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Mechanical properties of rubberized lightweight aggregate concrete

Nathan M. Miller, Fariborz M. Tehrani *

Department of Civil and Geomatics Engineering, California State University Fresno, CA 93740, United States

HIGHLIGHTS

- Tire-derived aggregates (TDA) contribute to sustainability of concrete applications.
- Mechanical properties of light-weight aggregate concrete with TDA are investigated.
- Experimental studies include six mix designs containing 0–100% of TDA substituion.
- The effect of TDA on compressive, tensile, flexural, and impact tests are reported.
- Results provide insights on the toughness and ductility of TDLWAC.

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ABSTRACT

A detailed investigation of rubberized lightweight aggregate concrete was conducted using 38 cylindrical and 36 beam specimens. Six mix designs, incorporated in the study, contained rubber replacement ratios from 0% to 100% by volume replacement of a lightweight expanded-shale coarse aggregate. The objective of this study is to investigate mechanical properties of lightweight tire-derived aggregate concrete, including compressive strength, modulus of elasticity, splitting-tensile strength, flexural strength, and flexural toughness. Further, an impact test was conducted using a falling weight to investigate dynamic properties of specimens subjected to flexure. Results suggest tire-derived aggregates reduces the mechanical strength of specimens, but, enhances ductility and toughness of materials. These enhancements are valuable for dynamic applications of lightweight concrete.

1. Introduction

Many researchers cited in this section have been intrigued by the concept of adding a flexible material such as rubber to a material that is typically known for its rigidity, such as concrete. The development of a concrete performing with ductile behavior has been the object of ambition for many researchers. Other motivations stem from the fact that if aggregates often used in rubberized concrete (tire derived aggregates) can be incorporated into the concrete matrix, there exists a potential to divert a significant amount of waste materials away from landfills.

According to the Environmental Protection Agency (EPA), the United States alone generates 289 million scrap tires annually. Beyond the amount of waste alone, the EPA provides that stockpiled waste tires can pose significant health and safety hazards including rodent and mosquito habitation which can facilitate the spread of disease and an increased risk of fire [1]. More recently, the EPA published that leather and rubber accounted for 6.18 million tons of waste after the recycling rate of 44.6% had been accounted for [2].

Countless researches conducted since the early 1990s concern rubberized normal weight aggregate concrete. Although few have shown an increase in rubber content improves durability, compression strength has been observed to decrease as rubber content is increased [3–8]. Other common properties such as the static modulus of elasticity [9–11], splitting tensile strength [4,9,11], and static flexural strength [4,12,13] have also been found to decrease as rubber content increases. However, while the strength properties decrease, material toughness has been observed to increase [10,13,14] which research suggests may serve as one of the most beneficial properties of this material. Due to the fact that material solidity can be used as a measure of a materials ability to absorb energy, researchers suggest it may be best suited for dynamic loading conditions. Two studies were found using a falling weight impact [11,15], two studies were found investigating the

* Corresponding author.
E-mail address: ftehrani@csufresno.edu (F.M. Tehrani).

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Nomenclature

Notation

$A_{10.5FC}$	Area under load-deflection curve up to 10.5 times the first crack deflection, N-m (lbf-in.)
$A_{5.5FC}$	Area under load-deflection curve up to 5.5 times the first crack deflection, N-m (lbf-in.)
$A_{3.0FC}$	Area under load-deflection curve up to 3.0 times the first crack deflection, N-m (lbf-in.)
A_{FC}	Area under the load-deflection curve up to first crack deflection, N-m (lbf-in.)
b	Width of beam specimen, mm (in.)
d	Diameter of cylindrical specimen, mm (in.)
d_1	Depth of beam specimen, mm (in.)
E	Static modulus of elasticity, GPa (ksi)
g	Gravitational constant, m/sec^2 (in./sec^2)
h	Drop height used for impact testing, mm (in.)
I_{20}	Toughness index up to 10.5 times first crack deflection
I_{10}	Toughness index up to 5.5 times first crack deflection
I_5	Toughness index up to 3.0 times first crack deflection
L_1	Cylinder length, mm (in.)
L_2	Specimen clear span, mm (in.)
m	Mass of falling weight, kg (lb)
P	Peak applied load, kN (lbf)
$R_{10,20}$	Residual strength factor 2
$R_{5,10}$	Residual strength factor 1
T	Splitting-tensile strength, MPa (psi)
δ_1	Deflection corresponding to peak static load, mm (in.)
ε_1	Lower bound of strain used for the calculation of the modulus of elasticity
ε_2	Upper bound of strain used for the calculation of the modulus of elasticity
σ_1	Lower bound of normal stress used to calculate the modulus of elasticity, MPa (psi)
σ_2	Upper bound of normal stress used to calculate the modulus of elasticity, MPa (psi)
ω	Observed static load for static flexure test, kN (lbf)

free vibration using an impulse hammer [8,16], and a single study was found investigating the behavior of a full scale traffic barrier subject to a non-severe collision impact [6].

Few researches analyzing the properties of rubberized lightweight aggregate concrete created using rubber aggregates as replacement for lightweight mineral aggregates have been found [17,18]. By studying six mechanical properties that are of common interest for concrete, the investigation that follows was conducted to further the understanding of this material that has been researched by few.

2. Research significance

Presence of lightweight aggregate has the potential to alter the mechanical properties of rubberized concrete. The substitution of natural normal-weight aggregates with lightweight aggregates, such as expanded shale, has the potential to expand applications of rubberized concrete. This study is directed towards the advancement of existing literature on mechanical properties of rubberized lightweight-aggregate concrete including: compressive, splitting-tensile, flexural strength, flexural toughness and impact resistance.

3. Experimental procedure

Cylinder and beam specimens were cast containing various amount of crumb rubber, tire-derived aggregate (TDA), by volume replacement of the coarse lightweight aggregate (LWA). The constituents in the mix included the expanded shale lightweight coarse aggregate, natural sand fine aggregate, cement, and water. The target strength for the control mix was 21 MPa (3 ksi). The TDA was then added by volume replacement of the lightweight coarse aggregate. Replacement ratios of 0% to 100% in 20% increments were used in the investigation for both cylinder and beam specimens. Cylinders were used in testing compressive strength, static modulus of elasticity, and splitting-tensile strength. Beam specimens were used to examine flexural strength, toughness, and response to an impact flexure test.

3.1. Materials

The mix constituents included lightweight coarse aggregates, fine aggregates, cement, and water. Tire derived aggregates were later added by volume replacement of the lightweight coarse aggregate. The coarse aggregate used in the procedure consisted of expanded shale produced by Utelite Corporation, which is classified to be their structural medium grade. These materials have unit dry weight of nearly 750 kg/m^3 (46.8 pcf) and water content of 7.3%. Table 1 provides the gradation report for the expanded shale as published by the manufacturer. Natural sand as well as type I and type II cement blend were applied. The cement blend was used due to its availability, with no research suggesting this would adversely affect the rubberized concrete specimens. Tap water was incorporated in the procedure for all concrete specimens. The TDA, provided by West Coast Rubber Recycling located in Hollister, California, was produced using mechanical shredding and of comparable size to the mineral aggregate. The source of these materials is a combination of car and truck tires. The steel fibers were removed from the rubber during the manufacturing process; however, textile fibers remained mixed within the rubber particles (see Fig. 1). The unit weight of TDA was nearly 560 kg/m^3 (35.2 pcf). Table 1 provides the sieve analysis for the material. No additional mixtures were used in the designs, and no pretreatment of the rubber was conducted prior to incorporating it into the mix. Throughout the investigation, all mix design quantities were held constant with the exception of the lightweight coarse aggregate and the tire derived aggregates. Fig. 2 shows all six mix designs used. These values have been adjusted for water absorption of materials, when applicable.

3.2. Specimens

Both cylinder specimens, 0.15 m (6 in.) diameter and 0.30 m (12 in.) height, and beam specimens 0.15 m (6 in.) square size and 0.53 m (21 in.) length, were used for testing, in accordance to ASTM C39 and C78. Plastic, single use concrete cylinder molds, were used to cast cylindrical specimens. For the beam specimens,

Table 1
Gradation report for lightweight expanded shale aggregate (LWA) and rubber particles (TDA).

Sieve Size mm (in.)	LWA Retained (%)	TDA Retained (%)
12.7 (1/2)	0	0
9.5 (3/8)	5.66	0.38
4.75 (3/16)	72.8	77.82
2.36 (3/32)	20.89	20.73
1.18 (3/64)	0.35	0.38