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Effect of High Temperature Elastic Modulus on Thermal Strain Behavior of Ultra High Strength Concrete

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ABSTRACT

A large amount of strength degradation of high strength concrete is occurred when it is exposed to elevated temperatures. Therefore, fire resistance performance of concrete has to be verified. Furthermore, the stability of the structure is likely to be decreased due to the deformation of structural member under constant high temperature condition. In this study, the thermal strain of high strength concrete with the compressive strength of 80, 130, 180MPa were measured under 25% of compressive strength loading condition. As results, consistent thermal strain of 80MPa specimen has been occurred up to 500 °C remaining in the expansion area. However, 130 and 180MPa specimen showed the shrinkage strain after 300 °C. Especially, creep rupture was occurred on 180MPa specimen at 700 °C in the creep strain experiment. Therefore, it is considered that decline of the elastic modulus and shrinkage strain of high strength concrete become grater at the elevated temperatures.

1. INTRODUCTION

Since the applications of high-rise building structures have been increased, ultra-high-strength concrete (UHSC) is coming into use. Many previous studies have shown that the inside of ultra-high-strength-concrete (UHSC) becomes denser at low water/cement ratios, and they show an even greater degradation in mechanical performance compared to normal-strength concrete (NSC) at elevated temperatures.

Meanwhile, many situations have been reported where vertical members such as pillars suffered shear failure under a large load, due to the thermal expansion of horizontal members such as beams or slabs, as shown in Fig. 1. Also, creep strain can occur in concrete members, exposed to a fire for about 120–180 min, of comparable magnitude to the creep strain of concrete kept at room temperature for about 20 to 30

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years. As shown in these cases, for evaluation of the fire resistance performance of the concrete structures, the strain properties that are introduced in the event of a fire as well as the basic mechanical properties should be considered with design load applied to structural member.

In this study, therefore, concrete specimens with compressive strengths of 80, 130, and 180 MPa were subjected to a wide range of temperatures from room temperature to 700 °C under loading condition. Then, mechanical properties, total strain, high-temperature-creep at elevated temperature under loading condition were evaluated.

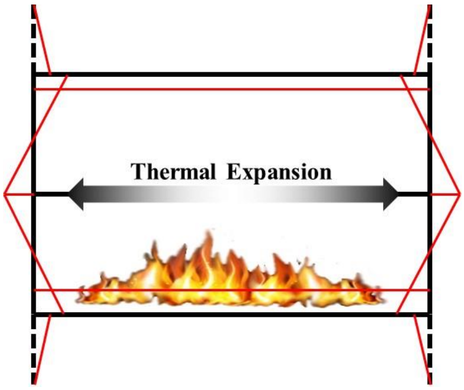


Fig. 1 Thermal expansion of concrete constituent material

Table 1 Experimental plan

Experiment factor				Test item
F_{ck} (MPa)	W/B[1)]	Restraining load Rate (f_{cu})	Temperature (°C)	
80	0.20	0.00[2)] 0.25[3)]	20, 100, 200, 300, 500, 700	· Compressive strength · Elastic modulus · Thermal expansion Strain · Total strain · High temperature creep
130	0.145			
180	0.125			

[1)] W/B : water-to-binder ratio, [2)] unstressed, [3)] stressed

Table 2 Concrete mixing proportion

f_{ck} (MPa)	W/B (%)	Slump flow (mm)	S/a (%)	Air (%)	Unit weight (kg/m^3)							
					W	C	BFS	SF	FA	AG	S	G
80	20.0	750 ± 100	43.0	2±1	150	525	0	75	150	0	644	870
130	14.5		35.0			652	207	124	0	52	448	848
180	12.5		35.0			660	240	240	0	60	389	736

Table 3 Physical properties of used materials

Materials	Physical Properties
Cement	Ordinary Portland Cement Density : 3.15g/cm^3, Specific surface area : 3,630cm^2/g
Fine aggregate	Washed sand Density : 2.65g/cm^3, Water absorption ratio : 1.00 %
Coarse aggregate	Crushed granite Max size : 13mm, Density : 2.70g/cm^3, Water absorption ratio : 0.97 %
Silica fume	Density : 2.23g/cm^3, Specific surface area : 200,000cm^2/g
Admixture	Polycarboxylic water reducing agent

2. EXPERIMENTAL PLAN AND METHOD

2.1 Experimental Plan and Concrete Mixing Proportion

Table 1 outlines the experimental plans and Table 2 presents mix proportion of UHSC specimen. To evaluate the thermal strain behavior of UHSC, the heating experiment was performed with ø100 × 200 mm cylindrical specimens that compressive strengths was 80, 130, and 180 MPa under non-loading, $0.25f_{cu}$ loading conditions. The target heating temperatures were the room temperature (20°C), 100, 200, 300, 500, and 700 °C. At the respective target temperatures, the compressive strength was measured. The thermal expansion strain, which occurs during heating to the target temperature, and the creep strain at high temperatures, which occurs when the temperature is maintained at a fixed value, were also measured.

2.2 Used Materials

The physical properties of the materials used in this study are described in Table 3. In this study, crushed granite gravel with a specific weight of 2.70, water absorption rate of 0.97%, and maximum size of 13 mm was used as the coarse aggregate. Sea sand with a specific weight of 2.65 and water absorption rate of 1.00% was used as the fine aggregate.

2.3 Heating Apparatus and Heating Method

The experimental apparatus used in this study is shown in Fig. 2. For simultaneous loading and heating, an electric heating furnace was installed loading apparatus with a capacity of 2000 kN. To increase the temperature inside and outside of the test specimens to the same level, an indirect heating method was used in which heat was transferred to the test specimens by heating the upper and lower loading jigs.

Furthermore, the heating rate was set at 1 °C/min to maintain the temperature difference within 5 °C between the inside and outside of the test specimens.

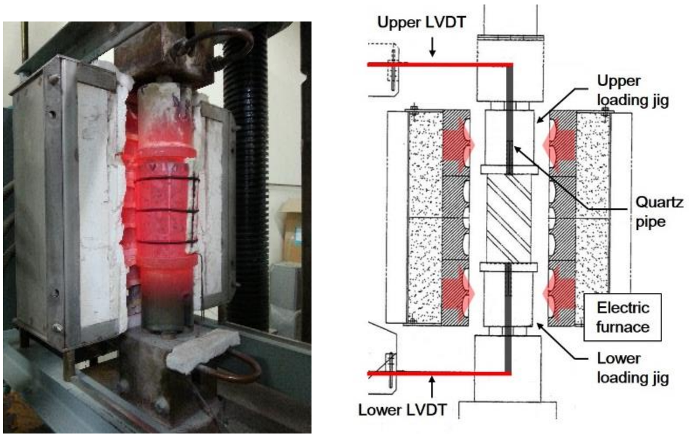


Fig. 2 Experimental apparatus used in this study

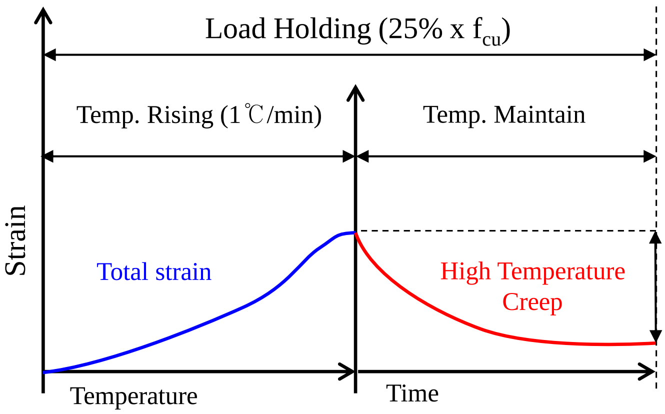


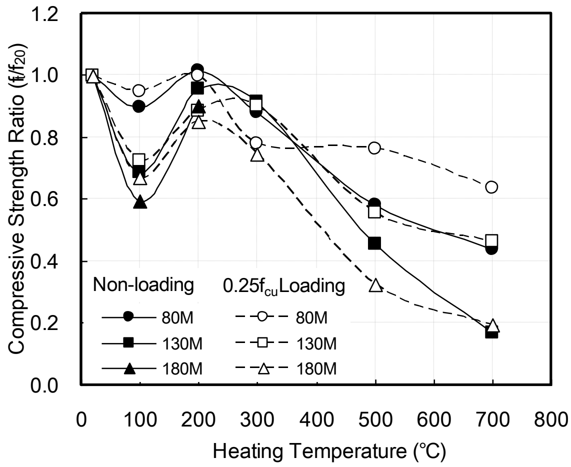
Fig. 3 Heating method of this study

Fig. 3 shows the heating method of this study. The total strain was measured under heating and loading conditions, at a load of 25% of the compressive strength at room temperature. The high-temperature-creep was measured for 300 min after the target temperature was reached, at the conditions of the heating temperatures and load of 25 % of the compressive strength at room temperature.

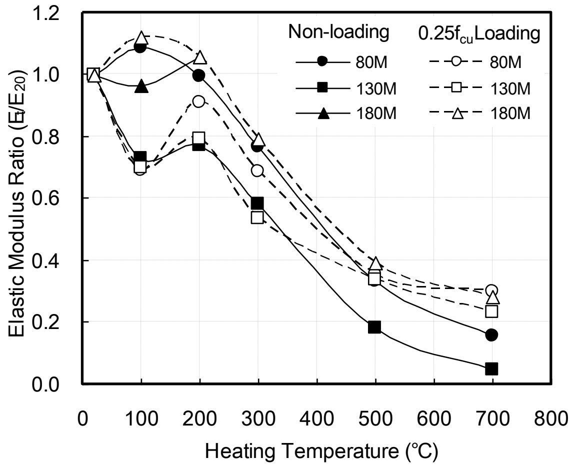
3. RESULTS AND DISCUSSION

3.1 Mechanical Properties of UHSC under High Temperature and Loading

In heating temperature of over 300 °C, compressive strength of 80 and 130 MPa specimens showed a tendency that $0.25f_{cu}$ loaded specimen was higher than that of non-loaded specimen. This tendency was similar in result of high temperature elastic modulus. It is considered that because of thermal expansion strain, which was causing cracks in the concrete, was offset by the shrinkage strain under loading condition.



a) Compressive strength



b) Elastic modulus

Fig. 4 Mechanical properties of UHSC under elevated temperature and loading conditions

3.2 Thermal Expansion and Total Strain

Fig. 5 shows the thermal expansion and total strain of UHSC depending on the temperature. The thermal expansion strain became larger as the heating temperature increases regardless of compressive strength of concrete. The total strain showed shrinkage behavior because of the reduction of the thermal expansion by offsetting effects caused by the load. And it tended to shrink at high temperatures as W/B decreased. This is because the rate of decrease in the compressive strength greatly increased for lower W/B as the temperature increased. Therefore, even though a load corresponding to 25% of the compressive strength at room temperature was applied equally, the rate of decrease in the compressive strength greatly increased for lower W/B as the temperature increased.

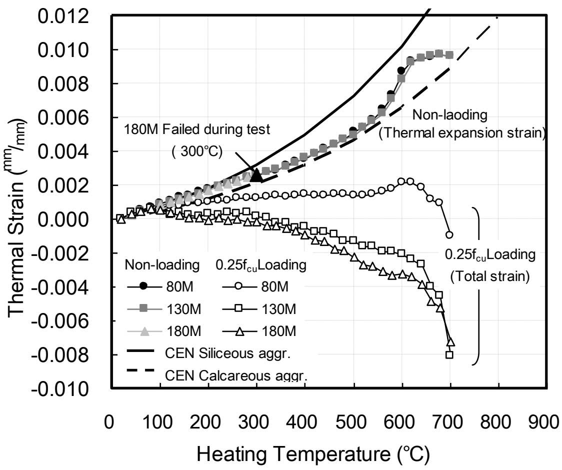


Fig. 5 Thermal expansion and total strain of UHSC under heating and loading condition

3.3 High Temperature Creep

Fig. 6 shows 5 h of high-temperature creep for the UHSC concrete as evaluated according to the high-temperature-creep test method. 180 MPa concrete; compressive fracture occurred from the preload during the test.

The high temperature creep of UHSC increased with the temperature. Very high-speed high temperature-creep behavior occurred in the first 50 min for every specimen. The strain gradually decreased after that. When the temperature was below 500 °C, about 80 % of the high temperature creep over 300 min was caused by the shrinkage in the initial 100 min. Above 500 °C, over 60 % of the high-temperature-creep of 300 min was caused by creep shrinkage in the initial 100 min. The strain behavior of the high temperature creep greatly increased at lower W/B ratios. This is because creep is linearly proportional to the axial loading ratio.

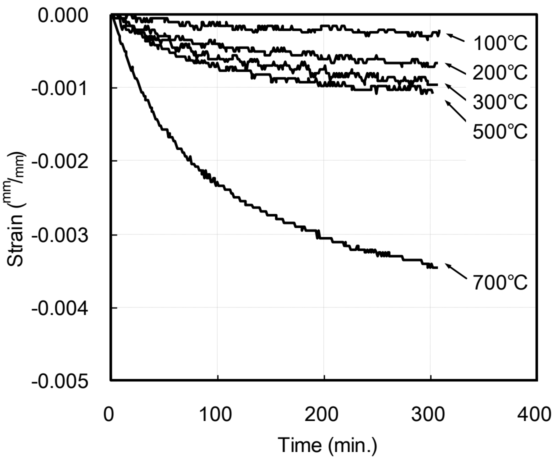
3.4 Relation between High Temperature Creep and Elastic Modulus

Fig. 7 shows relation between high temperature creep strain and high temperature elastic modulus. The high temperature elastic modulus was decreased and the high temperature creep strain was increased with the heating temperature rising.

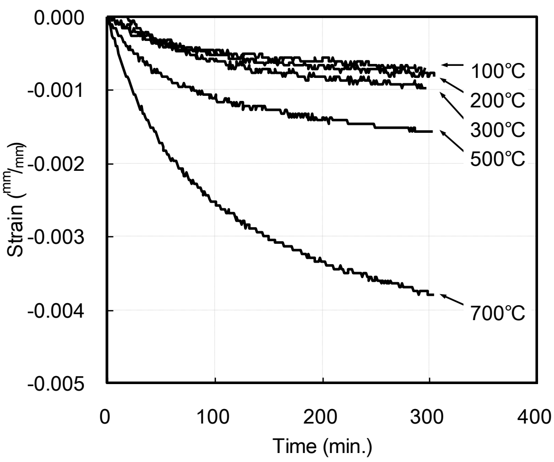
As the heating temperature increased to 500°C, the high temperature elastic modulus and high temperature creep strain were decreased at a steady rate. At the heating temperature of more than 500 °C, however, unlike the high temperature elastic modulus, high temperature creep strain was sharply increased.

4. CONCLUSIONS

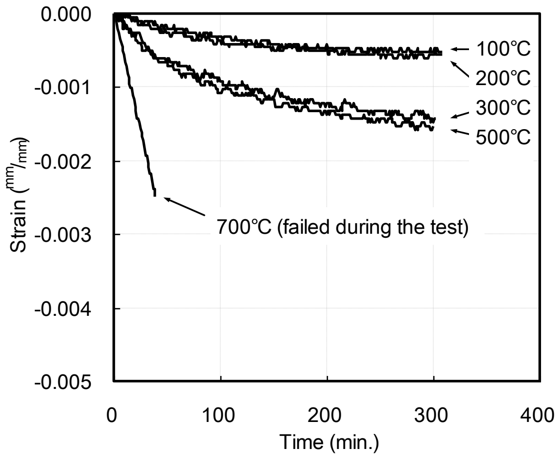
1) High temperature mechanical performance of high strength concrete have been decreased with increasing temperature and decreasing W/B. In addition, cracks generated inside the concrete is suppressed by 0.25fcu loading was confirmed that there is a large high-temperature compressive strength and modulus of elasticity than the non-loading conditions.



a) 80 MPa



b) 130 MPa



c) 180 MPa

Fig. 6 High temperature creep strain of UHSC under heating and loading condition

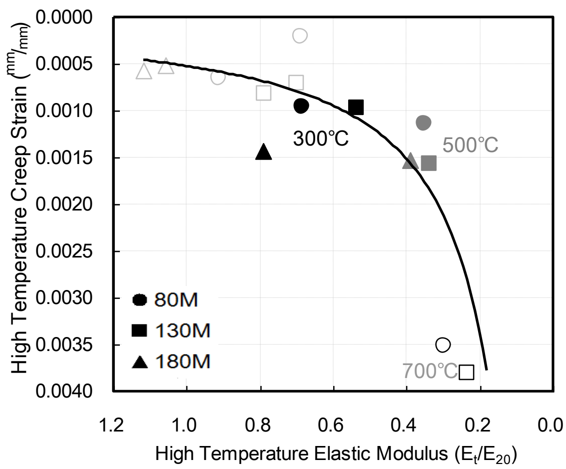


Fig. 7 Relationship between elastic modulus and creep strain at elevated temperature

2) Regardless of the compressive strength, the thermal expansion strain exhibited similar values. But as the compressive strength get bigger, the total strain was decreased because of the large amount of the cement hydrate causing thermal decomposition.

3) The high temperature creep of UHSC increased with temperature in every specimen. Also, it was shown that the high temperature creep sharply occurred at initial time and showed much higher shrinkage at 700 °C even if the constant load level has been kept.

4) At the temperature above 500 °C, the shrinkage strain of UHSC was sharply increased. So, for the evaluation of dimensional stability of the UHSC structure after fire, the thermal strain must be considered.

ACKNOWLEDEMENTS

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