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Effect of retempering with superplasticizer admixtures on slump loss and compressive strength of concrete subjected to prolonged mixing

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Abstract

To have concrete possesses the specified engineering properties, its slump loss has to be compensated somehow at construction site so that concrete could be placed and compacted properly. Several attempts have been tried so far to render concrete workable at construction site including starting with a high initial slump at the stationary plant, or retempering with water and/or with chemical admixtures at construction site. In this investigation, ASTM C 494 Type F superplasticizer was used for retempering concrete to restore its initial slump. Concrete mixes having an initial slump of about 19 cm were prepared and subjected to prolonged mixing with different mixing duration such as 30, 60, 90, 120, and 150 min following an initial mixing of 5 min to ensure homogeneity. At the end of each mixing period, cube specimens of 15 cm were cast from concrete retempered to its initial slump level and tested at the age of 28 days for compressive strength. Results revealed that compared to the concrete retempered with water, those retempered with a superplasticizer admixture have yielded significantly higher strength regardless of the mixing duration.

Keywords: Workability; Hydration products; Strength; Superplasticizer; Retempering

1. Introduction

The slump loss of fresh concrete at construction site is one of the chief rheological properties considered to be responsible for the strength and durability aspects of concrete. Prolonged mixing in a truck mixer accelerates stiffening of concrete so does the rate of slump loss, and the increased rate of the slump loss mostly brings about inconvenience, particularly when long hauling periods are involved as generally it is the case for ready-mixed concrete deliveries.

Slump loss is defined as the loss of consistency of concrete with mixing time [1]. This is directly related to the depletion of the free water in fresh concrete. Theoretically, slump loss involves chemical and physical processes taking place during mixing. No matter what sort of process takes place, the depletion of the free water begins as soon as the mixing operation of the ingredients that makes up the concrete initiates and keeps on till the placement and subsequent operations are completed. The free water of fresh concrete is used up mainly by the hydration of the cement and by evaporation [2]. This implies that acceleration in the hydration process and evaporation would certainly increase slump loss and this in turn would undoubtedly reduce the consistency of concrete. The most conspicuous manifestations of slump loss in concrete include difficulty in handling and manipulation during placement and compaction, reduced ultimate strength, and worse durability [3]. The duration that elapses in the course of mixing, delivering, placing, compacting, and finishing operations of concrete is considered to be the chief parameters that affect the slump loss appreciably. The depletion of the free water in fresh concrete increases as

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the length of delivery time extends since the hydration of the cement and evaporation are directly related to elapsed time [4]. This is the usual case that is frequently encountered in the ready-mixed concrete production owing to the long distances travelled, traffic jamming or flat tire involved in transporting, and delays associated with placement and subsequent operations at the job site. Temperature rise in the drum of the truck mixer due to prolonged mixing is another parameter that should be taken into account in relation with the depletion of the free water in fresh concrete [5]. This is because the temperature in the drum increases owing to the continuous mixing or agitation of concrete during transportation that this in turn accelerates the rate of the hydration of the cement and so does the evaporation of the free water in the fresh concrete.

Reduction in the free water due to the long time involved in handling of the ready-mixed concrete and temperature rise took place owing to prolonged mixing directly reflects on a reduced slump. As a result of slump loss, concrete begins stiffening right away, which this in turn results in appreciable losses in its rheological properties such as consistency, workability, and fluidity [6]. To be able to maintain the consistency of concrete to a desired level just before placement is the main dilemma in the production of ready-mixed concrete since concrete poor in workability is difficult to be placed and compacted so as to have a strength high enough to comply with the specified requirements [7]. Concrete with low strength and poor durability is undesirable, particularly when it is exposed to aggressive environments with the consequences of ease permeation of deleterious external species through the concrete.

By starting with a high initial slump in order to compensate for the expected slump loss at the job site, inconveniences associated with slump loss of ready-mixed concrete may be undertaken in some sort. However, this may not be reliable since it is usually not possible to estimate the time needed before discharge of concrete. Slump loss can also be overcome by adding extra water and/or chemical admixture to the concrete mixture right before discharge [8]. This operation is known as retempering. Although it is common, adding extra water to the mix is unwanted as it causes a considerable loss in strength since the water to cement ratio increases significantly. Therefore, retempering with chemical admixtures or mineral additives is considered to be advantageous over retempering with water [9]. Reported elsewhere [10], the use of water together with chemical admixtures for retempering can be convenient in relation with quite lower strength losses obtained. The use of chemical admixtures for retempering, however, needs undoubtedly more attention with respect to their possible adverse effects on the rheological properties and the ultimate mechanical characteristics of concrete depending on the amount and the type of admixtures used [11,12].

2. Experimental procedure

2.1. Objective and scope

The present investigation was intended to assess the effect of retempering operation with a superplasticizer on the compressive strength of concrete subjected to prolonged mixing and to compare the results with those obtained from concrete retempered with water. Comparisons were also carried out with respect to reference concrete that was not subjected to retempering.

2.2. Materials used

A crushed calcareous aggregate with a maximum size of 16 mm and an ordinary Turkish Portland cement, similar to ASTM Type I cement, with a content of 300 kg/m^3 were used in preparing concrete mixes. The chemical analysis of the cement, provided by the cement manufacturer, together with its physical and mechanical properties, is given in Table 1. The admixture used in the investigation was ASTM C 494 Type F melamine-based superplasticizer with a specific gravity of 1.21 kg/l, which has an extensive use in the construction industry.

2.3. Program schedule

An initial slump of 19 cm, which is usually assumed to be a convenient slump level in ready-mixed concrete to compensate for the unexpected slump loss at construction site, was adopted. To achieve this, the required slump was determined by adjusting the mixing water following an addition of 1% admixture by weight of the cement content for the all batches. The admixture used was a superplasticizer type that was used for retempering in the second stage of the investigation. The mixing was carried out in a laboratory mixer with an adjusted continuous rotation speed of 6 rpm to simulate the agitation speed of ready-mixed

Table 1
Physical and mechanical properties and chemical analysis of cement

Chemical composition (%)	Silica (SiO_2), total	20.70
	Alumina (Al_2O_3)	4.88
	Ferric oxide (Fe_2O_3)	3.74
	Lime (CaO), total	63.53
	Magnesia (MgO)	1.10
	Sulphur trioxide (SO_3)	2.51
	Insoluble residue	0.79
	Loss on ignition	2.37
	Lime (CaO), free	1.90
Potential compounds (%)	C_3S	61.4
	C_2S	10.8
	C_3A	6.6
	C_4AF	11.4
Physical properties	Specific gravity, g/cm^3	3.03
	Specific surface (Blaine), m^2/kg	353
Mechanical tests	7 days, MPa	42.6
	28 days, MPa	53.6

concrete in a truck mixer. The temperature in the laboratory was 23 °C throughout the experimentation. All batches were mixed for 5 min initially to ensure homogeneity before retempering with water and/or with superplasticizer was applied relevant to the objective of the study.

Initially, a batch of concrete with a slump of 19 cm was prepared as the reference concrete, indicated as no-retempered concrete in the study, and a set of three cubes of specimens of 15 cm was cast following an initial mixing of 5 min. This procedure was then repeated at 30-min intervals for up to 180 min. To do this, the mixer was briefly stopped at the end of each 30 min of mixing and then three cubes of specimens were cast following measuring of respective slumps. In this manner, cube specimens of 15 cm for compressive strength testing and respective slump measurements were taken at the end of each 30 min of mixing.

The second stage of the experimentation involved with retempering of concrete using water. Five concrete batches with an initial slump of 19 cm were prepared. Each batch was large enough to yield three cubes of specimens of 15 cm. The first batch was mixed for a period of 30 min, the second batch for 60 min, the third batch for 90 min, the fourth batch for 120 min, and the fifth batch 150 min. The cube specimens were cast after restoring the initial slump of 19 cm by adding water to the concrete mixture. All batches were initially mixed for 5 min to ensure homogeneity.

The third stage of the investigation was limited with retempering of concrete using a superplasticizer of the same type used for the initial mixing. The procedure followed in this case was the same as the one employed in the second stage of the program with the main difference that restoration of the initial slump was achieved using a superplasticizer instead of water. Similarly, three cubes of specimens were cast following restoration of the initial slump of concrete at the end of each mixing period. Again, each batch was initially mixed for 5 min to ensure homogeneity prior to the application of retempering procedure.

Following 1-day moist-room storing, the cube specimens were demolded and cured in water at 20±1 °C until the testing of the compressive strength at the age of 28 days. The compressive strength measured is an average of three cubes of 15 cm.

3. Results and discussion

3.1. Effect of mixing time on slump loss

Fig. 1 illustrates the slump loss of concretes produced with a superplasticizer and plain concrete in relation to the mixing time at ambient temperature of 23 °C. As seen from the plot, the slump loss of concrete produced with a superplasticizer of 1% by weight of the cement with respect to the elapsed time indicates the very same trend that of the plain concrete does with the exception that the trend of slump loss is a little steep for plain concrete up to 30 min of mixing and then slows down later on. This implies that when prolonged mixing is involved, the time that required for an equal slump for such concretes is about 90 min. Overall, the plot indicates that the magnitude of slump loss is quite high for a mixing period of 90 min and it does decrease slightly for longer mixing duration whether admixture is used or not. No doubt that the magnitude and the trend of slump loss do vary depending on the ambient temperature, the initial slump level, and the admixture adsorption capacity of the cement used [13].

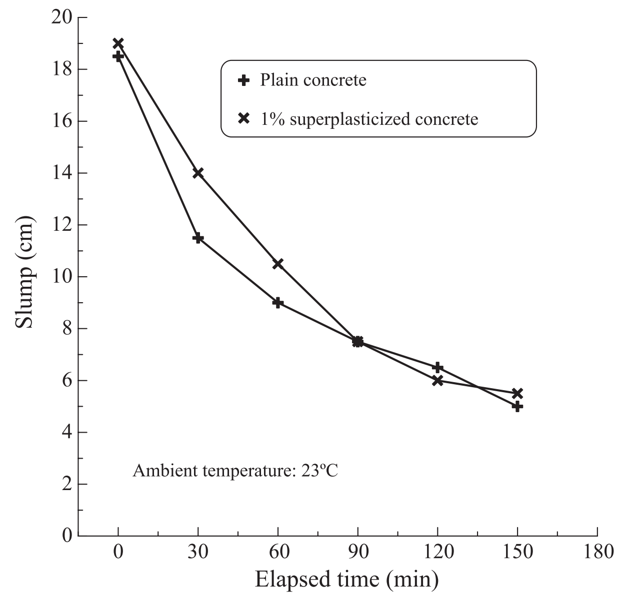

Fig. 1. Slump loss of plain and 1% superplasticized concrete.

3.2. Effect of mixing time and retempering on compressive strength

Fig. 2 represents the effect of retempering with water and with a superplasticizer on the strength of concrete in relation with mixing time. The effect of mixing time on the strength of reference concrete with no retempering is also given in the graph. A slight increase in the strength of reference concrete is observed due to the increase observed in its unit weight as seen from Fig. 3. The total increase in the unit weight of reference concrete with no retempering is about 27 kg/m^3 which corresponds to a decrease in the air content of concrete slightly over 1%. This in turn reflects basically an increase of about 15% in the strength of concrete at the end of 150 min of mixing. This can mostly, but not completely, be attributed to the decreased air content of concrete, as known, is reduced during prolong mixing. Although it seems to be usually negligible in the laboratory climatic conditions, evaporation of free water in concrete in conjunction with hydration of cement can also affect the strength of concrete favorably [2]. This proves that concrete with low slump yields higher strength as long as it is placed

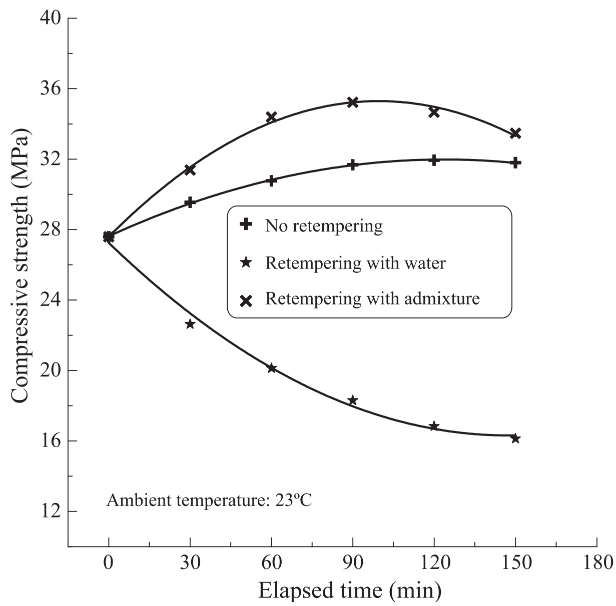

Fig. 2. Effect of retempering on the compressive strength of concrete subjected to prolonged mixing.

and compacted properly as it is the case in the study. The strength of concrete retempered with water decreased sharply up to 90 min of mixing and then flattens out, resulting in a strength loss of over 40% at the end of 150 min in relation with its initial strength. This clearly indicates that the greater amount of free water in concrete results in the larger percentage of reduction in the strength of concrete. It can also be seen from Fig. 3 that the strength of concrete retempered with superplasticizer rises sharply up to 90 min of mixing, but a moderate decrease is observed beyond that age. The strength gain compared to the 28-day strength of reference concrete is slightly over 10% at the end 90 min, while it is still about 8% higher for a mixing period of 150 min. This is the obvious beneficial effect of the superplasticizer on the strength development of concrete even for longer duration of mixing rather than anything else [11]. This is because the rheological properties of fresh concrete can be strongly affected by the interaction between the cement and chemical admixture, the method of admixture addition, or the water to cement ratio and this reflects basically an increase in the strength of concrete, accordingly [12]. This is of great importance for the ready-mixed concrete industry. Considering the contribution to the strength development of concrete, this consequence clearly indicates that retempering with superplasticizer is superior to retempering with water, regardless of the mixing duration. The strength gain with respect to reference concrete can be attributed to ease placement and proper compaction of concrete retempered with superplasticizer. The reason for the slight drop in the strength of concrete retempered with superplasticizer beyond 90 min of mixing can be attributed to the distorted rheological properties of fresh concrete due to prolonged mixing.

3.3. Water needed for retempering

Fig. 4 illustrates the water needed for retempering of concrete mixture in relation with mixing time. As seen from the graph, the relation between the amount of water used for retempering and the mixing time is of a parabolic shape with a statistically significant coefficient of correlation of 0.999. The relation is rather steep up to 120 min of mixing, and then the increase is slight later on. Based on the relationship, for instance, for a mixing period of 120 min, an amount of about 36 kg/m^3 water is needed for retempering to restore the initial slump. Such a significant amount of water addition to the concrete mixture resulted in an appreciable increase

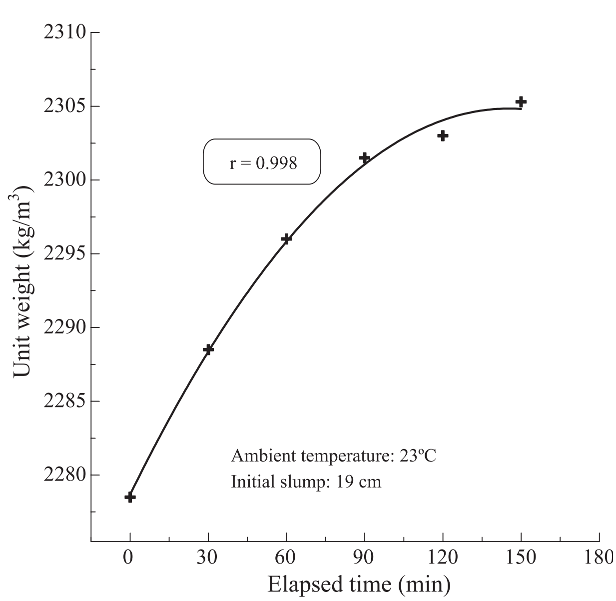

Fig. 3. Effect of prolonged mixing on the unit weight of concrete.

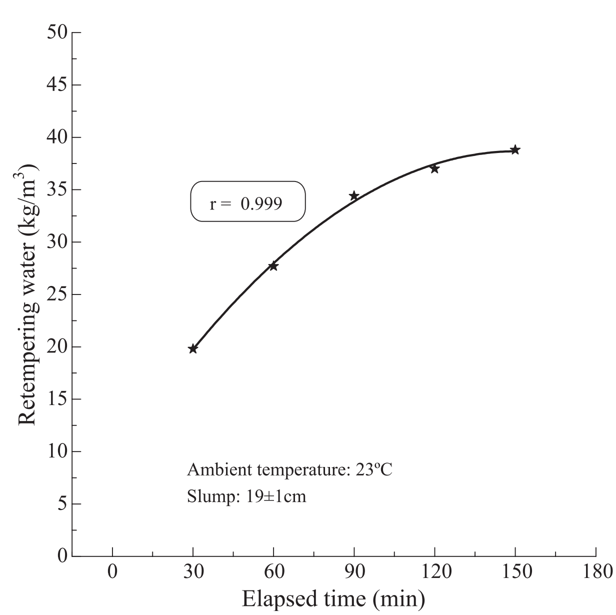

Fig. 4. Retempering water added to concrete to restore the initial slump.

in the water to cement ratio, and this reflected in a substantial strength loss, accordingly. The amount of water needed for retempering will obviously be varied depending on the specific properties of cement used and the ingredients of concrete. For instance, the amount of water added to the mixture will decrease as the initial slump increases. In practical terms, the strength of concrete decreases as the additional water increases and that is why a strength loss of over 40% corresponding to a mixing time of 150 min is observed for concrete retempered with water as seen from Fig. 2.

3.4. Admixture needed for retempering

The relation between the amount of admixture used for retempering to restore the initial slump with respect to mixing time is given in Fig. 5. As seen from the graph, the increase in the superplasticizer used for retempering is quite straightforward with mixing time and the relationship is statistically significant with a coefficient of correlation of 0.998. It is clearly seen that an additional superplasticizer of about 0.7% by weight of the cement content is needed at the end of a mixing period of 30 min for retempering to restore the initial slump of concrete, and it is only about 1.2% by weight of the cement at the end of 150 min of mixing. For a cement content of 300 kg/m^3, the latter resulted in an addition of 3.6 kg/m^3 of superplasticizer to the concrete mixture to restore its initial slump of 19 cm. The amount of superplasticizer needed for this purpose will surely be dependent on the specific properties of cement and the admixture–cement compatibility and the ingredients of concrete [12–14]. It should be reminded that use of admixture could be logical as long as its effects are beneficial with respect to the strength development of concrete. Otherwise, particularly for economical aspects and possible adverse effects on concrete such as excessive amount of air entrainment, bleeding, and segregation; an engineering justification has to be made in terms of effective use of admixture.

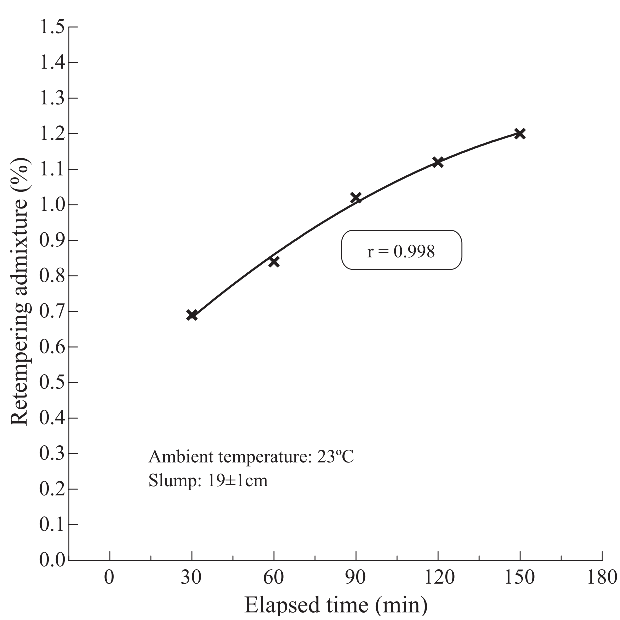

Fig. 5. Retempering admixture added to concrete to restore the initial slump.

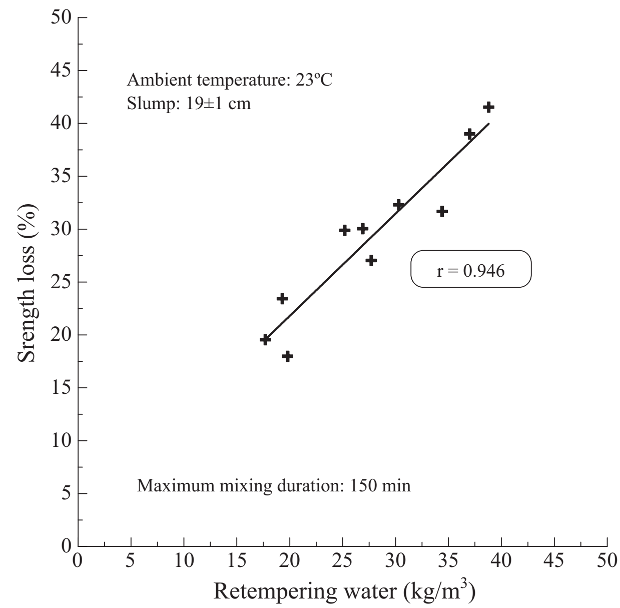

Fig. 6. Relationship between retempering water and strength loss of concrete.

3.5. Relation between retempering water and strength loss

As pointed out earlier, the stiffening of fresh concrete, and the associated slump loss, which is brought about mainly by the hydration of cement and evaporation of the mixing water due to prolong mixing, resulting in an appreciable reduction in the free water of concrete mixture. For full compaction, such concrete needs to be retempered using additional water to restore its initial slump. However, this is undesirable because additional water results mostly in an increase in the water to cement ratio and this in turn causes a substantial decrease in the strength of concrete. Fig. 6 represents the relationship between the water needed for retempering of concrete and the strength loss in relation with mixing time. As seen from the graph, the relation increases linearly with a statistically significant coefficient of correlation of 0.946. In other words, the increase in the loss of strength is consistent with the retempering water used for restoring the initial slump of 19 cm. The relationship represents the results obtained from concretes subjected to a mixing period of up to 150 min at 30-min intervals. Regarding the relationship, for instance, a water addition of 30 kg/m^3 for retempering caused a reduction in the strength of concrete slightly over 30% of its initial strength level. Undoubtedly, such a significant strength loss is of great importance with regard to the sustainment of structural integrity and the performance characteristics of concrete.

4. Concluding remarks

Concerning the foregoing experimental investigation associated with retempering concrete of subjected to prolong mixing, the following main conclusions can be drawn:

(i) Whether admixture is used or not, concrete subjected to prolong mixing resulted in rather a quick slump loss up to 90 min of mixing. It is then slowed down beyond that age. This clearly indicates that a mixing period of 90 min seems to be a turning point with regard to proper placement, compaction, and subsequent operations of concrete.
(ii) The strength of concrete with no retempering revealed a slight increase even for a rather long mixing period of 150 min. The reason for this is preferably attributed to the reduced air content in addition to the esteemed effect of proper placement and compaction of concrete.
(iii) The strength of concrete retempered with water decreased considerably with mixing time. The reduction is rather sharp for up to 90 min of mixing and then a slight decrease is observed later on. At the end of 150 min of mixing, a strength loss of over 40% is observed with regard to the initial strength of concrete.
(iv) The strength gain of concrete retempered with superplasticizer for a mixing duration of 90 min is about 30% with respect to the initial strength of concrete and it is slightly over 10% compared to the strength of reference concrete, corresponding to the same mixing duration. The decrease in the strength observed beyond 90 min of mixing implies that mixing duration longer than 90 min causes a considerable strength loss due to the possible existence of bleeding and segregation even when a superplasticizer admixture is used for retempering
(v) The relationship between the retempering water and mixing time is of a parabolic shape with a statistically significant coefficient of correlation of 0.999.
(vi) The relationship between the amount of admixture used for retempering against mixing time is quite straightforward.
(vii) Overall, there is a strong relationship between the water used for retempering and the strength loss of concrete. The relationship is quite straightforward with a statistically significant coefficient of correlation of 0.946. Based on the relationship, a water addition of 30 kg/m^3 to the concrete mixture to restore the initial slump of 19 cm resulted in a strength loss of slightly over 30% with respect to its initial strength.

References

[1] RW. Previte, Concrete slump loss, ACI J. Proc. 74 (1977) 361–367.
[2] I. Soroka, D. Ravina, Hot weather concreting with admixtures, Cem. Concr. Compos. 20 (1998) 129–136.
[3] H.J. Al-Gahtani, A.G.F. Abbas, O.S.B. Al-Amoudi, Concrete mixture design for hot weather: experimental and statistical analyses, Mag. Concr. Res. 50 (1998) 95–105.
[4] D. Ravina, I. Soroka, Slump loss, compressive strength of concrete made with WRR and HRWR admixtures and subjected to prolonged mixing, Cem. Concr. Res. 24 (1994) 455–1462.
[5] D. Ravina, Retempering of prolonged-mixed concrete with admixtures in hot weather, ACI J. Proc. 72 (1975) 291–295.
[6] L.M. Meyer, F. Pernechio, Theory of concrete slump loss as related to the use of chemical admixtures, ACI Concr. Int. 1 (1979) 36–43.
[7] D. Ravina, Effect of prolonged mixing on compressive strength of concrete with and without fly ash and/or chemical admixtures, ACI Mater. J. 93 (1996) 451–456.
[8] M. Takeyama, Present technology of ready-mixed concrete and future prospects, Mag. Concr. Res. 48 (1996) 199–209.
[9] D. Ravina, Slump retention of fly ash concrete with and without chemical admixtures, ACI Concr. Int. 17 (1995) 25–29.
[10] Ö. Kırca, L. Turanlı, T.Y. Erdoğan, Effect of retempering on consistency and compressive strength of concrete subjected to prolonged mixing, Cem. Concr. Res. 32 (2002) 441–445.
[11] H. Uchikawa, K. Ogawa, T. Shirasaka, D. Sawaki, Effect of admixture on hydration of cement, adsorptive behavior of admixture, and fluidity and setting of fresh cement paste, Cem. Concr. Res. 22 (1992) 1115–1129.
[12] S. Hanehara, K. Yamada, Interaction between cement and chemical admixture from the point of cement hydration, absorption behaviour of admixture, and paste rheology, Cem. Concr. Res. 29 (1999) 1159–1165.
[13] D. Bonen, S.L. Sarkar, The superplasticizer adsorption capacity of cement pastes, pore solution, and parameters affecting flow loss, Cem. Concr. Res. 25 (1995) 1423–1434.
[14] Ş. Erdoğdu, Compatibility of superplasticizers with cements different in composition, Cem. Concr. Res. 30 (2000) 767–773.