Effect of rubber particles on dynamic mechanical properties of ultra-lightweight cement composites

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Abstract. This paper develops a novel rubberized ultra-lightweight cement composites (RULCC) incorporated with different amount of rubber particles and investigates the static and dynamic mechanical properties of the RULCC experimentally. This study shows that the rubber particles have significant effect on the compressive strength, stress-strain curve and failure mode of the RULCC. A volume replacement of fine aggregates with 10% and 20% rubber particles results in a reduction in static compressive strength and elastic modulus. The dynamic experiments show the RULCC is a strain-rate sensitive material and the dynamic stress-strain curves illustrate that the capacity of energy absorption of RULCC is better than the composites without rubber particles. The experimental and analytical studies are essential to better understand the fundamental dynamic behaviour of RULCC for its further applications.

1. Introduction

With the development of society, the height or span of the buildings is increasing so that the dead weight and the cross-section area of the components are also increased [1]. Because of the advantages of small self-weight and good thermal insulation, the lightweight concrete has been gradually applied to the high-rise buildings, long-span bridges and offshore platforms [2, 3]. However, the further application of lightweight concrete is limited due to its low strength and brittleness. Fly ash cenospheres (FAC) are white or grey hollow spheres which have high crushing strength and smooth shape and are very suitable for light aggregates [4]. Based on the theory of compact packing, Wang et al. put forward the design density method and utilized FAC as light aggregates to develop the ultra-lightweight cement composites (ULCC) with density of 1400 kg / m³ and compressive strength of 60MPa [5]. Besides the static load, the structures may suffer the dynamic loads. Many studies show that rubberized concrete has good impact resistance and energy consumption capacity [6-8]. Guo et al. investigated the strain rate strengthening effect of rubber concrete with different rubber content. When the rubber content was constant, the strengthening effect increased with the increase of strain rate; when the strain rate was at the same level, the deformation ability of rubberized concrete increased with the increase of rubber content [6]. Atahan et al. simulated the impact of automobiles on bridge barriers and found that the rubberized concrete barriers significantly reduced the damage of automobiles [8]. In conclusion, rubberized concrete has good impact resistance. However, the addition of rubber will also affect the strength of concrete. Therefore, this paper utilized the waste tire particles to the ULCC to make the
RULCC and investigated the static and dynamic mechanical properties under impact load with different rubber content.

2. Experimental program

2.1 Materials and mix proportions
The raw materials of the experiment include P · O 52.5 grade ordinary Portland cement, silica fume, FAC rubber particles and superplasticizer. The particle size of FAC is between 20-300um and the density is 0.902 gcm⁻³. The average size of 380 um rubber particles is selected, and its micro morphology in the c is shown in figure 1. The mix proportion of the control group is cement: silica fume: FAC: water = 1.0: 0.111: 0.484: 0.369. In the test groups, 10% and 20% of FAC were replaced with rubber particles by volume respectively.

| Mix ID | Cement | SF   | FAC | Rubber | Water | SP  | SRA |
|--------|--------|------|-----|--------|-------|-----|-----|
| R0     | 1.0    | 0.111| 0.484| 0.000  | 0.369 | 0.001| 0.001|
| R10    | 1.0    | 0.111| 0.436| 0.054  | 0.369 | 0.001| 0.001|
| R20    | 1.0    | 0.111| 0.387| 0.107  | 0.369 | 0.001| 0.001|

2.2 Experimental apparatus
The static compressive strength test measured cylinders which the diameter is 100mm and the height is 200mm. Before the test, the two ends of the specimens are levelled with gypsum [10]. The dynamic test measured by the split Hopkinson pressure bar with rod diameter of 120mm. To reduce the friction effect between the rod and the surface of the specimen, vaseline is applied at both ends. There are four different loading pressure are applied in the test which correspond to the strain rate 94.1-105.3, 123.5-130.6, 150.5-155.7, 181.5-186.5 s⁻¹ respectively.

3. Results and discussions

3.1 Compressive strength and elastic modulus
The results of the static compression test were shown in figure 1 and figure 2. With the increase of the replacement of rubber particles, the compressive strength and elastic modulus decreased significantly. As an organic polymer material, rubber particles may have weak adhesion with cement inorganic materials, resulting in a reduction of strength in the interfacial transition zone (ITZ). Each rubber particle distributed in the cement composites is equivalent to a weak spot that may initiate micro cracks and reduce compressive strength of the cement composites further. The elastic modulus of rubber is much lower than that of cement composite, leading to large deformation of the rubber particles under quasi-static loading. Due to the larger deformation of rubber, the specimen with rubber particles cracked with loose fragments rather than dense fragments and the failure mode was shown in figure 2. This observation indicates that the rubber particles reduce the brittleness of the ULCC.

![Figure 1. Compressive strength and elastic modulus](image1)

![Figure 2. Failure mode](image2)
3.2 Dynamic test results

3.2.1 Failure mode. Figure 3 illustrates the failure modes of two mix groups after the impact tests. Within a group, a higher strain rate causes more serious damage of the specimens. Within a mix group, a higher strain rate causes more serious damage of the specimens. At the same strain rate, an increase of rubber content results in larger but less. Unlike the static responses discussed previously, the rapid release of the impact energy under the high strain rate impact cannot be completed by the propagation of a single crack as the rate of crack opening is much slower. This delay leads to initiations of multiple cracks until the ultimate fragmentation occurs. After adding rubber particles into the cement composite, kinetic energy can be released more effectively due to the elastic deformation and energy dissipation capacity of rubber, thus reducing the number of the cracks with less fragmentation at failure. This observation is more obvious when more rubber is added.

3.2.2 Dynamic compressive strength. Figure 5 shows the dynamic compressive stress-strain curves of each group under different strain rates. At the same strain rate, the dynamic compressive strength decreases with the increase of rubber content. The results illustrate that the RULCC also has the strain rate strengthening effect which is similar to the rubberized concrete and the normal concrete. Comparing figures 4 (a) and (b), as rubber particles are added, it is found that the stress-strain curves become fuller and the dynamic peak strain increases which means the capacity of the energy absorption better. During the impact process, the rubber particles tend to dissipate impact energy due to the large peak strain when the crack propagates to the rubber particles, leading to enhanced deformation capacity of the RULCC and, thus, reduced size of the fragments at failure. However, the negative effect is that the compressive strength of the material tends to be reduced significantly with increase of the rubber content.

4. Conclusion
This paper develops a novel rubberized ultra-lightweight cement composites (RULCC) incorporated with different amount of rubber particles and explores the static and dynamic behaviour. Based on the test results, there are several conclusions as follows:

(1) The static compressive strength and elastic modulus of RULCC are reduced by adding rubber particles, and the degree of reduction increases with the increase of replacement.
(2) Under the impact load, with the increase of strain rate, the breaking degree of the specimen becomes more and more serious and the dynamic compressive strength gradually increases; when the strain rates are approximate, the fragments gradually reduce and the dynamic compressive strength gradually decreases with the increase of rubber replacement.

(3) The SHPB compressive test shows that the rubber particles particle (less than 10% in volume) can improve the impact resistance of ULCC. Compared to that without rubber addition, the specimens exhibit better energy absorption performance.

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