EFFECT OF RETEMPERING ON CONSISTENCY, COMPRESSIVE STRENGTH AND DURABILITY RELATED PROPERTIES OF OPC, SILICA FUME AND FLY ASH CONCRETE IN EGYPT

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أثر اضافة الماء لاستعادة التشغيلية المفقودة على مقاومة الضغط و الخواص المرتبطة بالديمومة للخرسانة التي تحتوى الأسمنت البوتلاندي العادي و بدائل الأسمنت.

ملخص البحث:

تنص الكثير من كودات البناء في الشرق الأوسط اليوم على استخدام بدائل الأسمنت في الخرسانة لتحسين ديمومة الخرسانة. نتيجة ارتفاع درجات الحرارة بالمنطقة فانه في بعض الاحيان تفقد التشغيلية من الخرسانة قبل الصب و قد يقوم البعض في المواقع باضافة الماء لاستعادة التشغيلية المفقودة. الدراسات السابقة في هذا الموضوع ركزت على أثر هذه العملية على مقاومة الضغط للخرسانة فقط و تم اجراؤها على الخرسانة التي تحتوي على الأسمنت البورتلاندي العادي بدون أية بدائل. ان هدف البحث الحالي هو دراسة أثر اضافة الماء لاستعادة التشغيلية على مقاومة الضغط و معدل فقدان التشغيلية بعد اضافة الماء و كذلك بعض الخواص بالديمومة مثل معدل الامتصاص بالخاصية الشعرية و المسامية و ذلك للخرسانات التي تحتوي على الاسمنت البوتلاندي العادي و كذلك بدائل الاسمنت. و خلص البحث الى أن الخرسانة التي تحتوي على البدائل تتأثر بالسلب بواسطة عملية اضافة الماء لاستعادة التشغيلية بصورة أكبر من الخرسانة بدون بدائل الأسمنت. و بهذا فان الفوائد المتوقعة من استخدام بدائل الأسمنت، بالنسبة لديمومة الخرسانة، قد تتلاشى بسبب اضافة الماء لاستعادة التشغيلية المفقودة.

ABSTRACT

Hot climate causes the concrete to loose its workability at a higher rate to the extent that placing the concrete may become difficult or impossible. Site engineers may be tempted to apply retempering, a controversial practice by which water is added to restore the original slump of the concrete before placing, to save some concrete batches. Previous investigations have focused on the effect of retempering on the compressive strength of concrete made with Ordinary Portland Cement (OPC) only and were inconclusive. This study was mainly carried out to investigate the effect of retempering on the compressive strength and some durability related properties, i. e. capillary absorption and porosity, of OPC, silica fume and fly ash concrete. Retempering of pozzolanic mixes lead to a loss in the compressive strength greater than that observed in the OPC counterpart, but the strength would still be greater than a comparable OPC mix with the same w/c ratio. However, the improvement in durability, expected from the inclusion of pozzolanic materials, may be diminished due to retempering.

INTRODUCTION

Retempering is the practice of adding water to concrete to restore the original workability, when concrete placing has been delayed. Gonnerman and Woodworth [1] investigated retempering and concluded that it was a harmful practice as the strength is lowered due to the increase in w/c ratio of the retempered mix. However, since that the topic was re-examined by several researchers. Cook [2] found that the decrease in strength is much less than that expected from the increase in the w/c ratio.

Hawkins [3] added water, every hour for up to 8 hrs, to a mix of w/c=0.5 to restore the original slump of 80-100 mm. The mix was covered and undisturbed between water additions. He observed that the strength was slightly reduced with water additions. In discussing Hawkins's work, Adams et. al. [4] presented data, which contradicts Hawkins's findings, and concluded that the reduction in strength follows the w/c ratio curve. However, in the same discussion Gaynor and Bloem [5] gave evidence that the reduction in strength upon retempering is less than what would be expected from the increase in w/c ratio. They attributed Hawkins findings to the loss of air from the mix with time.

Beaufait and Hoadley [6] carried out studies on the effect of mixing time and retempering on the compressive strength of the concrete. Samples were taken from truck mixers, which were continuously rotated at 3 rpm, but the speed was increased to 9 rpm for 30 revolutions when water was added. Retempering was shown to have an adverse effect on the compressive strength. However, extended mixing appeared to increase the strength by approximately 8% per hour of mixing in between water additions.

Burg [7] studied the effect of retempering on the air void system, which relates to the freeze – thaw durability of concrete used in pavements. He concluded that up to an extra 8 to 10% of the total unit water content may be added to restore the slump without adversely affecting the concrete properties.

Cheong and Lee [8] proposed a formula for predicting the strength after retempering. The formula was based on the regression analysis of all the data available in the literature. The formula reads:

$$f_c'/f_c = 3.265\,(0.321)^{(w/c)'/(w/c)}$$

Where:

f_c' = predicted strength after retempering

f_c = original strength

$(w/c)'$ = modified w/c after retempering

(w/c) = original w/c

Based on the formula, they inferred that the w/c may be increased by 5% at retempering without a significant loss in strength.

Anderson and Carrasquillo [9] found that retempering the concrete with an extra 5% above the design mix water consistently reduced the abrasion resistance and the compressive and flextural strengths. However, the freeze- thaw durability was only slightly affected by the retempering process.

Ravina [10] found that prolonged mixing increased the strength by 5% every hour, up to 135 minutes, for OPC concrete. Therefore, retempering within these limits was considered acceptable. He used the traditional compressive strength - w/c ratio curve to predict the allowable increase in water content upon retempering to give constant strength. He calculated that for a w/c = 0.55 mix 9 and 15 Kg/m^3 of water may be added at 90 and 135 min respectively, without adversely affecting the strength.

Gassman et. al. [11] studied controlled low strength material (CLSM), also known as flowable fill or controlled density fill which is a self compacting cementitious material used primarily as a backfill instead of compacted earth fill. They concluded that mixing beyond 30 minutes reduces the compressive strength of CLSM. In addition, retempering with up to 20% extra water reduced the strength by 35% at 28 days, but the reduction was only 15% at 90 days. Therefore, they concluded that up to an extra 20% of water for retempering has no adverse effect on the design compressive strength of CLSM.

Extensive research has been carried out in the Middle East recently in order to find ways to improve the performance of concrete structures in the region [12,13]. The use of silica fume was shown to significantly reduce the water transport through well-cured concrete [14]. Allan and Kukacka [15] demonstrated that partial replacement with silica fume improves the impermeability and wet-dry durability of concrete. Hussain and Rasheeduzzafar [16] found that 30% fly ash replacement caused significant pore refinement and reduced permeability to water and chloride ions. Poon et. al. [17] reported that the fly ash increased the porosity but reduced the average pore size of the pastes tested in the early age of 28 and 56 days.

As a result of the reported positive effects of pozzolanic materials inclusion on the durability related properties of concrete, many codes of practice in the middle east now recommend the use of these materials, especially where there is a danger to reinforcement corrosion. For example, Saudi Consolidated Electricity Company, Saudi Arabian Oil Company and Royal Commission of Jubail and Yanbu, recommend the use of 7 – 8 % silica fume, total cementitious materials content of 360 – 400 kg/m^3, w/c < 0.4, minimum strength of 350 kg/cm^2 and minimum cover of 75 mm [18]. The Egyptian Code for the Design of Reinforced Concrete Structures [19] recommends the use of high slag cement (85 % slag) where the concrete is subject to both chloride and sulphate attack. In addition the Egyptian code [19], recommends the use of pozzolanic materials where the concrete is at risk from the alkali – silica reaction.

Slump loss problems occur most often in hot weather as that encountered in the Middle east during the long summer season. The effect of the inclusion of silica fume and fly ash on slump loss has been investigated previously [20 and 21]. However, studies on the properties of retempered mixes containing pozzolanic materials has not been cited in the literature. Obviously, it would be crucial to study the effect of retempering on the durability related properties of mixes with pozzolanic materials, since the improvement in durability is the main reason for using these materials in hot climates.

RESEARCH AIM AND SIGNIFICANCE

The effect of retempering on the compressive strength of concrete is still inconclusive. In addition, little attention has been given to studying the effect of retempering on other concrete properties, apart from the limited investigations on abrasion resistance and freeze thaw durability. Moreover, retempering of mixes with pozzolanic materials has not been studied. The aim of this investigation was to study the effect of retempering on compressive strength and some durability related properties (i.e. initial surface absorption, capillary absorption and porosity) of concrete with and without pozzolanic materials. Tests on the retempering process shall be carried out using local materials from Egypt in order to predict the possible effects of such practice in this country.

EXPERIMENTAL PROGRAM

Materials

The cement used was Ordinary Portland Cement (OPC) conforming to E.S.S. 373/1991 [22] and was manufactured by Helwan company. The coarse and fine aggregates used were natural gravel and siliceous sand conforming to E.S.S. 1109/1971 [23]. Tap water was used in mixing, curing and testing the samples. The silica fume and fly ash used were from local sources. Chemical analysis of the OPC, Silica Fume and Fly Ash are shown in Table 1. The chemical analysis of the fly ash used conforms to ASTM C 618-85 Type F ash [24].

Table 1 Chemical analysis of OPC, silica fume and fly ash

Oxide	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**LOI**	**IR**	**Na_2O**	**K_2O**	**P_2O_5**	**TiO_2**
OPC	20.38	4.78	3.93	62.58	1.96	2.18	2.68	0.55	0.45	0.16	-	0
Silica fume	96.51	0.26	0.38	0.31	0.55	0.05	0.95	-	0.39	0.47	0.11	0
Fly ash	57.30	25.15	3.34	5.21	0.33	0.13	5.85	-	0.13	0.32	0.03	1.78

LOI : Loss on ignition IR: Insoluble residue

Mix Proportions and Curing

Two series of concrete mixes were prepared for this investigation. Series I was for the mixes made with OPC only as a cementitous material. The w/c ratio of this series was varied as shown in Table 2. Series II had a water to cementitous material ratio = 0.55. Ten percent Silica Fume or 30% Fly Ash were used as partial cement replacement for some specimens in this series. Mix proportions for this series are also shown in Table 2. All Samples were 100 mm cubes and were water cured at 21 °C for 28 days prior to testing. Testing was carried out immediately on oven dried samples at 105 °C to constant weight. The room temperature during the test period was 20 to 23 °C. Each reported test data point is the mean of the results for three samples.

Table 2 Mix proportions for concrete mixes

	Weight (Kg/m^3)						
	Series I				**Series II**		
Type of Mix	**OPC**				**OPC**	**Silica fume**	**Fly ash**
Cement	450				450	405	315
Water	See w/c ratio				247.5		
Fine Aggregates	680				680		
Coarse Aggregates	1100				1100		
% Pozzolan (p)	0				0	10	30
Silica fume	0				-	45	-
Fly ash	0				-	-	135
w/c	0.4	0.45	0.55	0.65	0.55	0.61	0.79
w/(c+p)					0.55		
Initial slump	50	75	100	175	100	80	75

Testing Program and Techniques

The slump Test

The test was carried out in accordance with E.S.S 1658: part 2 [25]. The test was carried out when mixing is completed and after the retempering. The aim of the retempering was to restore the original slump of the concrete mix.

The Compressive Strength Test

The compressive strength test was carried out in accordance with BS 1881: Part 116 [26]. Samples were prepared for compressive strength testing from the original mix and after retempering in order to study the effect of retempering on the concrete mixes of this investigation.

The Capillary Absorption Test

The capillary absorption test was based on the method suggested by Hall [27]. Capillary absorption measurements were carried on oven dried 100 mm cubes. The lower sides of samples were coated with grease to allow only unidirectional flow. Then the samples were placed on rods in water containers and care was taken to maintain the water level not higher than 5 mm above the bottom of the samples. The cumulative water adsorbed was recorded at different time intervals, up to 2 hours from the start of the test, by weighing the specimens after wiping the excess water with a damp cloth. Concrete samples were prepared from the original mix and after retempering in order to study the change in their capillary absorption due to retempering.

The porosity Test

To perform the porosity test, the weight of evaporated water, from water cured saturated samples that were oven dried to constant weight at 105 °C, was determined. This weight was then divided by the volume of the sample, in order to obtain the porosity of concrete. This method was suggested by Parrott [28]. The porosity of the original and retempered mixes was studied.

RESULTS AND DISCUSSION

Retempering Results for Mixes with Different W/C Ratios (Series I)

Slump-Time Profile Before and After Retempering

The relative slump (% slump of the original slump) for the mixes of Series I, having different w/c ratios, are plotted versus time in Figure 1. It can be seen that the mixes with low w/c ratio (low initial slump) tend to loose their slump at a higher rate than the mixes with higher w/c ratio (high initial slump). Data from Pigeon et. al. [29] indicated that the mixes with w/c ratio = 0.45 and 20 and 135 mm initial slump lost 100 and 66 % of their original slump value at 45 minutes, respectively. Dewar [30] made a similar observation with measurements on the rate of compacting factor loss for mixes with w/c of 0.63 and 0.94.

On the other hand, Ravina [21] studied the slump loss of mixes with w/c = 0.65 and 0.7. The cement and aggregate contents of these mixes where adjusted to give initial slump values of 150 and 120 mm, respectively. He reported that after 90 minutes the mixes lost 80 and 58% of their original slump values, respectively. In analysing his data he stated that mixes with fluid consistency lost more slump than mixes with plastic consistency.

Previte [31] studied the slump loss of mixes having w/c ratios of 0.58, 0.61 and 0.63 at two different temperatures 21 and 29 °C using two different types of cement. His data at 21°C was inconclusive. However, at 29 °C data obtained using a high alkali cement, similar to the cement used in this investigation, indicated that the mixes lost 63, 65 and 66 % of their original slump at 90 minutes, respectively. He concluded that the slump loss is proportional to the original slump level, (i.e. the higher the original slump, the greater the slump loss).

By examining the data reported herein, and that from Pigeon et. al. [29], Dewar [30], Ravina [21] and Previte [31], it can be concluded that mixes with high original slump loose more slump, <u>in terms of absolute magnitude value</u>. However, mixes with low w/c ratio loose slump at a <u>faster rate</u> than mixes with high w/c ratio. The later observation can be explained by the fact that there is a quicker consumption of the water by chemical reactions in the concrete with low w/c ratio. Moreover, a higher mix temperature is achieved in low w/c mixes, which in turn would promote evaporation of mix water.

The relative slump – time relationship for OPC concrete retempered at 1 hour after mixing is shown in Figure 2. It can be seen that retempering has caused a slump increase for only a short period. All mixes retained less than 20 % of their original slump after 240 minutes regardless of whether they were retempered or not. In addition, the slope of the lines for each mix before and after retempering, is similar. Therefore, the slump loss pattern is mainly dependant upon the original mix composition. This supports the conclusions of Anderson and Carrasquillo [9], who reported that the slump loss profile of retempered concrete was the same as that of the corresponding control mix (without retempering).

Increase in W/C Ratio due to Retempering

In this investigation, mixes were retempered in order to restore the original slump of the mix after one hour of mixing. The amount of water needed for retempering was found to be dependant on the original w/c ratio. The percentage increase in w/c ratio upon retempering is plotted versus the original w/c ratio of the mix in Figure 3. It can be seen that low w/c mixes required greater water additions upon retempering compared to their high w/c counterparts. Mixes with w/c = 0.4 and w/c = 0.65 required 30 and 9 % increase in their w/c ratios upon retempering, respectively. This supports the findings of Previte [31] who reported that the final w/c ratios of concrete, containing a high alkali cement like the one used in the current investigation, retempered at 126 minutes after mixing, at a temperature of 21 °C, were 0.62 and 0.64 when the original w/c ratios were 0.55 and 0.59, respectively. This corresponds to an increase of 12.7 and 8.5 % in the w/c of the mixes, respectively. The increase in w/c upon retempering, at 1 hour, in this investigation was higher in spite of the fact that the retempering was done earlier than Previt's study [31]. This may be attributed to the utilization of 450 kg/m^3 of cement in the mixes of the present investigation compared to only 307 kg/m^3 in Previt's work.

Effect of Retempering on Compressive Strength

The relationship between the compressive strength and w/c ratio for control and retempered concrete is shown in Figure 4. Also plotted is the ideal relationship obtained from Neville and Brooks [32]. This ideal relationship is based on British cements produced between 1950 and 1980. The mixes used in this investigation produced lower strengths than the values expected from the ideal relationship. Retempering has shifted the strength –w/c curve to the right and down, due to the increase in w/c ratio and decrease in strength. For the range of w/c ratios in this investigation, i.e. w/c = 0.65 to 0.4, the increase in the w/c ratio upon retempering was between 9 – 30 % and the reduction in strength was between 11 and 16.6 %, respectively.

Considering the actual results for the increase in w/c ratio upon retempering obtained in the current investigation, the ideal strength w/c ratio curve can be used to predict the expected strength reduction due to retempering. In addition the formula suggested by Cheong and Lee [8] is applied to predict the strength after retempering. The results of the calculations are shown in Table 3.

Table 3 Comparison between actual and predicted compressive strength due to retempering

Original w/c ratio	**Original compressive strength**	**W/C ratio after retempering**	**Actual compressive strength after retempering**	**Predicted strength from the ideal relationship [32]**	**Predicted strength from Cheong and Lee [8]**
0.4	529	0.52	441	395	394
0.45	445	0.55	380	345	363
0.55	265	0.64	235	200	232
0.65	190	0.71	170	170	179

It can be seen from Table 3 that the ideal w/c ratio – strength relationship does not give a good estimate of the strength reduction especially for low w/c ratio mixes. It would appear that the actual strength after retempering is higher than that expected from the ideal

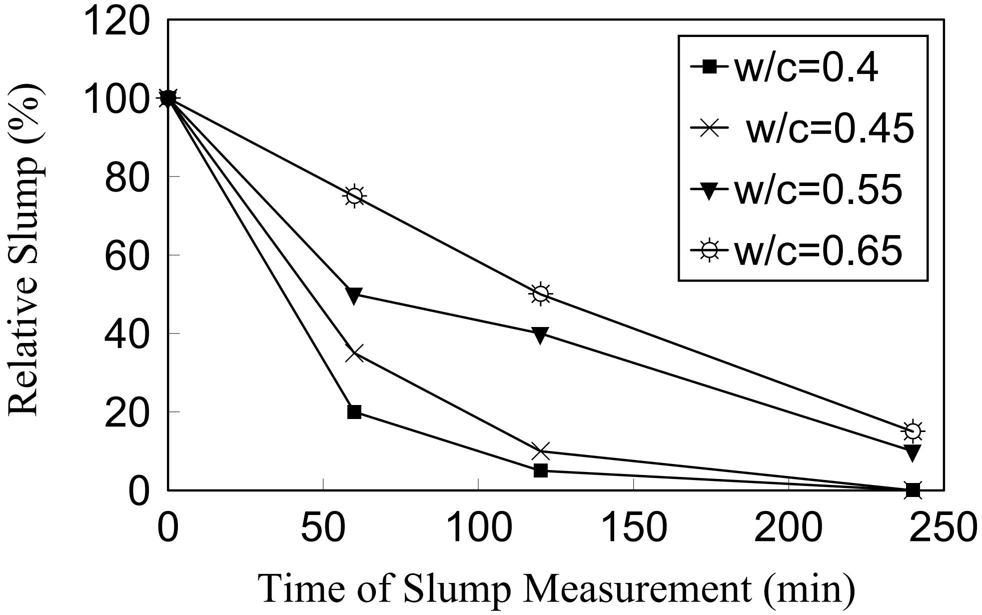


Figure 1 Slump loss profiles for OPC mixes with different w/c ratios

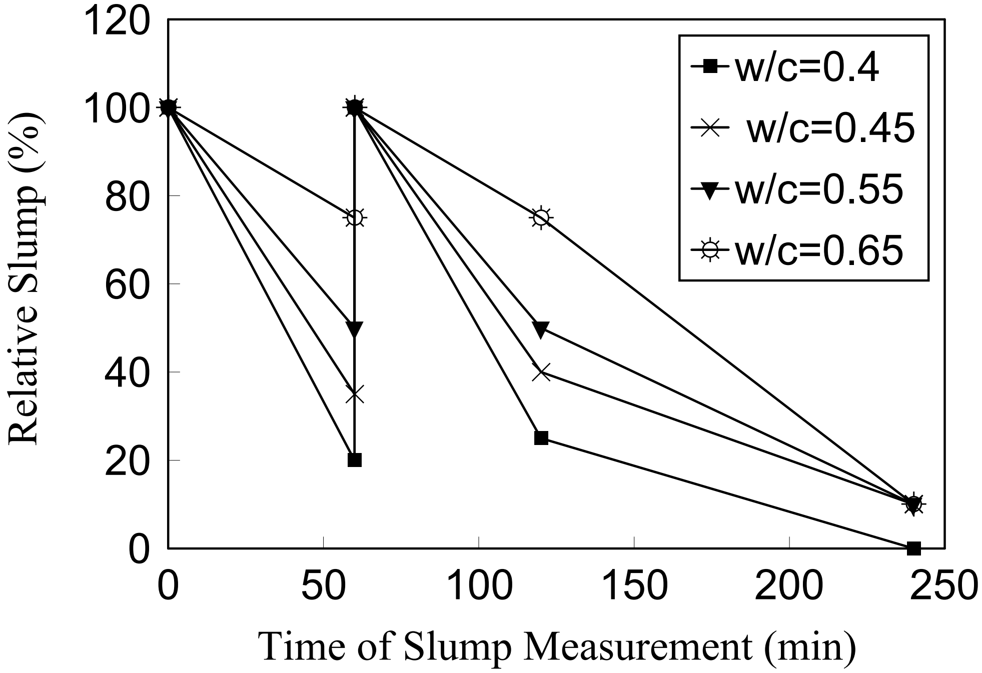


Figure 2 Slump loss profiles for retempered OPC mixes with different w/c ratios

(mixes retempered at 60 minutes)

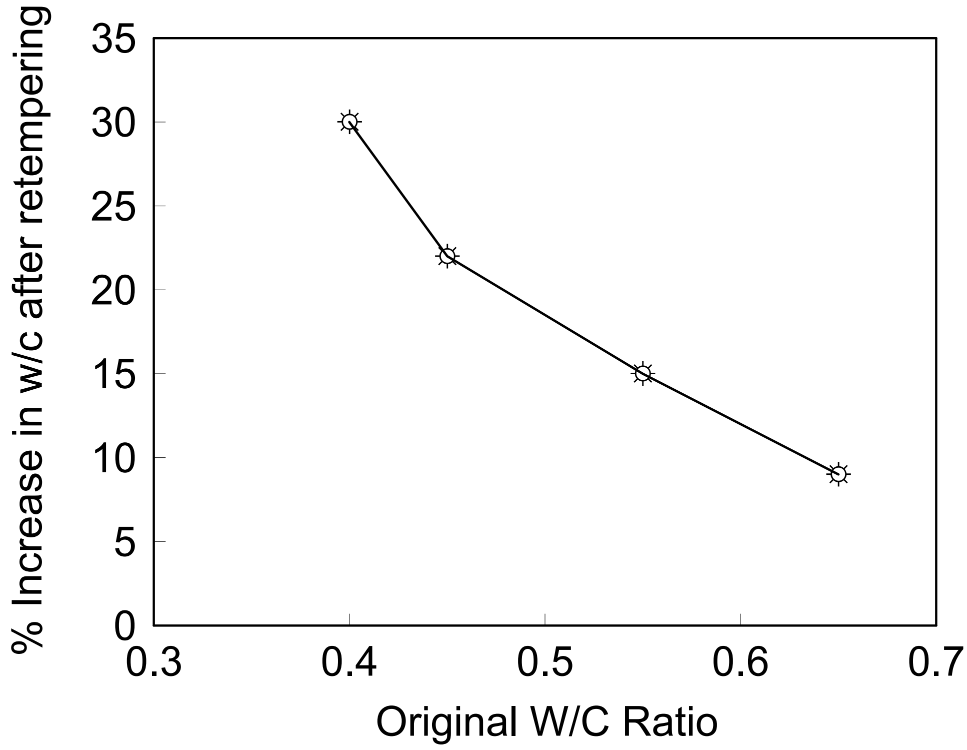


Figure 3 Relationship between original w/c and % increase in w/c after retempering

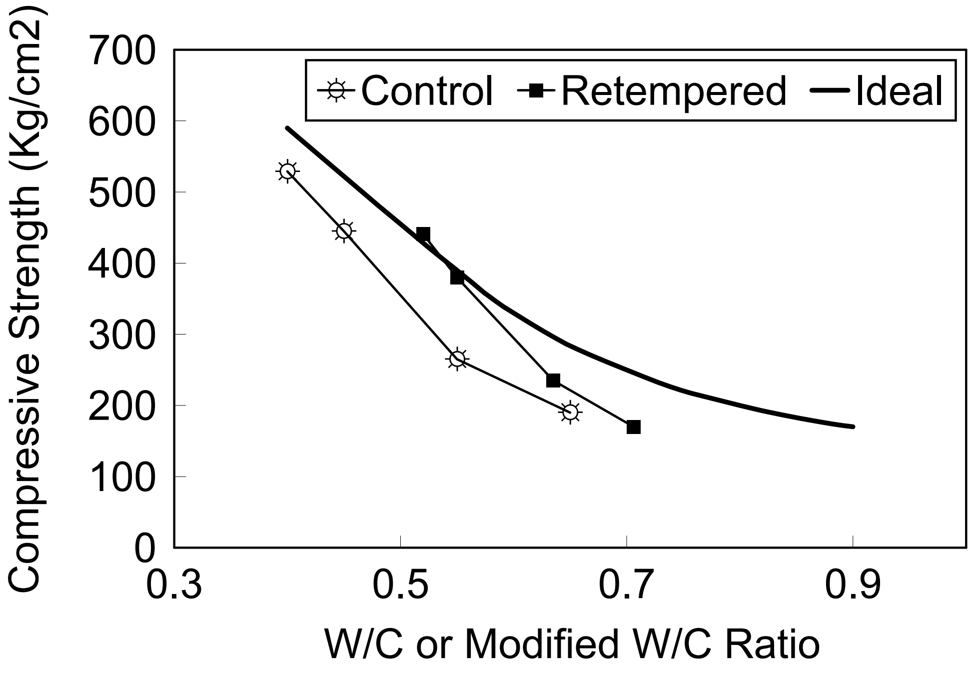


Figure 4 Relationship between compressive strength and w/c ratio for control and retempered concrete

relationship. This supports the findings of Gaynor and Bloem [5] who reported that the slope of the strength - w/c ratio relationship for concrete during retempering is flatter than normal. The formula proposed by Cheong and Lee [8] gave closer estimates of the compressive strength after retempering for the middle and high ranges of w/c ratio, but the prediction was not accurate for the low w/c ratio mix. It is clear from the above that it is not possible to accurately predict the strength after retempering based on the increase in w/c ratio value of the mix. However, it would appear the formula of Cheong and Lee [8] may be give a better estimate of the compressive strength than that from the ideal relationship especially with original mix w/c ratio greater than 0.45.

Retempering Results for Mixes With and Without Pozzolanic Materials (Series II)

Slump Loss Profile

The relative slump (% slump of original slump) versus time relationship for mixes with OPC only, 10% silica fume replacement and 30% fly ash replacement is shown in Figure 5. It can be seen that the silica fume mix exhibited the highest rate of slump loss amongst the mixes used. Punkki et. al. [20] studied the slump loss of superplasticized mixes with and without silica fume. They concluded that the addition of silica fume increases the slump loss. The slump loss was also directly proportional to the silica fume content, but inversely proportional to the superplasticizer content. In their study, the relative slump values of the OPC and 10 % silica fume mixes after 60 minutes were 77 and 40 %, respectively. The observed slump loss in the current study was higher, probably due to the use of higher cementitious material content (450 Kg/m^3 compared to 420 Kg/m^3 in Punkki et. al. [20]). Khayat et. al. [33] found that even a slight increase in cement content, in the order of 20 Kg/m^3, causes an increase in slump loss. In addition, the inclusion of superplasticizers in Punkki et. al. [20] caused a reduction in the rate of slump loss. Although Punkki et. al. [20] did not report the temperature during which the tests were carried out, their experimental program took place in Norway. Therefore, the temperature and, hence the slump loss, are expected to be less than those in Egypt.

Data in the literature concerning the effect of fly ash on the workability and rate of slump loss of fresh concrete is contradictory [34]. The effect of fly ash on these properties was reported to depend mainly on the loss on ignition of the ash and its content in the mix [21]. The replacement of 30 % cement with fly ash, in the current investigation, caused a slight reduction in the original slump of the mix (see Table 2) and a slight increase in the rate of slump loss after one hour from mixing (see Figure 5). In view of the above, no general conclusion can be drawn regarding the effect of fly ash on the rate of slump loss. Tests should be conducted on the fly ash mixes for each individual job conditions.

Increase in w/c Ratio Upon Retempering

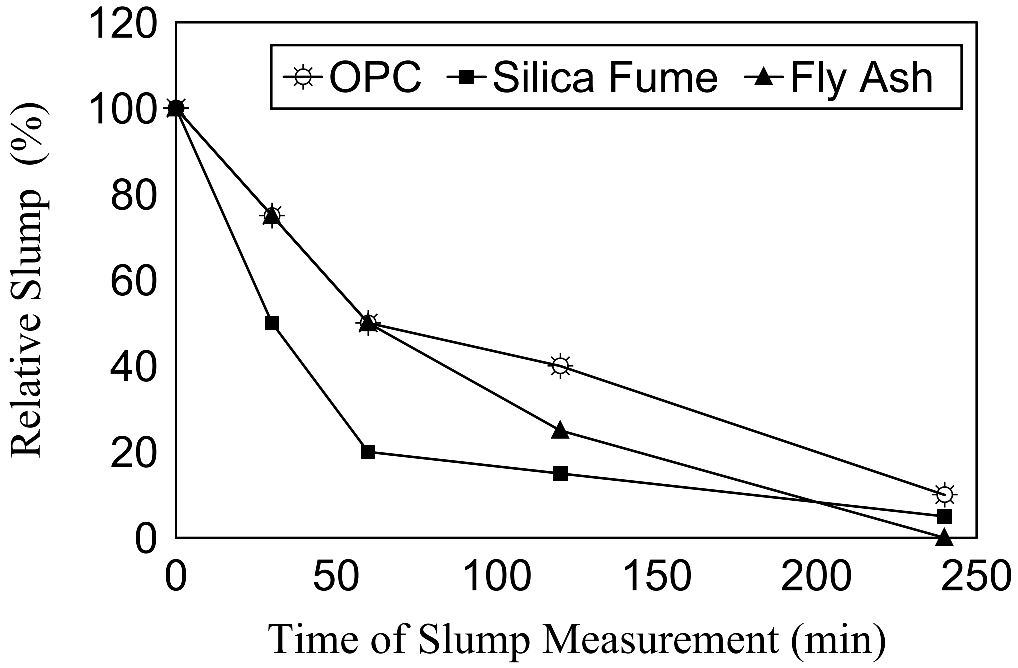
The effect of time of retempering on the percentage increase in the w/c ratio of the retempered mixes, is shown in Figure 6. It can be seen that late retempering requires higher water additions to the concrete. In addition, fly ash has the highest retempering water demand, especially for retempering up to 2 hours after mixing. In spite of increasing the slump loss rate as discussed above, the mix with 10 % silica fume required only 10% increase in the w/c ratio upon retempering, after 2 hours from mixing. In other words, lost slump was restored with less water in the mix containing silica fume. However, retempering after 4 hours caused 35-42 % increase in w/c ratio for all mixes.

Effect of Retempering on the Compressive Strength

The relationship between the relative compressive strength after retempering (% strength of the original strength) and retempering time is shown in Figure 7. It can be seen that the inclusion of pozzolanic materials increases the rate of compressive strength loss upon retempering. However, the compressive strength - w/c ratio, before and after retempering, relationship for the different concrete mixes is shown in Figure 8. It is clear that pozzolanic materials improve the strength, at a given w/c ratio, when used as partial cement replacement. It can be stated that mixes with pozzolanic materials suffer greater losses in strength than the OPC mixes when retempered. In spite of that, their compressive strengths would still be higher than the OPC mixes with similar w/c ratios.

Effect of Retempering on the Durability Related Properties

Figures 9 and 10 show the results of the effect of retempering on the capillary absorption value at 120 minutes and the percentage porosity of the concrete with and without pozzolanic materials, respectively. It can be seen from the figures that the capillary absorption and porosity of the OPC concrete were somewhat improved by retempering during the first hour after mixing. Retempering at later times, however, has caused an increase in the capillary absorption values of OPC concrete, but the porosity value remained constant. Beaufait and Hoadley [6] and Ravina [10] found that prolonged mixing increased the strength of the concrete. The mixes in the current investigation were not continuously mixed in between water additions, but through mixing was carried out at the time of retempering to ensure the adequate dispersion of added water. It may be possible that this mixing has caused an improvement in the durability related properties as was demonstrated before in the strength results by previous research. The benefits of prolonged mixing on the compressive strength were also apparent to lesser degrees in Ravina's [10] work for fly ash concrete. However, this effect was not observed at all for the pozzolanic mixes in the current investigation. The reasons for the anomaly are unclear.



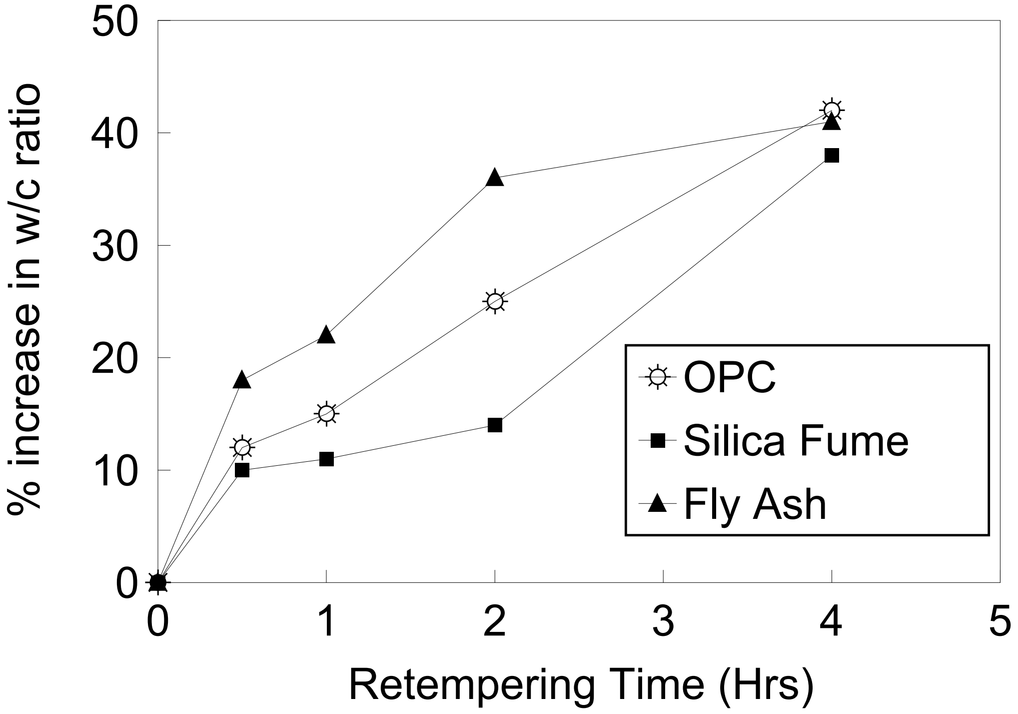


Figure 6 Effect of retempering time on the percentage increase in w/c value upon retempering

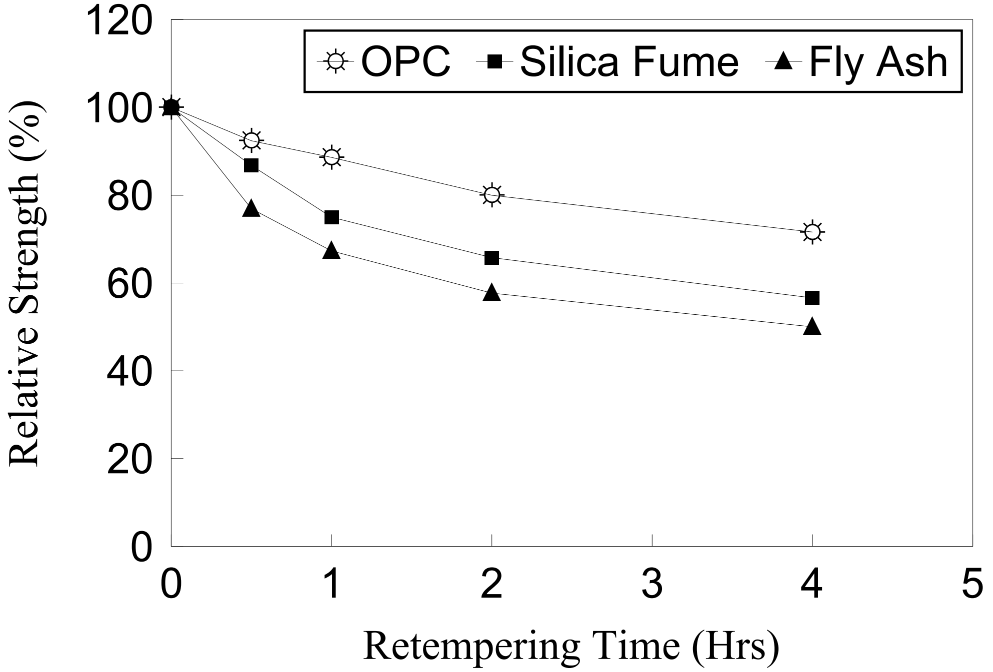


Figure 7 Effect of retempering time on the relative compressive strength (%)

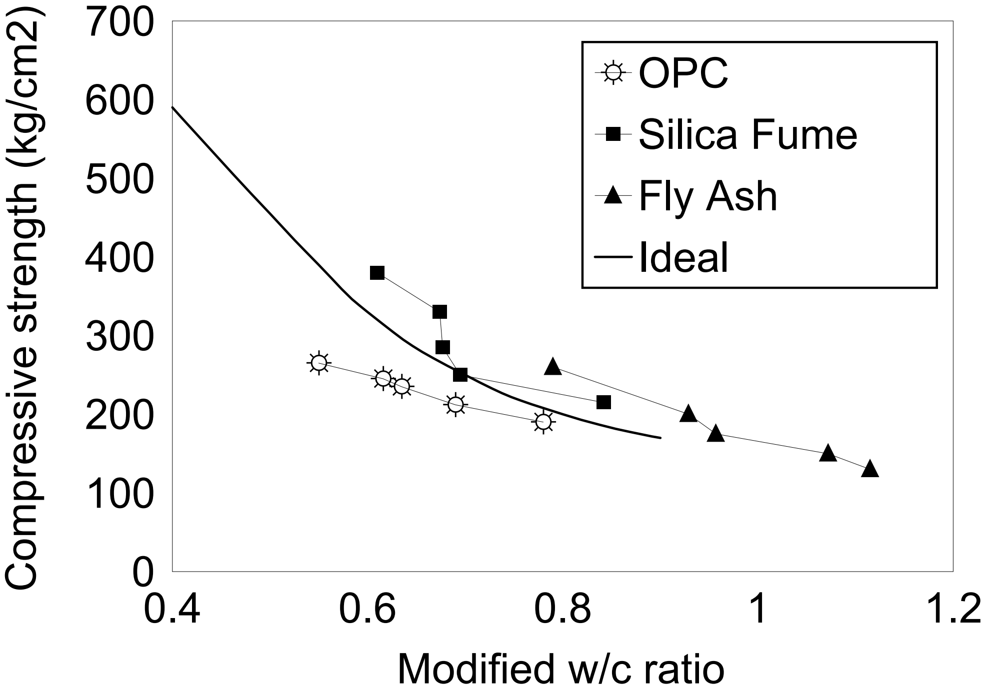


Figure 8 Relationship between modified w/c ratio and compressive strength (Kg/cm2)

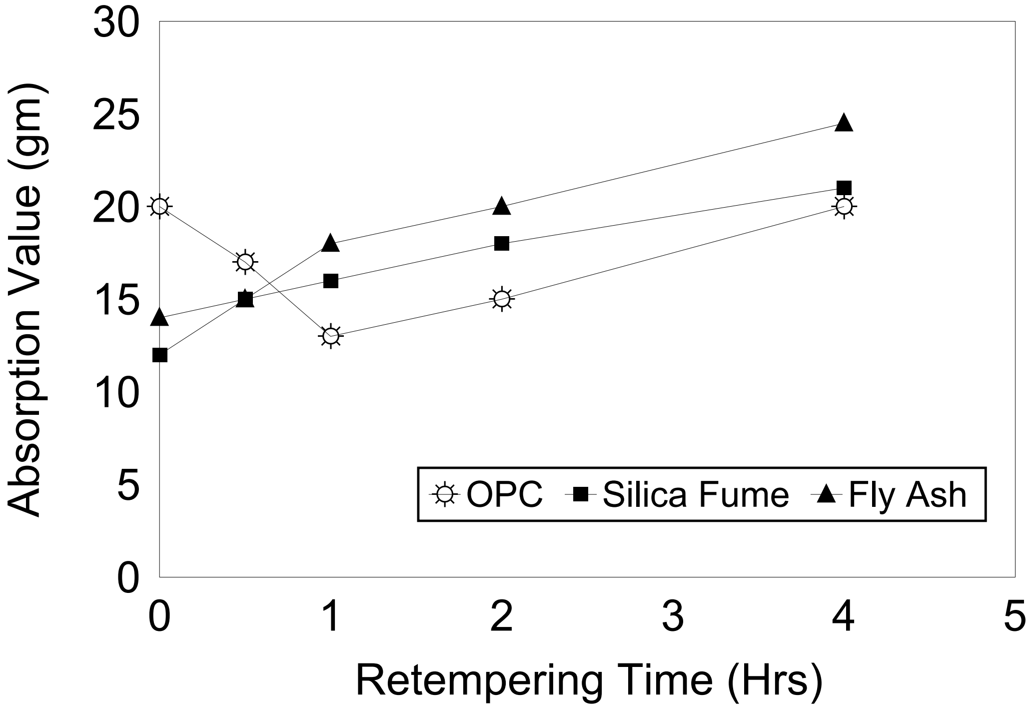
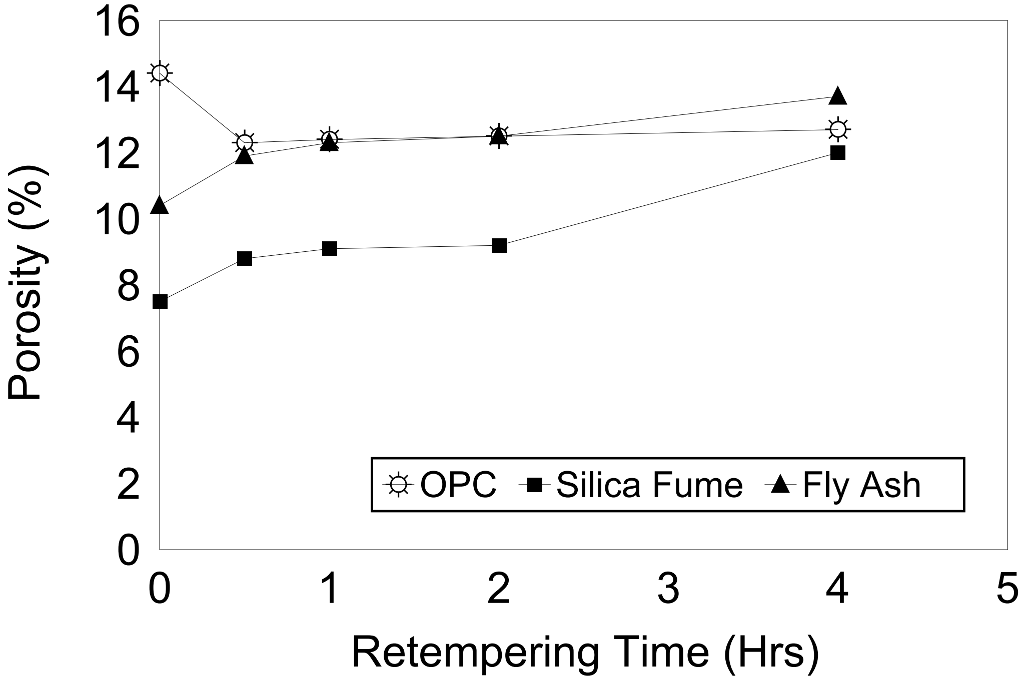


Figure 9 Effect of retempering time on Absorption value



It can be seen from Figures 9 and 10 that capillary absorption and porosity values of pozzolanic materials exhibited a slight or marked increase with retempering. The fly ash concrete seems to be affected more than the silica fume concrete by retempering. However, these mixes were tested at the age of 28 days. The fact that pozzolanic materials, and especially fly ash, react slowly in concrete [35] means that it may be possible that this effect is less pronounced in mature samples provided that water curing is continued. However, this would need further investigation. Based on the results reported herein, it would appear that the durability related properties of pozzolanic mixes are more prone to damage by retempering than their OPC counterparts.

CONCLUSIONS

Based on the results of this study the following conclusions can be drawn:

1. Although the magnitude of slump loss is higher for mixes with higher original slump, the mixes with low w/c ratio and low original slump loose their slump at a faster rate than mixes with higher slump.

2. Retempering restores the slump for only a short period of time. The slump loss – time profile is a characteristic of the original mix proportions of concrete whether the concrete is retempered or not.

3. The increase in the mix's w/c ratio upon retempering is higher for low w/c ratio mixes. However, the reduction in strength due to retempering in low w/c ratio mixes is less than that expected from the traditional strength – w/c ratio relationship. In other words, to restore the slump in low w/c ratio mixes a large amount of retempering water is needed, but such mixes do not suffer the expected strength loss due to the addition more water. In general it is not possible to accurately predict the reduction in strength from the increase in w/c ratio upon retempering especially when the original w/c ratio of the mix is lower than 0.45. A formula proposed by Cheong and Lee [8] may give a good estimate for higher w/c ratios.

4. Silica Fume increases the rate of slump loss of concrete. The fly ash mix tested in this investigation lost its slump at a higher rate than the OPC mix.

5. Late retempering causes greater increases in the w/c ratio of the retempered mixes. In this investigation, the silica fume mix exhibited the least increase in w/c ratio upon retempering. This effect was more pronounced when retempering was carried up to two hours after mixing. The highest increase in w/c ratio due to retempering at all retempering times was for the fly ash concrete mix.

6. Mixes containing either silica fume or fly ash lost their strength at a higher rate than the OPC mix in this investigation as a result of retempering. However, the strength after

retempering of these mixes is still higher than an OPC mix with a similar w/c ratio (i.e. the modified w/c ratio after retempering).

7. The capillary absorption and porosity values, referred to here as the durability related properties, of the pozzolanic mixes are adversely affected by retmpering at all times. This effect was apparent only when the OPC mix was retempered after two hours from mixing. Early, retempering of the OPC mix, somewhat improved it's durability related properties.
8. The main reason for using the pozzolanic materials in concrete produced in the Middle East is to improve it's durability. However, the results of this investigation demonstrated that the pozzolanic mixes tend to loose their slump at a higher rate than the OPC only mixes. This may promote the practice of retempering such mixes. If this occurs, the expected benefits on the concrete durability, as a result of the inclusion of pozzolanic materials, may be diminished.

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