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Effect of elevated temperature and cooling regimes on mechanical and durability properties of concrete containing waste rubber fiber

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HIGHLIGHTS

- Waste rubber fiber used for partial replacement of fine aggregate in concrete.
- Effect of elevated temperature on the properties of waste rubber fiber concrete is examined.
- Strength, modulus of elasticity, water permeability and chloride diffusion were studied.
- Inclusion of rubber fiber causes higher reduction in properties of concrete on exposure to elevated temperature.
- Temperature higher than 150 °C leads to decomposition of rubber fiber in concrete.

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ABSTRACT

Accumulation of the waste tire is a major problem as degradation of these tires is extensively difficult. The results of experimental studies available for rubberized concrete provide a strong recommendation for the use of this waste where strength is not a major concern. The effect of partial replacement of fine aggregate by waste rubber fiber on the properties of concrete subjected to elevated temperature has been evaluated in this paper. A systematic experimental investigation has been carried out to evaluate the effect of elevated temperature on compressive strength, mass loss, static modulus of elasticity, dynamic modulus of elasticity, water permeability and chloride-ion permeability of control mix (no replacement of fine aggregate by rubber fiber) and waste rubber fiber concrete. Two types of cooling, normal cooling and fast cooling have been considered for the effect on compressive strength. Six levels of temperature with three exposure durations have been considered in this study for all the specimens. Microstructure analysis of waste rubber fiber concrete has also been carried out to investigate the effect of elevated temperature on crack pattern and bonding of rubber fiber and cement matrix.

1. Introduction

Fire is one of the most potential risks to the buildings and structures [1–2]. Many studies have observed that in case of natural or accidental fire the elevated temperatures can reach up to 1000 °C [3–5]. The concrete structures can be affected greatly by the exposure to elevated temperatures. Reduction in compressive strength and static modulus along with loss in mass and increase in permeability due to elevated temperature have been reported by many researchers [6–8]. These changes have been reported to be affected by cooling methods of concrete subjected to elevated temperature [7–9]. Fast cooling method has been found to result in more compressive strength loss as compared to normal cooling due to wider cracks in fast cooling method [7,8].

In the past decades, studies have been carried out to replace traditional materials with alternative materials such as recycled aggregates, steel slag, dimension stone waste and brick waste to produce concrete [10–15]. The effect of elevated temperature on such alternative concrete has been the focus of many studies [16–28]. Yuksel et al. [16] carried out a study for establishing effect of elevated temperature on the compressive strength and mass loss properties of concrete containing blast-furnace slag or bottom ash as fine aggregate. Mass loss at elevated temperature was found to be independent from the replacement ratio of slag or bottom ash. The percentage loss in compressive strength of these concrete specimens due to elevated temperature was reported to be more as compared to control mix for all replacement ratio.

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A study was carried out by Albano et al. [17] for the effect of elevated temperature on shredded Polyethylene Terephthalate (PET)-aggregates as a replacement of fine aggregates. It was reported that the percentage loss in flexural strength, due to elevated temperature, increased with the increase of replacement levels.

Poon et al. [18] carried out a study on the compressive strength of normal and high strength pozzolanic concretes incorporating silica fume, fly ash, and blast furnace slag at elevated temperatures up to 800 °C. An explosive spalling occurred in the concrete containing silica fume whereas distributed network of fine cracks was observed in all fly ash and blast furnace slag concretes without any spalling. The pozzolanic concretes showed a severe loss in compressive strength as compared to control mix.

Siddique and Kaur [19] carried out a study on ground granulated blast-furnace slag (GGBS) concrete and reported that at 100 °C temperature there was no significant change in loss in mass and compressive strength whereas at 350 °C, the mass loss increased and compressive strength and modulus of elasticity reduced significantly as compared to control mix. Nadeem et al. [8] carried out a performance study of fly ash and metakaolin concrete at elevated temperature and it was reported that loss in mass, increase in chloride permeability and sorptivity was more in concrete specimen containing fly ash and metakaolin in comparison of control mix at elevated temperature.

Accumulation of the waste tire is a major problem as degradation of these tires is extensively difficult. The results of experimental studies available for waste rubber tire in concrete provide a strong recommendation for the use of this waste where strength is not a major concern [22]. The utilization of waste rubber tire in concrete can thus provide innovative economic material and solve the problem of accumulation of discarded waste rubber tire. Limited studies have been carried out for the effect of elevated temperature on concrete containing replacement of natural aggregates by waste rubber tire particles [21–28].

Nayaf et al. [21] studied the effect of microsilica addition on compressive strength of rubberized concrete, containing coarse rubber aggregate and fine rubber aggregate, at elevated temperatures. It was observed that compressive strength of rubberized concrete could improve at elevated temperature of 150 °C on addition of microsilica by up to 5%.

A study was carried out by Li et al. [22] for the effect of elevated temperature on concrete containing rubber aggregates (1–4%) as addition and partial replacement of fine aggregates. It was reported that low content (1%) of rubber particles improved the efficiency to resist spalling as compared to control mix.

Hernandez-Olivares et al. [23] carried out a study on effect of elevated temperature on rubberized concrete, containing rubber fibers up to 8%, for an exposure duration of 90 min. Reduction in explosive spalling, depth of damage and curvature of long prismatic specimens was observed due to addition of rubber fibers. However, the reduction in compressive strength and stiffness was found to increase with increase in rubber content.

Guo et al. [24] investigated the behavior of concrete specimens containing crumb rubber, steel fiber and recycled aggregate when subjected to elevated temperatures. The specimens were exposed for 120 min at 200 °C, 400 °C and 600 °C temperature. Constant heating rate of 8 °C/min was maintained in the entire study. They observed that high quantity of crumb rubber results in significant loss of compressive strength at elevated temperature.

Mousa [25] studied the effects of recycled crumb rubber aggregate on the properties of concrete exposed to elevated temperature of 300 °C, 400 °C, 600 °C and 800 °C for 120 min. They observed many visible cracks on the surface of concrete samples containing 5% recycled rubber aggregate. The loss in compressive strength was higher in samples containing rubber aggregates.

Marques et al. [26] replaced both and fine and coarse aggregate with recycled crumb rubber aggregate in concrete. The samples were exposed for a period of 60 min to elevated temperature of 400 °C, 600 °C and 800 °C. They observed steep loss in compressive and split tensile strength when higher doses of recycled rubber aggregate is utilized in concrete.

Correia et al. [27] studied the effect of coarse and fine recycled crumb rubber aggregates on the fire reaction properties of concrete. They observed that presence of recycled rubber aggregate leads to poor performance of concrete samples when exposed to fire.

Guelmine et al. [28] investigated the performance of recycled crumb rubber mortar when exposed to elevated temperature of 150 °C, 200 °C, 300 °C and 400 °C. They observed that incorporation of recycled rubber has slight effect on the residual properties of mortar exposed at 300 °C and strong effect when temperature reaches 400 °C.

It is evident from the work reported above that though there are some studies available for the rubberized concrete subjected to elevated temperature; however waste rubber in form of fiber, with more than 10% replacement, has not been considered in these studies. Therefore, there is a need to carry out systematic and comprehensive experimental study to evaluate various properties of concrete containing rubber fibers for different exposure duration and elevated temperatures.

In the present work, detailed experimental studies have been carried out for the effect of elevated temperature on mass loss and change in compressive strength, ultrasonic pulse velocity, static modulus of elasticity, dynamic modulus of elasticity, water permeability and chloride ion permeability in control mix (no replacement) and rubberized concrete. The microstructure analysis of waste rubber fiber concrete subjected to elevated temperature has also been carried out. The study is undertaken for varying percentage of waste rubber fibers (0–25%) as fine aggregates with 0.45 w/c ratio. All types of specimens were exposed to six levels of temperature (27–750 °C) and three different exposure durations (30, 60 and 120 min). Two types of cooling, normal cooling and fast cooling have been considered for the effect of elevated temperature on compressive strength of control mix as well as rubberized concrete.

2. Experimental studies

2.1. Material

Ordinary Portland cement of specific gravity 3.12 and silica fume of specific gravity 2.18 were used for the concrete mixes in this study. Chemical composition of cement is shown in Table 1. Fine aggregates were quartz based natural sand having maximum grain diameter of 4.75 mm and specific gravity 2.56. The basalt based coarse aggregates of specific gravity 2.59, having continuous grain size distribution were used in this study. Super plasticizer "Glenium Sky 777" of BASF was used as an admixture to obtain the desired workability.

In this study, rubber fibers were used as partial replacement of fine aggregates. These rubber fibers are of 2 to 5 mm width, with length up to 20 mm (aspect ratio 4–10), and have a specific gravity 1.07. These fibers were obtained from mechanical grinding of waste rubber tire. Chemical composition of rubber fiber is shown in Table 2. The thermal characteristics of rubber fibers obtained by thermo gravimetric analysis (TGA) (Fig. 1) show rapid decrease in weight above 300 °C temperature. Nearly 70% loss in weight is observed when temperature reaches 800 °C.

2.2. Mix proportions

Concrete mixes were prepared using water cement ratio of 0.45 with partial replacement of fine aggregate (FA) by rubber fibers