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Damage and its restraint of concrete with different strength grades under double damage factors ☆

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Abstract

This paper presents the damage and its regularity of concrete of different grades under the simultaneous actions of load and freezing–thawing cycles, and analyzes the inhibiting effect of air entraining and steel fibers on damage. The loss of dynamic elastic modulus and the flexural strength of specimens are tested. Experimental results show that the damage process is accelerated and the damage extent increased under simultaneous actions of load and freezing–thawing cycles. The lower the grade of concrete is, the greater the damage is. At higher stress ratio, concretes suffer more serious damage. The addition of steel fiber or air entraining admixture or the combination of the two to concrete can improve its resistance to damage. Experimental results also show that stress ratio has little influence on the weight loss of high strength concrete under double damage conditions.

Keywords: Air entraining admixture; Damage; Freezing–thawing cycles; Load; Steel fiber; Stress ratio

1. Introduction

Improving the concrete durability and prolonging its service life has been a significant scientific and technical problem in the world [1–4]. For half a century, studies of concrete durability have been confined to the influence of single factor. In practical engineering, however, two or more actions but not one usually cause the worsening of properties of concrete, the damage thus follows the law that one plus one is larger than two are. For some engineering, such as highway pavements, airport pavements, bridge decks and dams in hydraulic engineering, the damage might come from double actions of load and freezing–thawing cycles, which is especially the case in cold northern places [5]. In this paper, the damage process of various concretes under the simultaneous actions of load and freezing–thawing cycles is demonstrated. Surely it is of great importance for critically assessing the durability of concrete under comprehensive conditions.

2. Materials and experiments

2.1. Materials

A portland cement, its specific surface area being 3000 cm^2/g and its specific gravity 3.1 g/cm^3 was used. The fineness modulus of fine aggregate was 2.6. The coarse aggregate used was a crushed stone with a maximum diameter of 10 mm. Superplasticizer was supplied by Shanghai Xinpu Chemical Factory. The Materials College of Tongji University provided air-entraining admixture. The length, aspect ratio and tensile strength of steel fiber were 20 mm, 60 and 750 MPa, respectively. The mixture proportions of various concretes are given in Table 1.

2.2. Experiments

The specimens sizes were $40 \times 40 \times 160$ mm for flexure and $40 \times 40 \times 40$ mm for compression. In order to materialize the simultaneous action of load and freezing–thawing cycles and to control the loading process so that no stress relaxation should be produced while the specimens were under freezing–thawing cycles, a special loading device was designed (Fig. 1). The force was applied by adjusting the deformation of springs.

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Table 1
The mixture proportions of various concrete

Series of concretes		Vf (%)	Cement (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Air entraining (%)	W/C
C40	PC	0	409	180	658	1169	0	0.45
	SFRC	1.5	409	180	819	961	0	0.45
C50	PC	0	398	151	734	1198	0	0.38
	SFRC	1.5	398	151	849	1038	0	0.38
C60	PC	0	440	142	666	1237	6.7	0.32
	SFRC	1.5	440	142	817	1039	6.7	0.32
C80	PC	0	477	124	700	1299	4.2	0.26
	SFRC	1.5	477	124	787	1133	4.2	0.26

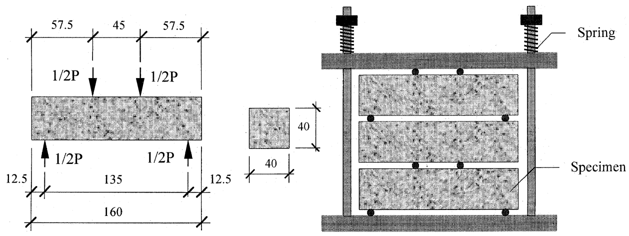

Fig. 1. Schematic description of the loading device.

The loading and freezing–thawing cycles were simultaneously applied to specimens in an automatic freezing–thawing cycles machine according to ASTM 666. The force applied was decided according to various stress ratios, which were 0, 0.1, 0.25 and 0.5, respectively. The dynamic elastic modulus and the strength at the end of freezing–thawing cycles were tested. The weight loss of some concrete samples was examined as well.

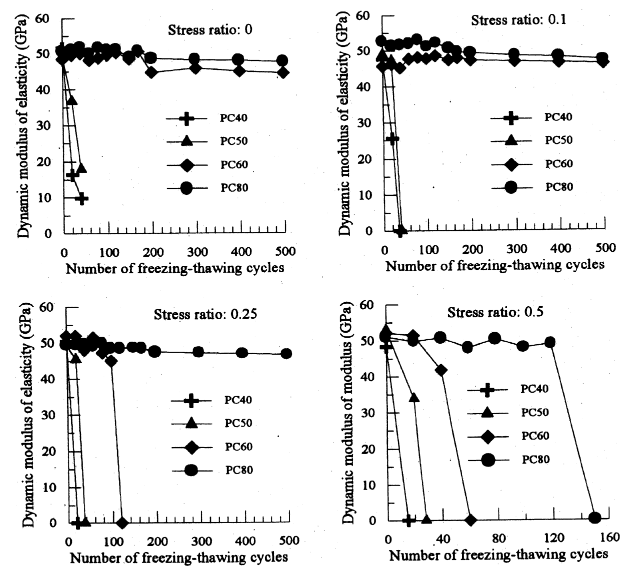

Fig. 2. The loss of dynamic modulus of elasticity of portland cement concrete under the double actions of load and freezing–thawing cycles.

3. Results and analysis

3.1. Damage regularity of ordinary concrete under the simultaneous action of load and freezing–thawing cycles

The concrete strength grades were C40, C50, C60 and C80, with corresponding W/C of 0.45, 0.38, 0.32 and 0.26. Fig. 2(a)–(d) show the changes of dynamic elastic modulus of different grade concretes under the simultaneous actions of load and freezing–thawing cycles at the stress ratio of 0, 0.1, 0.25 and 0.5. It can be seen that, for ordinary cement concrete, strength grade, stress ratio and freezing–thawing cycles are important factors that determine the properties of concrete under the double damage actions. At the same stress ratio, concrete of higher strength can undertake more freezing–thawing cycles, and the dynamic elastic modulus decreases slower with freezing–thawing cycles. Obviously, the damage caused by the double actions at high stress ratio is the most serious. At stress ratio of 0.5, PC80 concrete can endure only 150 cycles of freezing–thawing which is much lower than at stress ratio of 0.25. When compared with the test results under freezing–thawing cycles without loading, not only the damage extent is increased, also is the damage rate accelerated.

Table 2 shows the results of flexural strength of different grades concrete. It can be seen that, for low strength concrete, the loss of flexural strength after the simultaneous actions of both load and freezing–thawing cycles is evident. For high strength concrete, however, the influence of stress ratio on flexural strength is slight.

Table 2
Flexural strength (Mpa) of concrete after double damage actions

Stress ratio	0, no frost Strength	0, frost Strength (cycles)	0.1, frost Strength (cycles)	0.25, frost Strength (cycles)	0.5, frost Strength (cycles)
PC40	7.63	5.15 (20)	5.13 (20)	4.15 (20)	4.13 (20)
PC60	8.76	6.54 (20)	–	–	6.55 (60)
PC80	9.80	8.46 (500)	8.43 (500)	8.37 (500)	8.33 (500)
SFRC40	10.70	7.09 (20)	6.88 (20)	–	–
SFRC60	12.50	11.03 (500)	10.50 (500)	10.48 (500)	9.98 (500)
SFRC80	13.40	13.20 (500)	12.90 (500)	12.43 (500)	12.40 (500)

3.2. Damage of concrete with steel fiber and air-entraining admixture

In order to improve the ability of resisting damage under the double actions, steel fiber, air-entraining admixture and the combination of the two were added to the concrete. It is recognized that the crack resisting effect from steel fiber and the pressure releasing effect from air entraining admixture can improve the properties of concrete [6–8]. The results are shown in Figs. 3 and 4. It can be seen that, the ability of steel fiber reinforced concrete (SFRC) to resist the damage of double factors is greatly improved. For the same grade concrete, SFRC can undertake more freezing–thawing cycles than ordinary concrete at the same stress ratio. At the stress ratio of 0.1, SFRC50, SFRC60 and SFRC80 can ensure 500 cycles of freezing–thawing without failure of concrete. At the stress ratio of 0.5, SFRC80 suffers little after 500 cycles of freezing–thawing.

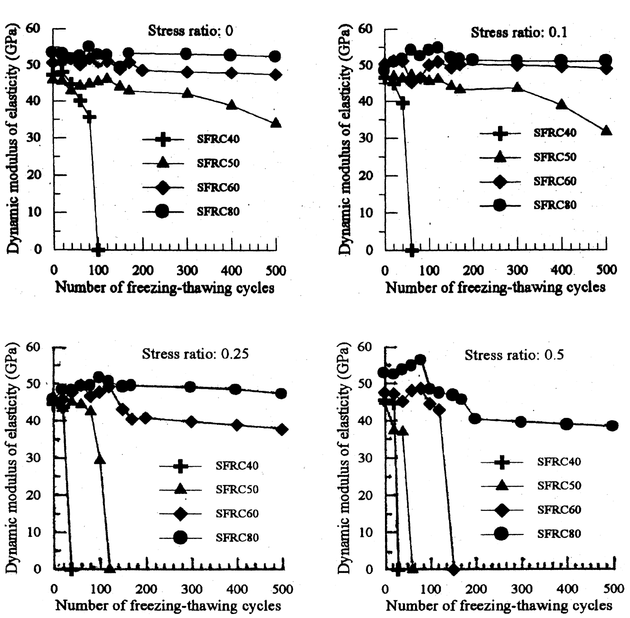

Fig. 3. The loss of dynamic modulus of elasticity of SFRC under the double actions of load and freezing–thawing cycles.

Furthermore, the combination of steel fiber and air entraining to concrete can further improve the ability of inhibiting damage under the simultaneous actions of load and freezing–thawing cycles (Fig. 5). At the stress ratio of 0.25, the air entrained steel fiber reinforced concrete SFRC60 shows little change in dynamic elastic modulus after 500 freezing–thawing cycles. Even if at the stress ratio of 0.5, the loss of dynamic elastic modulus is slight. For SFRC80 concrete, the dynamic elastic modulus keeps almost unchanged. The results show that the ability of frost resistance of air-entrained steel fiber reinforced concrete under different stress ratios might be enhanced further by using the crack resisting effect from steel fiber and the pressure releasing effect from air entraining.

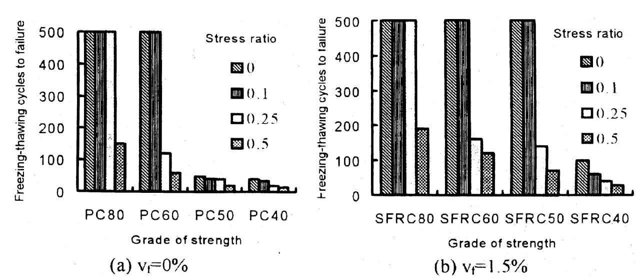

Fig. 4. Comparison of SFRC and PC concrete under the double actions of load and freezing–thawing cycles.

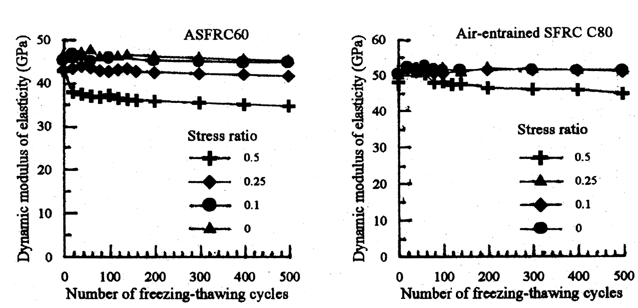

Fig. 5. The effect of the combination of steel fiber and air-entraining admixture on the properties of concrete under the double actions of load and freezing–thawing cycles.

3.3. Weight loss of concretes under double damage factors

The weight of some of the concretes before and after the double actions of load and freezing–thawing cycles was examined and compared. The calculated weight loss is shown in Table 3. Unlike common strength concrete, high strength concrete lose very little weight even after the simultaneous action of load and 500 freezing–thawing cycles.

4. Discussion

From the above results, it is evident that the damage of different kinds and different grades of concrete under the simultaneous actions of different stress ratios and freezing–thawing cycles is a very complex fatigue process. This process results from the double effects of factors that deteriorate the structure and that resist the deterioration. The damage process depends mainly on two factors. One is the strength grade of concrete matrix. For the matrix, the improvement of the microstructure, in particular, the pore size and the pore morphology, is good for resisting damage. Furthermore, the decrease of pore size might decline the freezing point. Therefore, higher strength concrete usually has better resistance to the double damage factors. The other is the ability to resist damage. The incorporation of air-entraining admixture may increase the amount of closed pores and relax the pressure during the freezing–thawing cycles. The addition of steel fiber may play a role in inhibiting the initiation and propagation of cracks. When air entraining agent and steel fiber are incorporated in concrete, both the pressure releasing effect and the crack resisting effect contribute to the good ability of resisting deterioration due to the simultaneous actions of load and freezing–thawing cycles.

Table 3
Weight loss (%) of concrete after the action of loading and 500 freezing–thawing cycles[a]

Concrete series	Stress ratio			
	0	0.1	0.25	0.5
PC80	0.8	0.8	0.4	0.5
APC60	0.8	0.6	0.8	0.8
APC80	0.7	0.6	0.6	0.7
SFRC50	1.9	2.0	2.0	2.5

[a] APC: air-entrained portland cement concrete.

5. Conclusions

1. Stress ratio is an important factor that influences on the resistance of concrete to damage under the simultaneous actions of load and freezing–thawing cycles. The higher the stress ratio is, the more the damage rate and extent is.
2. The buffering effect from steel fiber and the pressure-releasing effect from entrained air may inhibit the damage of concrete incorporated with steel fiber or air entraining or the combination of the two.
3. Under the simultaneous actions of load and freezing–thawing cycles, the damage rate and extent depend on the grade of concrete, the higher the grade is, the less the damage is.
4. High strength concretes suffer much less weight loss than those of common strength concretes under the simultaneous actions of load and freezing–thawing cycles.
5. The loading device is proved to be effective for preventing the stress relaxation under freezing–thawing cycles.

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