報 告

# [2138] STRENGTH DEVELOPMENT OF HIGH STRENGTH CONCRETE UNDER DIFFERENT TEMPERATURES

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## 1.INTRODUCTION

It is well known that the strength development of concrete is a function of age, curing method and temperature during casting and hardening. Temperature has a marked effect on strength, for example, although a higher temperature increases strength at an early age, it may adversely affect it at the later age.

A preliminary study on the effect of different constant curing temperatures during casting and hardening of high strength concrete was done and by using the maturity concept the strength development of concrete with different W/C ratios was compared.

This report shows the strength development of high strength concrete within maturity about 15 °D.D-840 °D.D, including the comparison with a typical ordinary concrete.

## 2.SCOPE OF EXPERIMENTAL INVESTIGATION

Four series of specimens were made with the following water-cement ratios: 0.45, 0.37, 0.32 and 0.28. They were cast and cured at a constant temperature as follows: 5°C, 10°C, 20°C, 30°C and 40°C. The total number of the specimens were 580 which were cast in cylindrical molds (100 by 200 mm). The cement used was TypeⅠ, Ordinary portland cement. The coarse and fine aggregates were crushed stone (maximum size 20 mm) and river sand respectively. A special type of superplasticizer(sp-9) was also used. The mixer used was a drum fitted with a vertical shaft and rotary blades. The procedure for mixing the concrete was as follows:

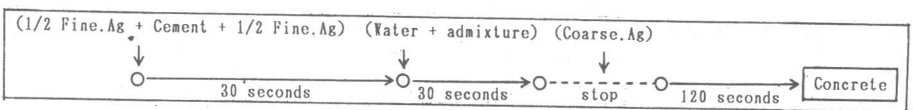


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Table 1. Mix Proportion of the Concrete

| W/C | S/A | Water | Volume(l/m3) | | | Weight(Kg/m3) | | | |
|---|---|---|---|---|---|---|---|---|---|
| % | % | (Kg/m3) | Cement | Fine Agg. | Coarse Agg. | Cement | Fine Agg. | Coarse Agg. | Add(%) |
| 28 | 41 | 170 | 192 | 253 | 365 | 607 | 683 | 964 | 2.2 |
| 32 | 43 | 170 | 168 | 276 | 366 | 531 | 745 | 967 | 1.8 |
| 37 | 44 | 170 | 145 | 293 | 372 | 459 | 791 | 983 | 1.5 |
| 45 | 47 | 170 | 120 | 324 | 366 | 378 | 875 | 967 | 1.5 |

Table 2. The Characteristics of the Fresh Concrete

| Curing Temp. (℃) | W/C % | Concrete Temp. (℃) | Slump (cm) | Flow (mm) | U.Weight (Kg/m3) | Air Content(%) Method Pressure | Gravimetric |
|---|---|---|---|---|---|---|---|
| 5 | 45 | 5.0 | 18.5 | 290 | 2382 | 2.5 | 2.3 |
| | 37 | 4.5 | 18.5 | 259 | 2387 | 2.7 | 2.7 |
| | 32 | 5.2 | 9.0 | 227 | 2398 | 2.6 | 2.6 |
| | 28 | 6.0 | 4.0 | 209 | 2428 | 2.0 | 1.8 |
| 10 | 45 | 11.0 | 21.5 | 357 | 2385 | 2.5 | 2.2 |
| | 37 | 10.0 | 18.5 | 259 | 2399 | 2.5 | 2.1 |
| | 32 | 9.7 | 18.0 | 261 | 2401 | 2.7 | 2.5 |
| | 28 | 10.5 | 21.0 | 279 | 2429 | 2.0 | 1.8 |
| 20 | 45 | 22.0 | 20.0 | 337 | 2401 | 2.2 | 1.6 |
| | 37 | 21.5 | 21.0 | 357 | 2406 | 1.7 | 1.9 |
| | 32 | 22.0 | 22.0 | 387 | 2431 | 2.3 | 1.3 |
| | 28 | 21.8 | 23.0 | 515 | 2447 | 1.6 | 1.0 |
| 30 | 45 | 29.5 | 17.0 | 283 | 2408 | 1.8 | 1.3 |
| | 37 | 30.5 | 19.5 | 293 | 2425 | 1.3 | 1.1 |
| | 32 | 31.0 | 15.5 | 234 | 2442 | 1.6 | 0.8 |
| | 28 | 30.5 | 15.0 | 220 | 2454 | 1.5 | 0.8 |
| 40 | 45 | 34.0 | 13.0 | 235 | 2409 | 2.3 | 1.2 |
| | 37 | 35.0 | 18.0 | 258 | 2425 | 2.2 | 1.1 |
| | 32 | 39.0 | 21.0 | 278 | 2441 | 2.0 | 0.8 |
| | 28 | 40.0 | 18.0 | 248 | 2469 | 1.9 | 0.1 |

All materials were stored at the desired temperature before making the concrete. The mix proportion and characteristicsof fresh concrete are summarized in Tables(1 and 2).

## 3.CURING AND COMPRESSION TEST PROCEDURE

A polyethylene sheet was used to cover the specimens thus minimizing evaporation. The specimens were located in a room with controlled temperature and the temperatures of the specimens were recorded by electronic instruments.

At predetermined maturity, three cylinders were tested and the average strength value was used in data analyses. The compressive strength was determined by standard test method described in JIS A 1108.

## 4.EXPERIMENTAL RESULTS

### 4.1 Strength development of high strength concrete

In this report, maturity concept refers to JASS 5.13, which is widely used for winter concreting in JAPAN. It was applied as a mathematical criterion for the comparison of the different concrete specimens. The maturity concept is defined as follows: $M=\Sigma(\theta-T_0)\Delta t$, where M=maturity in D-days, $\theta$=temperature of concrete in °C during time interval, $T_0$=datum temperature in °C which is equal to minus 10, $\Delta t$=time interval in days.

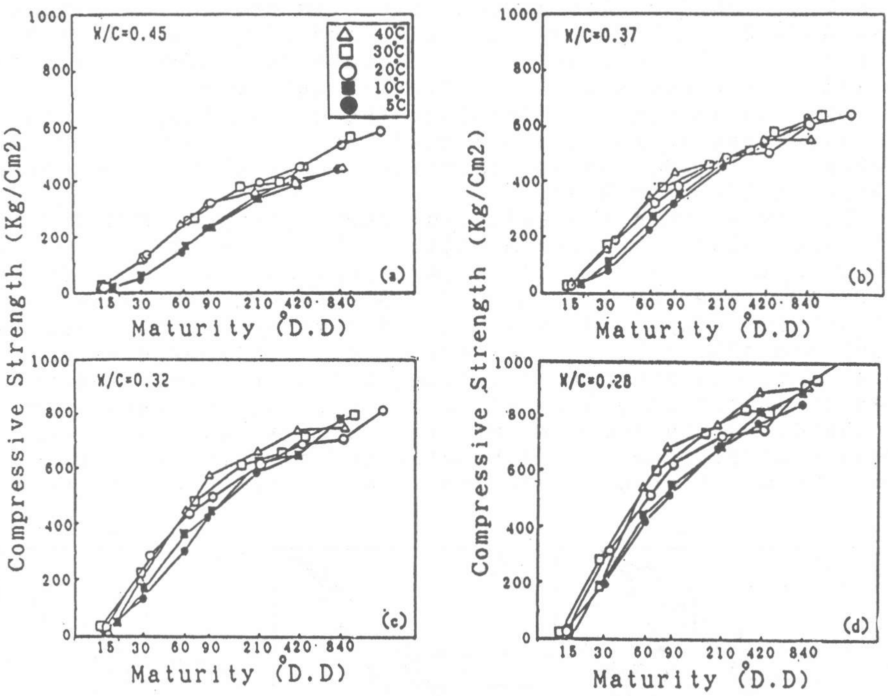



Fig. 1 Comparison of Compressive Strength under Different Temperatures

Figure 1 shows the results of experiments on strength development with different water-cement ratios, which is plotted against the maturity. For high W/C ratio, Fig. 1(a), the maturity-strength curves are very clearly grouped into two sets: the 5°C and 10°C samples and the 20°C and 30°C samples. These two sets in Fig. 1(a) have a nearly constant difference in strength of about 100kg/cm2 and show a similar maturation process, with the exception of the 40°C curve, which initially follows the 20°C and 30°C curves but departs from them and joins the 5°C and 10°C after M=90 °D.D. For lower W/C ratios, Fig. 1(b),1(c) and 1(d), the properties of the curves are different. The 5°C and 10°C curves are closely related, but for the 20°C, 30°C and 40°C samples the strength for intermediate maturity values increases with curing temperature. The strength for higher maturity values however shows a smaller difference.

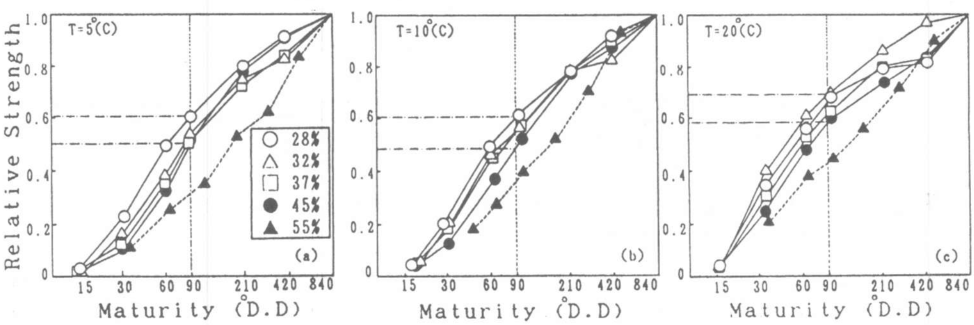
From Fig. 1 the concrete with lower W/C ratios has greater strength differences at intermediate maturity values which depends on curing temperature.

## 4.2 Effect of curing temperatures on maturity-relative strength curves

Figure 2 shows the relative strength of the concrete, which were plotted against the maturity. Relative strength is defined as the strength of concrete with respect to strength at M=840°D.D. In Figures 2(a), 2(b) and 2(c) the relative strength of a typical ordinary concrete (W/C=0.55) was also plotted to compare with high strength concrete.

By considering the effect of the curing temperatures on relative strength gain, the lowest W/C ratio (0.28) grew more quickly in 5°C, 10°C and 30°C than the other, with the exception of Figures 2(c) and 2(d).

To investigate the effect of curing temperature differential, the relative strength value of high strength concrete at 90°D.D is shown in Fig. 2. It is approximately 50% to 60% at 5°C and 10°C, whereas is 70% to 80% at 30°C and 40°C. This means that within 3 days 70% t0 80% of 28 days strength is achieved at 30°C and 40°C. Also in the same maturity higher curing temperature affects strength development faster. The relative strength in ordinary concrete also increased as temperature increased, but in the case of high strength concrete, rapid strength development could be observed at very early age which shows different curve from that of ordinary concrete.



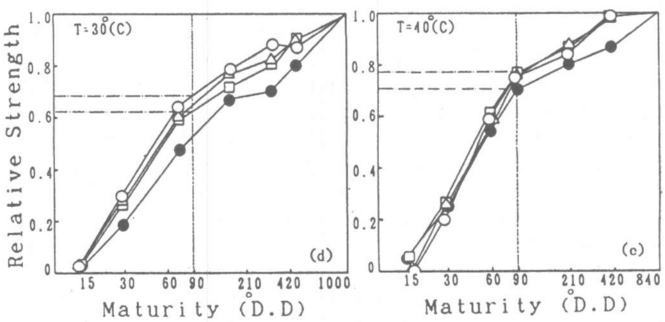




Fig. 2 Comparison of Relative Strength Gain under Different Temperatures

5.DISCUSSION

In this report all experimental results were explained by maturity concept. It is evident that freshly placed concrete gains strength as a result of the chemical reaction between cement and water in the mixture. The thermal history of the concrete, that is from casting until later ages, can be expressed either in terms of the temperature-time factor or in terms of the equivalent age at a specified temperature according to the assumption of hydration rate of cement.

Several maturity concepts were proposed in the last few decades, for example, Saul(1), Bergstrom(2),Plowman(3), Naik (4), Malhotra(5), and.... published reports related to maturity. This concept is also reviewed in RILEM(1971) and ASTM (1987). In this report, as described in section 4, maturity is calculated using the equation : $M=\Sigma(\theta+10)\Delta t$.

As an important result, this report demonstrates that using the maturity concept mentioned above, there is no unique strength-maturity relation in high strength concrete. This is because of a multiplier effect of low W/C ratio and high curing temperature which quickens hydration at early age.

As results of this report show, care should be taken in applying degree-day method and logistic curve to high strength concrete; Although they show good conformity to strength development for ordinary concrete.

Even though it seems that concrete which was cured in high temperature at early age, tends to have slow strength development at later age, results of the experiment show that no such obvious tendency is recognized. In this regard Fig. 3 shows the variation of strength development with temperature, at maturities of 210 °D.D and 840 °D.D. It illustrates that the strength of high strength concrete is not greatly influenced in later ages (M=840 °D.D), when constant curing temperature is 5°C, 10°C, 20°C, 30°C or 40°C.

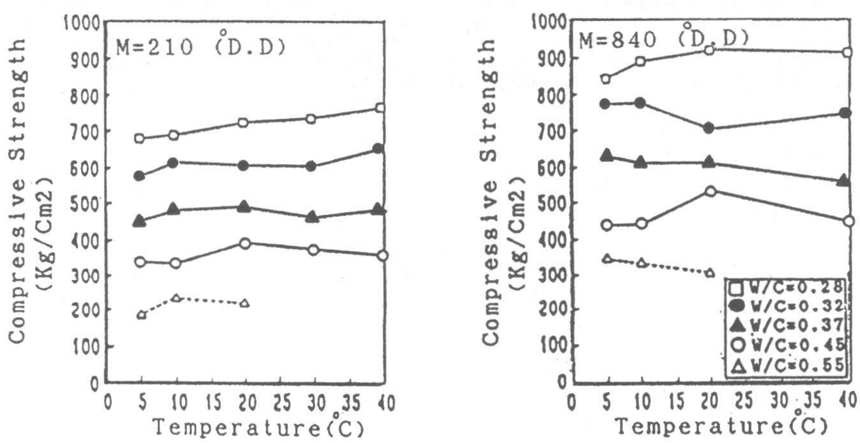



Fig. 3 Variation of Compressive Strength under Different Temperatures

In summary, the maturity-strength relation varies in a systematic manner with curing temperature. This suggests that an alternative approach may exist for computing maturity which correlates more closely with the maturity-strength relation.

This study was carried out as a joint research project with Research Institute of Shimizu corporation

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