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Effects of retempering on consistency and compressive strength of concrete subjected to prolonged mixing

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Abstract

In this study, effects of prolonged mixing and four different retempering processes on some properties of fresh and hardened concrete, such as temperature, slump loss, and strength, were investigated. Two types of concrete mixtures with different compression strength having 15 cm initial slump were produced in a laboratory mixer. After mixing for 5 min at 20 rpm speed to ensure homogeneity, the mixing was continued at 4 rpm for a period of up to 4 h to simulate the prolonged agitation of ready-mixed concrete in truck mixers. Concrete samples were taken out of the mixer at the end of first, second, third, and fourth hour for estimating the effects of prolonged mixing on properties of fresh concrete. For restoring the initial workability, four different retempering methods were used and their effects on properties of concrete were investigated. Results show that compared to the untempered concrete mixtures, those tempered with solutions prepared by 3% or 4.5% solid superplasticizer by mass of retempering water had significantly less loss of 28-day compressive strength. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Prolonged mixing; Ready-mixed concrete; Retempering; Slump loss; Strength

1. Introduction

In the manufacture and delivery of ready-mixed concrete, the mixture is continuously mixed or agitated for different periods. Although economic and technological considerations dictate minimization of the hauling time, there are some cases in which prolonged mixing cannot be avoided, owing to the distances involved or delays in placing [1].

Prolonged mixes induce stiffening of the mix, i.e., consistency change or slump loss. Increase in the mixing period of concrete prior to discharging, particularly in hot weather, results in temperature rise, which accelerates cement hydration and causes rapid loss of moisture due to evaporation, leading to increased slump loss that needs to be compensated by adding water at the jobsite. Retempering with water is a common practice to restore the initial workability. The amount of water required to produce a given slump increases with the extended mixing time. The addition of water without proper adjustments in mix proportions adversely affects the ultimate quality of concrete [1].

When concrete is observed at the delivery point to have a lower-than-specified workability, there may be one or more of the three possible reasons [2]:

(i) Insufficient water batched initially;
(ii) Higher rate of evaporation (or absorption by aggregate) than anticipated; and
(iii) Higher rate of hydration than expected.

Retempering water added to offset (i) or (ii) will not result in a lower strength than expected, whereas extra water to combat (iii) will result in a lower strength. This is because the extra water increases the water–cement ratio or water–cementitious material ratio. However, by examining the concrete mixture at delivery point, it will not be possible to determine which reason applies [2].

Another method of retempering is to use chemical admixtures. The addition of chemical admixtures at the delivery point allows close control of the slump loss with no loss of strength. It should be noted that the addition of chemical admixtures at the ready-mix plant, while easier to

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adjust, could lead to an accelerate slump loss as compared with a concrete with no additions [3–5].

2. Experimental

2.1. Materials

2.1.1. Cement

An ordinary Turkish Portland cement (PC 42.5, similar to ASTM Type I) was used for the production of the concrete. The chemical composition and the physical properties of the cement are shown in Tables 1 and 2, respectively.

2.1.2. Aggregates

An aggregate mixture was obtained by combining natural river sand, crushed sand, and two types of crushed stone having a maximum size of 25 mm. The aggregates conformed to ASTM C 33.

2.1.3. Mixing water and admixture

Potable tap water (that was normally free from oil, organic matter, and alkalis) was used for making concrete, and as retempering water.

No admixture was used in the production of concrete. The retempering of the concrete after a preselected mixing time was done by either adding water alone or superplasticizers and water. The superplasticizer was a melamine-based polymer dispersion conforming to ASTM C 494 Type F.

2.2. Concrete mixtures

The concrete was designed according to ACI 211. Concrete mix proportions used in the experimental study are given in Table 3.

2.3. Experimental study

Two types of concrete mixtures designated as C25 and C35 according to European Standard with 150-mm slump after initial mixing were planned to be produced in a stationary mixer in the laboratory. Note that C25 and C35 concrete were required to have a 28-day minimum compressive strength of 25 and 35 MPa, respectively.

A special concrete mixer (of 330 l capacity), which could rotate at different speeds, was used for the concrete production. After mixing the concrete for 5 min at normal mixing speed (about 20 rpm), the material was kept in the mixer for 4 h, while the mixer was rotating at 4 rpm. This low speed was chosen to simulate the agitation of the ready-mixed concrete in the truck mixer.

To take concrete samples to be tested, the mixer was briefly stopped after 5 min, and after the first, second, third, and fourth hours. First, the temperature and the slump were determined. Then, the samples showing a slump of less than 15 cm were placed into a smaller mixer and four different retempering processes were applied to bring the slump value up to the original value, 15 cm:

1. Retempering with "plain water"
2. Retempering with "water + 1.5% superplasticizer by mass of water"
3. Retempering with "water + 3.0% superplasticizer by mass of water"
4. Retempering with "water + 4.5% superplasticizer by mass of water."

In all cases, the amount of water was adjusted to obtain the desired slump of 15 cm.

Finally, each sample was used to prepare 15×30 cm cylindrical concrete specimens for compressive strength tests at the ages of 7 and 28 days. The specimens were kept

Table 1
Chemical composition of Portland cement

Oxides	(%)
CaO	61.88
SiO_2	19.83
Al_2O_3	5.32
Fe_2O_3	3.47
MgO	1.78
SO_3	2.84
K_2O	0.82
Na_2O	0.20
LOI	3.06

Table 2
Physical properties of Portland cement

Property	
Specific gravity	3.11
Specific surface area (cm^2/g)	3250
Time of setting (min)	
Initial	70
Final	230
Compressive strength (MPa)	
7 days	32.6
28 days	45.3

Table 3
Concrete mix proportions (SSD basis) for 15 cm slump, kg/m^3

Materials	C25 concrete	C35 concrete
Cement	295	375
Water	205	205
Natural sand (0–7 mm)	550	490
Crushed sand (0–3 mm)	445	450
Crushed stone (3–9 mm)	130	125
Crushed stone (10–25 mm)	655	660

in a moist room for 1 day and after demolding they were cured in water at 21°C until the time of testing.

3. Test results and discussions

3.1. Effects of prolonged mixing on workability and compressive strength

As seen from Fig. 1, the increase in mixing time leads to an increase in concrete temperature, although the ambient temperature does not change significantly. This is due to the fact that progress in hydration reaction causes heat evolution, since hydration reaction of cement is an exothermic reaction. That is why, the slump loss is significant depending upon the duration of mixing. That can be seen from the Fig. 2, for two classes of concrete.

The temperatures measured in the samples taken from concrete C35 were slightly higher than those obtained on concrete C25. This was due to the fact that concrete C35 had higher cement content than concrete C25. In addition to that, the ambient temperatures for C35 were slightly more than those for the C25 and increased during the test (as shown in Fig. 1).

Both concrete mixes experienced significant slump loss as the mixing time increased. The slump loss for concretes C25 and C35 was the same at the end of 1 h of mixing. However, the slump loss of concrete C35 was slightly higher than that of concrete C25 at the end of 2, 3, and 4 h of mixing (see Fig. 2). This difference in slump loss could be due to the higher cement content in concrete C35 and also to the higher ambient temperature that concrete C35 was subjected to. This higher temperature may have accelerated the hydration process, leading to a decrease in workability.

Seven- and 28-day compressive strengths of the specimens obtained from C25 and C35 types of nonretempered concrete are shown in Fig. 2.

According to the results presented in Fig. 2, the compressive strengths of those specimens obtained from C25

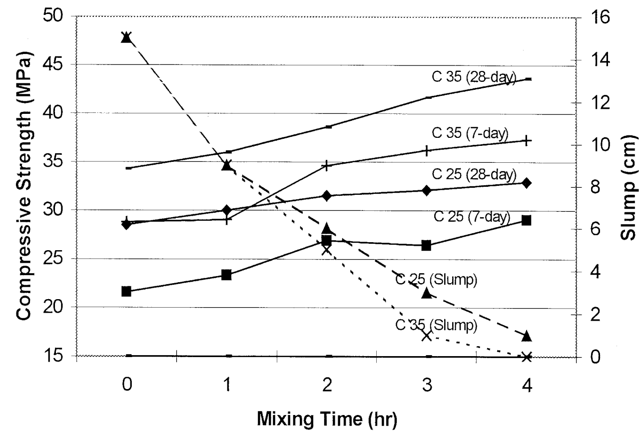

Fig. 2. Compressive strengths and slumps of concretes C25 and C35, which were not subjected to retempering process.

and C35 types of nonretempered concretes were found to increase as the mixing time increased. This might be due to the fact that the increase in mixing time caused a decrease in water–cement ratio due to the loss of water by evaporation. Another possible reason for the increase in compressive strength due to prolonged mixing might be the grinding effect of overmixing. This effect can be explained by the fact that during the hydration progress, the hydration products were removed from the surface of cement grains, causing finer grading of cement and greater amount of hydration. Thus, compressive strength increase was observed as a result of prolonged mixing.

3.2. Effects of superplasticizer on slump readjustment

The amounts of retempering water needed to raise the slump of the concrete samples obtained from concretes C25 and C35 are given in Figs. 3 and 4, depending on the solution concentration (from 0% to 4.5% solid superplasticizer by mass of retempering water).

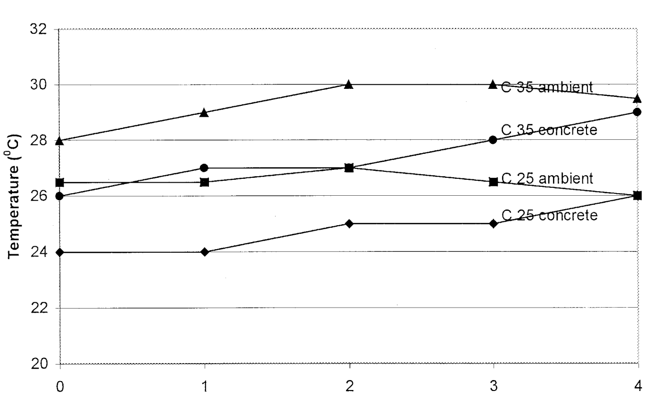

Fig. 1. Effects of prolonged mixing and ambient temperature on concrete temperatures.

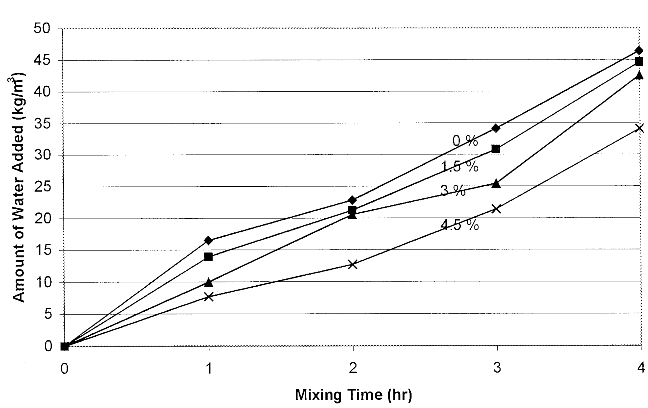

Fig. 3. Amount of retempering water added to concrete C25 for readjusting the slump to 15 cm, depending on the solution concentrations (from 0% to 4.5% solid superplasticizer by mass of retempering water).

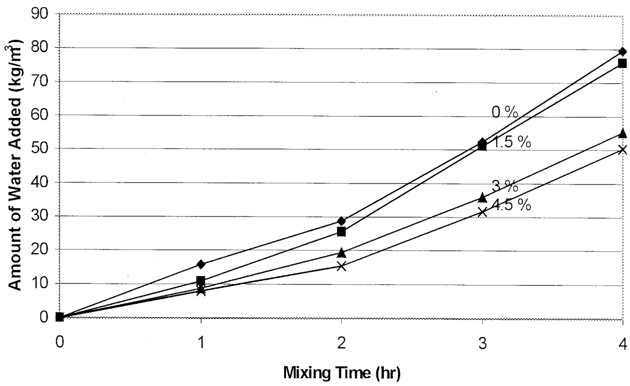

Fig. 4. Amount of retempering water added to concrete C35 for readjusting the slump to 15 cm, depending on the solution concentrations (from 0% to 4.5% solid superplasticizer by mass of retempering water).

As it is seen from Figs. 3 and 4, less amount of water was needed when superplasticizer was used for retempering process. As the dosage of superplasticizer used in retempering water increased, the amount of water for slump readjustment decreased significantly.

Since C35 showed higher slump losses compared to C25, the amount of water added to C35 for readjustment was higher than that added to C25.

3.3. Effects of retempering on compressive strength

The effects of different retempering applications on 7- and 28-day compressive strengths of concretes C25 and C35 are given in Tables 4, 5, 6, and 7. Based on the experimental results presented in Figs. 1, 2, 3, and 4, the following remarks could be made.

• The addition of water for readjustment of initial slump leads to changes in the original water–cement ratios of concretes, provided that there is no evaporation compensation. Since the slump losses increased as the mixing time of concretes increased, more water was added during retempering and water–cement ratios increased. Increase in water–cement ratios usually results in lower compressive strengths. This was observed with both concretes, suggesting that no evaporation took place.

• Retempering processes applied on concrete C35 caused relatively higher strength decreases when compared to that of concrete C25. This was due to the fact that relatively higher amounts of water were needed to readjust the slump of concrete C35.

• Using superplasticizer for the retempering process decreased the amount of water needed to readjust the concrete slump to the original value of 15 cm, as compared to no addition of superplasticizer. Therefore, it can be assumed that the water–cement ratios of the concretes retempered with superplasticizer to be relatively lower as compared with no superplasticizer addition. This is confirmed by the lower decrease in compressive strengths of the concretes retempered with superplasticizer than that of the concretes retempered with plain water alone.

• The amount of water needed to offset the slump loss was lesser as the dosage of admixture was increased. Thus, the decrease in the strengths of those concretes, which were retempered with 1.5% superplasticizer, was much less than those retempered with "plain water." Also, slight increases were observed in compressive strengths of concrete C25 when it was retempered with 3.0% and 4.5% superplasticizer. Similarly, compressive strengths of concrete C35, which

Table 5
Twenty-eight-day compressive strengths of concrete C25 whose slump was raised to 15 cm by different retempering applications throughout 4 h of mixing

Type of retempering	Twenty-eight-day compressive strength of concrete C25, MPa				
	0 h	1 h	2 h	3 h	4 h
No retempering	28.5	30.0	31.5	32.1	32.9
Plain water	29.0	27.6	26.1	25.4	24.3
1.5%[a] Superplasticizer	28.0	26.0	26.2	26.6	26.9
3.0%[a] Superplasticizer	27.7	27.8	29.1	29.9	27.8
4.5%[a] Superplasticizer	27.5	27.8	27.1	29.4	26.6

[a] Solution concentration (by mass of retempering water).

Table 4
Seven-day compressive strengths of concrete C25 whose slump was raised to 15 cm by different retempering applications throughout 4 h of mixing

Type of retempering	Seven-day compressive strength of concrete C25, MPa				
	0 h	1 h	2 h	3 h	4 h
No retempering	21.6	23.3	26.9	26.4	29.0
Plain water	21.7	20.5	19.8	19.1	17.7
1.5%[a] Superplasticizer	21.9	21.5	21.4	21.2	20.9
3.0%[a] Superplasticizer	21.8	22.6	23.0	23.1	23.4
4.5%[a] Superplasticizer	21.6	21.7	24.7	24.0	23.5

[a] Solution concentration (by mass of retempering water).

Table 6
Seven-day compressive strengths of concrete C35 whose slump was raised to 15 cm by different retempering applications throughout 4 h of mixing

Type of retempering	Seven-day compressive strength of concrete C35, MPa				
	0 h	1 h	2 h	3 h	4 h
No retempering	28.8	29.0	34.6	36.2	37.3
Plain water	29.8	27.7	26.9	25.1	23.9
1.5%[a] Superplasticizer	30.6	29.7	28.1	27.9	27.1
3.0%[a] Superplasticizer	27.7	26.6	26.0	25.5	24.1
4.5%[a] Superplasticizer	27.8	29.8	31.8	31.6	29.6

[a] Solution concentration (by mass of retempering water).

Table 7
Twenty-eight-day compressive strengths of concrete C35 whose slump was raised to 15 cm by different retempering applications throughout 4 h of mixing

Type of retempering	Twenty-eight-day compressive strength of concrete C35, MPa				
	0 h	1 h	2 h	3 h	4 h
No retempering	34.3	36.0	38.6	41.7	43.6
Plain water	34.6	32.4	32.1	30.5	28.1
1.5%[a] Superplasticizer	35.5	34.3	32.9	31.1	29.2
3.0%[a] Superplasticizer	35.1	34.6	34.5	32.3	31.9
4.5%[a] Superplasticizer	36.6	35.4	36.2	36.7	34.2

[a] Solution concentration (by mass of retempering water).

were retempered with 4.5% superplasticizer, did not diminish, even increased, as the mixing time increased. So, water–cement ratios of concretes were lower after retempering with 3.0% and 4.5% superplasticizer as compared with 1.5% superplasticizer, even though the slump was raised to original value, 15 cm.

4. Conclusion

As a result of this investigation, the following conclusions are derived.

• High slump losses are experienced as the mixing time increases. The increase of the concrete temperature, of the degree of hydration, and of the possible grinding action of the mixer is a main cause of slump losses.

• Temperatures of concretes are greatly raised by prolonged delivery time. High ambient temperatures and high amount of cement used for making concrete contribute to higher concrete temperature.

• High slump losses, of course, make the placing, compaction, and surface finishing of the concrete very difficult, if not impossible. Therefore, retempering of the concrete at the job site is a common process to render the concrete more plastic. On the other hand, inclusion of extra water (plain water) causes strength losses. The decrease in concrete strength is larger for those concrete samples showing higher slump losses because more water is needed for retempering.

• Less amount of water is needed when superplasticizer is used for the retempering process, as compared to the use of plain water alone. The final water–cement ratios of mixes retempered with superplasticizer are lower than that of mixes retempered with plain water alone. Thus, the decrease in the compressive strengths of those concretes retempered with superplasticizer is less than the decrease in the strengths of those concretes retempered with "plain water." Even slight increases are observed in compressive strengths of those concretes, which are retempered with superplasticizer (especially for the case of retempering with 4.5% superplasticizer).

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