Influence of High Temperatures on the Workability of Fresh Ready-Mixed Concrete

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Abstract. Properties of fresh concrete made in tropical countries, which is mixed, transported (with agitation), placed and initially cured in places where the temperature ranges from about 20°C to 40°C and relative humidity above 60%, are not completely understood. Applicable requirements also differ from country to country and government agencies and private enterprises have their own specifications. Assuming such temperature and relative humidity conditions, the present study is an attempt at evaluating the properties of hot weather concrete in fresh state with using a method of ready–mixed concrete. The fresh concrete was mixed and agitated at varying concrete and ambient temperatures. Three groups of the component materials, each material having such temperature as to bring resulting temperature of the fresh concrete to about 20°C, 30°C, 35°C, were chosen. The temperature of cement was conditioned to about20°, 40°C and 60°C for each of groups respectively. The aggregate was made warm enough to simulate the condition of outdoor pile in ready-mixed concrete plant. The temperature of tap water was always 20°C as it was easily controlled and unlikely affected by outdoor temperature. With the fresh concrete prevented from evaporation, slump loss is caused solely by increased temperature of concrete. During agitation, the slump loss increases rapidly during the first 30 minutes but moderately during the remaining period. Concrete-placing temperature (upon arrival at the work site) could be estimated by a proposed formula derived from this study. Besides the freshly mixed concrete temperature, this formula also takes into consideration the ambient temperature, agitating time in transit and hydration heat. The achievement as described in this study may be useful to control concrete quality in terms of strength, shrinkage and other properties of concrete to be placed in hot-humid environment.

Keywords*: ambient temperature; formula; fresh concrete temperature; ready-mixed concrete; slump loss.*

1 Introduction

High temperature ambience is a well-known factor that affects the concrete mixed and agitated in transit from the batching plant to the site, leading to, for instance, reduction in workability of fresh concrete. Munday [1] observed this

Received January 27th, 2011, Revised April 28th, 2011, 2nd Revision May 19th, 2011, 3rd Revision June 28th, 2011, Accepted for publication July 25th, 2011.
 ISSN: 1978-3051, DOI: 10.5614/itbj.eng.sci.2012.44.1.2

phenomenon leading to the decrease in quality of hardened concrete. Mehta and Monteiro [2] found that under hot weather, a concrete mixture exhibiting an unusually large loss of slumps during the first 30 to 60 minutes may have the effect of making the mixing, placing, compacting, and finishing operations difficult or, at times, even impossible.

As illustrated in Figure 1, a ready-mixed concrete is defined as concrete that is manufactured in a batching plant for delivery to a purchaser, or project site, in a plastic and unhardened state. And this method involves the mixer trucks, agitator trucks, concrete pumps, drop chutes, belt conveyors, cranes, buckets and the other equipments to support the operations.

Experiment was carried out with the aim of explicating workability using method of ready-mixed concrete, particularly, in term at slump of the fresh concrete that has been mixed and transported (with agitation method) in various high temperature ambiences.

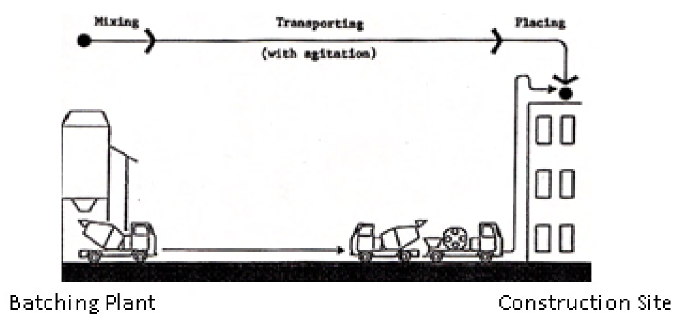

Figure 1 A Method of ready-mixed concrete.

Results of this experiment to determine effects 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. In particular, the experiments were focused on relation between the ambient and the concrete temperature during agitation or before placing.

2 Outline of Experiment

2.1 Materials and Mix Proportion

Ordinary Portland cement, river-sand as fine aggregate and crushed stone as coarse aggregate are used together with Air Entrained (AE) water-reducing agent of retarding type as admixture. Physical characteristics of aggregate used are shown in Table 1.

Table 1 Physical characteristic of aggregate used.

Physic Characteristic / Aggregates	Maximum Size (mm)	Spesific Gravity		Absorbed Moisture (%)	Absolute Volume (%)	Fineness Modulus
		Absolute Dry	Saturated Surface-dry			
Coarse	20	2.62	2.64	0.80	58.4	86.7
Fine	2.5	2.54	2.58	1.76	63.9	2.51

The mix proportion that is most popular with the ready-mixed concrete suppliers in Indonesia for building construction during the high temperature was employed. Table 2 shows the proportion. Other reasons of employing this single mix proportion are that, it enables to meet with good comparisons and enables limiting other variables that may be appear at the time of mixing. In this experiment, the single mix proportion will be a constant one within the different conditions of sample groups to be differentiated according to design of experiment (Table 3), so that the other variables will be easily measured without an influence of many different mix proportions.

Table 2 Design of mix proportion.

W/C (%)	Materials (ℓ/m3)				AE Water-Reducing Agent of Retarding type (g/m^3)
	Water	Cement	Aggregates		
			Fine	Coarse	
57	182	101	312	365	798

2.2 Experimental Method

The concrete was mixed and agitated at various temperatures of both the concrete itself and its ambience. The design of the experiment is given in Table 3.

Table 3 Design of experiment.

Temperature of Materials			Mixing	Agitating	
Cement (°C)	Aggregates (°C)	Water (°C)	Ambient Temperature (°C)	Ambient Temperature (°C)	Time (Minute)
20	20	20	20		
40	30	20	30	20/30/40	30/60/90
60	40	20	40		

Three groups of the component materials, each material having such temperature as to bring resulting temperature of the fresh concrete to about 20°C, 30°C and 35°C, were chosen. The temperature of cement was conditioned to about 20°C, 40°C and 60°C for each of group respectively.

The aggregate was made warm enough to simulate the condition of outdoor pile in ready-mixed concrete plant. The temperature of tap water was constantly maintained at 20°C in the curing room as it was easily controlled and unlikely affected by outdoor temperature.

A tilting mixer with a capacity of 30 litres was used for mixing at ambient temperatures of 20°C, 30°C and 40°C. The same mixer was used for agitation. In simulation of actual transport of ready-mixed concrete it was operated at a drum speed of 6 m/minute in terms of circumferential velocity in equivalence to 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 fresh concrete from drying. This method is also described by Munday [1].

Five minutes after mixing, two samples of suitable size were withdrawn for the initial slump reading and for determining subsequently the air content and unit weight. After finishing all measurements at this period of mixing, the samples were returned again to the mixer, and then, the drum was tilted at a steeper inclination to simulate a continuous agitation-type mixing associated with ready-mixed concrete operations. The measurement of slump test was done in the different rooms having the temperature of 20°C, 30°C, and 40°C. Two times of slump test was measured in each of the rooms that was at the end of the mixing stage and the agitating stage respectively.

3 Results and Discussion

Results of fresh concrete are shown in Table 4. The results show that the air content in both periods of mixing and agitating is not substantially changed. But the slump and fresh concrete temperature substantially change during agitating (transporting) under various ambient temperatures.

Table 4 Results of fresh concrete.

Code of Specimen (*)	Period of Mixing Stage			Period of Agitating Stage		
	Slump (cm)	Temperature (°C)	Air Content (%)	Slump (cm)	Temperature (°C)	Air Content (%)
LL30	16.0	20.5	2.9	8.5	20.5	2.8
LL60	16.5	21.0	2.8	7.0	21.0	2.8
LL90	16.5	21.0	3.1	5.0	20.5	2.8
LM30	16.5	21.0	3.0	6.5	23.3	2.8
LM60	16.5	20.8	3.1	5.0	25.0	2.6
LM90	16.5	20.0	3.3	4.0	26.5	2.8

Code of Specimen (*)	Period of Mixing Stage			Period of Agitating Stage		
	Slump (cm)	Temperature (^oC)	Air Content (%)	Slump (cm)	Temperatu re (^oC)	Air Content (%)
LH30	18.0	19.5	2.8	6.0	28.5	2.6
LH60	16.0	19.5	3.0	4.5	31.0	2.8
LH90	17.0	20.0	3.0	2.5	34.5	3.0
ML30	7.0	30.0	2.8	6.5	23.0	2.5
ML60	13.5	26.5	3.2	5.5	22.8	3.0
ML90	11.0	30.0	3.0	3.5	23.5	3.0
MM30	11.5	28.0	3.0	6.0	28.0	3,0
MM60	14.0	27.8	3.2	4.5	28.0	3.2
MM90	14.0	27.5	3.3	3.5	28.8	2.6
MH30	13.0	26.5	3.3	5.5	34.5	3.0
MH60	6.0	29.0	3.0	1.0	36.2	3.0
MH90	13.5	27.1	2.8	2.0	40.0	2.7
HL30	4.0	36.2	3.0	2.0	29.5	3.0
HL60	5.0	36.0	2.8	2.0	27.0	3.0
HL90	12.5	33.0	2.8	2.5	22.0	3.0
HM30	10.0	32.5	2.7	3.0	31.0	2.8
HM60	7.0	38.0	3.0	3.0	32.0	2.8
HM90	6.5	33.0	3.1	1.5	30.0	3.0
HH30	6.0	35.0	3.0	2.0	35.0	3.4
HH60	5.0	36.8	2.9	1.0	41.0	3.2
HH90	7.0	35.0	3.0	0.5	41.0	-

(*)The code indicates that,

(a) The first letter : ambient temperature during the period of mixing
L=20°C, M=30°C, H=40°C

(b) The Second letter : ambient temperature during the period of agitating, placing, and initial curing
L=20°C, M=30°C, H=40°C

(c) The last numeral : time of agitation 30, 60, 90 minutes

3.1 Workability

3.1.1 Mixed Concrete

In the past experiments, it was recognized that the slump decreased as the mixed concrete temperature rose or in other words the rate of slump loss increased as the temperature went up [3,4]. The reason for the slump loss when concrete temperature went up has not been clarified.

Now, assuming that the slump decreasing rate $\frac{dx}{d\theta_i}$ at the mixed concrete temperature θ_i, is proportional to θ_i the rate is expressed as follows:

$$\frac{dx}{d\theta_i} = \alpha\theta_i \tag{1}$$

From the Eq. (1) the following expression representing the relation between the slump loss $\boldsymbol{x}$ and the mixed concrete temperature θ_i is obtained:

$$\int \frac{dx}{d\theta_i} = \alpha\theta_i.d\theta_i$$

$$x = a\theta_i^2 + b \tag{2}$$

The result of the present experiment representing the relation between the slump loss $\boldsymbol{x}$ and the mixed concrete temperature θ_i is shown in Figure 2, in which the curve of solid line is plotted from the Eq. (2) where a=-0.012 and b= 21.5. As is seen in the Figure, the Eq. (2) agrees with the result to a satisfactory degree, implying justification of the above-mentioned assumption.

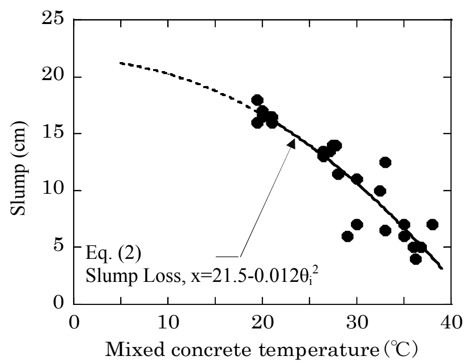

Figure 2 Slump characteristics at the measured temperature of fresh concrete when mixing period ended.

3.1.2 Agitated Concrete

The duration of agitation versus slump relation is shown in Figure 3. In common to the batches of mixed concrete with different the initial mixed temperatures (20.5, 28.0, and 35.0°C), the slump decreases rapidly in the first 30 minutes 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 [2]. The lower the initial slump or at 35°C of initial mixed concrete temperature, the smaller the rate of slump loss throughout the agitation period. The time where the slump loss is substantial is different between that found before and by this experiment. This may be caused by the difference of the first time measurement which 45 minutes in Ravina's experiment [5] and 30 minutes in this experiment. But we found the same phenomena over the remaining interval or after the first time measurements in which the rate of slump loss was more moderate.

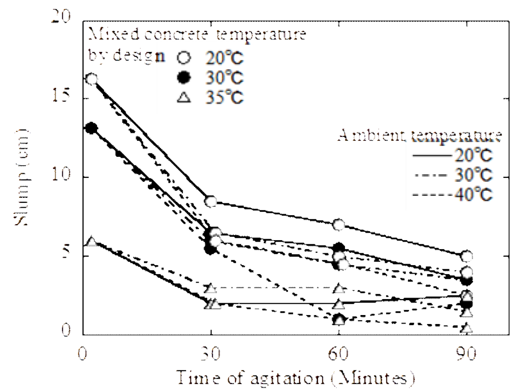

Figure 3 Slump characteristics of each mixed concrete temperature in various ambient temperatures during agitating period.

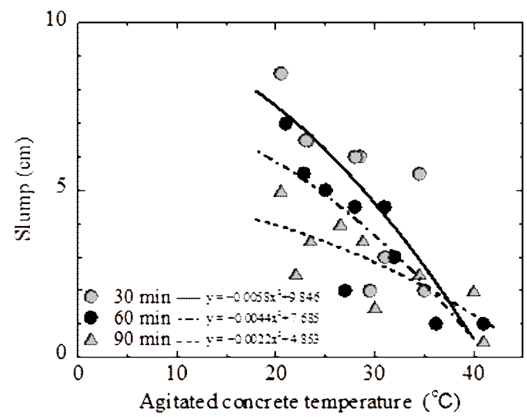

Figure 4 Slump characteristics at the measured temperature of concrete when agitating period ended.

The relation between the slump and the temperature of concrete at the end of agitation or at the time of placing is shown in Figure 4. It is obvious that the temperature of concrete at the end of the agitation affects slump significantly as the temperature at the end of mixing does. However the rate of the slump loss as concrete temperature was increased became smaller with the long period agitation. In addition, although the concrete became very stiff as it had lost much water within the body of fresh concrete caused by cement hydration and rapid evaporation [6] and difficult to work (nearly zero slump) particularly at the longest period of agitation and the highest concrete temperature, it could be placed as usual in molds.

3.2 Temperature of Concrete

A formula, Eq. (3), is specified in JASS 5 AIJ* [7] for calculating temperature of freshly mixed concrete. However, the effect of the ambient temperature and time of agitation are not taken into consideration in it.

$$\theta = \frac{0.2\theta_c W_c + \alpha_a \theta_a W_a + \theta_m W_m}{0.2W_c + \alpha_a W_a + W_m} \tag{3}$$

where:

W_c, W_a,and W_m = weight of cement, aggregate and water
θc, θa, and θm = temperature of cement, aggregate and water
α_a = specific heat of aggregate

* JASS 5 AIJ = Japanese Architectural Standard and Specification, Volume 5, of Architectural Institute of Japan

The temperature of concrete at the end of agitation or at the time of placing affects its workability significantly and thus its strength characteristics after curing, too [2,8]. 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 of agitation versus concrete temperature relation is shown in Figure 5, where the trend of 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.

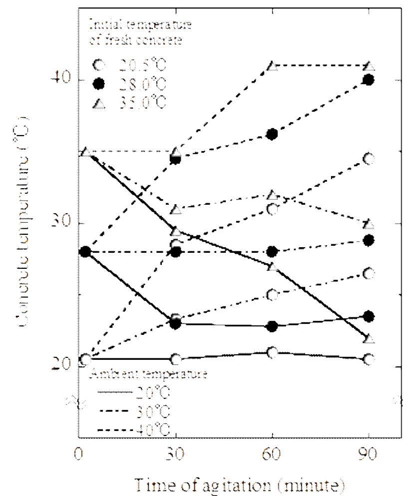

Figure 5 The changes of concrete temperature in various ambient temperatures during agitation period.

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. In so far 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 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 $\frac{d\theta}{dt}$ in a given batch of fresh concrete having temperature θ and being agitated in an ambience the following equation is deduced:

$$\theta_r - \theta = \alpha \frac{d\theta}{dt} \tag{4}$$

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

$$\theta = \gamma . \exp(-\alpha_t) + \theta_r \tag{5}$$

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):

$$\theta = (\theta_0 - \theta_r + \beta)\exp(-\alpha_t) + \theta_r \tag{6}$$

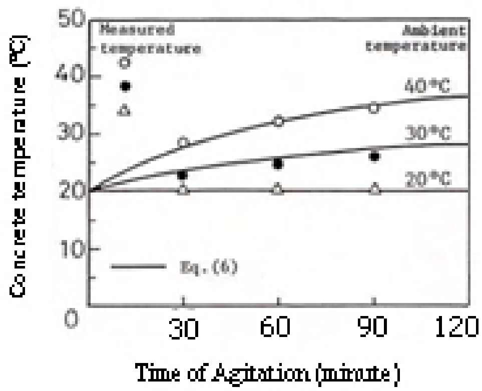

Figure 6 Initial fresh concrete temperature, t=0, $\theta = \theta_0 + \beta = 20.5^o c$.

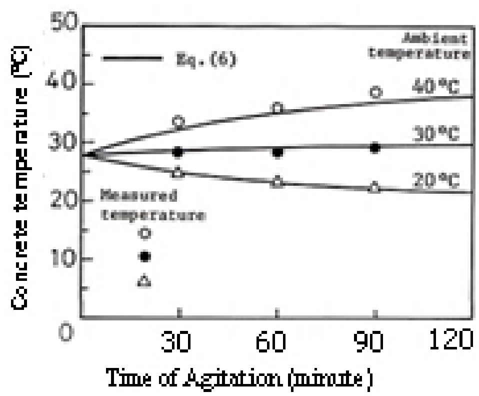

Figure 7 Initial fresh concrete temperature, t=0, $\theta = \theta_0 + \beta = 28^o c$.

The concrete temperature measurements resulted from the present experiment are compared with the calculations obtained from Eq. (6) in Figure 6, 7 and 8 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 experiment system including the mixer with its own thermal features such as specific heat, temperature and so on. The present experiment resulted in α = 0.9 and β = 2.3 of which interpretation in a specific way is left to future study.

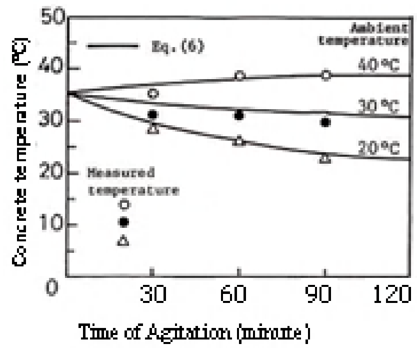

Figure 8 Initial fresh concrete temperature, t=0, $\theta = \theta_0 + \beta = 35^o c$.

These three Figures are the results of the comparison between temperature measured during agitating period and temperature calculated by Eq. (6)

4 Conclusions

Several effects of the high temperature ambience on the fresh concrete at various temperature levels were studied. As the results, two formulae and several interesting conclusions were obtained.

(a) The rapid rate of slump loss when air temperature is high, is remarkably affected by the temperature of fresh concrete measured at the end of a period of mixing. Starting from 20°C of concrete temperature, the higher the concrete temperature, the higher the increase of slump loss. The slump loss could be estimated on the basis of the concrete temperature and, thus controlled by a formula derived from this study.
(b) In the period of agitation, a slump loss increase substantially during the first 30 minutes but moderately during the remaining period.
(c) The temperatures of fresh concrete after the mixing period vary and easily change during transportation from the batching plant to the site under ambient temperature which is different from that of the concrete.
(d) The formula for the temperature of concrete (concrete-placing temperature) upon arrival at the site or before placing is derived from this study in which a predetermined formula of AIJ in JASS 5, ambient temperature, heat of hydration, and time of agitation during transport, are taken into consideration. As the last three factors affecting the concrete temperature during transportation are not found in JASS 5's formula, this formula may

not be used for the case of ready-mixed concrete. In this study, the alternative formula is presented and proposed for universal use if ready-mixed method with agitation is to be applied in hot weather

Observation of the effect of high temperatures on the slump loss behaviour of fresh ready-mixed concrete described in this study may be of use for quality control, including strength control in particular, of concrete to be placed in hot humid environment.

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