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Mechanical properties of the concrete containing recycled fibers and aggregates

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HIGHLIGHTS

- Mixed Recycled Aggregates contain recycled materials such as concrete, facade stones.
- The recycled steel wires recovered from waste tires are used as fibers.
- Recycled fibers can retrieve adverse effect of recycled aggregates in concrete.
- The required slab thickness reduces as the recycled fibers dosage was increased.

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ABSTRACT

Mixed Recycled Aggregates (MRA) is a mixture of recycled concrete and masonry materials. These kinds of aggregates have lower strength and higher water absorption than natural aggregates. Therefore, the concrete with recycled aggregates has lower strength than the concrete with natural aggregates. Using the steel fibers recovered from waste tires in the concrete with recycled aggregates improves the mechanical properties of this concrete as well as solving the environmental problem of these waste steel wires. In this study, the effect of recycled steel fibers on the mechanical properties of normal concrete and the concrete with recycled aggregate are investigated. Additionally, the effect of fibers on the reduction of concrete pavement thickness is studied. The replacement percentage of natural coarse aggregates with these aggregates is 0, 50 and 100%, with fiber percentage being 0.5 and 1% of concrete volume. Main results indicate that by adding recycled fibers into the concrete with recycled aggregates lead to the production of structural concrete by 50% replacement of aggregates. Moreover, adding recycled fibers by 0.5 and 1% of concrete volume reduces the thickness of concrete pavement for the amount of 8 and 16%, respectively.

1. Introduction

Due to restriction in resources and maintenance the environment quality, the need to recycle materials has become inevitable. Construction and demolition waste (CWD) are considered to have a good potential to be recycled. CDW can be graded after separation and crushing, and can be used as aggregates in concrete production. Generally, CDW is buried underground. Therefore, their recycling not only solves the environment problems, but also helps to maintain the limited natural resources. Recycled concrete aggregates (RCA), recycled masonry aggregates (RMA) and Mixed Recycled Aggregates (MRA) which is a mixture of concrete and masonry materials having the highest volume amount, are the three types of aggregates produced from the recycling of CDW [1]. In industrial countries, concrete waste has the most volume quantities in construction waste so that 150 million tons of construction waste are being produced annually in the European Union [2]. 170 million tons of waste was estimated to be produced in the United States in 2003 [3].

Both increment and reduction in the strength of concrete with recycled aggregates compared with normal concrete have been reported in previous researches [4–7]. The amount of this increment or reduction of concrete strength depends on water to cement ratio (w/c) in the mixture, replacement percentage of natural aggregates, type of aggregates and aggregates moisture conditions [4]. In general, by increasing the replacement of normal aggregates with recycled aggregates, mechanical properties of concrete are reduced [5]. Moreover, in lower water to cement ratio, this reduced amount is intensified [6,7]. Based on the research

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results, if the ratio of water to cement is more than 0.55, the compressive strength of concrete with 100% of recycled aggregates is approximately equal to the strength of normal concrete [8].

Xiao et al. studied the use of recycled coarse aggregates by 30% to 100% and the results showed that replacing of these aggregates up to 30%, the decrease in compressive strength of concrete is negligible [9]. Debieb and Kenai investigated the use of crushed brick as aggregates in concrete production. The reduction in concrete compressive strength is considered by the replacement of crushed bricks as coarse aggregates, fine aggregates and a mixture of both to be 35%, 30%and 40%, respectively [10]. Wagih et al. Results indicated that the optimum percentages of recycled coarse aggregates are between 25% and 50% [5]. Carneiro et al. studied recycled aggregates replacement with a combination of 55% mortar, 20% concrete and 25% brick. Concrete with 25% of recycled aggregates has a greater strength in comparison with concrete containing natural aggregates. The increment in the strength of concrete with these aggregates is due to the change in concrete failure (fracture of aggregates) owing to better adhesion of recycled aggregates with cement paste [4].

Several solutions have been proposed to compensate the concrete strength reduction with recycled aggregates such as adding fly ash, silica fume, increasing cement amount and using fibers [2,11,12]. Since concrete is a brittle material, and its brittleness increases by strength increment, adding fibers not only strengthens the concrete, but also converts it into a ductile material, increasing its energy absorption [13]. The ability of fibers in improving concrete properties with recycled aggregates depends on type of fibers, content, aspect ratio, surface friction and tensile strength of fibers [14].

Carneiro et al. studied the effect of steel fibers on concrete with recycled aggregates. In this study, the recycled coarse aggregates by the amount of 25%, the hooked steel fibers with the aspect ratio of 65 and the volumetric ratio of 0.75% were used in the concrete. The results indicated that adding fibers and recycled aggregates increases concrete strength properties and improves failure process as compared with the control concrete. The stress-strain behavior of concrete with recycled aggregates is affected by recycled aggregates, and concrete with these kinds of aggregates is more brittle than control concrete [4]. Guo et al. showed that the fibrous concrete with the recycled aggregates has equal or less strength as compared with the fibrous concrete with natural aggregates, having more strength than plain concrete [15].

Awchat et al. used recycled concrete with steel and polymer fibers in concrete. Investigations demonstrated that increasing fibers in concrete with the recycled aggregates, the flexural and compressive strengths are increased [16]. In another study performed on glass fibers in the concrete with the recycled aggregates, the results indicated that fiber increment to 0.03% of concrete volume increases the compressive, tensile and flexural strengths [17]. Vytlacilova utilized the recycled masonry aggregates (RMA) and the recycled concrete aggregates (RCA) individually, as recycled aggregates by the amount of 100% with Polypropylene fibers. According to the results, RMA showed better performance in the concrete rather than RCA [18].

In previous researches, in addition to industrial fibers, recycled fibers are used in the concrete [19–22]. Maddah et al. investigated the effect of recycled steel fibers and recycled Polypropylene fibers on the concrete, individually and in combination, with different percentages and aspect ratios. They concluded that generally, ductility, toughness and failure of concrete after cracking are improved with these fibers, especially in combination condition [13]. Nowadays, a lot of waste tires are being released into the nature. As a case in point, 600,000 tons of waste tires are being buried annually in the European Union [23]. Every year, 242 million waste tires are produced in the United States, being approximately 1.2% of urban waste [24]. On the other hand, according to the European Commission, the burial of waste tires has been announced illegal since July 2006 [25]. However, recycling waste tires are being increased. 80% of them are being recycled, while this percentage was equal to 20% in 1990. One of the byproducts in the process of recycling waste tires is waste steel beads. Beads are made by the steel wires with high tensile strength (1500–1900 MPa), and used in car tires to ensure keeping the tire in the rim [26].

Recently, many researches have been conducted on the concrete reinforcement with these recycled steel fibers, providing acceptable results [25–26]. Moreover, the effect of various recycled fibers of car tire such as recycled tire steel, recycled tire Fabric and recycled tire rubber strip have been examined [22]. The behavior of concrete reinforced with these fibers can be comparable to that of concrete reinforced with industrially produced steel fibers [27]. The modulus of rupture, flexural toughness, and compressive strength tests on fiber reinforced HPC confirm the promising application of waste fiber to reinforce the concrete. The use of waste fiber within the range of volume ratio of 0.2–0.5% is recommended [28]. Centonze et al. investigated the behavior of reinforced concrete with the recycled steel fibers and industrial steel fibers after cracking. The results indicated that the positive effect of recycled steel fibers on the matrix toughness of concrete is similar to industrial steel fibers [29]. Based on Aiello et al. results, disordered and wave-shaped steel fibers from waste tires provide a better adhesion between cement paste and fibers. However, it seems that despite their geometrical disordered shape, these fibers have no effect on the compressive strength of the concrete [30]. Papakonstantinou et al. concluded that adding waste steel beads to the concrete, compressive strength is reduced, toughness is considerably increased and concrete workability is almost not affected [26].

The use of fibers in concrete pavements and subgrade slab production goes back to 40 years ago [31]. Fibers are used to improve the cracking performance of concrete pavements, reduce slab required thickness, and increase the allowable distance of joints [32]. Regarding Rolling's results, using steel fibers with the volume ratio of 1–2% in the airport rigid pavement increases the concrete flexural strength by the amount of 35–70%. Moreover, the slab ultimate capacity is increased according to the full-scale traffic loading test [33]. Parker's study results, the guidance for the army rigid pavement design was published in 1979 for the first time. Parker's results showed that the steel fibrous concrete with the high ratio of fiber content decreases the pavement slab thickness by an amount of 30–50% [34]. Fiber reinforced concrete, increasing concrete efficient flexural strength by 30%, reduces the required thickness of the airport rigid pavement by 17% [32]. Most of the published information about fibrous concrete pavements is associated with 1% and 2% of fibers which increases the amount of cement in these kinds of concrete compared to the plain concrete. Nowadays, using fibers in concrete slabs on the subgrade and concrete pavements has been restricted to 0.5% of concrete volume, due to economic and executive reasons [32].

2. Research aims

In this study, in order to investigate the effect of recycled aggregates on the compressive, tensile and flexural strengths of the concrete, the natural coarse aggregates are replaced with these aggregates by the amount of 0.50% and 100%. Furthermore, the Steel wires recycled from waste tires are used as fibers in the normal concrete and the concrete with the recycled aggregates by the volume ratio of 0.5 and 1%. In order to study the effect of aggregates on the concrete strength, a similar gradation is utilized for both natural and recycled aggregates. After concrete production and 28 days of curing in water, compressive strength, indirect