EXPERIMENTAL STUDY ON TENSION AND COMPRESSION BEHAVIOR OF PLAIN CONCRETE AFTER FREEZING AND THAWING EXPOSURE

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1. INTRODUCTION

Air entrainment has been successfully used for over 50 years to protect concrete from freezing and thawing deterioration. A well dispersed air void system with a small spacing factor (less than 0.2 mm) normally guarantees good freezing and thawing durability on concrete(1). Many recent study emphasized to durability of concrete due to freezing and thawing effect and deicing resistant. However, the important aspects, tension softening, fracture energy, and stress strain relationship under compression of concrete after freezing and thawing exposure has apparently escaped attention. Fracture energy is related to tension softening curve as a material law, which is necessary for numerical simulations of fracture phenomena of concrete due to cracking(2). For understanding of the fracture behavior of concrete structures, knowledge of the post cracking behavior of concrete material is essential. The tension softening diagram can describe the post cracking behavior of concrete in tension(3). In this paper the post cracking behavior in tension for concrete after freezing and thawing exposure were studied. To determine the fracture energy of concrete the recommended method by RILEM(4) has been adopted. At the end of this paper the stress strain behavior under compression was presented.

2. MATERIAL AND MIX PROPORTION

A single source of portland cement was used. Gravel with maximum diameter 16 mm and natural river sand were used as coarse and fine aggregates respectively. An AE agent was added to mixture A with portion 0.05 % of portland cement proportion. Two types of concrete mixture were cast, that is concrete mixture with adding AE agent (namely mixture A) and without adding AE agent (namely mixture E) in order to study the effect of AE agent on freeze-thaw resistance. Mix proportion for both mixtures for 1 m^3 concrete volume are given in Table 1.

Table 1 Mix proportions

Mix-ture	w/c	C (kg)	W (kg)	G (kg)	S (kg)	AE agent
A	0.50	160	320	1132.5	754.7	0.05 %
E	0.50	160	320	1132.5	754.7	-

3. EXPERIMENTAL PROGRAM

Seven prism specimens A and seven prism specimens E were cast. The size of specimens was 100 mm x 100 mm x 400 mm. 18 cylinder specimens with diameter 100 mm and height 200 mm also cast for each mixture. After the mould opened, the specimens cured in the water. Freezing and thawing exposure was started when the age of specimens 15 days. Freezing and thawing experiment was performed based to ASTM C666-92 procedure A with the minimum temperature during freezing at –17.8 °C and maximum temperature at 4.4 °C(5).

On specimens A, after freezing and thawing exposure, the three point bending test was held. Three point bending test was performed on notched beam specimens with notch on the center of beam. Notch was made by using sawing machine with the width of 4 mm and length 50 mm. Specimens put on two support with span 360 mm. Two displacement transducers placed on two size of loading bar beside the specimens at the center to perform the center deflection. Two other transducers placed on the top of specimen at the bearing point. Four π-gages (two in each side) mount on ligament portion of specimens to obtain the crack width. These π-gages placed at distance 12.5 mm, 25 mm, 37.5 mm, and 50 mm from the top of specimens respectively. The specimens were loaded using Autograph Bending Test Machine AG 250 kNE with maximum capacity 250 kN by controlled the deflection to obtain the complete load-deflection curve until the specimens separated into two halves. For detail, the dimension of specimens and test procedure is given in Fig. 1.

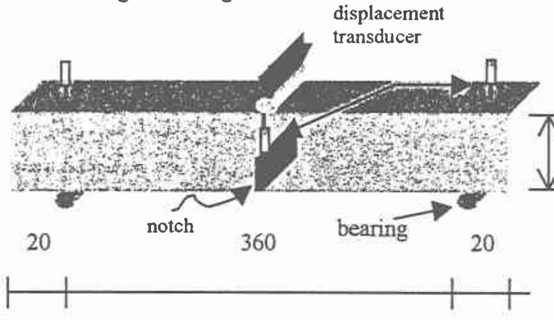


Fig. 1 Specimen dimension and test setup

After bending test finished, cored cube specimens took out to perform compressive test. Six strain gages placed on the cube specimens to obtain the axial and lateral strain. Compression load was applied by using Compressive Test Machine CCH-2000 kNA with maximum capacity 2000 kN. Location of strain gages is shown in Fig. 2.

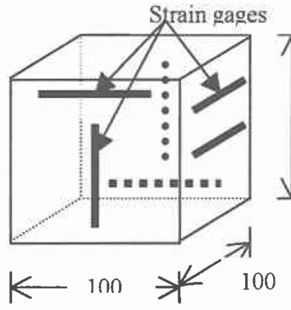


Fig. 2 Location of strain gages on cube specimen

4. RESULT AND DISCUSSION

4.1 Effect of AE Agent on Freeze-Thaw Resistance

The AE agent has extremely significant effect on the freeze-thaw resistance of concrete. Fig. 3 shows the comparison of relative dynamic elastic modulus (RDEM) for concrete with and without adding AE agent. For concrete specimens without adding AE agent, the relative dynamic modulus of elasticity reduced 69.1 % after 106 cycles, but for specimens with adding AE agent, the reducing of dynamic elastic modulus only 4.43 % after 300 cycles. This means that adding AE agent on concrete material can increase its resistance on freezing and thawing effect.

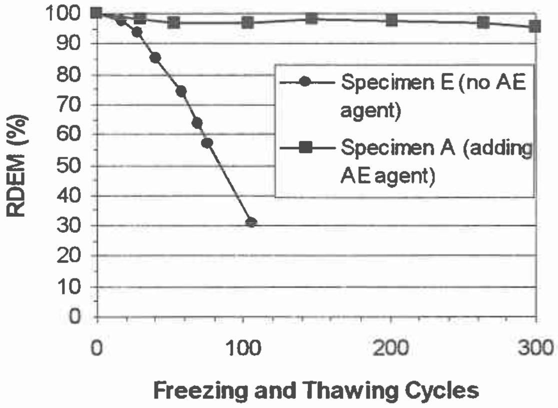


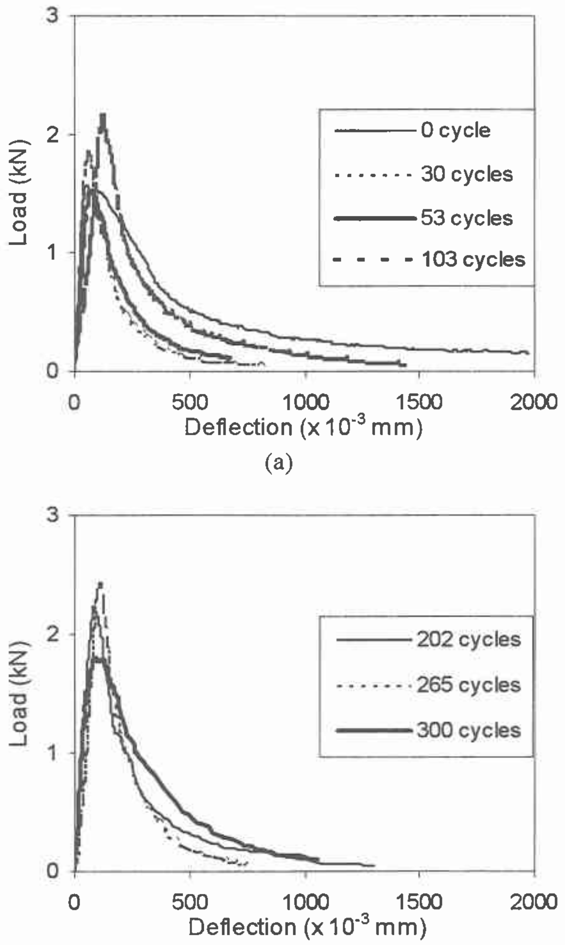
Fig.3 Effect of AE agent on relative dynamic elastic modulus

4.2 Load-Displacement Characteristics

The load-displacement characteristics for concrete specimens with adding AE agent after several cycles of freezing and thawing exposure are compared in Fig. 4 and main parameter were studied are summarized in Table 2. To make the figure more clear, the figure divided into Fig. 4 (a) for 0, 30, 53, and 103 cycles; and Fig. 4 (b) for 202, 265, and 300 cycles. Fig. 4 shows very clear difference in both ascending and descending branch of load-deflection curve for different cycle number. In ascending branch the slope of curve decreased with increasing cycle number and caused the deflection corresponding with maximum load (D_o) also increased as show in Table 2. This means that freezing and thawing exposure caused degradation of initial stiffness in tension. This phenomena should be caused by appearing some internal crack during freezing and thawing exposure. In descending branch the drop of load more precipitous for higher cycle specimens that caused the concrete more brittle.

Table 2 Summary of bending test result

Speci men	Cycle number	P_{max} (kN)	D_o (mm)	D_{max} (mm)	G_F (N/m)
A1	0	1.57	0.051	1.970	213.37
A2	30	1.86	0.057	0.822	69.59
A3	53	1.53	0.069	0.678	81.83
A4	103	2.17	0.126	1.444	147.04
A5	202	2.23	0.088	1.297	136.35
A6	265	2.44	0.112	0.757	107.56
A7	300	1.80	0.121	1.053	141.01



(b)

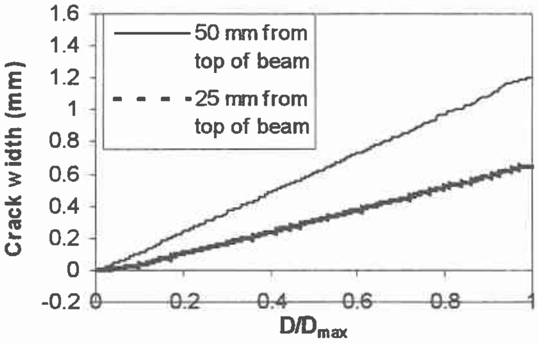
Fig. 4 Load-displacement characteristics

Increasing of maximum load (P_{max}) for increasing of cycle number were not affected by freezing and thawing exposure, but there were be age effect, because for increasing the cycle number, the age of specimens also increased. Fracture energy of concrete after freezing and thawing exposure was smaller than before freezing and thawing. This phenomena should be caused by more precipitous drop of load after peak load for concrete after freezing and thawing exposure.

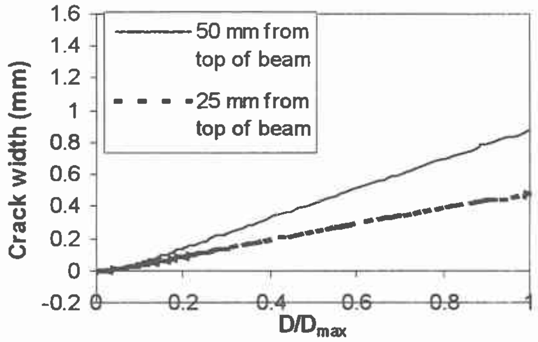
4.3 Propagation of Crack

Crack propagated throughout the ligament area gradually as the deflection increases. To evaluate the propagation of crack in ligament portion, the crack width has been measured in two location for specimens A1, A2, A3, and A4; and four location for specimens A5, A6, and A7 in ligament area. This crack width should include the elastic deformation in this portion. The elastic stress generated in this portion is less than the level of tensile strength of concrete. Relationship between crack width and D/D_{max} for all specimens are shown in Fig.5

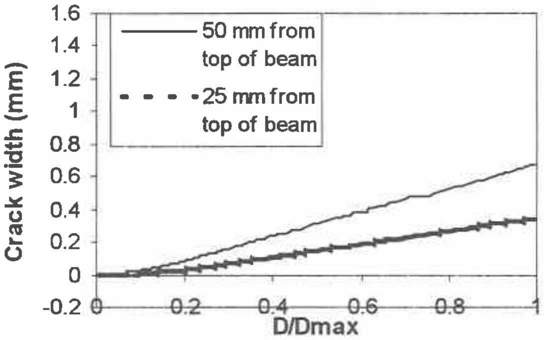
In the Fig. 5 it can observed the clear compression zone near the upper edge of the beam when D/D_{max} less than 0.2 and in this condition crack did not reach to the top of beam. When deflection increased, the compressive zone narrows and become tension followed by propagation of crack throughout the ligament portion.



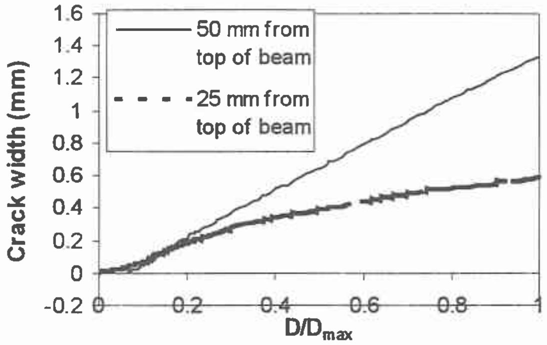
(a) Specimen A1 (0 cycle)



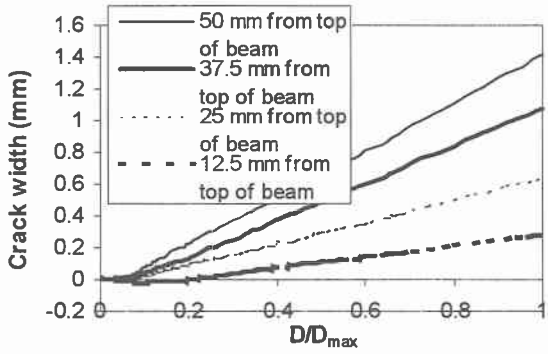
(b) Specimen A2 (30 cycles)



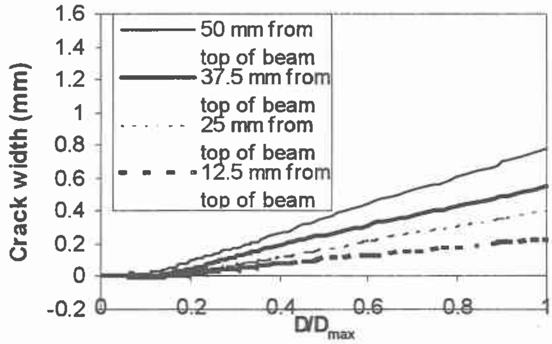
(c) Specimen A3 (53 cycles)



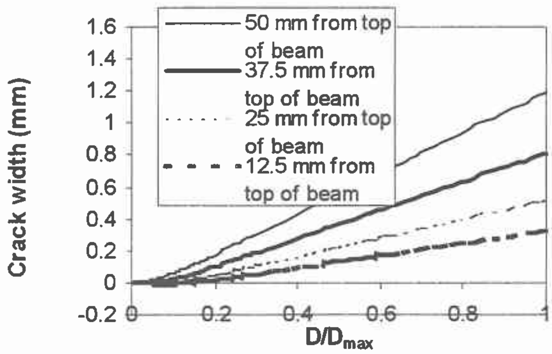
(d) Specimen A4 (103 cycles)



(e) Specimen A5 (202 cycles)



(f) Specimen A6 (265 cycles)



(g) Specimen A7 (300 cycles)

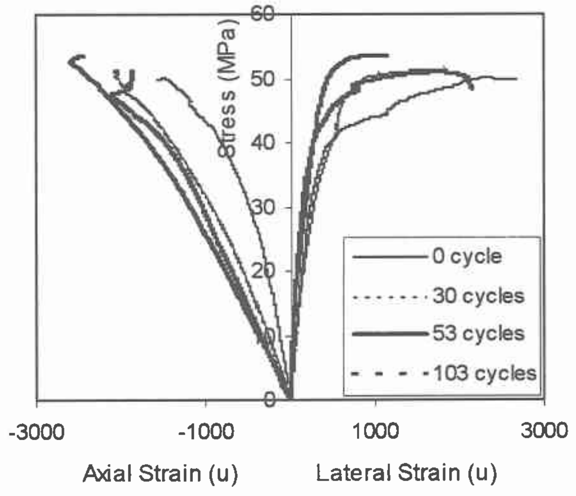
Fig. 5 Relationship between crack width and δ/δ_{max}

4.4 Stress-Strain Relationships under Compression

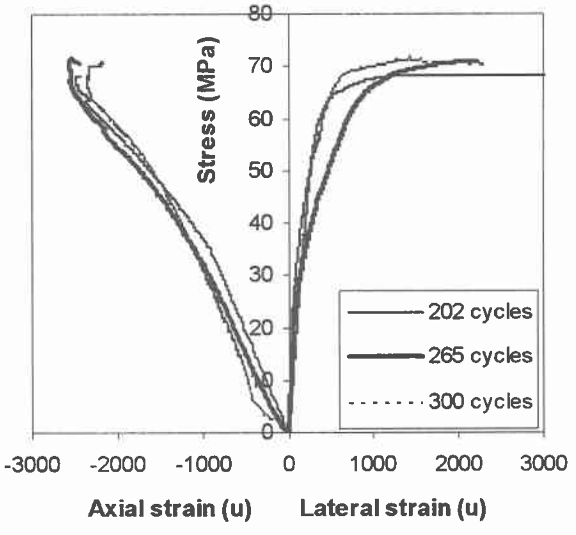
Stress-strain relationships under compression for all specimens are presented in Fig. 6. The main parameters obtained from compression test are given in Table 3. Table 3 shows that freezing and thawing exposure did not affect the compressive strength concrete with adding AE agent. The increasing of compressive strength for specimens A5, A6, A7 was caused by age effect, because the age of specimens A5, A6, and A7 more older than other specimens. Fig. 6 shows that the initial tangent modulus reduced with increasing the cycle number. In fact the compressive strength increase actually the initial tangent modulus also increase, but in this case the initial tangent modulus decreased with increasing the freezing and thawing cycle number. From this phenomena, it can conclude that the freezing and thawing exposure caused the degradation of initial tangent modulus of concrete.

Table 3 Summary of compression test result

Spe-cimen	Cycle number	Age (days)	Compressive strength (MPa)	
			Cube	Cylinder
A1	0	45	50.12	39.03
A2	30	45	51.36	39.03
A3	53	45	53.58	39.03
A4	103	72	51.00	42.63
A5	202	135	71.44	48.44
A6	265	135	70.80	48.44
A7	300	135	68.17	48.44



(a)



(b)

Fig. 6 Compressive stress-strain curve

At the same stress level, higher cycle number had more less lateral strain, but axial strain more big; that caused the Poisson's ratio reduced with increasing of freezing and thawing cycle number.

5. CONCLUSION

An experimental investigation was conducted on plain concrete to study the tension and compression behavior after freezing and thawing exposure. From the investigation the following conclusion were derived.

1. Adding AE agent on concrete mixture caused the concrete more resistant to freezing and thawing effect.
2. Freezing and thawing exposure did not affect the strength of concrete with using AE agent both in tension and compression, but caused the stiffness degradation.
3. Freezing and thawing reduced the fracture energy of concrete and caused the concrete more brittle.
4. Crack propagated throughout the ligament area gradually as the deflection increases. When the deflection less than 20 % maximum deflection, a clear compression zone can observed near the upper edge of the beam.
5. Poisson's ratio reduced with increasing the cycle number of freezing and thawing.

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