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An experimental investigation of the mechanical performance and structural application of LECA-Rubcrete

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HIGHLIGHTS

- Mechanical properties and structural performance of LECA-Rubcrete were measured.
- Static cyclic loading was applied on reinforced concrete beams.
- Pre-treatment of LECA and rubber particle was carried out.
- Cement paste pre-treatment method showed the best strength enhancement.
- Rubcrete produced similar energy dissipation to that of conventional concrete.

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ABSTRACT

Due to the high number of discarded end-of-life tyres around the world every year, the use of rubber waste in concrete has been researched for some years in normal and high strength concrete. Rubcrete is a type of concrete which is similar to conventional concrete, but uses scrap tyre rubber as a partial substitution for mineral aggregates. Lightweight concrete is another type of concrete with the advantage of reducing the self-weight of the structure. Utilizing rubber waste in concrete as a replacement of fine and/or coarse aggregates to produce lightweight concrete is of great interest as it can potentially provide a ductile lightweight concrete. This study investigates the possibility of using rubber waste, lightweight expanded clay aggregate (LECA), or a combination of both, in producing ductile lightweight concrete at the material level as well as the structural level. Fourteen concrete mixes were produced with different rubber content as replacement of fine aggregate volume, and different rubber/LECA content as replacement of coarse aggregate volume. The pre-treatment of the rubber/LECA particles using water, cement/silica fume paste, and cement/silica fume solution was also investigated. Three reinforced concrete beams with 130 mm × 230 mm cross-section and 1000 mm length were made out of selected mixes and tested under cyclic loading. Several rheological and mechanical properties, and structural performance characteristics were measured and compared. The results indicated that the LECA performs better than coarse rubber as a replacement for concrete coarse aggregate. Pre-treatment of fine rubber by soaking in water for 24 h had no significant effect on concrete slump; however, it increased the compressive strength by 15%. Rubcrete had an insignificant effect on the general behaviour of the reinforced concrete beams. Using LECA-Rubcrete decreased the strength and ultimate displacement of the reinforced beam by 22% and 21%, respectively compared with the Rubcrete beam.

1. Introduction

With the rapid increase in the number of high rise buildings and large-size structures being constructed around the world, lightweight concrete has become an effective class of concrete that provides less self-weight, higher fire resistance, and lower foundation cost. The use of lightweight concrete in earthquake resistant buildings is also beneficial because of the weight and mass reduction of the structures. Lightweight concrete can be produced by partial/-full substitution of mineral aggregates by natural or manufactured lightweight aggregates [1]. Lightweight expanded clay aggregate (LECA) is a traditional lightweight aggregate that is made by firing pure natural clay in a rotary kiln at 1200 °C [2]. LECA concrete has

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become a popular type of lightweight concrete since the raw material is clay which is available on a global scale [3]. Using LECA in concrete can provide a lightweight, self-thermal/sound insulation, and weather resistant structure [4,5].

Many previous research studies conducted in LECA concrete have shown the advantage of having less concrete unit weight, but the disadvantages of a more porous, high water absorption, low strength, and hence low durability concrete [6,7]. Jafari and Mahini [6] have reported that LECA is able to provide a smoother concrete surface than that of concrete made out of other types of lightweight aggregates, such as pumice. As the compressive strength of concrete is mainly affected by the strength of the aggregate, Mahdy [7] treated LECA with a solution of silica fume (SF) at different concentrations and found that the concrete compressive strength increased with the increase of silica fume content. He also found that using SF contents of 5% and 10% resulted in an increase of the flexural strength by 30% and 35%, respectively. In addition, the SF treatment led to high early age strength at 7 days, but had a smaller effect at 28 days. Sajedi and Shafigh [8] concluded that the particle size of LECA and its contents has significant effect on the concrete density and compressive strength; the higher the fineness of LECA, the higher the increase in the density and compressive strength.

Lightweight concrete has also been applied in large-scale concrete structure research [9–11]. Charif et al. [9] tested a lightweight reinforced concrete beam having cross-section dimensions of 250 × 300 mm, and length of 3000 mm and made out of natural basalt tuffs (scoria) and volcanic rocks, under monotonic 4-point bending. They found that the lightweight concrete beams were able to develop more ductile behaviour than the normal weight concrete beams due to their relatively reduced strength. El-Shaer [10] tested lightweight reinforced concrete columns having cross-section dimensions of 200 × 200 mm, and height of 1500 mm. The columns were made out of LECA concrete and subjected to elevated temperature and axial monotonic loading. The results showed that under un-heated conditions, a slight reduction in the load carrying capacity, stiffness, and toughness in lightweight concrete occurred compared with normal weight concrete. However, under heated conditions, the lightweight concrete showed an enhancement of about 25% in the load carrying capacity compared with that of normal weight concrete. Rabbat et al. [11] tested sixteen reinforced concrete columns having cross-section of 381 × 381 mm or 381 × 508 mm and height of 3050 mm. The lightweight concrete columns were made out of expanded clay or expanded shale. They concluded that lightweight concrete columns with properly detailed reinforcement could provide ductility and maintain strength when subjected to constant axial load and slow moment reversals at increasing inelastic deformations.

Scrap tyres are among the largest and most problematic sources of waste of modern societies, due to their durability and the huge volumes of discarded tyres every year. In Australia, 51 million of end-of-life tyres were produced in 2014, but only 5% were recycled domestically, 32% were exported, 16% were disposed to licensed landfills, and the fate of the remaining 47% is either unknown or unverified disposal in landfill on mining sites [12–15]. When tyres are dumped to landfill they can cause numerous environmental problems, such as becoming breeding grounds for mosquitoes and other pests. In addition, when such tyre dumps catch fire they are notoriously difficult and costly to extinguish [16]. Recycling of used rubber in concrete (Rubcrete) conserves valuable natural resources (by reducing the use of natural aggregates) and reduces the amount of rubber entering landfill [17].

Experimental studies on Rubcrete materials have shown that using rubber in concrete as a partial replacement of mineral aggregates enhances its ductility, toughness, impact resistance, energy dissipation, and damping ratio [18,19]. However, it reduces its compressive strength, tensile strength, and modulus of elasticity compared to conventional concrete [20–23]. The dynamic characteristics of rubberized concrete make it a potential candidate for concrete members subjected to dynamic loading conditions [24]. Very little research has been undertaken to combine or even compare rubber aggregate and LECA to produce lightweight ductile concrete. Fantilli et al. [25] have compared the mechanical properties of Rubcrete and LECA concrete. They found that the Rubcrete was more environmentally friendly than LECA concrete, but the compressive strength was reduced. The flexural strength of Rubcrete and LECA concrete was comparable. In addition, rubber prevented rapid growth of cracks in the tensile zones of beams and plates under bending. Miller and Tehrani [26] replaced LECA by rubber in lightweight concrete up to 100% by volume. Their results showed that the static mechanical properties decreased as the rubber content increased. The flexural toughness significantly increased at rubber content higher than 80%. They suggested that the coarse rubber could be used as lightweight aggregate only when energy absorption is the primary concern rather than the strength.

To that end and to the best of the authors' knowledge, the combination of rubber aggregate with LECA aggregate in concrete has not been studied previously either at the material or structural levels. Combining LECA aggregate with rubber may produce a new lightweight concrete structure that has adequate strength and ductility. In this research, fourteen concrete mixes with different rubber content as replacement of fine aggregate volume, and different rubber/LECA content as replacement of coarse aggregate volume, were investigated. In addition, the behaviour of three reinforced concrete beams made out of selected mixes were tested under incrementally increasing cyclic loading. The data from this research will provide additional information necessary to support the further development of lightweight structures utilizing rubber waste.

2. Experimental program

2.1. Materials

Blended cement, according to Australian Standard (AS) 3972 [27], was used as the binder material in the concrete mixes. Dolomite stone with nominal maximum sizes of 10 mm and 20 mm was used as coarse aggregate. River sand with a maximum aggregate size of 5 mm was used as fine aggregate. The fine rubber used during the course of this study had particle sizes of 2.36–4.75 mm and was used as a partial replacement of sand by volume. The coarse rubber and LECA had particle sizes of 9.5–16.0 mm and

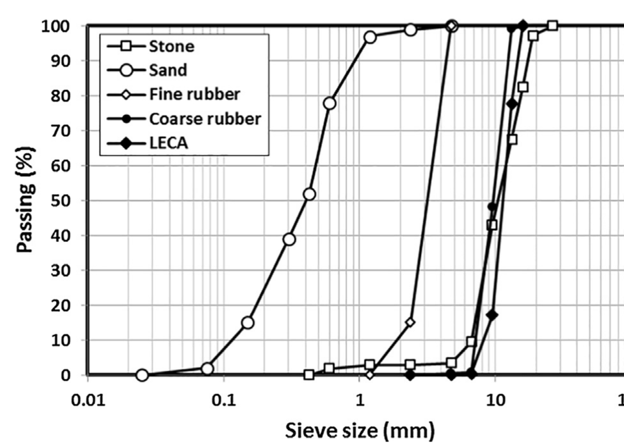

Fig. 1. Sieve analysis of the aggregates used.