[1145] 署中環境下で練りまぜて運搬される フレッシュコンクリートのワーカビリチーに関する研究

WORKABILITY CHARACTERISTIC OF FRESH CONCRETE MIXED AND AGITATED IN HIGH TEMPERATURE AMBIENCE

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1. INTRODUCTION

The concrete that is mixed and agitated at a high ambient temperature tends to give rise to defects such as reduced workability, and diminishable strength and potential occurrence of cracks in long-term aging. In this view, many of the concrete work specifications provide requirements for works to be performed in high temperature ambiences. However, in many cases no specific term for which such requirements be applied is defined due to lack of a unified criterion.

This study was carried out with the aim of explicating workability particularly in term of slump of the fresh concrete that is mixed and transported in various high temperature ambiences.

Results of our experiments to determine effect of high ambient temperature on the workability of fresh concrete, which were conducted in the same manner as those being practiced in some ready-mixed concrete plants are discussed in this paper.

2. HIGH TEMPERATURE AMBIENCE

Some differences may be found between concrete work specifications in the way of specifying the term for which requirements for works in high temperature ambiences be applied. Nevertheless, the ways of specifying the term fall into two categories: one is to define the term as periods covering the days of which daily average temperatures are 25℃ or higher and the other is the term as periods covering the days of which the daily maximum temperatures are 30℃ or higher.

Based on the data for past 20 years provided by the Meteorological Observatory, the areas where daily average temperature becomes 25℃ or higher, i.e. those where the first category of the term definition is applied are shown in Figs. 1(a) to 1(d). The high temperature ambience as defined by the first category is experienced in some areas of the southern part of Kyushu late in June and all over Japan except a part of Tohoku, Hokkaido and some highland areas in the middle of and late in August.

With the second category of the term definition, the high temperature

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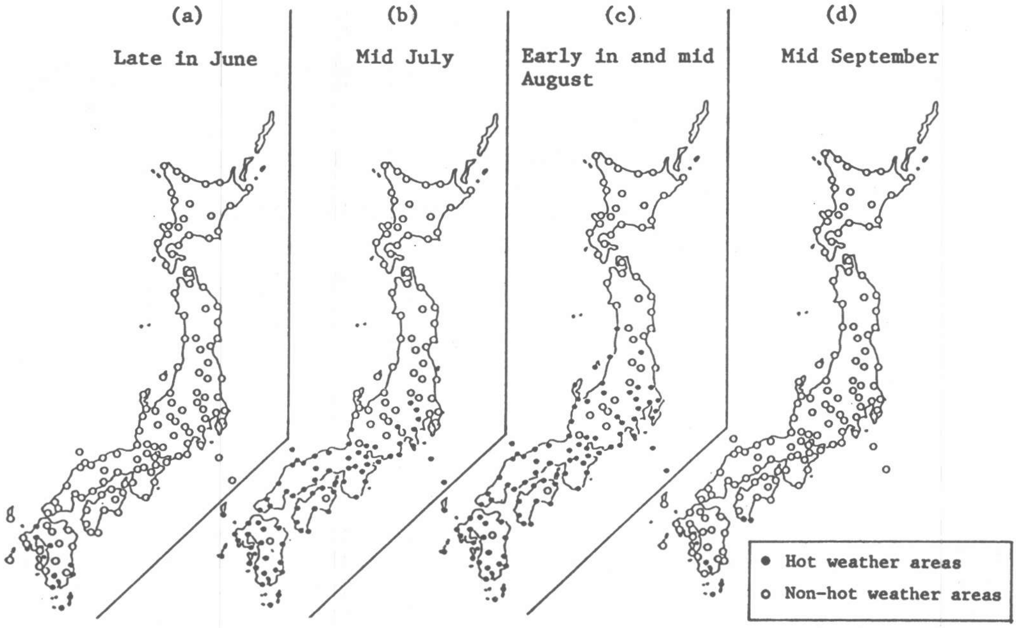


Fig. 1. Hot weather in Japan

ambience represents distributions similar to those shown in Figs. 1(a) to 1(d). Nonetheless the high temperature ambience term may be applied differently to some areas depending on the term definition.

What determines the quality of cured concrete is the temperature of the concrete itself over the period of mixing and agitating. The ambient temperature is merely one of the factors that affect it.

This paper covers our experiment that was focused to the relation between the ambient and the concrete temperatures during agitation before placing.

Table-1 Mix proportion

W/C (%)	Volume (ℓ / m³)				AE water-reducing agent of retarding type (g/m³)
	water	cement	aggregate fine	aggregate coarse	
57	182	101	312	365	798

3. OUTLINE OF EXPERIMENT

3.1 MATERIALS AND MIX PROPORTION

Ordinary Portland cement, sea-sand as fine aggregate and crushed stone as coarse aggregate are used together with AE water-reducing agent of retarding type as admixture.

The proportion that is most popular with the ready-mixed concrete suppliers in Fukuoka City for building construction during the summer was employed.

Table-2 Experiment procedures

Temperature of materials			Mixing	Agitating	
cement (℃)	aggregate (℃)	water (℃)	ambient temp. (℃)	ambient temp. (℃)	time (hours)
20	20	20	20	20/30/40	0.5/1.0/1.5
40	30	20	30		
60	40	20	40		

Table 1 shows the proportion.

3.2 METHOD OF EXPERIMENT

The concrete was mixed and agitated at various temperatures of both the concrete itself and its ambience. The schedule of the experiment is given in Table 2.

Three sets of the component materials, each material having such temperature as to bring resulted temperature of the mixture to about 20℃, 30℃ and 35℃, were chosen. The cement of which temperature was 60℃ immediately after pulverized had 60℃, 40℃ and 20℃ for the respective sets. The aggregate was made warm enough to simulate the condition of piling outdoor in a ready-mixed concrete plant. The temperature of tap water was always 20℃ as it was easily controlled and unlikely subject to outdoor temperature.

A tilting mixer with a capacity of 30 liters was used for mixing at ambient temperatures of 20℃, 30℃ and 40℃. The same mixer was used for agitation, too. In simulation of actual transport of ready-mixed concrete it was operated at a drum speed of 6 m/min in terms of circumferential velocity in equivalence of that of the drum of a ready-mixed concrete lorry. The agitation was kept going for 30, 60 and 90 minutes as planned for the respective batches. The opening of the mixer was covered with wet jute bags during operation so as to prevent the concrete from drying.

4. RESULT AND DISCUSSION

4.1 WORKABILITY

(a) Mixed Concrete Temperature and Slump

In the past experiments, it was recognized that the slump decreased as the mixed concrete temperature rose and the rate of slump loss increased as the temperature went up. The reason for the slump loss when concrete temperature went up has not been clarified.

Now, assuming that the slump decreasing rate $dx/d\Theta_i$ at the mixed concrete temperature Θ_i is proportional to Θ_i, the rate is expressed as follows:

$$\frac{dx}{d\theta_i} = \alpha\theta_i \qquad (1)$$

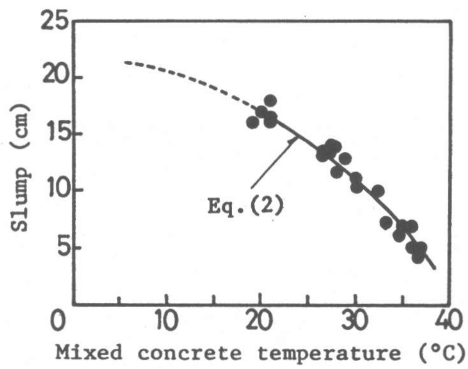


Fig. 2. Slump characteristics at the measured temperature of concrete when mixing period ended

From the Eq.(1) the following expression representing the relation between the slump x and the mixed concrete temperature Θ_i is obtained:

$$\int\frac{dx}{d\theta_i}\,d\theta_i = \int\alpha\theta_i\cdot d\theta_i \longrightarrow x = a\theta_i^2 + b \qquad (2)$$

The result of the present experiment representing the relation between the slump X and the mixed concrete temperature Θ_i is shown in Fig.2 in which the curve of solid line is plotted from the Eq.(2) where a= -0.07 and b =21.8. As is seen in the figure, the Eq.(2) agrees with the result to a satisfactory degree, implying justification of the above-mentioned assumption.

(b) Agitated Concrete Temperature and Slump

Figure 3 shows the duration of agitation vs. slump relation. In common to the batches of mixed concrete with different mixed temperatures, the slump decreases rapidly in the first 30 minute and not so in the successive period. In addition, it is apparent that the higher the ambient temperature, the higher the slump losses during a fixed period of agitation.

Fig. 4 shows the relation between the slump and the temperature of concrete at the end of agitation or at the time of placing. It is obvious that the temperature of concrete at the end of agitation affects slump significantly as the temperature at the end of mixing does. However the rate of the slump loss as concrete temperature increased became smaller at the long period agitation.

4.2 TEMPERATURE OF CONCRETE

A formula, Eq.(3) is specified in JASS 5 by AIJ for calculating temperature of mixed fresh concrete. However no effect of the ambient temperature is taken into consideration in it.

$$\theta_o = \frac{0.2\theta_c W_c + \alpha_a \theta_a W_a + \theta_m W_m}{0.2W_c + \alpha_a W_a + W_m} \qquad (3)$$

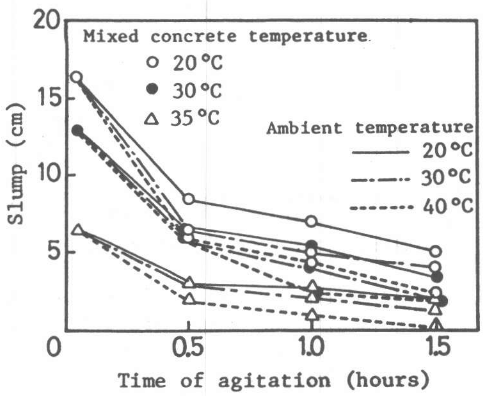


Fig. 3. Slump characteristics of each mixed concrete temperature in various ambient temperature during agitating period

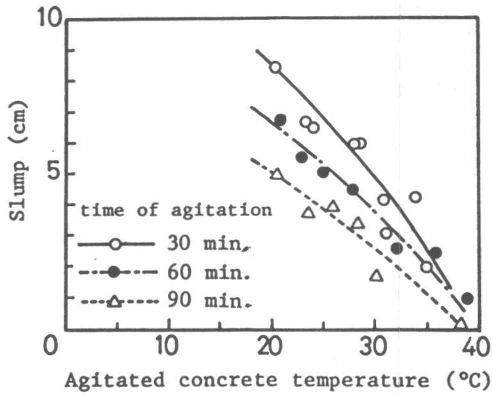


Fig. 4. Slump characteristics at the measured temperature of concrete when agitating period ended

where

Wc, Wa and Wm : weight of cement, aggragate and water,
Θc, Θa and Θm : temperature of cement, aggregate and water, and
α_a : specific heat of aggregate.

The temperature of concrete at the end of agitation or at the time of placing affects its workability significantly and thus its strength characteristic after curing, too. Therefore, it is meaningful to determine a formula for calculating concrete temperature at the time of placing taking the effect of such factors into consideration as ambient temperature during mixing and transport and time requirement for transport.

The duration ot agitation vs. concrete temperature relation is shown in Fig. 5 where you will see the trend that the temperature of concrete under agitation comes close to the ambient temperature as time elapses. The trend provides a ground for the concrete-placing temperature greatly affected both by the length of transport time and by the ambient temperature during transport.

The value Θ_0 to be obtained from Eq.(3) represents an estimated fresh concrete temperature in equilibrium based on the temperatures and weights of the respective component materials. Insofar as agitation is given during transport, the value should be modified so as to incorporate the effect of ambient temperature into it. Assuming an ambient temperature Θ_r higher than Θ_0 obtained from Eq.(3) for a given batch of concrete, the temperature Θ after agitation may be higher than Θ_0 , and obviously vice versa.

On the supposition that the rate of temperature change $d\Theta/dt$ in a given batch of fresh concrete having temperature Θ and being agitated in an ambience the following equation is deduced:

$$\theta_r - \theta = \alpha \frac{d\theta}{dt} \qquad (4)$$

where α is a coefficient representing the thermal conductivity from the ambience to the concrete. The general solution of the differential equation (4) is expressed as follows:

$$\theta = \gamma \cdot \exp(-\alpha t) + \theta_r \qquad (5)$$

Since fresh concrete temperature Θ in Eq.(5) is not yet affected by ambient temperature Θ_r at the initial time of agitation or at t=0, it can be expressed as $\Theta=\Theta_0+\beta$ where β is a coefficient representing the effect caused by hydration heat. Hence, the following equation is derived from Eq. (5):

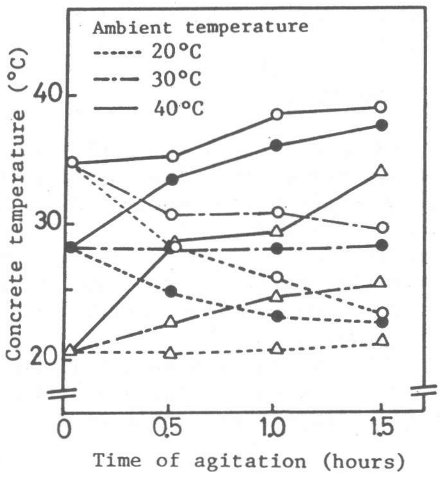
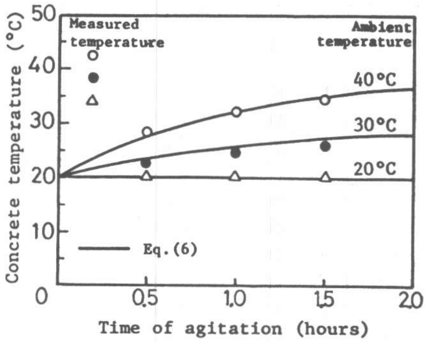
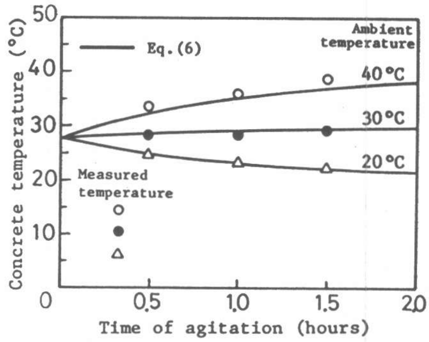


Fig. 5. The changes of concrete temperature in various ambient temperature during agitating period

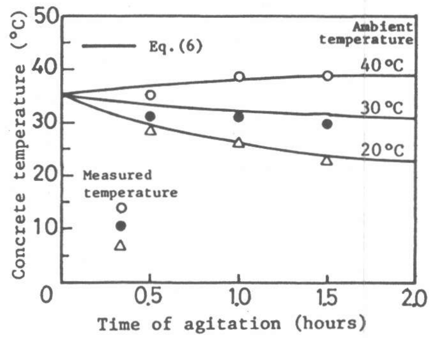
$$\theta = (\theta_0 - \theta_r + \beta) \cdot \exp(-\alpha t) + \theta_r \qquad (6)$$



(a) Initial concrete temperature, $\theta_0+\beta=20.5\,°C$



(b) Initial concrete temperature, $\theta_0+\beta=28\,°C$



(c) Initial concrete temperature, $\theta_0+\beta=35\,°C$

Fig. 6. The comparison between temperature measured during agitating period and temperature calculated by Eq.(6)

The concrete temperature measurements resulted from the present experiment are compared with the calculations obtained from Eq.(6) in Fig. 6 in which the calculations are plotted with the solid lines. The curves well agree with the measurements. In regard to Eq.(6), the coefficient α is attributed to the experimental system including the mixer with its own thermal features such as specific heat, temperature and so on. The present experiment resulted in $\alpha=0.9$ and $\beta=2.3$ of which interpretation in a specific way is left to future study.

5. CONCLUSION

Some effect of the high temperature ambience on the fresh concrete at various temperature levels was studied. This paper also described the relation between the concrete temperature and the workability in terms of slump. Further, in view of a significant impact of the concrete-placing temperature on resulted strength after curing, a formula for estimating concrete-placing temperature was determined taking such factors into consideration as ambient temperature and duration of agitation throughout the transport period.

The achievement as described in this paper may be of use for quality control, including strength control in particular, of concrete to be placed in high temperature ambiences.

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