Effect of Freeze-thaw Cycles on Dynamic Mechanical Properties of Ceramsite Concrete

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Abstract. The effect of freeze-thaw cycles on dynamic mechanical properties of the ceramsite concrete is studied by using SHPB experimental technique. Four kinds of the specimens with different ceramsite volume fraction including 0%, 15%, 30% and 45% and experienced 0, 10, 20, 30 and 40 cycles of freezing and thawing respectively, are tested. The results of experiment showed that the dynamic behaviors of ceramisite concrete are decreased with increasing of the number of freeze-thaw cycles. The relationship between dynamic compressive strength of the concrete and freeze-thaw cycles is given.

Introduction

Ceramsite concrete is a kind of lightweight concrete in which the ceramsite is instead of coarse aggregate. There are many advantages, such as light weight, good thermal insulation performance, as well as good anti permeability and so on, ceramsite concrete can be used for building construction, roads, bridges and other infrastructure. The researches of ceramsite concrete[1, 2] and other lightweight concrete[3, 4] on mechanical properties and failure mechanism are mostly limited to statics, and a little related in dynamic mechanical properties [5, 6]. Some researchers have talked about the effect of the freeze-thaw cycles on the static mechanical properties of lightweight aggregate concrete [7, 8], but little attention has been paid to the dynamic ones of ceramsite concrete under freeze-thaw cycles. In this paper, the effect of the freezing and thawing cycles on dynamic compression strength of ceramsite concrete with different volume fraction of ceramsits have been studied. It would be useful for guide the using of ceramsite concrete in extreme environment.

Preparation of Specimens

Tab. 1 Specimen Types and Sizes

Specimen types	Volume fraction of ceramsites	Specimen sizes
Mortar concrete A	0	
Ceramsite concrete B	15%	Φ70 mm×35mm
Ceramsite concrete C	30%	
Ceramsite concrete D	45%	

The specimens of mortar concrete and ceramsite concrete are made by same batch for ensure the consistency of basic properties. Raw materials consist of 45 cement, medium sand and shale ceramsite with diameter 3-6 mm. Ceramsite aggregate is shown in figure 1. The quality ratio of mortar concrete specimens is water: cement: medium sand = 0.43:1:1.2 and same ratio of ceramsite concrete specimens mixed with ceramsite volume fraction of 15%, 30% and 45%. And the ceramsits were used after 24 hours of flooding and dried surface water half an hour before mixed for specimen molding. The types of specimen are shown in table 1.

The specimens are formed after processes of stirring, vibrating and etc. Set the specimens in molds in natural environment (approximately 20℃) for 24 hours, then released mold, standard curing 28 days. Grinding faces assures parallelism of the end surfaces of the specimens with precision of 0.05 mm. Grinded specimens are shown in figure 2.

Fig. 1 Aggregate of Ceramsite

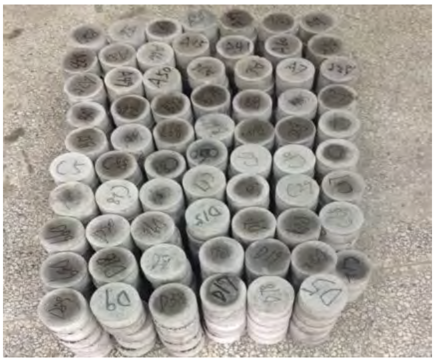


Fig. 2 Specimens after Grinding

Test of Freeze-thaw Cycles

Use fast freeze-thaw test machine as shown in figure 3 (a) to finish freeze-thaw test. The temperature of the center of specimens is from -10℃to 10℃during freezing to melting. A cycle time is 4 hours, thawing time is more than a quarter of the freeze-thaw cycle.5 groups specimens had been processed 0, 10, 20, 30 and 40 times freeze-thaw test respectively. The ultrasonic wave velocity of all specimens are measured before and after the freeze-thaw cycles tested to preliminary observe the influence of freeze-thaw cycle on the internal damage. Repeated freezing and thawing caused damage and even failure (more than 50 times). The surface spalling damage was increased significantly with the increase of the number of cycles of freezing and thawing. The figure 3 (b) and (c) are specimens after 10 and 40 freeze-thaw cycles.

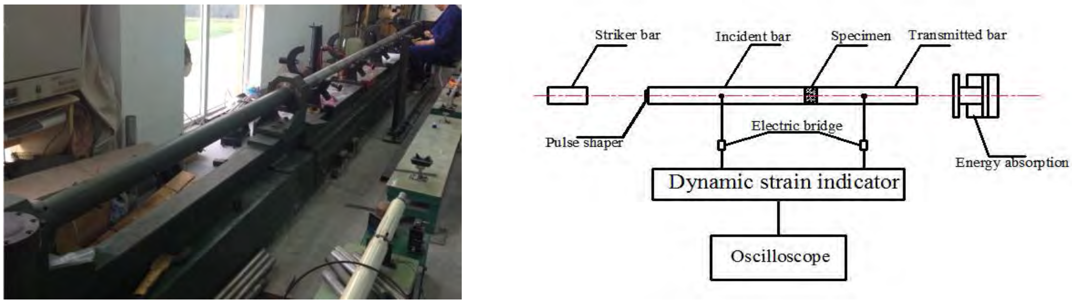
(a) Freeze-thaw cycle test machine (b) Specimen after 10 freeze-thaw cycles (c) Specimen after 40 freeze-thaw cycles

Fig. 3 Freeze-thaw Cycle Test Machine and the Specimens（D group）

Dynamic Compression Testing

Experimental Equipment

SHPB (Split Hopkinson Pressure Bar) device can be used to collect the propagated stress pulses in the bars under impact loading. It is one of the main equipment for measuring the dynamic mechanical response of materials. SHPB device is consisted of the striker bar, incident bar, transmitted bar, and energy absorption and measurement system. Specimen is putted between the incident bar and transmitted bar. Different strain rate in specimen can be obtained under different fire pressures of striker bar. In this paper, the 74 mm diameter SHPB device was used as shown in figure 4(a). Figure 4(b) is the schematic of SHPB device.

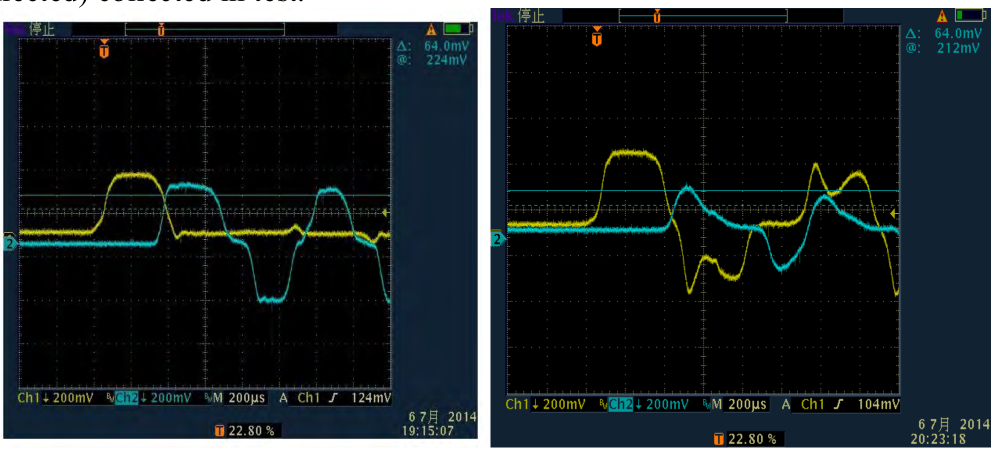


(a) Φ74 SHPB device (b) Schematic of SHPB device

Fig. 4 SHPB Device

Results of SHPB Experiments and Analysis

Each group of specimens is impacted by the SHPB with two fire pressures 0.3MPa and 0.5MPa.The original wave-forms are collected by oscilloscope as shown in figure 5. Based on the principle of stress waves, combined related parameters of the specimen, the stress-strain curve of specimen under impact loading can be derived from the any two of three waveforms(incident, transmit, reflected) collected in test.



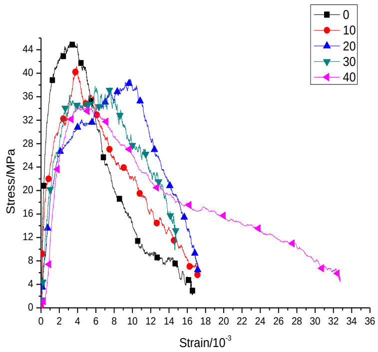
(a) The waveform without specimen (b) The waveform with specimen

Fig. 5 Original Waveforms

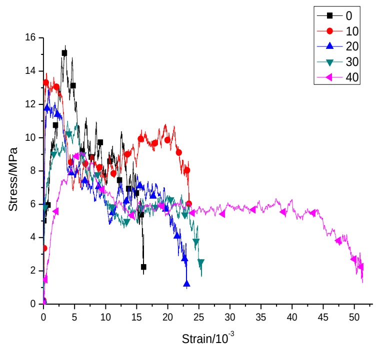
(a) B8 (0 times) (b) B11 (20 times) (c) B49 (40 times)

Fig. 6 Impact Damage Form of Ceramsite Concrete B, 0.3MPa

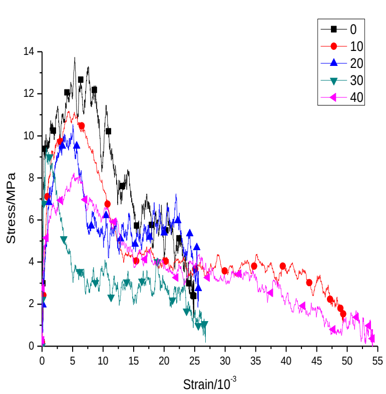
The first batch specimen is tested by means of SHPB with fire pressure 0.3MPa. After test, all of specimens are broken. Impacted damage form of ceramsite concrete B, as illustrated in figure6. Experimental results under fire pressure 0.3MPa and 0.5MPa are shown in figure 7(a) ~ (d) and figure 8(a) ~ (d), respectively.



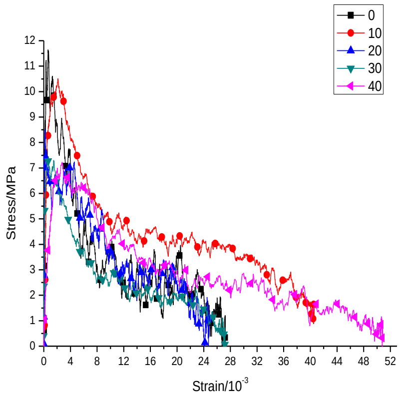
(a) Specimen of group A, 0.3MPa



(b) Specimen of group B, 0.3MPa

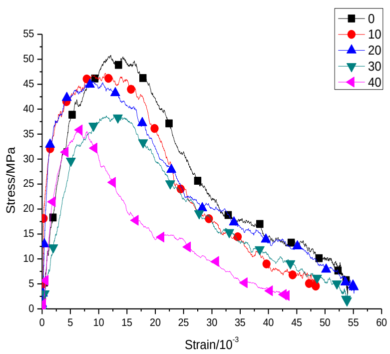


(c) Specimen of group C, 0.3MPa

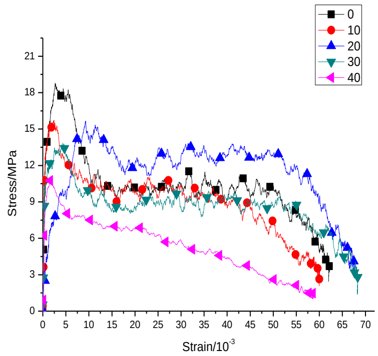


(d) Specimen of group D, 0.3MPa

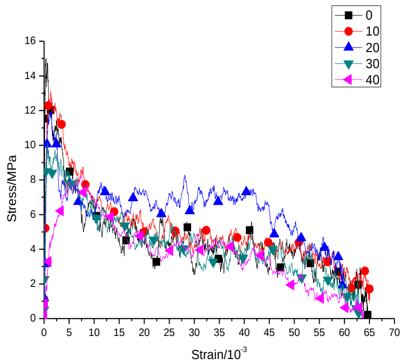
Fig. 7 Stress-strain Curve under Fire Pressure 0.3MPa



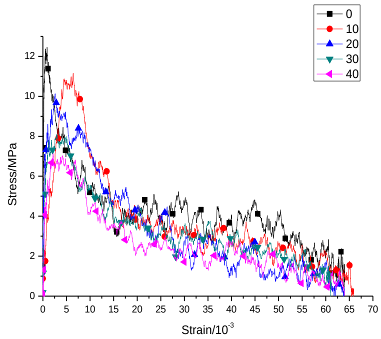
(a) Specimen of group A, 0.5MPa



(b) Specimen of group B, 0.5MPa

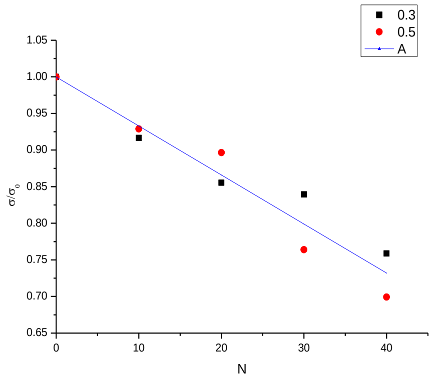


(c) Specimen of group C, 0.5MPa



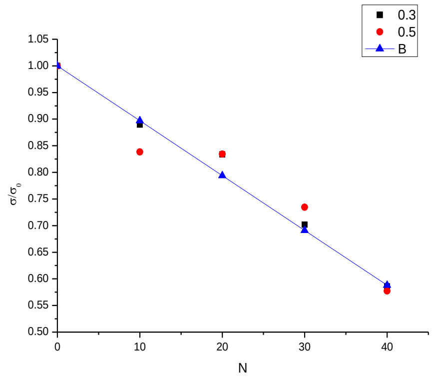
(d) Specimen of group D, 0.5MPa

Fig. 8 Stress-strain Curve under Fire Pressure 0.5MPa



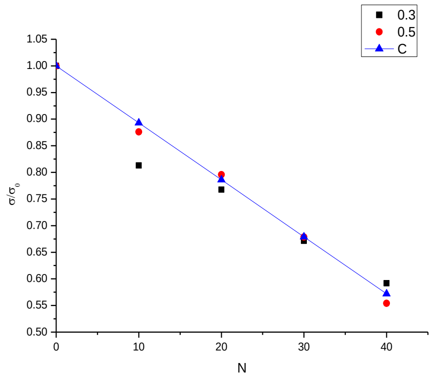
(a)Relative maximum stress curve of mortar concrete (group A)

$f=1-0.0067N, r^2=0.936$



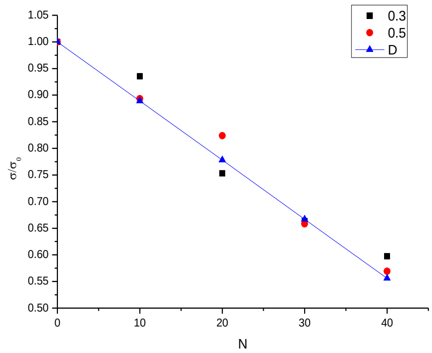
(b)Relative maximum stress curve of ceramsite concrete (group B)

$f=1-0.0103N, r^2=0.956$



(c) Relative maximum stress curve of ceramsite concrete (group C)

$f=1-0.0107N, r^2=0.964$



(d) Relative maximum stress curve of ceramsite concrete (group D)

$f=1-0.0110N, r^2=0.972$

Fig. 9 Fitting Curve of Relative Maximum Stress

Figures 7 and 8 showed that the maximum stress decreased with the increase of number of freeze-thaw cycles N. The relationships between relative maximum stress and N can be indicated by figure 9 (a) ~ (d). And simulated formulas (1) and (2) represented mortar concrete and ceramsite concrete respectively.

$$f=1-0.0067N \quad (1)$$

$$f=1-(0.0099+0.0004V_I/V_B)N \quad (2)$$

where relative maximum stress $f=\sigma/\sigma_0$, σ_0 is the maximum dynamic stress (no freeze-thaw experienced), σ is the maximum dynamic stress (after N freeze-thaw cycles),N is number of freeze-thaw cycles, V_I/V_B is ratio of ceramsite volume fraction, V_I is ceramsite volume fraction(I may be B or C or D) and V_B is ceramsite volume fraction of group B, r^2 is the correlation coefficiet(the largest deviation is 8.9%).

Conclusion

Experiments and numerical simulations are performed to study the effect of number of freeze-thaw cycles on dynamic behaviors of ceramsite concrete. The following conclusions can be drawn from the investigation.

(1)The curves of stress-strain obtained from SHPB testing showed that the maximum stress increased with increase of fire pressure, either mortar or ceramsite concrete. But the stress-strain curve of ceramsite concrete is existed a level stage after peak stress point. It means that the tendency of stress decreases with the increase of strain is slowed down. The toughness of the concrete is improved effectively when ceramsite's volume increased.

(2)Teste results showed that the dynamic compressive strength of ceramsite concrete decreased with increasing of ceramsite volume fraction. The dynamic compressive strength of mortar significantly is greater than one of ceramsite concrete.

(3)Both of mortar and ceramsite concrete, the dynamic compressive strength decreased with the increase of cycles N. The curves of relative maximum stress change with N are given. Repeated freezing and thawing leads to change in the temperature and internal stress caused damage of sample, particularly surface changed bigger than inside inducing seriously spall at surface. Especially after 40 freeze-thaw cycles, ceramsite concrete specimen falls off seriously, and dynamic compressive strength of ceramsite concrete is only half of original specimen.

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