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Investigation on the safety concrete for highway crash barrier

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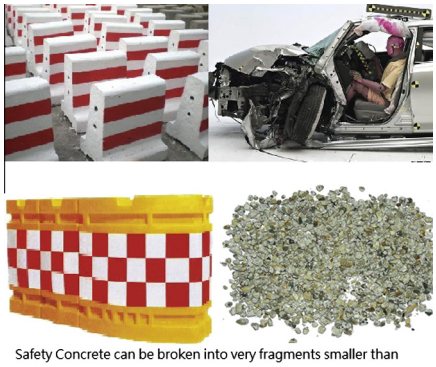
HIGHLIGHTS

- We prepare a no-fine concrete with AAS for highway safety barrier.
- Optimum aggregate gradation ensures the concrete high strength and fragmentability.
- This concrete has strength around 20 MPa and high energy absorption ability.
- High energy absorption results from the micro-crack and low specific surface area.

GRAPHICAL ABSTRACT



Safety Concrete can be broken into very fragments smaller than 4.75 mm, which keep the vehicle on the pavement and save lives.

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ABSTRACT

A new type of concrete named "safety concrete" for traffic safety is developed. A no-fine concrete solidified by Alkali Activated Slag (AAS) can form a network of micro-cracks throughout the concrete to ensure its good energy absorption under the sudden and severe loading, the mixture design and microstructure of this new concrete is studied. Results indicated that, the optimum aggregate gradation with 2.36 mm passing ratio around 20% and around 5% of particles bigger than 4.75 mm ensure this concrete reach compressive strength of 20 MPa and fragmentability of 90%, the micro-cracks generate in different scales in the paste of this concrete, there are much more micro-cracks generated in AAS than in OPC paste, laboratory manufactured no-fine safety concrete blocks are broken into fragments smaller than 4.75 mm when they are dropped from 7th floor (18 m), safety concrete can serve as frontier guard railing or crash barrier installed for highway traffic safety.

1. Introduction

Cement concrete is a kind of quasi-brittle material [1], under sudden, severe loading e.g. traffic crash, automobile race or terrorist bomb explosion, it typically tends to fracture into large chunks which will act as massive, dangerous projectiles that can cause considerable damage to the property and loss of live. A new type of concrete has been developed which can disintegrate into small fragments when subjected to those loading, it can be used as concrete perimeter wall installed for highway guard railing or crash barrier to save the vehicle out of control. This kind of concrete named as "safety concrete" for the hurt to the driver and rider in the automobile will be minimized similar to the working mechanism of the safety glass (tempered glass). In order to obtain this function for the safety application, the safety concrete must meet

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enough compressive strength and high fragmentability [1]. To gain this unique properties of this new type of cement-based material, in this paper the material science approach is employed to design the composition, multi-scaled structures and the manufacture process of the safety concrete. By optimization the gradation of aggregate, utilization the alkali activated slag (briefed as AAS) and heat treatment, a network of micro-cracks throughout its volume [2] and a state of internal tensile stress is obtained. Under static compressive loading, it will behave as a normal concrete, under catastrophic loading, the microcracks can propagate and connect and cause the safety concrete to fracture into small fragments. When is used as energy absorption material at guard railing for the highway, it can largely release the load of the vehicle out of control, reduce the speed of the vehicle and keep the vehicle on the pavement and save lives in it.

2. Experimental

2.1. Raw materials

(a) *Aggregate:* two types of bird eye gravels, one is 2.36–6.0 mm, the other is 2.36–4.75 mm bird eye gravels, a kind of fine gravel 1.18–2.36 mm (>90%) and a kind of fine sand 0–2.36 mm is used to adjust the gradation of the aggregate. All of those aggregate is commercial products.

(b) *Binder:* The chemical compositions and the properties of slag were listed in Table 1. The Alkali Activated Slag (AAS) is prepared with sodium silicate, fine Ground Granulated Blast Furnace Slag (GGBS) with specific surface area of 380 m^2/kg, activating agent is prepared with commercial product sodium silicate (water glass) and sodium hydroxide, the proportion of this binder is optimized elsewhere [1].

2.2. Experiment process

(a) *Specimen preparation:* The slag, sodium silicate solution, sodium hydroxide solution and water were mixed together to make a very flowable paste, then the gravels were added in the paste, the matrix was mixed till all the gavels were covered by the paste, cast the matrix into a mould with size of $\phi 5.0 \times 10.0$ cm, every specimens were cast into two lay and bound upon the table to compact. The specimens were cured in a seal box in the room temperature for 6 days, then saw it into one $\phi 5.0 \times 5.0$ and one $\phi 5.0 \times 2.5$ cylinder, the cylinders were cured in the plastic sheets for 1 day, then all the cylinders were put in the oven with a temperature around 105 °C for 24 h and quenched in the room temperature, the tests on the properties were carried out after the specimens were cooled for 24 h.

(b) *Compressive strength:* Three $\phi 5.0 \times 5.0$ cm cylinders were tested for each date point.

(c) *Impacting experiment:* The fragment ability of the safety concrete was measured with compacting experiment, the fragmentability is calculated as Eq. (1).

$$F = \frac{m_{4.75}}{m_0} \cdot 100\% \quad (1)$$

where F is the fragmentability of concrete, $m_{4.75}$ is the mass of those fragments passing 4.75 mm sieve after the impacting test, m_0 is the mass of the testing specimen. Three $\phi 5.0 \times 2.5$ mm cylinders were tested for each date point. The test equipment is illustrated in Fig. 1.

(d) The manufacture of the safety concrete block, no-fine concrete block was the mixed with a concrete testing mixer with a similar process as the test specimen preparation, a block machine was used to form the blocks.

Table 1
Chemical compositions and the properties of Portland cement and slag.

Compositions or properties	GGBS (%)
CaO	38.2
SiO_2	33.2
Al_2O_3	13.8
Fe_2O_3	0.6
SO_3	2.4
MgO	8.7
Alkali Na_2O	0.4
Blaine specific surface area (m^2 kg)	380

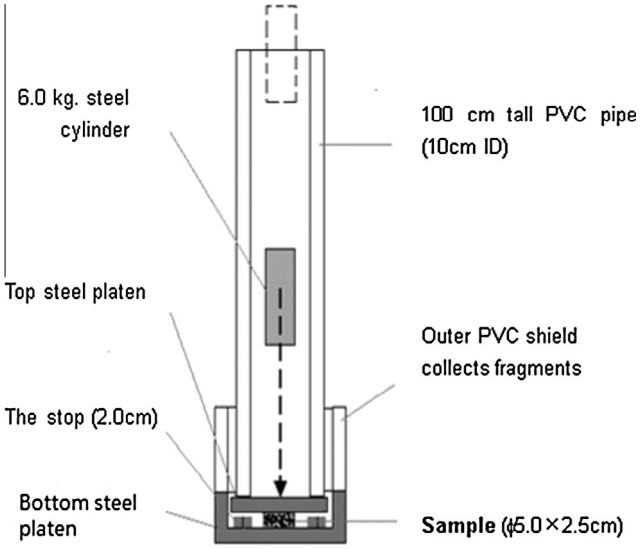

Fig. 1. The schematic diagram of the impacting test equipment [1].

3. Results and discussion

3.1. The effect of the gradation on the properties of the safety concrete

It is very important to set up a raw material requirement of the safety concrete. The gradation of aggregate is one of the most significant parameter of concrete raw materials requirements. The aggregates with different gradations are prepared with a bird eye gravel (2.36–6.0 mm) and fine gravels (1.18–2.36 mm) or sands with different size distributions, the proportions of the aggregates are listed in Table 2 and the gradations of the aggregates are shown in Fig. 2. Those aggregates was stabilized by AAS binders with optimum proportion [1], the matrixes were all prepared with the aggregate to paste ratio of 3.6 and the water to binder ratio of 0.46. The compressive strengths and the fragmentabilities of the safety concretes are listed in the Table 2.

Table 2
The proportion of the aggregate G-1–G-7.

No.	Gravel:sand	Gravel > 2.36:<2.36	Compressive strength (MPa)	<4.75 mm (Wt%)
G-1	100:0	–	18.1	90.88
G-2	90:10	–	32.7	34.79
G-3	80:20	–	40.2	24.54
G-4	–	90:10	15.6	84.30
G-5	–	85:15	16.0	86.06
G-6	–	80:20	18.1	90.84
G-7	–	75:25	20.5	82.20

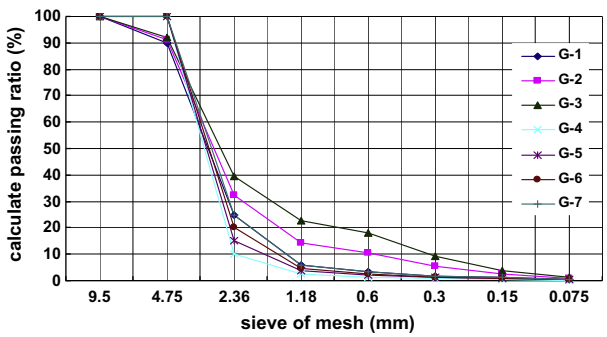

Fig. 2. The gradations of the aggregates G1–G7.