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Effect of polymer fibers recycled from waste tires on properties of wet-sprayed concrete

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HIGHLIGHTS

- Study compares properties of wet-sprayed concrete made with PP and RTPF fibers.
- RTPF as received from factory can serve as substitute for multifilament PP fibers.
- RTPF do not impair the pumpability of sprayed concrete.
- Higher amounts of RTPF lowers deformations caused by autogenous shrinkage.
- Addition of RTPF improves freeze–thaw resistance.

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ABSTRACT

This study explores the possibility of using recycled tire polymer fibers (RTPF) as a micro-reinforcement in wet-sprayed concrete mixes. Two groups of mixes were made: sprayed concrete mixes with and without an air-entraining admixture. Each group comprised mixes with 0.9 and 1.8 kg/m^3 of RTPF. To facilitate comparison, the groups contained either a plain mix, without fibers, or a mix with polypropylene (PP) fibers, usually used to control early-age cracking. The mixes were tested for their transport properties, including capillary absorption and gas permeability, freeze–thaw resistance, and autogenous and restrained deformation. Results show the beneficial effect of RTPF during freeze–thaw cycles and the deformation resistance of wet-sprayed mixes. Observed differences in the transport properties between mixes with and without air entrainment are explained by changes in pore structure, tested using mercury intrusion porosimetry (MIP).

1. Introduction

Sprayed concrete can be employed in many applications, from tunneling and mining to slope stabilization and concrete repair. It offers several advantages in industrial applications, including good substrate adhesion, the opportunity to dispense with formwork, strength that rapidly increases during curing, good compaction, and ease of application in restricted areas. During the production of sprayed concrete, different admixtures and additions are used to regulate the required properties of the final product. Air-entraining agents are added to wet-sprayed concretes to increase freeze–thaw resistance. However, during pumping under high pressure, entrained air can be compressed or destroyed, causing up to half of the air being lost [1]. Morgan et al. [2] investigated the influence of 38-mm-long fibrillated polypropylene (PP) fibers on the freeze–thaw resistance of shotcrete mixes lacking entrained air. Their testing included measuring the fundamental transverse frequency and mass change and showed a correlation between the freeze–thaw resistance and PP fiber content, since by increasing the fiber content, the resistance of the concrete to freeze–thaw cycles improved.

Due to the large exposed surface, sprayed concrete is prone to cracking induced by early-age plastic shrinkage. To control this phenomenon, synthetic microfibers, applied at up to 1 kg/m^3, can be used to reduce plastic shrinkage cracking. Additionally, microfibers reduce permeability and increase the fire-spalling resistance of sprayed concrete [3–6]. The material content and transport properties of sprayed concrete are dependent on nozzlemen skills during application and the use of appropriate equipment, especially during dry-mix spraying [7,8]. Compared to the conventional concrete, sprayed concrete usually has a better compaction, leading to higher compressive strength, higher rapid chloride penetration resistance and lower water absorption [8]. However, presence

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of fibers can make compaction more difficult, causing more entrapped air in the concrete [9]. At the same time, if present, PP fibers can reduce concrete permeability by filling pores in the structure of the matrix [10].

To design an eco-friendly cement-based composites, including sprayed concrete, several types of alternative, natural or recycled fibers have been investigated in the literature [11–13]. One is recycled tire polymer fibers (RTPF) from end-of-life tires [14]. Currently, RTPF are mainly sent to landfills or valorized as an alternative fuel during cement production. The main challenge when using RTPF is storage, since they are extremely flammable and their low weight allows them to be easily carried by the wind. Based on limited literature data [15–18], RTPF do not induce negative effects on the mechanical properties of concrete and may have beneficial effects on the early-age deformation of concrete [15,17,18]. The effect of RTPF on sprayed concrete has not been sufficiently investigated, and due to the difference in compaction processes, fiber-reinforced poured and sprayed concrete are expected to have different properties [9].

The main aim of this experimental study is to investigate the effect of RTPF on the properties of wet-sprayed concrete and to investigate whether recycled polymer fibers (RTPF) obtained from waste tires can be used as an alternative to polypropylene fibers (PP) in wet-sprayed concrete mixes. To compare mixes with RTPF and PP fibers, their transport properties, freeze–thaw resistance, deformation and cracking control by restraints were tested. In the framework of this experimental study, RTPF are used for the first time for producing sprayed concrete mixes that can be used for slope protection in different classes of environmental exposure.

2. Experimental program

2.1. Materials

All concrete mixes were prepared with CEM II/B-M (S-V) 42.5 N, crushed limestone aggregate (0/4 mm, 4/8 mm) and with chemical admixtures (plasticizer and air-entraining admixture with superplasticizer). Fig. 1 shows the aggregate grading curves with a reference grading curves taken from [19]. All mixes had the same w/c ratio of 0.46.

For this study, two types of fibers were used as reinforcement: multifilament polypropylene (PP) fibers presented in Fig. 2a and recycled tire polymer fibers (RTPF) as shown in Fig. 2b. The properties of the two types of fibers are presented in Table 1.

Microscopic examination (Olympus BX 51, micromorphology) of RTPF was performed to determine the average diameter of the RTPF. Three different types of fibers were found with average diameters of 10, 20, and 30 μm (Table 1). Fiber distribution length analysis showed that 80% of the RTPF are <12 mm long (Fig. 3). Taking into account the high contamination of RTPF by rubber particles, an investigation determined the mass of each constituent in the RTPF sample. Statistical analysis showed that fine rubber with very short RTPF occupied more than 65% of the mass in each sample, with rubber particles less than 0.5 mm in diameter. Hereafter, the results presented refer to as-received RTPF without further cleaning, but the information gathered while cleaning the RTPF was taken into consideration during analysis of the results.

Based on the length analysis, polypropylene fibers with maximum lengths of 6 mm and diameters of 32 μm were selected for this investigation.

2.2. Mix design

Mixes were divided into two groups based on whether an air-entrainment agent was used (Table 2). In both groups, wet-sprayed mixes without fibers were prepared as a reference (labeled SC and SC_A). Two mixes with the same base composition as SC, but with two different amounts of multifilament polypropylene fibers were prepared and labeled 0.9 PP and 1.8 PP, with the first number denoting the mass of fibers (in kg/m^3) used in the mix. Finally, two mixes with the same composition, but with PP fibers substituting for RTPF, were prepared, and likewise labeled as 0.9 RTPF and 1.8 RTPF. Since in all mixes plasticizer or air-entraining admixture with superplasticizer were used, any significant differences in fresh concrete properties were expected to arise from the difference in fibers used.

2.3. Casting and curing

To obtain the mechanical and transport properties of the sprayed concrete, test panels were prepared using onsite spraying equipment and according to the standard HRN EN 14488-1 [20]. Sprayed concrete was sprayed into 600 × 600 × 100-mm plywood formwork using a Putzmeister BAS 1002 SV D concrete pump, with a maximum output of 20 m^3/h (Fig. 4). Concrete was sprayed from a distance of 1–2 m perpendicular to the plywood molds.

After spraying, the panels remained covered with plastic sheets to prevent water evaporation for 24 h until removing the molds. The specimens were sprayed daily with water before replacing the plastic sheets (Fig. 5c). After 28 days, cylindrical cores and cubes were extracted from the test panels (Fig. 5d) and tested to obtain the mechanical and durability properties of the sprayed concrete.

Specimens used for characterizing deformation properties (here, autogenous and restrained shrinkage) were produced under laboratory conditions, using the same mix design but with a conventional casting technique instead of spraying. Shrinkage depends on environmental conditions such as temperature and humidity, making it difficult to compare results from testing onsite and in the laboratory. A ring test is a typical method for evaluating restrained shrinkage, but due to the geometry used here, it was difficult to produce this type of specimen by standard spraying techniques [21]. If a ring specimen is prepared by spraying, cracking will occur in non-representative materials next to the form, and the results will be difficult to interpret [22]. Following, here presented results are not fully representative of behavior of mixes placed by spraying, since the effects of spraying process such as rebound have not been considered due to testing setup limitations. Results presented hereafter rather give valuable information on the comparison of mixes with

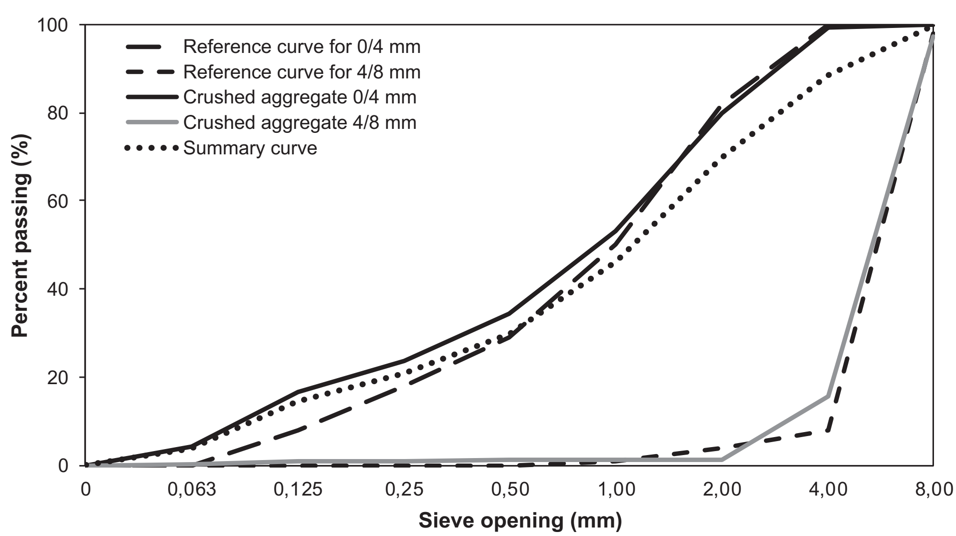

Fig. 1. Aggregate grading curves.