STRENGTH DEVELOPMENT PROPERTIES OF MORTAR SUBJECTED TO TRIAXIAL STRESS UNDER DIFFERENT TEMPERATURE AND HUMIDITY CONDITIONS IN HARDENING PROCESS

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ABSTRACT

At early ages during hardening, mass concrete is affected by high temperatures due to cement hydration, changes in moisture content due to moisture transfer, and temperature stress due to differences between the surface and internal temperatures of concrete. It is therefore necessary for elucidating the strength-developing properties of mass concrete to comprehensively investigate the temperature, moisture content, and stress. In this study, the authors investigated the strength properties of mortar cured under different temperature, humidity, and triaxial stress conditions during early hardening period up to an age of 3 and 7 days.

INTRODUCTION

Concrete members used for large-scale structures, such as high-rise reinforced concrete buildings and nuclear power plants, tend to be massive. Because of the large cross-sectional size, concrete within mass concrete members is subjected to high temperatures due to cement hydration in the process of strength development. Also, the differences between the surface and internal temperatures cause internal moisture transfer, which leads to changes in the moisture content. Such temperature differences also cause temperature stress within members, which may adversely affect the strength developing process. It is therefore necessary for elucidating the strength developing properties of mass concrete to comprehensively investigate the temperature, moisture content, and stress. A variety of studies have been conducted, separately dealing with concrete subjected to thermal histories during the strength-developing process [1, 2] and changes in moisture content within concrete members [3, 4, 5, 6]. There have also been reports on the triaxial stress of concrete [7, 8]. However, few studies have comprehensively investigated these three factors.

With this as a background, the authors devised a Thermal Moisture Three-dimension Stress testing machine (TMTS), which is capable of applying triaxial stress to specimens in a thermohygrostatic container [9].

This paper reports on the results of investigation into the strength properties of mortar cured under varying temperature, humidity, and triaxial stress conditions up to an age of 3 and 7 days using the TMTS. The concept of this study is shown in Fig. 1.

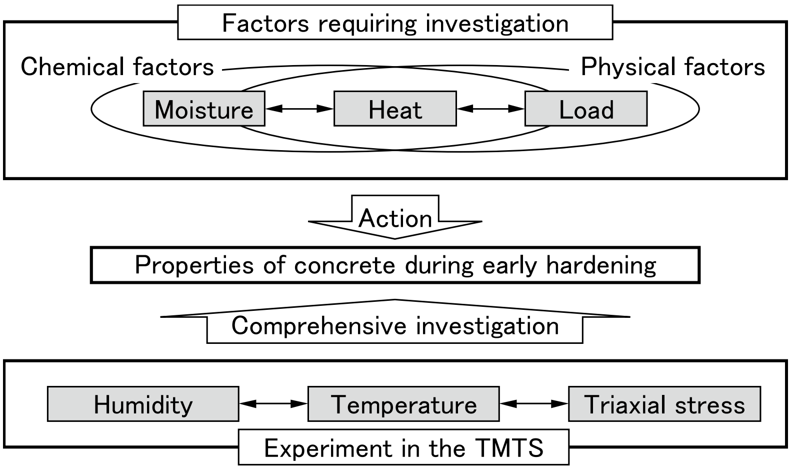

Fig.1: Concept of this study

OUTLINE OF EXPERIMENT

Outline of the TMTS

Photo 1 shows the appearance of the TMTS. This testing machine cures prismatic specimens 40 by 40 by 40 mm in size for a specified period while simultaneously subjecting the specimens to temperatures, humidities, and triaxial stresses. It consists of a loading unit integrating a thermohygrostatic container and a loading device, a hygrothermal supply unit, hygrothermal and stress measuring unit, and a PC for logging the data.

The size of the specimen used in this study is 40 by 40 by 40 mm. The size was determined based on a consideration that the influence of temperature and humidity gradients that occur inside a specimen when rapid change of temperature and humidity is caused to the specimen at the early stage of hardening process exercised on properties of a specimen can not be ignored, and it is therefore necessary to minimize the difference of the temperature and humidity gradients that occur inside the specimen by using a small specimen.

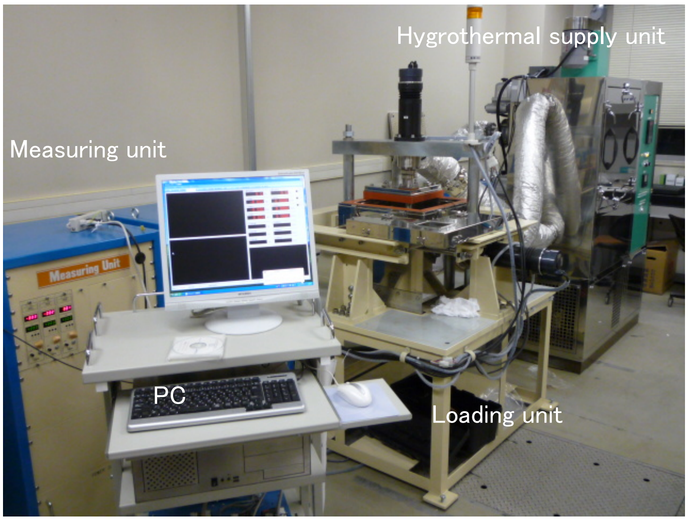

Photo 1: Appearance of the TMTS

Photo 2 shows the appearance of the specimen supports and Fig. 2 shows the outline of the loading jigs to come into contact with specimens. The area of a loading jig coming into contact with a specimen is 38 by 38 mm. The loading control axes and specimen supports, which are made with an invar alloy, are designed to minimize thermal expansion within the loading unit. The loading jigs are treated to minimize the moisture migration to and from specimens.

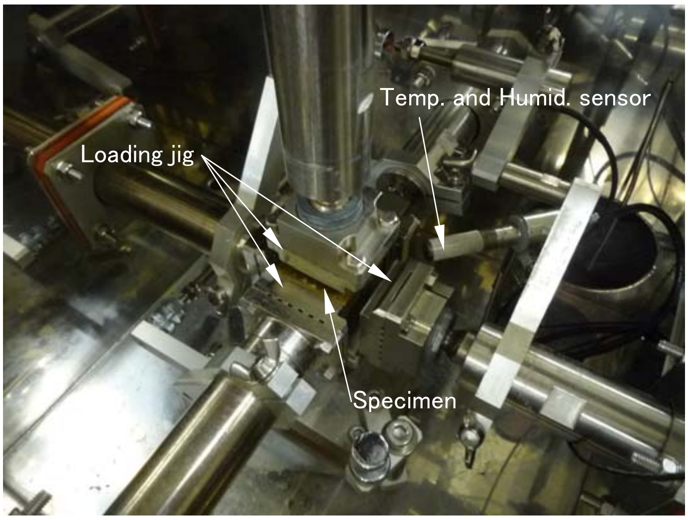

Photo 2: Appearance of the specimen supports

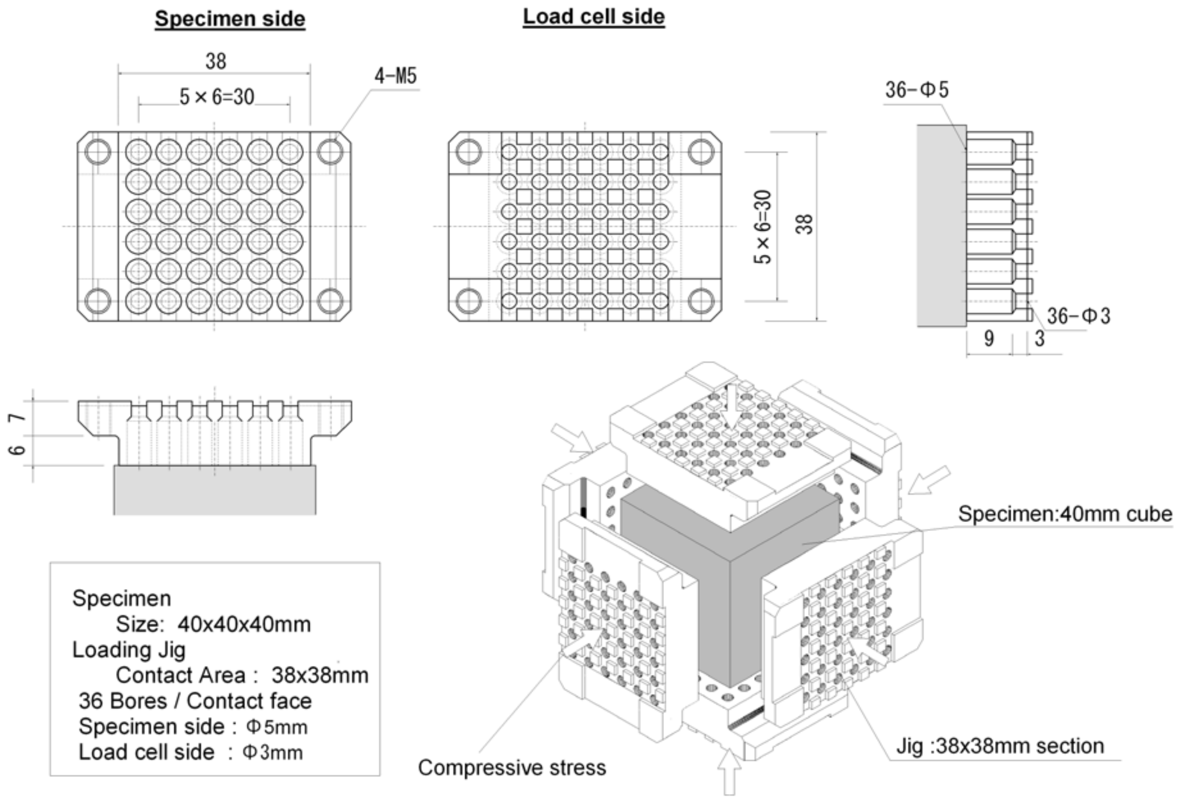

Fig.2: Loading jigs

Temperature and humidity are controllable, in the range of 10 to 90°C of temperature and in the range of 10 to 90% R.H. of humidity, by the programmable controller in the hygrothermal supply unit. It can be programmed to make temperature and humidity follow stepwise changes during tests. Temperature and humidity inside the chamber are controlled by using the temperature and humidity sensor set close to the specimen.

The load, which is controlled by the PC, is controllable in the range of -10 to +10 kN in all three directions, with the setting being independently adjustable. The load is applied by a linear actuator with a servo control. It is necessary to bond the specimen and loading jigs by using heat-resistant adhesive upon carrying out the tensile load tests.

When making a specimen cure using the TMTS, it is difficult to measure temperature and humidity inside the specimen because all 6 faces of the specimen are contacted to the loading jigs. Therefore, in this study, temperature and humidity controlled using the temperature and humidity sensor placed near the specimen.

Outline of specimens

Tables 1 and 2 give the materials and mixture proportions, respectively. Specimens were made of mortar proportioned with ordinary portland cement and silica sand from Toyoura as the fine aggregate with a water-cement ratio (W/C) of 50%.

Table 1: Materials

Materials	Type	Mark	Physical properties
Cement	Ordinary portland cement	C	Density: 3.16g/cm^3
Fine aggregate	Silica sand from Toyoura	S	SSD density: 2.62g/cm^3, Water absorption: 0.75%

Table 2: Mixture proportions (in weight ratio)

W/C [%]	s/c [vol.]	W	C	S
50	2.0	1.00	2.00	3.32

Using a mortar mixer with a capacity of 10 liters, mortar was mixed as follows: Place cement and fine aggregate in the mixer and dry mix for 30 seconds. Add water and mix for 30 seconds. Scrape off the material adhering to the mixer wall back into the mass and mix further for 60 seconds. The as-mixed mortar was then placed in cubic molds 40 mm on a side.

Test procedure

Specimens were demolded 8 hours after placing and set in the TMTS approximately 30 minutes later for curing under the specified temperature, humidity, and stress conditions until strength testing.

Temperature, humidity, and stress histories in the TMTS

Figures 3 and 4 show the temperature, humidity, and triaxial stress histories applied to specimens using the TMTS. After being set in the TMTS, each specimen was cured under temperature, humidity, and compressive stress conditions of 20°C, 90% R.H., and 0 N/mm^2, respectively, until an age of 12 hours and then subjected to respective curing conditions thereafter.

In the 3-day curing tests, the temperature and stress were linearly raised to the specified levels in 12 hours from an age of 0.5 day to 1 day, kept at the levels for 12 hours, linearly lowered then to 20°C and 0 N/mm^2, respectively, in 12 hours from 1.5 to 2 days, and kept at the levels thereafter. The relative humidity was linearly lowered to the specified levels in 12 hours from 0.5 to 1 day and kept at the levels thereafter.

In the 7-day curing tests, the temperature and relative humidity were kept constant at 20°C and 90% R.H, respectively, while the stress was linearly increased to the specified level in 12 hours from 0.5 day to 1 day, kept at the level for 12 hours, reduced to 0 N/mm^2 in 108 hours from 1.5 to 6 days, and kept at 0 N/mm^2 thereafter.

For the cases of 20°C, 90% R.H., and 6 N/mm^2, the number of loading axes ranged from 1 to 3. In the other cases, the loading conditions were the same for all three axes.

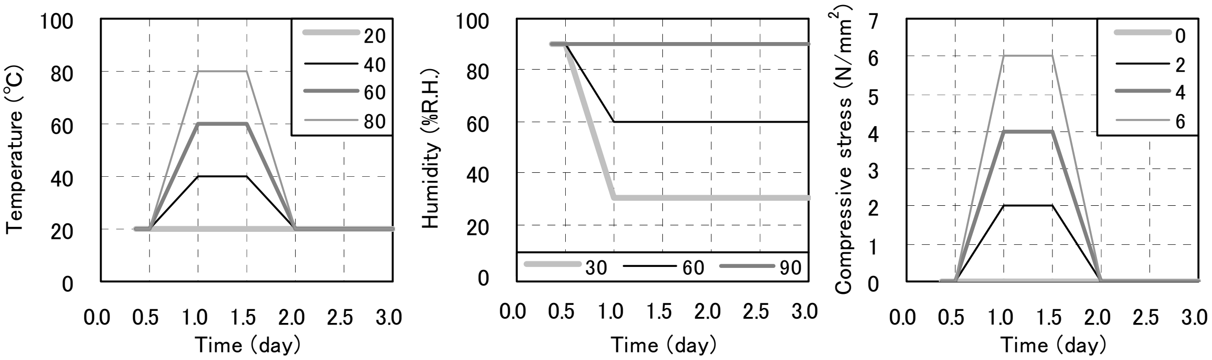

Fig.3: Temperature, humidity, and stress histories in the TMTS up to an age of 3 days

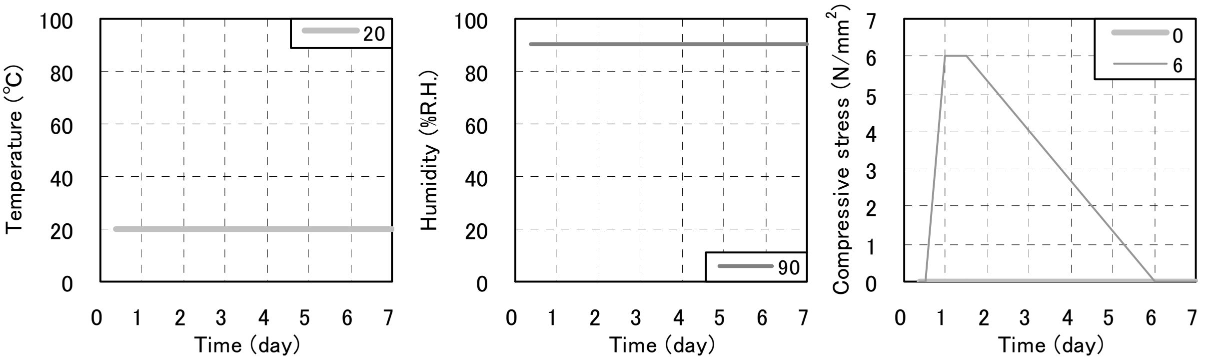

Fig.4: Temperature, humidity, and stress histories in the TMTS up to an age of 7 days

TEST RESULTS AND DICUSSIONS

Table 3 lists the curing conditions in the TMTS and strength test results of standard-cured specimens at 3 days and 7 days. This table shows that there are variations in the compressive strength of each standard-cured specimen. Thus, the compressive strength of the TMTS-cured specimens is expressed as ratios to the compressive strength of standard-cured specimens under respective curing conditions.

Table 3: Curing conditions in the TMTS and strength test results

Curing conditions in the TMTS					Compressive strength of standard-cured
Curing period (days)	Temperature (°C)	Humidity (%R.H.)	Compressive stress (N/mm^2)	Number of loading axes	
3	20	90	0	-	28.5
			2	3	29.5
			4	3	30.0
			6	1	24.4
				2	25.1
				3	30.7
	40	90	0	-	29.1
			2	3	33.4
			4	3	34.9
			6	3	31.9
	60	90	0	-	30.0
			2	3	34.1
			4	3	28.6
			6	3	31.0
	80	30	0	3	39.8
			6	3	38.5
		60	0	3	39.0
			6	3	34.9
		90	0	3	28.8
			2	3	26.6
			4	3	30.5
			6	3	24.0
7	20	90	0	-	41.0
			6	1	44.3
				2	43.0
				3	40.9

Figure 5 shows the relationship between the compressive strength of specimens cured for 3 days under triaxial loading in the TMTS and the temperature setting in the TMTS. The compressive strength ratio is found to increase as the curing temperature increases. This can be attributed to cement hydration accelerated by curing in a high temperature environment.

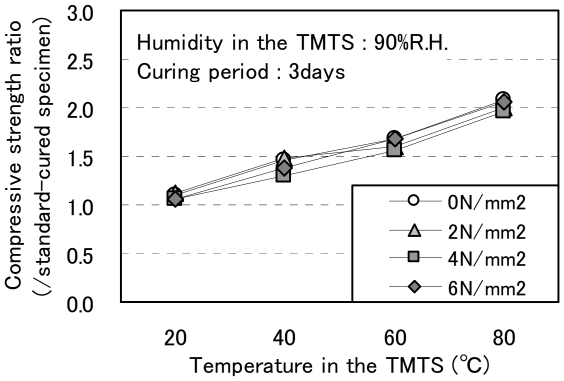

Fig. 5: Relationship between compressive strength ratio and temperature (Loading axes: 3, Curing period: 3 days)

Figure 6 shows the relationship between the compressive strength of specimens cured for 3 days under triaxial loading in the TMTS and the relative humidity setting in the TMTS. The compressive strength ratio increases as the humidity during curing increases. This is presumably because the high humidity environment supplied water necessary for cement hydration.

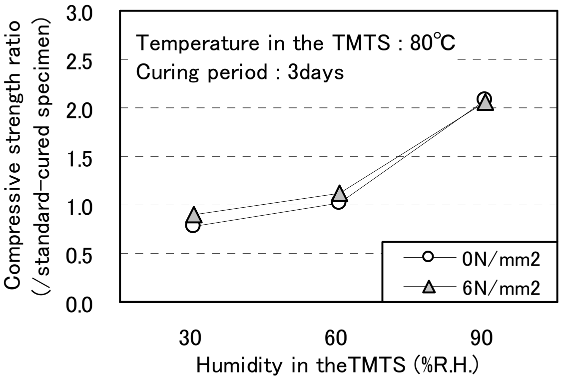

Fig. 6: Relationship between compressive strength ratio and humidity (Loading axes: 3, Curing period: 3 days)

Figure 7 shows the compressive strength cured in the TMTS at 20°C and 90% R.H. related to the number of loading axes. The number of loading axes scarcely affects the compressive strength. As is evident from Figs. 5 and 6, the stress scarcely affects the compressive strength immediately after curing.

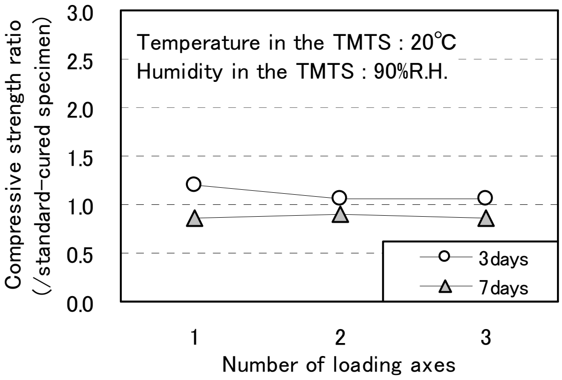

Fig. 7: Relationship between compressive strength ratio and the number of loading axes

CONCLUSIONS

The strength properties of mortar were investigated using specimens cured under environments with different temperatures, relative humidities, and stresses up to ages of 3 and 7 days. Within the range of this study, the following were found:

(1) Compressive strength increases as the curing temperature increases.
(2) Compressive strength increases as the humidity during curing increases.
(3) Compressive stress during curing scarcely affects the compressive strength. Also, the number of loading axes scarcely affects the compressive strength.

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