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Laboratory Investigation of Self-Consolidating Waste Tire Rubberized Concrete

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A detailed laboratory investigation of waste tire rubberized self-consolidating concrete (SCC) was carried out in two phases. The first phase focused on proportioning rubberized mixtures using local materials that meet European specifications for SCC in terms of flow, passing ability, and resistance to segregation. This phase resulted in a selection of four mixtures: one control mixture (no rubber) and three rubberized mixtures containing 10, 20, and 30% waste tire rubber. The second phase of testing concentrated on analyzing the hydration process of the retained mixtures using the results of the semi-adiabatic calorimetry test as well as performing conventional mechanical tests. Results show that rubber particles do not affect concrete hydration rate, but do decrease the adiabatic temperature, given its high specific heat. As reported by other researchers, conventional mechanical properties were also found to decrease as the percent of rubber increases.

Keywords: compressive strength; flexural strength; heat of hydration; hydration rate; rubberized concrete; self-consolidating concrete; semi-adiabatic calorimetry.

INTRODUCTION

Economic development characterized by excessive industrialization led to a significant increase in solid waste, particularly scrap tires. For instance, in Tunisia, 3 million scrap tires are piled in landfills and present serious ecological and hazardous problems for the country. Developed countries, on the other hand, have faced this problem many years ago and created legislation programs to manage scrap tires. For example, since the 1990s, several U.S. agencies provided funding to develop waste tire recycling solutions that help reduce the number of tires in landfills.[1] These programs encouraged civil engineering researchers to recycle waste rubber by using it as a construction material. Early attempts in this direction were focused on the use of crumb rubber in the construction of hot-mix asphalt pavements,[2] which, over the years, has become a common practice in different states, with Arizona considered as the leading and most experienced state using this material. Then, portland-cement concrete (PCC) researchers started to investigate the effects of adding rubber tires into the concrete and called the new composite material "rubberized concrete." Early studies with this composite were conducted by Eldin and Senouci,[3,4] Fattuhi and Clark,[5] Fedroff et al.,[6] Tountaji,[7] Goulias and Ali,[8] and Khatib and Bayomy.[9] All these studies showed that the addition of rubber particles reduces the mechanical properties of PCC. Reduction in the compressive strength was more pronounced than other properties such as tensile or flexural strengths. These studies also showed that rubber particles tend to increase air content and reduce workability of PCC. A positive finding for rubberized concrete reported by most of the studies is that it has higher toughness and is therefore more ductile than conventional PCC. Studies performed during the 2000s on rubberized concrete confirmed the older findings reported on its fresh or hardened properties.[10-12] Many researchers investigated the possibility of improving the mechanical properties of rubberized concrete by incorporating supplementary cementitious materials (SCMs)[13-15] or by improving the adhesion between cement paste and rubber particles.[16] More recently, PCC researchers started to investigate the addition of rubber particles into self-consolidating concrete (SCC) mixtures. Research has shown that, for the same water-cement ratio (*w*/*c*), a higher amount of high-range water-reducing admixtures (HRWRAs) was needed for the rubberized mixtures.[17] The same findings as for conventional rubberized concrete were reported for self-consolidating rubberized concrete.[18-20] A literature review on the fresh and hardened properties of conventional and self-consolidating rubberized concrete (SCRC) was performed by Najim and Hall in 2010.[21]

The research described in this paper focuses on characterization of self-consolidating waste-tire rubberized concrete. In addition to the successful formulation of such a composite using local materials in a developing country such as Tunisia, a confirmation of the reported hardened state behavior is presented—the results of the semi-adiabatic calorimetry testing and the modeling of the compressive strength, flexural strength, and Young's modulus as a function of the degree of hydration.

RESEARCH SIGNIFICANCE

The possibility of formulating SCRC mixtures seems particularly interesting because this composite offers benefits such as ease of installation and absence of segregation, in addition to recycling a worldwide industrial waste (tires). In current literature, most researchers focus on the hardened-state mechanical properties of such material, with a few looking at its durability characteristics. In this research, special attention was given to hydration kinetics of SCRC mixtures made using local materials. To the authors' best knowledge, the heat-of-hydration data of this composite is presented for the first time and will be useful to concrete technology. In

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(a) (b) (c)

Fig. 1—Fresh-state specification tests for SCC: (a) slump flow; (b) L-box; and (c) sieve stability.

fact, rubber particles, with higher specific heat as compared to mineral aggregates, would alter the kinetics of hydration and result in different adiabatic temperature generation. This might allow the use of such material in applications where conventional SCC might not be recommended, such as in mass concrete.

EXPERIMENTAL INVESTIGATION

The experimental program was performed in two phases. The first phase focused on proportioning rubberized SCC mixtures to meet European specifications (slump flow, passing ability, and segregation resistance) for such concretes.[22] Four mixtures were retained after this phase: one control mixture (no rubber) and three mixtures with different rubber percentages (10, 20, and 30% with respect to the total aggregate volume). In the second phase, the retained four mixtures were tested at early ages and at a hardened state. The innovative early-age test performed in this study was the semi-adiabatic calorimetry, which is used to monitor the degree of hydration of different tested mixtures. In the hardened state, conventional mechanical tests were performed—compressive strength, flexural strengths, and secant modulus of elasticity calculated using the slope of compressive strength data and a stress equal to 40% of the ultimate strength.

Materials

Portland cement produced at a local plant, classified as CEM I-42.5 according to Tunisia specification NT47-01,[23] was used. This cement has a specified 28-day compressive strength of 40 MPa (5800 psi), a 2-day compressive strength of 10 MPa (1450 psi), a specific gravity of 3.10, and a Blaine fineness of 440 m^2/kg. According to the manufacturer data sheet, the percentages per mass of its main constituents are: 54% of tricalcium silicates (C_3S); 22% of dicalcium silicates (C_2S); 8% of tricalcium aluminates (C_3A); and 13% of tetracalcium aluminoferrite (C_4AF). Washed siliceous river sand graded as 0/4 was also used in this study. It has a fineness modulus of 2.3, a dry specific gravity of 2.608, and an absorption of 0.78%. Two different grades of crushed calcareous coarse aggregates were used: 4/8 and 8/16. The gradation notation *d*/*D* used for the aggregates means that at least 95% of the material passes the *D* sieve and is retained on the *d* sieve (*d* and *D* are expressed in mm). The dry specific gravity of the coarse aggregate was 2.737 and its absorption was 0.79%. Waste tire rubber was ground to two different grades (2/4 and 4/8) and used for making the rubberized concrete mixtures. The specific gravity of the rubber used was 1.2 with 0% absorption. Potable water was used for all mixtures. To achieve the early-age properties of SCC and following several laboratory trials with different commercially available HRWRAs, a non-chlorinated, acrylic copolymer HRWRA was chosen for this study.

Mixture proportioning and specimen preparation

The concrete proportioning method adopted in this study was the theoretical procedure known as the compressible packing model, developed in France for formulating different types of concrete mixtures, including self-consolidating ones.[24] The cement content was kept constant at 350 kg/m^3 (590 lb/yd^3) for all the mixtures. Knowing that the volume of the paste required to make SCC is more important in comparison with that used for conventional concrete, an inert calcareous product obtained by crushing limestone, composed mainly of calcium carbonate ($CaCO_3$), ground to particles size less than 10 μm (0.393 mils) and with a specific gravity of 2.71, was used for all mixtures. To meet the fresh-state European specifications for SCC, varying amounts of HRWRA were added to different mixtures. The performed fresh-state tests, shown in Fig. 1, are the slump-flow, the L-box, and the sieve stability. The slump-flow test is correlated with the filling ability of SCC. The reported value for the test is the diameter of the flow spread of the mixture after lifting a conventional Abrams cone. Therefore, the higher the reported value, the better the filling ability of the mixture. The specifications call for a minimum value of 700 mm (27.6 in.). The L-box test determines the passing ability of SCC. The reported value of the test is the ratio of the height reached by the mixture (in the horizontal section of the box) after passing the gaps between steel bars to the height of the mixture prior to the steel bars (in the vertical section of the box). The closer the value is to 1, the better the passing ability of the SCC. The specification calls for a minimum value of 0.8. The sieve stability test investigates the segregation resistance of SCC. The reported value of the test is the percentage of the mixture that passes through a 5 mm (0.2 in.) sieve with respect to the total mass of the mixture. A higher reported value of the test indicates a poor resistance to segregation because a lot of paste has gone through the sieve. The specification calls for a maximum value of 15%. After several trials, four mixtures labeled as SCC0, SCC10, SCC20, and SCC30 (the number indicates the percent of rubber used in the mixture) were retained and