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Experimental and analytical evaluation of rubberized polymer concrete

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HIGHLIGHTS

- Destructive tests and non-destructive methods were conducted on rubberized PC.
- The mechanical properties of rubberized PC were determined.
- The feasibility of adding waste tire rubber to PC was investigated.
- The optimum mixture of rubberized PC was obtained by using Taguchi and ANOVA.
- The most effective factor in the compressive and tensile strengths was chipped rubber.

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ABSTRACT

Polymer concrete (PC) has been widely used for quick repairing of concrete pavement and structures in recent years. This paper studies the mechanical behavior of the rubberized polymer concrete. Crumb and chipped rubber were used to replace fine and coarse aggregates in PC, respectively. A complete series of destructive tests including impact test, compression and splitting tensile tests and non-destructive methods including ultrasonic test, digital signal processing, electrical conductivity, and microstructure analysis was performed to demonstrate the various potential applications of the rubberized PC. X-ray diffraction (XRD) also provided information regarding the chemical composition and crystal structure of three different epoxy resin ratios. The results indicated that the rubberized PC reduced the workability and increased the porosity and air content of the mixture; however, reduced the cost and density, and improved ductility. Scanning electron microscope was used to analyze the interface between aggregates and adhesive materials. The correlation between the compressive strength and ultrasonic pulse velocity was determined and proposed for the rubberized PC. PC containing crumb rubber had a lower pulse velocity and higher damping properties than that of chipped rubber. Further, the Taguchi method was used to determine the optimum conditions for mechanical properties of the rubberized PC and ANOVA was then utilized to evaluate the level of influence and existence of interaction parameters. Based on this investigation, the rubberized PC can be an appropriate candidate for repair and rehabilitation applications.

1. Introduction

Sustainable development is a major global concern for the environment protection in many countries and has received considerable attention during the past decade. It is urgent to develop an appropriate waste disposal strategy for various types of waste such as plastics, tire, rubber and glass. It is estimated that approximately 1.5 billion rubber tires are discarded in the world each year [1]. Materials used in manufacturing tire consist of a complex mixture. A relatively small portion of the generated scrap tires is recovered, and more than 50% of waste tires remain unused [2,3].

Waste tire rubber (WTR) is a non-destructible and non-biodegradable material and are not recycled properly. Also, natural degradation of WTR takes a significantly long time due to the cross-linked structure of the polymeric material and additives such as stabilizers [4,5]. Burning WTR causes harmful gasses. Landfill and burying cause serious environmental pollution in soil, water, and atmosphere. It pollutes the soil by killing beneficial bacteria and producing toxic gasses [6].

The waste product can be considered as a potential resource and valuable material. A logical method to reduce the negative effects of waste rubber and the cost is using them in construction and industry [7]. Natural aggregates have a higher cost than waste materials. In locating economically viable deposit for aggregates production, the factors such as transportation cost, the available

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tonnage, mineable quality of aggregate, government regulation and operating and maintaining vehicles cost to be considered. Among them, the cost of transporting aggregates is very high. In addition, the energy required to crush rocks into aggregates is proportional to the amount of new surface area that is created; thus, an important percentage of the energy consumed to produce construction aggregates [8,9].

WTR can be employed in different applications due to its lightweight energy absorption, and sound and heat insulating properties. WTR has been used for playground matting, football pitches, erosion control, highway crash barriers, guardrail posts, noise barriers, and asphalt pavement mixtures [10–12]. Over the past two decades, researchers investigated the possibility of utilizing WTR as an aggregate in cement concrete mixtures [11,13–16].

Topcu [17] studied the particle size and content of waste tire rubbers on the mechanical properties of cement concrete. He demonstrated that the compressive strength of rubber-filled concrete was reduced; however, the plastic capacity was significantly increased. Topcu and Avcular [18] found that the rubberized cement concrete was able to absorb more energy under impact loads. Therefore, the use of WTR allowed a reduction in the damage caused by the collision. Zheng et al. [19] demonstrated that the addition of waste tire increased deformability and ductility of cement concrete. It can also improve the heat insulation, acoustics and elastic properties in concrete [16,20–23]. Barbuta et al. [24] used tire scrap and powder as aggregates in cement and polymer concretes, respectively. They demonstrated that the compressive strength of rubberized cement concrete of 25% scrap tires and rubberized polymer concrete with 23% epoxy resin and 17% tires powder had the highest results.

Cement concrete has shortcomings such as relatively low ductility, low tensile strength, low energy absorption capacity and it requires a long curing period. Thus, polymer concrete (PC) can be considered as an alternative replacement of cement concrete for repair and rehabilitation of infrastructures. PC was founded in the 1950s, and it became well-known in the 1970s for its use in repair and rehabilitation of structures [25]. PC is a composite material formed by aggregate mixture and polymerization of a monomer [26]. The mechanical properties of PC depend on its specifications such as binder content, aggregate-size gradation, curing and preparation conditions. PC provides excellent bonds to existing cement concrete. Therefore, the possibility of failure at the interface between the old cement concrete and new polymer concrete can be reduced.

The superior characteristics of PC compared to cement concrete are high compressive, flexural and tensile strengths, high durability [27,28], fast curing, low permeability, excellent bond to steel and concrete [29], high vibration damping [30,31] and good protection against corrosive environments [32]. However, PC has limitations such as lack of familiarity to contractors and high cost as compared to cement concrete [33,34]. Therefore, PC can be considered as an ideal material for repairing concrete infrastructures such as base foundations, bridges, dams, and pavement surfaces due to its outstanding properties. PC had also been used efficiently in precast components for buildings, bridge panels, hazardous waste containers, machine bases, and cover bridge surfaces [35–40]. Moreover, many researchers utilized waste disposal materials in the different types of polymer concrete to determine its mechanical behavior for different engineering applications [33,34,41,42]. Bulut and Şahin [34] utilized electronic plastic waste as a part of the filling materials in unsaturated polyester resin. They found that the increase in the ratio of the resin increases the compressive strength while it does not cause a change in the splitting tensile strength. Also, they reported that the compressive and splitting tensile strength values decrease as the ratio of electronic plastic increases and the ideal resin and electronic plastic ratio values are 15% and 5%, respectively.

Waste tire rubber has quite low bonding properties as compared with natural aggregates in cement concrete [20]. Therefore, the mechanical properties of cement concrete would be decreased significantly. However, there have been relatively few studies on the mechanical behavior of the rubberized PC. This study investigates the mechanical behavior of PC with different rubber size and content as a replacement of aggregates. For this reason, a number of destructive tests and nondestructive methods were performed to evaluate the characteristics of the rubberized polymer concrete. Moreover, the experimental work was designed to use the Taguchi method and analysis of variance (ANOVA) to optimize proportions and investigate the effective and interacting parameters, and the percent contribution of the parameters on mechanical properties of the rubberized PC. Fig. 1 illustrates overview flowcharts of these laboratory tests.

2. Materials and specimen preparation

2.1. Polymer

The epoxy resin used was Nitobond EP with a resin/hardener mixed ratio of 1.9:1.1 by weight [43]. The components were mixed using mixing paddle for approximately three minutes until a fully uniform color was obtained. The compressive strength and the corresponding strain of epoxy resin were approximately 71 MPa and 7.8%, respectively [44].

2.2. Aggregates

Two types of aggregates provided: fine aggregates with the grain size of lower than 4.75 mm and coarse aggregates with the grain size of higher than 4.75 mm. According to ASTM C33 [45] guidelines, the collected fine aggregates were not in the standard range. Therefore, a part of the fine aggregates between some sieves numbers was removed or added to ensure that the aggregates were between the maximum and the minimum range provided by ASTM C33 as shown in Fig. 2. The coarse aggregates were collected from natural crushed stone with a specific gravity of 2.61 g/cm^3 and maximum dimension of 20 mm. Fine aggregates were natural river sand with a specific gravity of 2.56 g/cm^3. The optimum mix ratio of fine to coarse aggregates was 1:1 according to ASTM C29 [46].

2.3. Waste tire rubber

The waste tire rubber was prepared by cutting the tires into small pieces and removing the steel insertions. Two types of recycled waste tire rubber were considered: chipped and crumb rubber as shown in Fig. 3. Chipped and crumb rubbers were used to replace the coarse and fine aggregates, respectively. The size gradation of crumb and chipped rubber were approximately equal to that of fine and coarse aggregates after modification, respectively.

2.4. Specimen preparation

Polymer concrete was prepared by mixing a polymeric resin with the aggregates. Three amounts of epoxy resin –10, 12, and 14%- were mixed with aggregates to investigate the role of binder content. The mixtures were blended to ensure epoxy resin completely covered all aggregates. Each mold was then filled three layers with each layer being rodded 25 times. PC specimens were cured at room temperature for six days after the specimens were demolded. The mix designs for three types of polymer concrete are presented in Table 1.