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ScienceDirect
Cement & Concrete Composites 29 (2007) 124–127
Cement & Concrete Composites
www.elsevier.com/locate/cemconcomp

Effect of retempering on the compressive strength of ready-mixed concrete in hot-dry environments

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Received 5 October 2005; received in revised form 21 August 2006; accepted 26 August 2006
Available online 20 October 2006

Abstract

The practice of retempering in hot-dry environments is frequently performed to increase slump beyond typical specification's limits (of 100 ± 25 mm) in order to cope with the need for expediting the casting operations and reducing the consolidation effort. In this study, the effect of retempering on the workability and strength of ready-mixed concrete (RMC) in hot-dry environments was investigated. This study covered 12 construction sites with concrete delivered by 11 different RMC suppliers. The results indicate that the reduction in strength due to water addition is proportional to the associated increase in slump. In cases where water was added to restore the slump to the specification's limits (100 ± 25 mm), the reduction of strength was below 10%. However, when water was added to increase slump beyond these limits, the reduction of strength may be as high as 35%. The study shows the change in slump can be used to predict reduction of strength due to jobsite water additions when practical considerations preclude accurate determination of the w/c ratio.

Keywords: Ready-mixed concrete; Hot-dry environments; Retempering; Workability; Compressive strength

1. Introduction

Retempering is defined by ACI 116 [1] as the "Addition of water and remixing of concrete or mortar which has lost enough workability to become unplaceable or unsaleable". Retempering inevitably results in some loss of strength compared with the original concrete. Laboratory research as well as field experience show that strength reduction and other detrimental effects are proportional to the amount of retempering water added [2–6]. When retempering of concrete is done only to restore slump as per ACI 116 definition, it typically causes a loss in compressive strength of 7–10% and it can be much higher depending on the amount of retempering water added [7]. The amount of water needed to raise the slump depends on the initial slump level [8]. Some empirical relationships have been suggested to quantify the effect of retempering on strength [5] but, in practice, the precise amount of retempering water may not be known because partial discharge of concrete from the mixer had occurred prior to the realization of the slump loss [7]. Since retempering increases the original water/cement ratio of the mix, it is arguable that it should not be permitted where the original w/c ratio was directly or indirectly specified. Although the subject of retempering has been discussed by many researchers, it is not well documented under hot-dry environments. Hot weather conditions adversely effect workability and increase rate of setting of concrete which reduce the time available for placing, consolidation and finishing operations [9]. Therefore, the practice of retempering under such conditions is expected to be worse as the addition of water at the jobsite is frequently performed to increase slump beyond the specification's limits in order to cope with the need for expediting the casting operations and reducing the efforts of consolidation.

In Saudi Arabia, a significant portion concrete work is done by small contractors. The addition of water at the

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doi:10.1016/j.cemconcomp.2006.08.007

jobsites is common practice especially in the extremely hot-dry summer months of June to August. The day-time temperature during this period in Riyadh (the capital city of Saudi Arabia), is constantly in the range of 42–48 °C and relative humidity is in the range of 15–20%. Such hot-dry weather conditions can be found in many parts of Middle East and other regions around the world during summer months. The need to add water to ready-mixed concrete (RMC) is particularly more serious as such hot weather conditions have a strong impact on accelerating the loss of slump with time [9,10]. Quantifying the effect of such practice on the properties of RMC is very important in relation to the quality scheme for concrete produced in Riyadh which was started by the Municipality of Riyadh in early 1995 [11]. As part of this scheme, random checking of the quality of concrete is done at all plants. The results from the Municipality program show that concrete with acceptable quality is produced by most RMC plants. Extensive studies have shown that the strength of RMC at the job site is identical to that measured at the RMC plant provided that water is not added to the delivery trucks after leaving the plant [12].

The objective of this study was to examine the adverse effects of adding water to the RMC at construction sites during the hot-dry summer months and its impact on the compressive strength. Physical properties of fresh concrete (slump and temperature), along with the 28-day compressive strength of hardened concrete, are measured for samples taken from the delivery truck immediately upon arrival to the construction site and later during the discharging operation. The addition of water, if any, is documented.

2. Experimental program and procedure

This investigation covers 12 construction sites which received the concrete from 11 RMC plants operating in Riyadh. The investigation was conducted during the hot summer months. The ambient temperature and the relative humidity (RH) at the construction sites at the time of sample collection were in the range of 43–47 °C and 15–20%, respectively. These figures are typical of environmental conditions prevailing in Riyadh during June to August.

The procedure involves sampling of concrete from delivery trucks both at the plant and after delivery to construction sites. For this purpose, plants were visited without prior arrangement and a truck already loaded with concrete was randomly selected. The truck was requested for concrete sample at the plant. The first wheelbarrow was discarded. Concrete from the second wheelbarrow was used as the study sample. For each sample, slump and concrete temperature were performed following ASTM procedures [13,14]. In addition, six cubes were molded using rigid plastic molds and sealed using plastic cover. The cubes were then stored in the plant's laboratory for the initial 24 h before transferring them to the Concrete Laboratory at King Saud University (KSU) for curing and testing. Most mixes had specified cube strength of 30 and 35 MPa with cement content in the range of 330–360 kg/m^3. The cement used was ASTM C150, Type I manufactured by local companies. No other cementitious materials were used. Coarse aggregate were typically a blend of 20 mm and 10 mm crushed limestone obtained from quarries around Riyadh. The fine aggregates were a blend of natural silica sand and manufactured sand obtained from the crushed limestone with the blend ratio selected by each plant to meet the gradation limits of ASTM C33 for fine aggregate. In all mixes, retarding water reducing admixtures complying with ASTM C494, Type D were used.

The truck was followed and monitored during the whole trip from the plant to the construction site, ensuring that no water was added to concrete in the delivery truck after leaving the plant and upon its arrival at site. Two concrete samples were procured from the same delivery truck. The first sample was collected from the truck immediately upon arrival to the construction site and before any water is added to the truck. The second sample was procured after discharging of approximately half of the truckload. Any addition of water to the delivery truck before taking the second sample was documented. For each sample, ambient conditions, concrete temperature and slump were measured and six cubes of concrete were made for the determination of compressive strength at 7 and 28 days. All cubes were molded using rigid plastic molds and sealed using plastic cover and stored under shade at the construction site for the first day, then were transported to KSU Laboratory for curing and testing. Cubes were cured in lime-saturated water until the day of testing. Molding and testing of all cubes were done in accordance with BS 1881 Part 108 and Part 116, respectively [15,16].

3. Results and discussion

The results of slump, concrete temperature, and compressive strength of concrete collected from the RMC truck upon arriving to the construction site and before any water was added are given in Table 1. The table also includes the same properties measured after discharging of approximately half of the truckload. Furthermore, any addition of water to the truck during discharging was noted. The strength reported in the table is the average compressive strength based on three cubes tested at the age of 28 days.

The results given in Table 1 were obtained from 12 concrete delivery trucks selected randomly for sampling concrete for this study. These trucks represent 11 different RMC plants operating in Riyadh. Out of these 12 samples, water was added to concrete in seven of the trucks during discharging operation at the site. It was added either to restore the slump within the specification's limits (100 ± 25 mm) or to increase the slump above the specification's limits upon the request of the contractor to expedite casting operations and to reduce efforts needed for compaction. The added quantity of water was not quanti-

Table 1
Summary of data and results from retempering of RMC at construction sites

Sample no.	Site (upon arrival)			Site (during discharge, about middle of load)			Water added	Change in slump (mm)	Change in strength (%)
	Concrete temperature (°C)	Slump (mm)	28-day strength (MPa)	Concrete temperature (°C)	Slump (mm)	28-day strength (MPa)			
1	34	80	33.2	37	110	30.4	Yes	+30	−8.43
2	39	75	41.6	39	220	31.2	Yes	+145	−25.0
3	39	95	43.1	35	230	28.3	Yes	+135	−34.3
4	34	70	28.4	34.5	220	20.7	Yes	+150	−27.1
5	35.5	145	40.3	35.5	220	30.2	Yes	+75	−25.1
6	33.9	100	41.0	34.0	180	32.7	Yes	+80	−28.6
7	32	75	39.6	32	93	35.9	Yes	+18	−9.3
8	31.0	70	46.6	32.3	60	48.0	No	−10	+3.0
9	33.0	160	33.7	34.0	155	36.1	No	−5	+7.1
10	36.5	120	44.0	35.5	125	43.8	No	+5	−0.5
11	36.0	210	42.7	36.0	190	43.8	No	−20	+2.6
12	33.5	220	30.4	33.0	190	28.9	No	−30	−4.9

fied because the increase in w/c ratio cannot be determined since partial discharge of concrete from the truck has occurred prior to adding water.

The data summarized in Table 1 was studied and analyzed to examine the changes in properties of RMC (slump, compressive strength) during discharging operation and the effect of the addition of water (if any) on these properties. The increase in slump as a result of adding water to concrete at site during discharge operation is shown in Fig. 1. From this figure it is clear that slump for concrete collected from middle of the truckload decreased when compared with the concrete slump collected upon the truck arrival as shown by the five cases where no water was added (Samples no. 8–12 in Table 1). In comparison, when water was added, the slump increased and the increase was dependent on the amount of water added during discharge, as shown by the other seven cases (Samples no. 1–7 in Table 1). Fig. 2 shows the effect of retempering on the compressive strength of RMC. The Figure shows, in general, a slight increase in compressive strength for samples where no water was added. By contrast, it can be seen from the figure that addition of water may result in a considerable decrease in strength depending on the amount of water added. In cases where water was added to restore the slump within the specification's limits (100 ± 25 mm) (Sample no. 1 and 7 in Table 1), the decrease in strength was below 10%. However, when water was added to increase slump beyond these limits the decrease in strength was in the range of 25–35% (see Samples no. 2–6, Table 1).

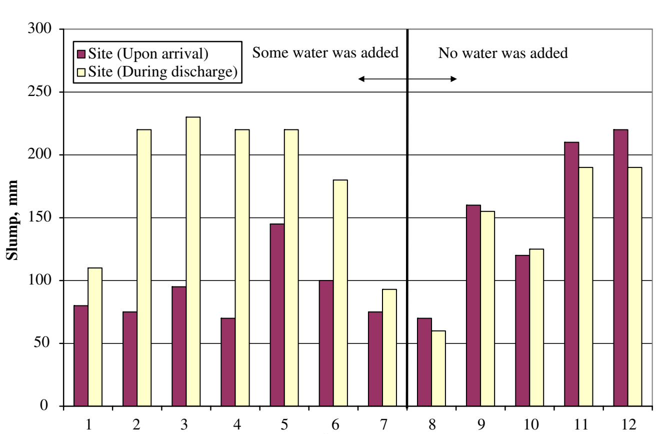

Fig. 1. Effect of retempering on the slump of ready-mixed concrete.

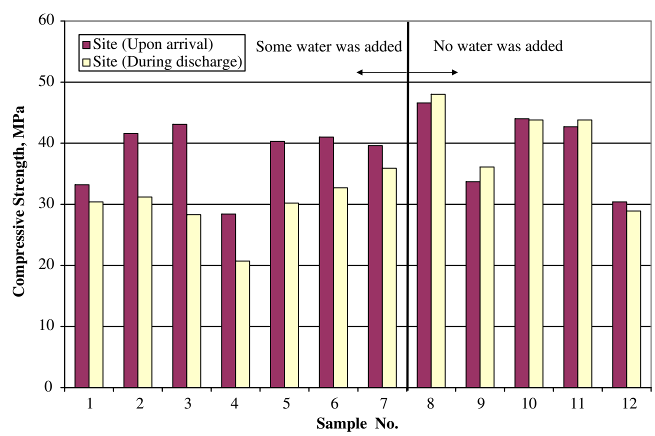

Fig. 2. Effect of retempering on the compressive strength of ready-mixed concrete.

The relationship between change in strength and change in slump is presented in Fig. 3. Correlation coefficient which provides a measure of interrelationship between changes in strength and slump was 0.92. This correlation coefficient as 0.92, which indicates that there is a strong correlation between the change in strength and slump. Hence, the increase in slump (due to the addition of water) resulted in proportional decrease in strength. The rate of the reduction in compressive strength was approximately 2% for each 10 mm increase in slump. In most cases, the increase in w/c ratio resulting from retempering of RMC in the field cannot be determined since partial discharge of concrete from the truck had already been occurred prior to adding water. The added water can be measured indirectly by the increase in slump. Therefore, the change

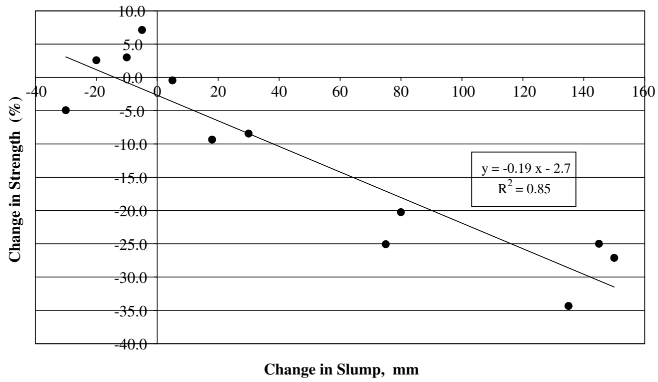

Fig. 3. Changes in strength vs. changes in slump as a result of retempering of ready-mixed concrete.

in slump, of a given concrete mixture, can be used to predict loss of strength due to jobsite water additions in the absence of accurate measurements of the w/c ratio.

Retempering with water is problematic since it has the potential of increasing w/c ratio beyond project specified limits, which may negatively impact service life of concrete. Furthermore, when water is used to increase workability, it may result in substantial reduction in compressive strength which may affect the safety of the structure. Therefore the practice of many agencies of prohibiting the addition of water to concrete at the jobsite and the allowance of using superplasticizer instead of water to adjust workability seems to be a reasonable approach to be adopted in hot-dry environments.

4. Conclusions

The results of this study can be summarized as follows:

1. Retempering of RMC in hot-dry environments may result in substantial reduction in strength. When water was added solely to restore the slump within the specification's limits (100 ± 25 mm), the reduction of strength was below 10%. However, when the amount of water was added to increase slump beyond these limits, the reduction of strength may be as high as 35%.
2. Under hot-dry environments, a strong correlation was found between the change in strength and the change in slump ($R = 0.92$). Therefore, the change in slump, of a given concrete mixture, can be used to predict reduction of strength due to jobsite water additions when practical considerations preclude accurate determination of the w/c ratio.
3. In hot weather, the practice of retempering with water should be discouraged since superplasticizer can be used to adjust workability of concrete without adversely affecting other properties.

Acknowledgements

The author wishes to express his appreciation to the Municipality of Riyadh for providing him with the opportunity to work as consultant to the Quality Scheme for RMC. The cooperation and assistance of the rest of the scheme management team is also gratefully acknowledged. This study was funded by KACST under Grant No. LG-1-54 and their financial support is highly appreciated. The help and commitment of everybody involved are gratefully acknowledged.

References

[1] ACI Committee 116R, Cement and concrete terminology (ACI 116R-90). Manual of concrete practice, Part I. American Concrete Institute, Detroit, 1997.
[2] Cook GC. Effect of time of haul on strength and consistency of ready-mixed concrete. ACI J 1943;43:413–26.
[3] Meininger RC. Study of ASTM limits on delivery time. National Ready-mixed Concrete Association, Publication No. 131, USA, 1969. p. 17.
[4] Beaufait F, Hoadley P. Mix time and retempering studies on ready-mixed concrete. ACI J 1973;70(6):810–3.
[5] Cheong HK, Lee SC. Strength of retempered concrete. ACI Mater J 1993;90(3):203–6.
[6] Kirca O et al. Effects of retempering on consistency and compressive strength of concrete subjected to prolonged mixing. Cem Concr Res 2002;32:441–5.
[7] Neville AM. Properties of concrete. 4th ed. England: Longman; 1995.
[8] Burg GRU. Slump loss, air loss, and field performance of concrete. ACI J 1983;80(4):332–9.
[9] ACI Committee 305. Hot weather concreting, ACI-305R-99, American Concrete Institute, Michigan, 1999. p. 17.
[10] Scanlon JM. Concrete problems associated with hot weather, ACI SP-139, Durable concrete in hot climates, ACI, Detroit, 1993. p. 131–42.
[11] Alhozaimy A, Al-Negheimish A. Introducing and managing quality scheme for RMC industry in Saudi Arabia. J Constr Eng Manage, ASCE 1999;125(4):249–55.
[12] Al-Negheimish A, Alhozaimy A. Ready-mixed concrete problems associated with hot and dry weather in Riyadh. Final report, King Abdulaziz City for Science and Technology, Grant No. LG-1-54, Riyadh, Saudi Arabia, 2001.
[13] ASTM C 143. Standard test method for slump of hydraulic cement concrete. Annual Book of ASTM Standards, vol. 4.02. 1996.
[14] ASTM C 1064. Standard test method for temperature of freshly mixed Portland cement concrete. Annual Book of ASTM Standards, vol. 4.02. 1996.
[15] BS 1881: part 108. Method for making test cubes from fresh concrete. British Standard Institute, London, 1983.
[16] BS 1881: part 116. Method for Determination of Compressive Strength of Concrete Cubes. British Standard Institute, London. 1983.