

Study on the Strength Development Properties of the Internal Characteristic of Mass Concrete

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Keywords: Mass concrete, Temperature, Humidity, Triaxial stress.

1 ABSTRACT

Large concrete structures such as nuclear power facilities include mass concrete members, within which concrete strength development is subjected to the effects of high temperatures due to cement hydration, humidity changes due to moisture migration, and thermal stress due to differences between the temperatures of subsurface and internal concretes.

In this study, the authors devised a testing apparatus with which concrete can be cured under arbitrary temperature, humidity, and triaxial stress conditions. The performance of this apparatus and the mechanical properties of specimens cured in this apparatus were investigated by curing mortar and concrete specimens while extremely changing these conditions during strength development. As a result, the testing apparatus was proven to be capable of testing with such extreme conditions, and the changes in the temperature, humidity, and triaxial stress in the process of strength development were found to lead to different compressive strengths of mortar and concrete.

2 BACKGROUND

Concrete members used for large-scale structures, such as high-rise reinforced concrete structures and nuclear power plants, tend to be mass concrete. Because of their large cross-sectional size, concrete within mass concrete members is prone to the effect of cement hydration heat in the process of strength development. Cement hydration heat within concrete members having a normal cross-sectional size is readily dissipated, but hydration heat deep within mass concrete is hardly dissipated, tending to remain in the concrete. Concrete portions within mass concrete are therefore exposed to high temperatures while developing strength. The resulting temperature differences between the subsurface and inside regions are considered to cause moisture migration and humidity changes within concrete. Moreover, such temperature differences generate thermal stress within the member, which may affect the properties of concrete deep within the member.

The strength development of concrete deep within mass concrete is affected by the temperature, humidity, and stress in the confined environment, leading to strength properties different from those of normal concrete members. It is therefore necessary to comprehensively investigate the temperature, moisture (humidity), and stress to elucidate the strength developing properties of concrete within mass concrete members.

Though studies have separately been conducted on the properties of concrete subjected to different temperature histories in the process of strength development (Chino et al. (1992), Sugiyama et al. (1999)), changes in the moisture content within concrete members (Yuasa et al. (1997)), and behaviour of concrete under triaxial stress (Okajima (1971)), few studies have comprehensively dealt with these subjects.

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.

3 PURPOSE OF STUDY

This paper reports on the results of investigation into the performance of the TMTS and the mechanical properties of mortar and concrete specimens when these are cured under extreme hygrothermal and triaxial stress changes in the process of strength development in the TMTS. Figure 1 illustrates the concept of this study.

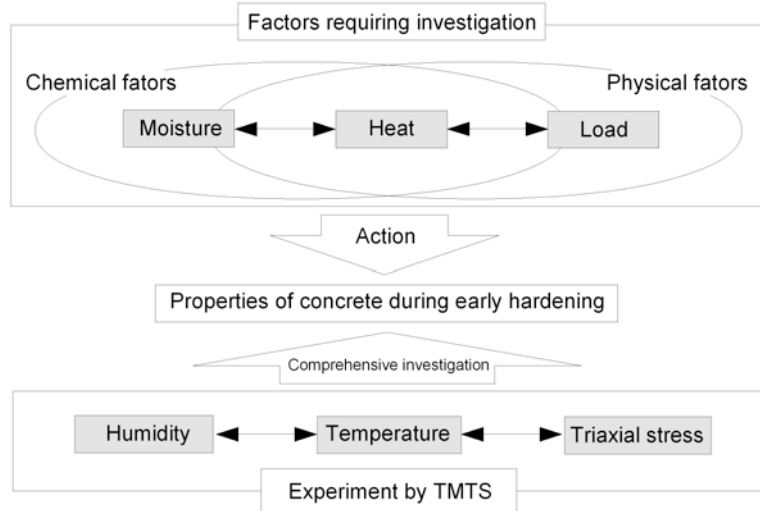


Figure 1. Concept of this study

4 OUTLINE OF EXPERIMENT

4.1 Outline of TMTS

4.1.1 Overview

Figure 2 and Photo 1 show the overall elevation and the appearance, respectively, 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 (currently limited to compressive stress). 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.

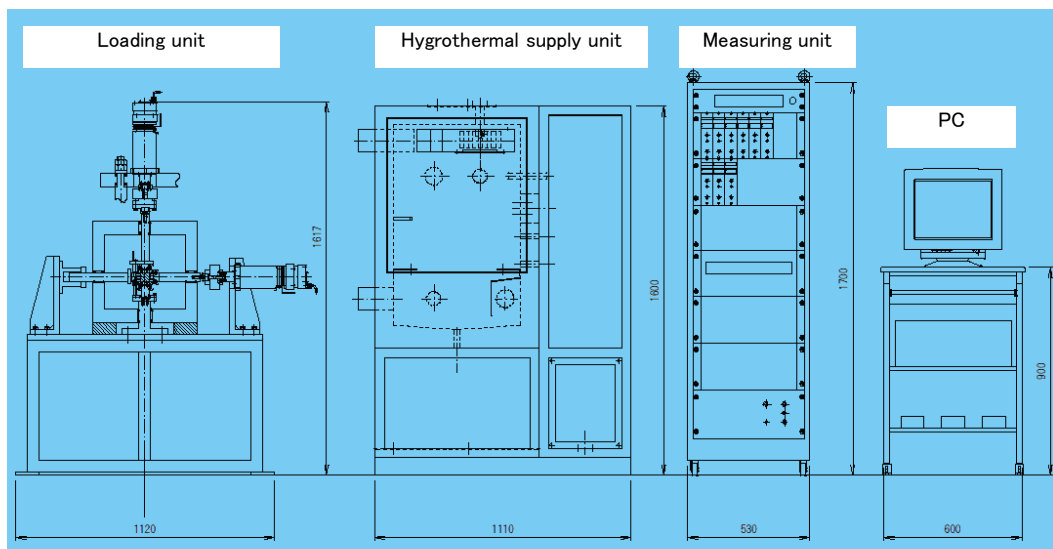


Figure 2. Overall elevation of TMTS

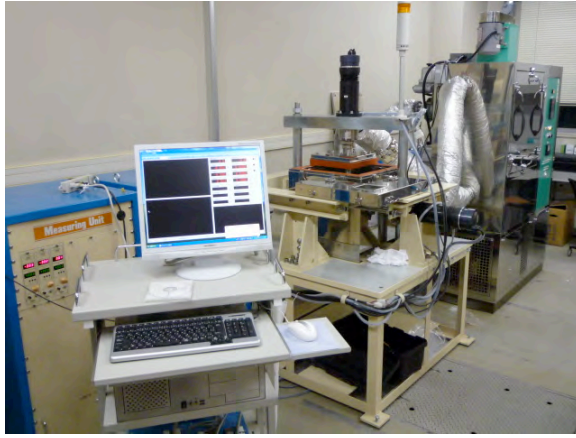


Photo 1. Appearance of TMTS

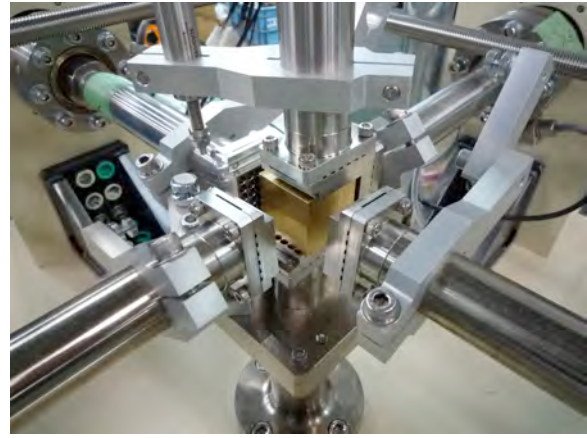


Photo 2. Appearance of the specimen supports

Figure 3 shows the outline of the loading jigs to come into contact with specimens. Photo 2 shows the appearance of the specimen supports. 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.

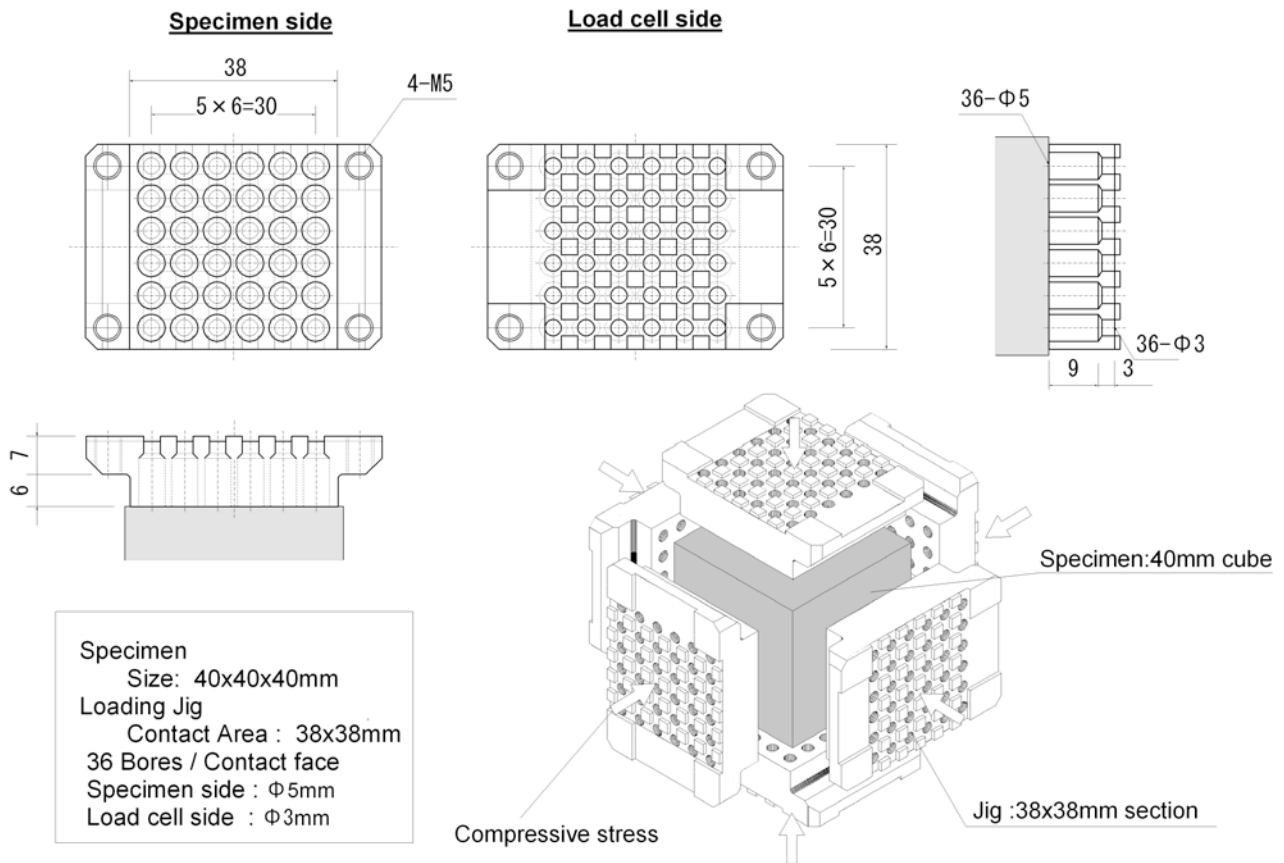


Figure 3. Loading jigs

4.1.2 Method of temperature control

The temperature is controllable in the range of 10 to 90°C by the programmable controller in the hygrothermal supply unit. Note that the temperature is also programmable to follow stepwise changes during testing.

4.1.3 Method of humidity control

The humidity is also controlled by the programmable controller in the hydrothermal supply unit in the range of 10 to 90% R.H. Note that humidity is also programmable to follow stepwise changes during testing.

4.1.4 Method of load control

The load, which is controlled by the PC, is controllable in the range of ± 10 kN in all three directions, with the setting being independently adjustable. The load is applied by a linear actuator with a servo control.

4.2 Outline of TMTS performance test

4.2.1 Specimens

Tables 1 and 2 give the materials and mixture proportions, respectively. Because of the specimen size of 40 by 40 by 40 mm, a maximum aggregate size of 10 mm was selected. Note that the water-cement ratio was 50% for both mortar and concrete.

A pan-type mixer with a capacity of 10 litres was used for mixing. The mortar was produced as follows: Dry-mix cement and fine aggregate in the mixer for 30 sec. Add water and mix for 30 sec. Scrape the mixture off the mixer wall and mix for 60 sec. The concrete was produced as follows: Dry-mix cement, fine aggregate, and coarse aggregate in the mixer for 30 sec. Add water and the chemical admixture and mix for 30 sec. Scrape the mixture off the mixer wall and mix for 60 min. Specimens were demolded 7 hours after placing and subjected to curing under different temperature, humidity, and stress conditions using the TMTS.

Table 1. Materials

Materials	Type	Mark	Physical properties
Cement	Normal portland cement	C	Density: 3.16 cm ³ , specific surface: 3,300 cm ² /g
Fine aggregate	Pit sand from Kimitsu	S1	SSD density: 2.50 g/cm ³ , water absorption: 2.45%, FM: 2.12, max. size: 5 mm
	Fine sandstone sand from Shiroyama	S2	SSD density: 2.64 g/cm ³ , water absorption: 1.23%, FM: 3.01, max. size: 5 mm
Coarse aggregate	Crushed sandstone from Shiroyama	G	SSD density: 2.66 g/cm ³ , water absorption: 0.97%, solid volume percentage: 59.5%, max. size: 10 mm
Chemical admixture	Air-entraining and high-range water-reducing admixture	SP	Polycarboxylic ether-based compound, density: 1.0 g/cm ³

Table 2. Mixture proportions (in kg/m³)

Mark	W/C (%)	G _{max} (mm)	Air (%)	s/a (%)	W	C	S1	S2	G	SP (%)
M	50	5	-	100.0	283	566	403	994	-	-
C	50	10	4.5	45.0	180	360	223	550	967	C×1.0

4.2.2 Temperature, humidity, and stress conditions during testing

Table 3 gives the test conditions. Three temperature-humidity combinations with and without stress (six sets of conditions in total) were applied to both mortar and concrete specimens. Stress-free specimens were left to stand in the thermohygrostatic container with or without loading jigs to compare the mass loss ratios with and without such jigs. The same stress curve was applied to all stress specimens: increase to compressive 8 kN from 0 to 24 h, keep compressive 8 kN from 24 to 48 h, and reduce to 0 kN from 48 to 72 h. The test period was thus three days. The specimens were subjected to compression tests after the TMTS performance tests.

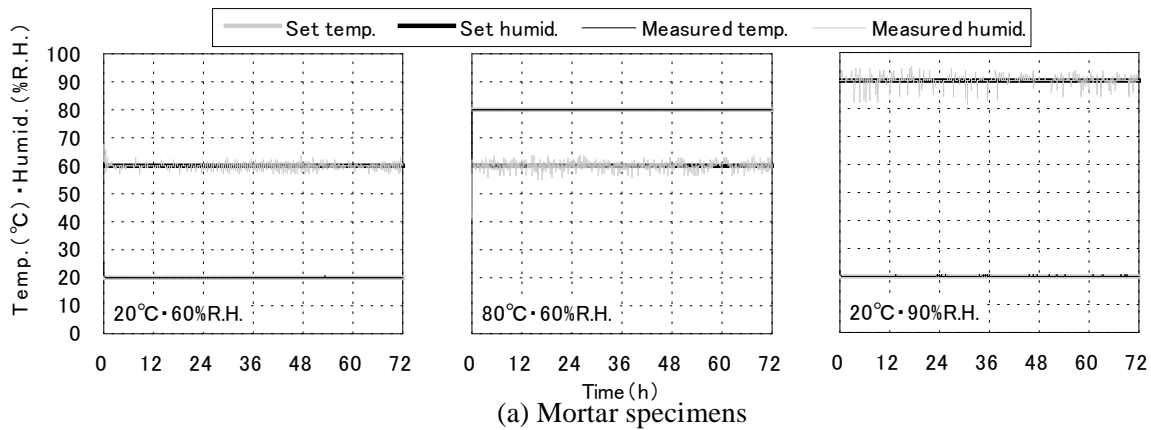
Table 3. Temperature, humidity, and loading conditions.

Test No.	Temp. (°C)	Humid. (% R.H.)	Compressive load
1	20	60	0-72 h: 0 kN (Leave to stand in the thermohygrostatic container)
			0-24 h: Linear increase to 8 kN, 24-48 h: Constant stress, 48-72 h: Linear reduction to 0 kN
2	80	60	0-72 h: 0 kN (Leave to stand in the thermohygrostatic container)
			0-24 h: Linear increase to 8 kN, 24-48 h: Constant stress, 48-72 h: Linear reduction to 0 kN
3	20	90	0-72 h: 0 kN (Leave to stand in the thermohygrostatic container)
			0-24 h: Linear increase to 8 kN, 24-48 h: Constant stress, 48-72 h: Linear reduction to 0 kN

5 TEST RESULTS AND DICUSSIONS

5.1 TMTS control test

Figure 4 shows the results of temperature and humidity control during testing. Figure 5 shows the results of stress control of mortar and concrete specimens at 20°C and 60% R.H. The temperature was controlled with little scatter. The humidity achieved the specified value for the most part, though the scatter tended to be wide in the high humidity range exceeding 90% R.H. The stress was controlled as specified in all directions on X, Y, and Z axes both for mortar and concrete specimens.



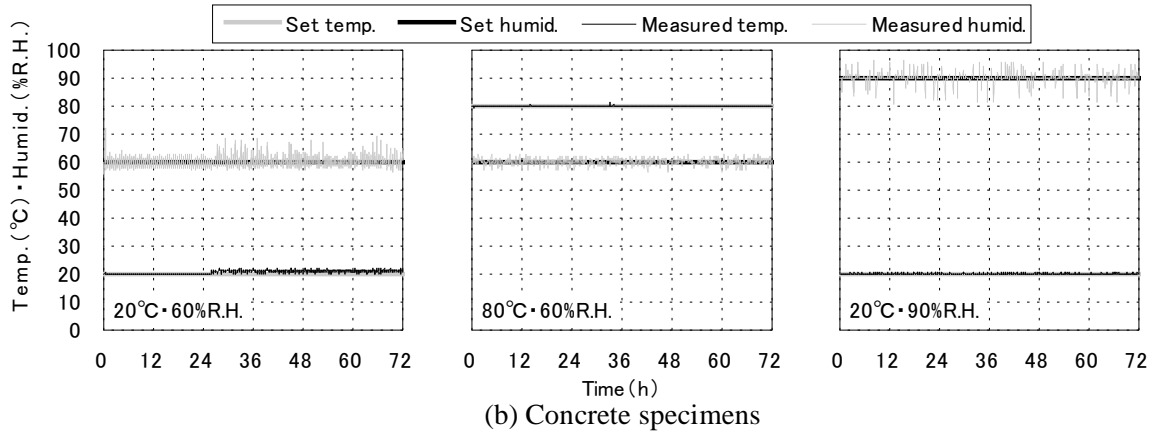


Figure 4. Results of hygrothermal control

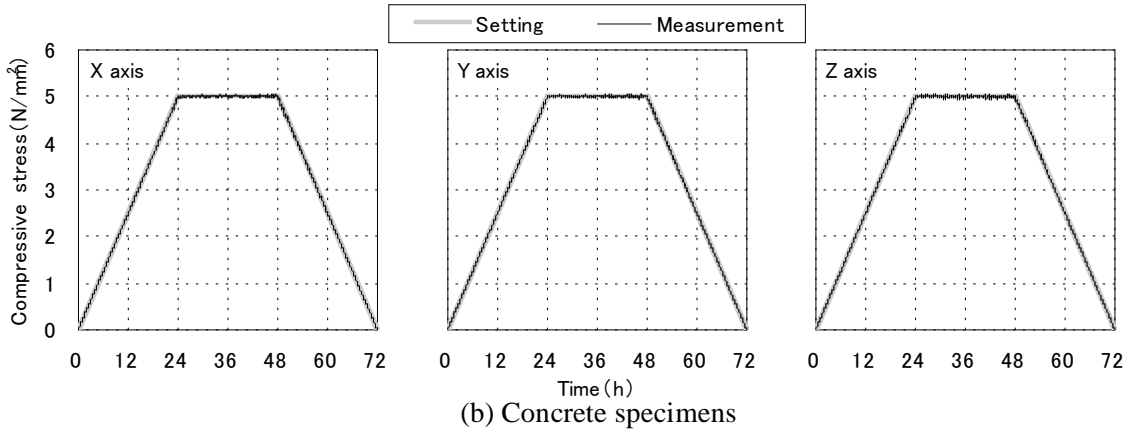
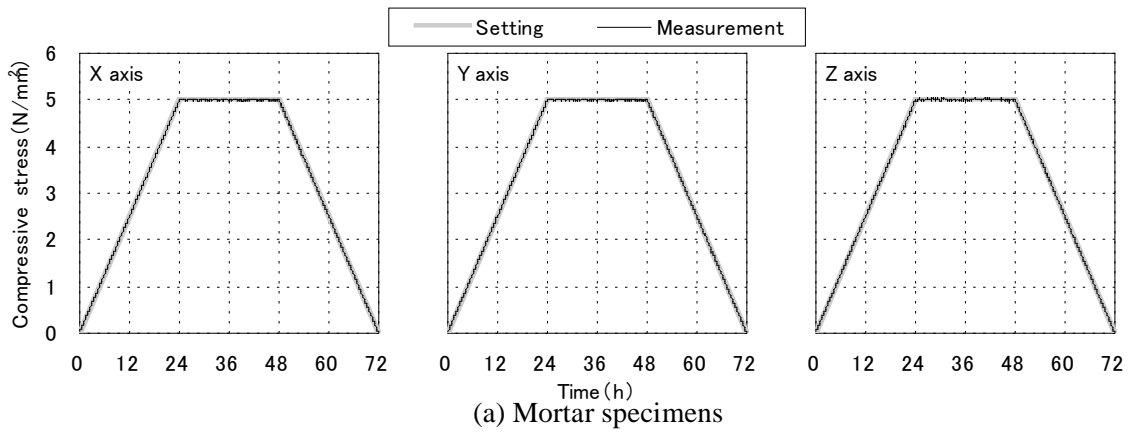
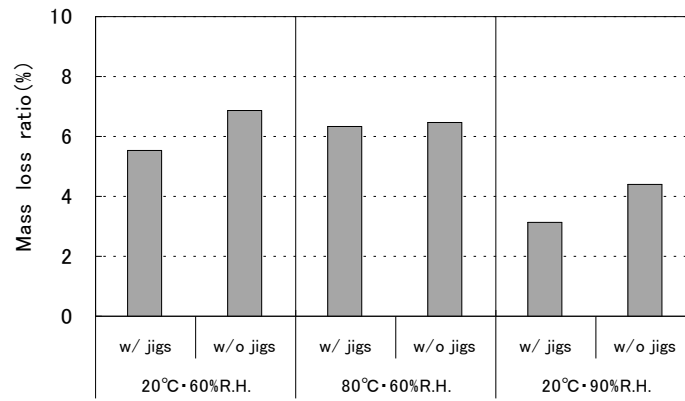


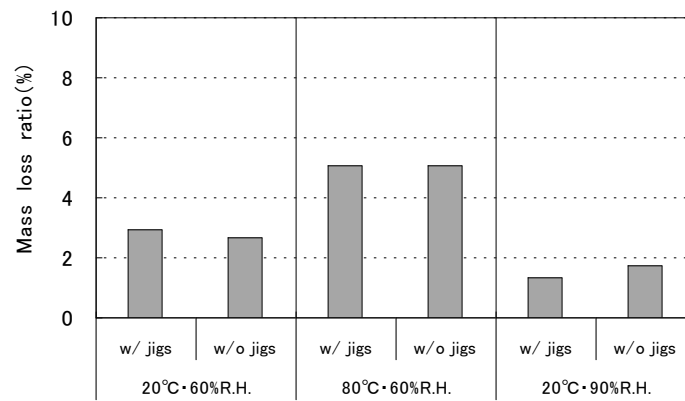
Figure 5. Results of stress control (20°C, 60% R.H.)

5.2 Mass loss ratio measurement

Figure 6 shows the mass ratios with and without loading jigs. The mass loss ratios without loading jigs were slightly higher. Though the jigs are design not to disturb the moisture migration to and from specimens, the presence of the parts in contact with the specimens caused the mass loss ratio to be slightly lower.



(a) Mortar specimens

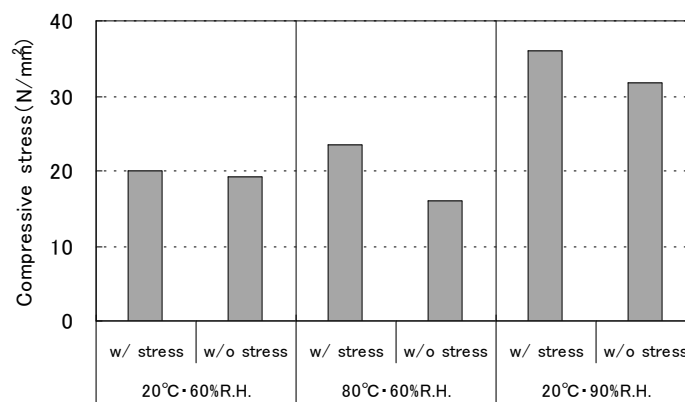


(b) Concrete specimens

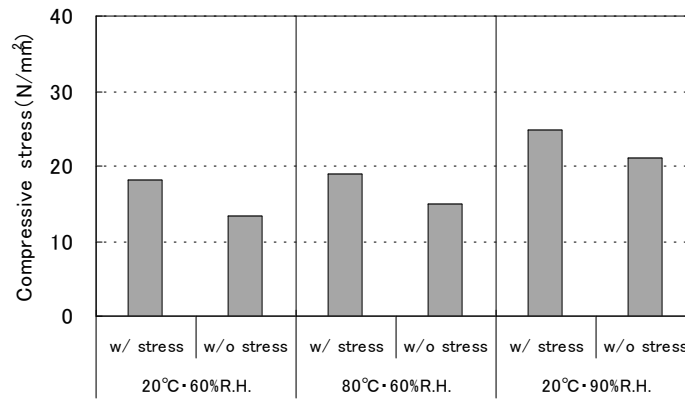
Figure 6. Results of mass loss ratio measurement

5.3 Compression test

Figure 7 shows the compression test results. The differences in the temperature, humidity, and stress led to different compressive strengths even with the short test period of 72 hours. It appears that the presence of compressive stress led to a higher early compressive strength and that humidity had a stronger effect on the strength than temperature.



(a) Mortar specimens



(b) Concrete specimens

Figure 7. Results of compression test

6 CONCLUSIONS

Within the range of this study, the following were found:

- (1) TMTS is capable of testing, though with a wider scatter under high humidity conditions.
- (2) The presence of loading jigs slightly affects the mass loss ratio.
- (3) Different temperature, humidity, and loading conditions lead to different compressive strengths.

Acknowledgements. This study was supported by a grant from the Nuclear and Industrial Safety Agency (NISA), the Japanese Ministry of Economy, Trade and Industry.

REFERENCES

- Chino S. and Sugiyama H. 1992. The developments of compressive strength for large dimension mass concrete : Influence of temperature variations be caused by the heat of cement hydration. Journal of structural and construction engineering, Transactions of AIJ No.436. P 1-12.
- Sugiyama H. and Chino S. 1999. Quantitative study on the effect of high-temperature curing at AN early age on strength development of concrete : Experiment with mortar using moderate-heat portland cement. Journal of structural and construction engineering, Transactions of AIJ No.525. P 7-13.
- Yuasa N., Kasai Y. and Matsui I. 1997. Measuring method for moisture content in hardened concrete using electric properties of a ceramic sensor. Journal of structural and construction engineering, Transactions of AIJ No.498. P 13-20.
- Okajima T. 1971. Failure of plain concrete under combined stresses (Axisymmetrically triaxial compression) : Part 1, Testing method and relationship between stress and strain under triaxial compression. Journal of structural and construction engineering, Transactions of AIJ No.189. P 15-24.