 100 × 500 mm [16,17] were prepared from the same batch to conduct flexural tests. For each mix design nine cubic and three prismatic specimens were tested. Fig. 2 shows specimens during casting.

One day after casting, the specimens were demolded and placed in a lime-saturated water tank at a temperature of 20 ± 2 °C and a relative humidity (RH) of 100% until the day of testing.

Prismatic specimens were tested with a three-point bending machine under displacement control at a gradient of 0.01 mm/s. The mid-point deflections at load point were measured. The specimens were tested at the structural dynamic strong floor lab at Sharif University of Technology.

An AC-Impedance spectroscopy was used to measure the electrical resistivity of the specimens. Ultrasonic tests were performed according to ASTM C597 [18]. The compressive strength, ultrasonic, and electric resistivity tests were performed on 100 × 100 × 100 mm cubic specimens at the age of 7, 28, and 91 days.

3. Results and discussion

3.1. Experiments on fresh concrete

The results of previous studies demonstrated that increasing the fibre volume percentage decreases the workability of concrete and mortar [8,19–22]; similar results were obtained in this study. As shown in Table 2, the amount of superplasticizer required to keep the slump flow diameter in the range of 40–60 cm increased as the fibre volume percentage increased. The increment of slump flow in fresh concrete is favourable if the consistency of the concrete is maintained and no segregation or bleeding occurs. Higher slump flow makes placing and compaction of concrete easier [2]. Visual inspection did not prove any segregation or bleeding of the fresh concrete.

3.2. Experiments on hardened concrete

3.2.1. Compressive strength

Fibres in concrete have two different effects on compressive strength. Firstly, fibres knit micro cracks together and help prevent crack propagation [1,23]. Limiting crack propagation increases compressive strength. On the other hand, adding fibre increases the porosity in fibre reinforced concretes as compared to plain concretes [1]. This increase of pore volume has a negative effect on