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Influence of High Temperatures of Mixing water on Setting, Consistency, Strength and Heat of Concrete

By

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Summary

During the past three years, a number of experiments have been performed in our laboratory on the subject above entitled, using Portland cement of normal cement type, of early strength type and of moderate heat type.

In these experiments, with the temperature of mixing water varying from 20°C to 80°C, the highest temperature of fresh concrete or of paste was found to be between 33°C and 53°C.

Concerning the properties of fresh concrete made under the preceding condition, the following points were examined: existence of any harmful, visible phenomena such as flash set, variation in consistency, setting time, compressive strength of concrete at 7, 28 and 91 days and heat of hydration.

It resulted from these experiments that heating-up of mixing water to as higt a temperature as 80°C just before mixing had no harmful effect either on the strength of concrete, or on the carrying out of winter concreting. This procedure was found to have rather favourable effects on green- and hardened concrete.

Introduction

In winter concreting it is generally recommended that the mixing water should be heated to bring the temperature of concrete at the mixer to the specified temperature, which is ordinarily between 10°C and 40°C, but it is not usually permitted that the loading of the mixer is in such sequence that the cement comes in contact with the water of high temperature.

However any papers, treating theoretically upon the influence of high temperature of mixing water on overall properties of fresh- and hardened concrete or upon the determination of allowable limit of water temperature, have hitherto rarely been published.

If no bad influence can be found, it must be recommended to use the water of comparatively high temperature, if possible, in order to carry out winter concreting more easily, more safely, and perhaps more economically.

Concerning this, a number of experiments were carried out in series during these three years in the author's laboratory.

In these experiments, Portland cements of normal, early strength and moderate heat type were used ; water temperatures were varied from 20°C to 80°C, with paste or concrete temperatures below 53°C.

Tested and discussed were the existence of any harmful, visible phenomena such as flash set, the variation in consistency of fresh concrete, the setting time, the effect on compressive strength of concrete at 7~91 days and the changes in the heat of hydration.

This paper presents the view that the high temperature of mixing water up to 80°C gives nothing of bad influence but some good ones on fresh- and hardened concrete, and accordingly that such high temperature may be recommended in practice.

1. Influece on setting

To test the influence of high temperatures of mixing water on on setting, the various times of the setting test were employed in accordance with the Japanese Industrial Standards JIS R 5201. The procedure of this test is generally similar to that of European or American countries.

First, the test was performed with the different temperatures of mixing water which varied gradually from 20°C to 80°C, but the water-cement ratio W/C of paste was controlled so that the paste should have normal consistency at normal temperature of mixing water, 20°C; this ratio was kept constant for each cement throughout the test. The results of this test are shown in Table 1.

Next, keeping the temperatures of the mixing water constant at 60°C and 80°C, but varying the paste temperatures right after mixing from 19°C to 48°C, results were obtained as shown in Table 2.

In general, with a rise in the water temperature the paste temperature right after mixing becomes higher ; this causes the time of initial and final set to shorten (Table 1), but the net time of setting

TABLE 1

Type of Portland cement	Water cement ratio W/C	Remarks	Temperature of mixing water, °C					
			20	40	50	60	70	80
N₁, normal	0.27	(1) Paste temperature right after mixing, °C	21	25.7	—	31.5	—	35
		(2) Time of initial set hr-min	4-04	3-59	—	3-23	—	2-40
		(3) Time of final set hr-min	5-14	4-52	—	4-23	—	3-40
		(4) Net time of setting hr-min	1-10	0-53	—	1-00	—	1-07
N₁, normal	0.27	(1) 〃	19	23.8	—	30.2	—	35-2
		(2) 〃	3-22	2-41	—	2-27	—	1-15
		(3) 〃	5-35	4-46	—	3-52	—	4-10
		(4) 〃	2-23	2-05	—	1-25	—	2-55
N₂, normal	0.278	(1) 〃	21.3	—	39.4	42.9	48.3	53.3
		(2) 〃	2-50	—	1-33	1-18	1-06	0-30
		(3) 〃	4-18	—	2-43	2-41	2-38	2-33
		(4) 〃	1-28	—	1-10	1-23	1-32	2-03
N₂, normal	0.278	(1) 〃	20.0	24.6	—	29.8	29.8	31.5
		(2) 〃	3-33	3-27	—	2-06	2-06	2-07
		(3) 〃	4-23	4-15	—	3-54	3-54	3-37
		(4) 〃	0-50	0-48	—	1-48	—	1-30
E₂, early strength	0.27	(1) 〃	22	27.3	—	39.5	—	36.5
		(2) 〃	3-49	3-13	—	2-55	—	2-14
		(3) 〃	4-47	4-18	—	3-52	—	3-15
		(4) 〃	0-58	1-05	—	0-57	—	1-01
M₁, moderate heat	0.27	(1) 〃	20.2	25	—	30.5	—	34
		(2) 〃	4-28	4-12	—	3-43	—	3-15
		(3) 〃	6-10	5-46	—	5-35	—	5-15
		(4) 〃	1-42	1-34	—	1-52	—	2-00

TABLE 2

Type of Portland cement	Water cement ratio W/C	Temperature of mixing water kept constant at							
		80°C				60°C			
		Paste temperature °C (1)	Time of initial set hr-min (2)	Time of final set hr-min (3)	Net time of setting hr-min (4)	Paste temperature °C (1)	Time of initial set hr-min (2)	Time of final set hr-min (3)	Net time of setting hr-min (4)
N_1, normal	0.27	19	3-30	4-36	1-06	19	3-30	4-36	1-06
		24	2-43	4-07	1-24	25.3	3-12	4-19	1-07
		26	2-28	3-43	1-15	29.5	2-49	4-10	1-24
		30.5	2-17	3-30	1-13	35.5	2-27	3-45	1-18
		40.5	1-24	2-48	1-24	37	2-16	3-36	1-20
		48	1-00	2-20	1-20	43.5	1-47	3-10	1-23

is not greatly affected. Further, from Table 2 it will be seen though the water temperature is kept constant, the time of setting is shortened by an increase of paste temperature. Therefore it is not the water temperature but the paste temperature that actually exerts influence on the time of setting.

Using the results shown in Tables 1 and 2, Fig. 1 and Fig. 2 are

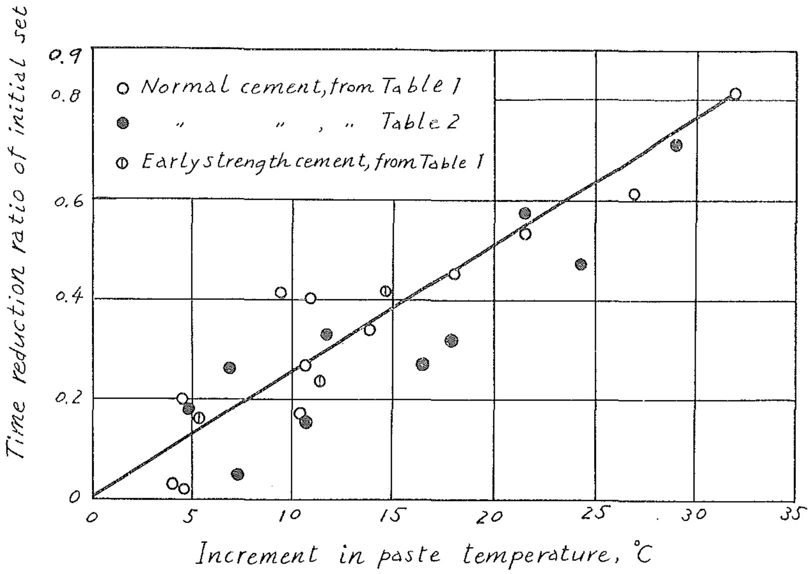

Fig. 1.

obtained. In the figures, the time reduction ratio of initial set is the ratio of time reduction to original time of initial set at water temperature 20°C, and the increment in paste temperature is computed on the basis of the original paste temperature.

Fig. 1 shows that a nearly linear relation exists between the time reduction ratio of initial set and the increment in paste temperature in case of normal and early strength cement; also Fig. 2 shows the same relation in case of moderate heat cement. From these, it is found that the time reduction ratio of initial set in case of normal and early

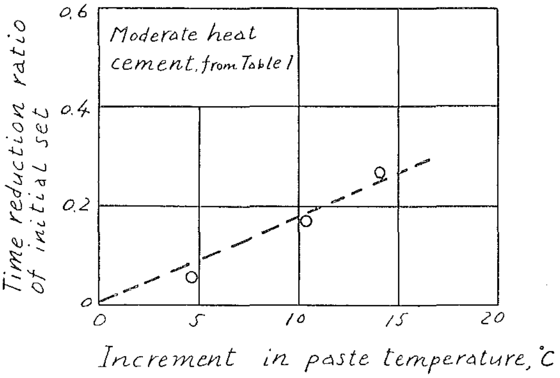

Fig. 2.

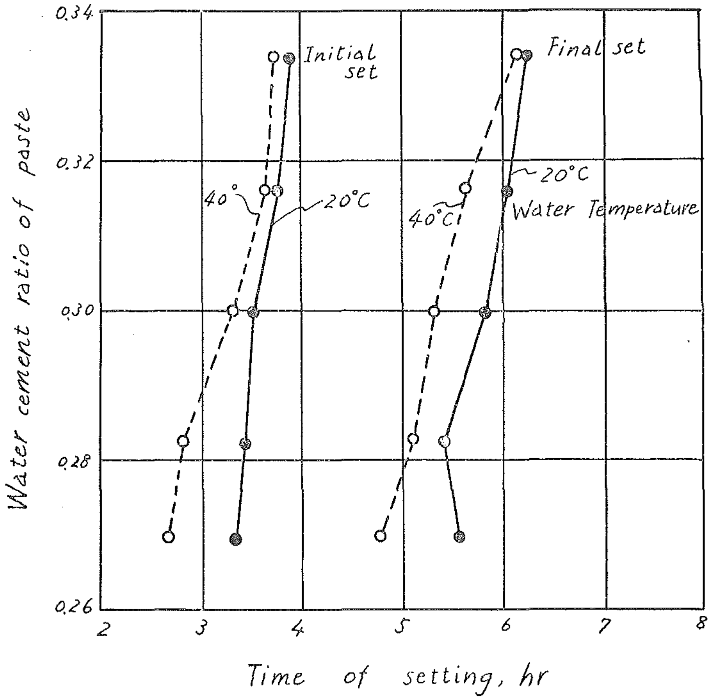

Fig. 3.

strength cement amounts nearly to 0.25 per 10°C of increment in paste temperature, and 0.18 in case of moderate heat cement (Fig. 2).

Next, varying the water cement ratio W/C, while keeping the temperatures of water and paste constant, Fig. 3 is obtained. This shows that the time of setting is reduced with increase of W/C.

In winter job sites, the temperatue of concrete at the mixer is usually lower than the paste temperature as shown in Table 1 or 2, and W/C is much greater than that in the tables. Accordingly from the above test results, it can be said that the setting time of concrete will not be accelerated very much. Moreover, since the time of initial set of Portland cement today is generally longer than 2.5 hours, though the setting is accelerated by hot water, it can be said that the paste never begins to set before 1 hour which is prohibited by the Standards for Portland cement. We can practically say therefore, that the high temperature of mixing water up to 80°C exerts no bad influence on setting time.

2. Influence on Consistency of Concrete

(1) Experimental Procedure.

The consistency of concrete is measured by the slump test in accordace with the Japanese Standards. This test is similar to American Standards "ASTM 143–52", using a cone of truncated form with internal dimensions: bottom diameter 20 cm, top diameter 10 cm, height 30 cm. To determine the influence of high temperature of mixing water on the consistency of concrete the experiment was performed by the following procedure:

(a) The temperature of water varied from 20°C to 80°C by degrees.

(b) The temperature of cements and aggregates nearly the same as the room temperature.

(c) Loading of the mixer:

First the cement was fed into the mixer, next the water of high temperature was added, and they were mixed for 2 min, finally the aggregates were added, and mixed for 3 min. It can be said that the experiment is more severe than the case of actual job sites, because in winter the hot water is usually added at the same time or after the other materials are fed, in order to avoid contact between cement and water.

(d) The slump of concrete was measured at the time 0, 10, 20, 30 and 60 min after discharging.

(2) **Materials.**

Portland cements of normal, early strength and moderate heat type are used. The fine aggregate is pit sand which has fineness modulus 3.01 and max. size 5 mm, the coarse aggregate is river gravel which has fineness modulus 6.98 and max. size 40 mm. The proportion of concrete used for the experiment is shown in Table 3.

TABLE 3

Symbol of the concrete	A	B	C	D	a	b
Type of Portland cement	N_3, normal	N_3, normal	N_2, normal	M_1, moderate	E_2, early strength	E_2, early strength
Cement content per cubic meter of concrete, kg	300	300	342	345	300	300
Water cement ratio W/C	0.57	0.52	0.514	0.488	0.62	0.57
Mix by weight	1 : 2.62 : 3.67	1 : 2.68 : 3.74	1 : 1.81 : 3.43	1 : 1.81 : 3.49	1 : 2.57 : 3 59	1 : 2.62 : 3.67
Consistency, cm (original slump)	15	4.6	11	6	16.7	5.4

(3) **Influence on Slump of Concrete Immediately after Mixing.**

Table 4 shows the results of experiment, from which it may be stated.

(a) The slump of concrete becomes smaller with the increase of temperature of mixing water, i. e., the consistency becomes worse.

(b) The rate of change in slump is not connected with the kind of cement.

(c) In Fig. 4, by the relative slump is denoted the ratio of slump to its original value. It is seen from Fig. 4a that there is a parabolic relation between the relative slump and the water temperature, and that the values of relative slump are 0.83, 0.63, and 0.36 at water temperatures 40°C, 60°C and 80°C respectably.

(d) However the value of relative slump above mentioned does not directly apply to actual job sites, because in winter concreting the temperature of concrete at the mixer is usually below 20°C, though hot water is used, while in the experiment the concrete temperatures are from 20°C to 33°C as shown in Table 4. Therefore, it is important to notice how much temperatures the fresh concrete has, regardless of how high the water temperature is.

TABLE 4

Water temperature °C	Concrete temperature right after mixing °C	Slump cm	Water temperature °C	Concrete temperature right after mixing °C	Slump cm
Concrete A, normal cement, room temperature 12~13°C			Concrete a, early strength cement, room temperature 18~19°C		
20	16.0	15.0 (1.00)	20	21.0	16.7 (1.00)
40	19.9	13.5 (0.09)	40	25.8	14.2 (0.85)
60	22.8	9.9 (0.66)	60	29.9	11.4 (0.68)
80	25.8	6.0 (0.40)	80	33.3	6.8 (0.41)
Concrete B, normal cement, room temperature 14°C			Concrete b, early strength cement, room temperature 15°C		
20	16.6	4.6 (1.00)	20	18.0	5.4 (1.00)
40	20.5	3.7 (0.80)	40	24.0	4.1 (0.76)
60	23.0	3.2 (0.70)	60	27.0	3.4 (0.61)
80	27.6	1.8 (0.39)	80	30.0	2.0 (0.37)
Concrete C, normal cement, room temperature 23°C			Concrete D, moderate heat cement, room temperature 23°C		
20	20.5	11.0 (1.00)	20	20.0	6.0 (1.00)
50	26.0	9.0 (1.82)	50	25.5	4.5 (0.75)
60	28.0	7.0 (0.64)	60	30.0	3.0 (0.50)
70	31.0	5.0 (0.45)	70	31.0	2.4 (0.40)
80	33.0	4.0 (0.36)	80	33.0	1.9 (0.32)

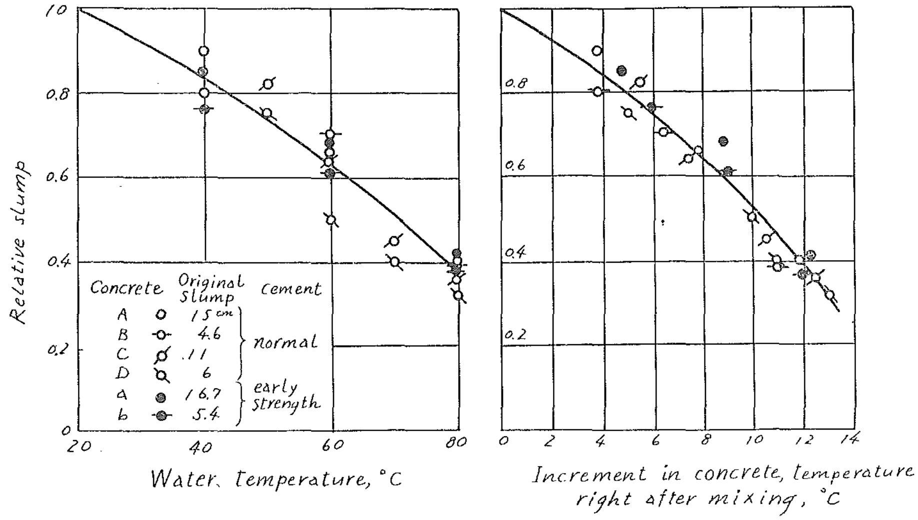

Fig. 4. a and b

Then advantageous use can be made of date in Fig. 4b which is plotted by taking the increment in concrete temperature instead of the water temperature on abscissa in Fig. 4a. Fig. 4b shows that plotted points gather more densely than in Fig. 4a, and there is also a parabolic relation between the relative slump and the increment in concrete temperature right after mixing, where the temperature increment denotes the difference between the concrete temperature at original water temperature 20°C and that at respective temperature.

From Fig. 4b one has:

Increment in concrete temperature	2°C	4°C	6°C	8°C	10°C	12°C
Relative slump	0.93	0.84	0.75	0.65	0.54	0.40

These values can be applied practically.

(4) Variation in Slump with Passage of Time.

Fig. 5a and Fig. 5b shows the relation between the slump and passage of time after mixing in case of normal cement and early strength cement respectively.

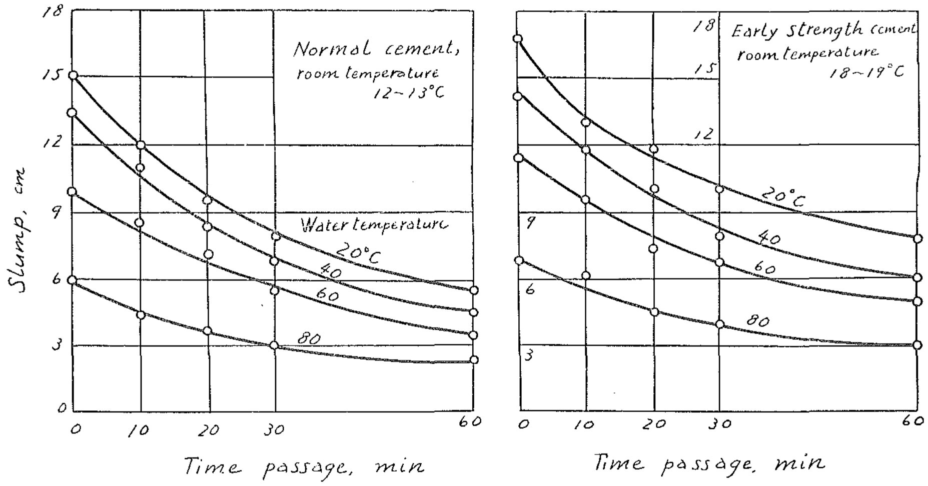

Fig. 5. a and b

From these figures it may be seen that the slump of fresh concrete decreases generally with the passage of time, but this tendency is always similar irrespective of the height of temperature of mixing water and the kind of cement. Therefore, so far as in this connection, it can be said that high temperature of mixing water exerts no bad influence on concrete.

3. Influence on Strength of Concrete

(1) Experimental Procedure.

The compressive strength of concrete test was performed in accordance with the Japanese Standards JIS A 1103. This test is similar to the American Standards ASTM C 39-49 and C 192-52. The compression test specimen has the form of a cylinder with dimensions: diameter 15 cm, heiht 30 cm.

In this experiment concretes A and a, of which the properties are shown in Table 3, are used. The loading of the mixer is the same as previously described above in article 2 (1) (c). The specimens are made with the mixing water of different temperatures 20°C, 40°C, 60°C and 80°C; they are tested at 7, 28 and 91 days. Three specimens are made for each one test.

The specimens were removed from the molds in 2 days and cured in water at the temperature of 20°C.

(2) Test Results.

The test results are shown in Fig. 6a and b, from which it is learned

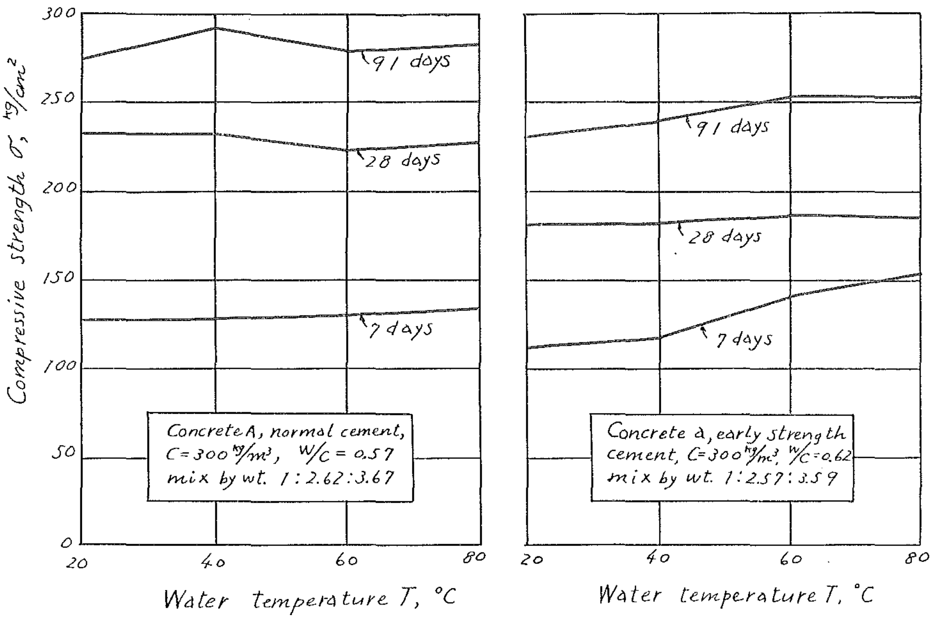

Fig. 6. a and b

(a) Denoting by σ the compressive strength of specimen and by T the temperatures of mixing water. the σ-T lines at each age are all approximately horizontal in case of normal cement (Fig. 6a).

This shows that the high temperature of mixing water does not affect the strength of concrete.

(b) In the case of early strength cement the σ-T line at 28 days is horizontal, but lines at 7 and 91 days are sloped with positive inclination against the horizontal axis (Fig. 6b).

This shows that the high temperature of mixing water, in case of early strength cement, gives no bad influence but does exert good influence on compressive strength of concrete, i. e., the compressive strength at 7 and 91 days becomes greater with the increase of water temperature. This tendency is especially remarkable at 7 days.

Taking the relative strength of concrete at 20°C as equal to 100, the relative strength of concrete at 7 days is equal to 105, 127 and 137 at 40°C, 60°C and 80°C respectively.

(c) Thus the high temperature of mixing water exerts generally no bad influence at early ages, specially in case of early strength cement.

4. Influence on Heat Hydration

(1) Experimental Procedure.

In this experiment the heat of hydration test was carried out in accordance with the Japanese Standards JIS R 5202 which is similar to the American Standards ASTM C 186-49. The experiment was divided into 2 parts as follows:

Test 1. The cement paste was made by mixing 125 gr of cement and 50 cc of distilled water of which the temperature was varied from 20°C to 80°C, and it was placed in four glass vials. The vials were stored in a curing box at 20 ± 2°C until the time of test.

Test 2. In order to let the curing temperature coincide with paste temperature right after mixing, the curing temperature was varied as 20°C, 25°C, 30°C and 35°C corresponding with water temperature 20°C, 40°C, 60°C and 80°C respectively.

(2) Test Results.

The results of Test 1 are shown in Table 5. From those data it will be seen that the high temperature of mixing water has a remarkable influence on the heat of hydration at 1 and 3 days, i. e., the rise in heat of hydration amounts to 20～50% of original value.

TABLE 5

Cement	Water temperature °C	Heat of hydration, cal/gr				
		1 day	3 days	7 days	28 days	91 days
N_1, normal Portland cement	20	32.5 (1.00)	54.3 (1.00)	73	94.1	96.0
	40	38.9 (1.27)	69.1 (1.27)	76.4	95.1	96.0
	60	49.4 (1.52)	64.4 (1.19)	70.0	89.1	96.8
	80	40.5 (1.25)	72.0 (1.33)	81.1	96.3	99.5

Table 6 shows the results of Test 2, from which it will be noted that the same tendency is observed more strongly–the rise amounts to 10～30% at least and to 50～130% in maximum.

TABLE 6

Cement	Water temperature °C	Paste temperature right after mixing °C	Heat of hydration, cal/gr			Curing temperature °C
			1 day	3 days	7 days	
N_2, normal	20	20.3	29.6 (1.00)	54.4 (1.00)	76.6	20
	40	33.1	34.8 (1.13)	58.4 (1.10)	81.9	25
	60	42.3	48.9 (1.49)	66.8 (1.23)	83.6	30
	80	50.0	50.5 (1.53)	72.7 (1.34)	77.0	35
E_2, early strength	20	22.7	38.5 (1.00)	60.7 (1.00)	81.0	20
	40	32.2	38.6 (1.00)	65.5 (1.08)	81.8	25
	60	42.8	50.6 (1.31)	72.0 (1.19)	82.1	30
	80	52.8	55.8 (1.45)	76.0 (1.25)	82.3	35
N_1, normal	20	22.9	23.7 (1.00)	40.9 (1.00)	74.2	20
	40	32.2	31.0 (1.30)	52.8 (1.29)	75.0	25
	60	44.0	39.9 (1.60)	62.6 (1.53)	76.8	30
	80	49.0	55.4 (2.34)	73.4 (1.79)	80.5	35
N_3, normal	20	21.9	29.3 (1.00)	46.4 (1.00)	58.7	20
	40	30.7	32.0 (1.10)	52.4 (1.13)	69.1	25
	60	44.0	—	57.1 (1.23)	72.4	30
	80	50.0	41.3 (1.41)	68.4 (1.47)	75.9	35

This tendency at early ages makes the curing of concrete in winter easy, because it is profitable to secure the specified curing temperature.

5. General Summary

When the mixing water of as high a temperature as 80°C with the corresponding temperature of fresh concrete or paste below 53°C is used, and when the such hot water comes in contact with the cement, the influence of such high temperature on the properties of concrete can be said to be as follows:

(1) Bad phenomena such as flash set or such other visible events are not observed.

(2) The time of setting becomes shorter, and this is proportional to the rise in the paste temperature which is generally much lower than the water temperature. However the time reduction of setting is not so remarkable as to be injurious in practice.

(3) The consistency of concrete is affected by the increase of water temperature. The variation in relative slump is connected rather with the concrete temperature than with the water temperature.

The temperature of fresh concrete in the winter job site is considerably lower than that in this experiment, therefore the above influence is not so great as to be injurious in practice. The variation in relative slump is not connected with the kind of cement.

(4) The rate of variation in slump with the passage of time is not affected by a rise in temperature of water.

(5) In case of normal cement the compressive strength is scarcely affected at all ages between 7 days and 91 days.

In the case of early strength cement, the compressive strengh increases strongly with a rise in water temperature at 7 days, also slightly at 91 days, but is not affected at 28 days.

(6) The heat of hydration of cement is strongly promoted before 3 days by the increase of water temperature. This is profitable to secure the curing temperature.

Lastly the author wishes to express his appreciation to Dr. Ichiki and to Assistant T. Matsui for their helpful and earnest assistance during these investigations.