EFFECT OF SIMULATED DESERT CLIMATE AND SUSTAINED MODERATE TEMPERATURE ON SOME PROPERTIES OF CONCRETE WITH AND WITHOUT POLYPROPYLENE FIBERS

Hanaa El Sayad*

ABSTRACT

In this investigation, the effect of simulated desert climate on moisture loss (as it is related to drying shrinkage), ultrasonic pulse velocity (internal crack detector), absorption (durability index) and compressive strength (mechanical properties pointer) were studied. Concrete mixes, having w/c ratios of 0.35, 0.45 and 0.55 and polypropylene fiber volumes of 0, 0.1, 0.2 and 0.3%, were prepared and subjected to one of three conditioning regimes after 14 days of moist curing. The samples were either kept in laboratory air, placed in an oven operating two daily temperature cycles between 75 °C and room temperature or placed in a continuous heating oven at the same temperature. It was found that heating adversely affected all studied properties of concrete. The moisture loss and absorption were increased by a factor that ranged between 4.23 – 29.96 or 2.8 – 18.67, respectively. The compressive strength was reduced by 3.16 to 33.82% compared to the samples kept in laboratory air. The inclusion of fibers improved the performance of concrete mixes compared to the no fiber mixes subject to temperature, to a certain degree. Fiber volumes 0.1 – 0.2% are recommended in these conditions depending on the type of mix. The presence of polypropylene fibers interferes with the elastic waves traveling through concrete and hence reduces the pulse velocity. Heating of fiber concrete seems to magnify this interference and therefore ultrasonic pulse velocity readings could not be used as internal crack indicators in the current study.

KEYWORDS:

Hot weather, moisture loss, compressive strength, absorption, polypropylene fibers.

الملخص العربي:

تتعرض الخرسانة في البيئات الصحراوية لدرجة حرارة ٥٠ °م في نهار الصيف في الظل وقد تصل إلى ٧٥ °م في ضوء الشمس المباشر. و في الليل تهبط درجة الحرارة بصورة ملحوظة. في هذا البحث تم محاكاة هذه الظروف عن طريق وضع عينات الخرسانة في فرن متصل بمؤقت لفصل الكهرباء و تشغيلها تلقائيا حيث يتم تعريض الخرسانة لدرجة ٧٥ °م لمدة ست ساعات ثم تهبط درجة الحرارة لحرارة الغرفة لمدة الست ساعات التالية و بعدها تتكرر هذه الظروف و ذلك لمدة أربعة عشر يوما. تم مقارنة نتائج الاختبارات لهذه العينات مع النتائج لعينات متطابقة تم إبقائها في هواء المعمل لنفس المدة و كذلك مع نتائج لعينات تم وضعها في فرن له درجة حرارة ثابتة تبلغ ٧٥ °م أيضا. العينات المختبرة كانت لها نسبة م/س = ٠,٣٥، ٠,٤٥ أو ٠,٥٥ و قد تم إضافة نسبة ٠,١، ٠,٢، أو ٠,٣ % من ألياف البولي بروبلين بالحجم أو كانت بدون ألياف و قد تم معالجة هذه العينات بالماء لمدة ١٤ يوما قبل تعريضها للظروف السابقة. و خلص البحث إلى أن العينات التي تعرضت

* Associate Professor, Department of Civil Engineering, Faculty of Engineering, Shoubra, Banha University

للحرارة بالصورة السابقة فقدت ٤,٢٣ – ٢٩,٩٦ أمثال الرطوبة التي فقدتها العينات التي ظلت في هواء المعمل. و أيضا زاد الامتصاص بمقدار ٢,٨ – ١٨,٦٧ أمثال الامتصاص للعينات التي بقيت في المعمل. أما مقاومة الضغط في العينات المعرضة للحرارة فقد انخفضت بنسبة ٣,١٦-٣٣,٨٢ % مقارنة بالعينات الضابطة التي بقيت في هواء المعمل. و قد لوحظ أن استخدام ألياف البولي بروبلين بنسبة ٠,١ – ٠,٢% بالحجم يقلل من التدهور الناتج من التعرض للحرارة. و في هذا البحث ظهر أن وجود ألياف البولي بروبلين في الخرسانة يشتت الموجات فوق الصوتية و هذا التشتت يزداد بالتعرض للحرارة. لذلك لم تكن سرعة الموجات فوق الصوتية مقياسا مفيدا للتشرخ الداخلي الناتج من الحرارة في هذا البحث.

INTRODUCTION

In the desert areas of the middle east the temperature during the day reaches 50°C in the shade and direct solar radiation increases the temperature of exposed concrete surfaces by 15-20°C (Abu-Tair et al., [1], El-Menshawy, [2]). At night there is a sharp drop in temperature. It has been shown that this cyclic change in temperature causes severe microcracking due to thermal in-compatibility of concrete components, which in turn leads to an increase in the concrete permeability and a reduction in its tensile strength (Rasheeduzzafar and Al-Kurdi, [3]). The effect of the heat cycles (80 °C for 24 hours followed by room temperature for 24 hours) on some mechanical properties of concrete has been studied by Al-Tayyib et al. [4] who found that the compressive and flexural strengths were reduced by 27 and 32%, respectively. Rasheeduzzafar and Al-Kurdi [3] reported that the w/c = 0.4 concrete was less damaged by daily heat cycles (27 to 60 °C) compared to the w/c = 0.6 concrete.

Concrete in hot climates suffers from plastic and drying shrinkage and differential thermal cracking [5]. Low volume polypropylene fibers contents (0.1-0.3%) have been shown to be effective in reducing cracking tendency in the plastic stage. Grzybowski and Shah [6] conducted tests in controlled laboratory conditions (20 °C & 40% RH for 6 weeks), which indicated that samples reinforced with 0.25 % polypropylene fibers exhibited half the crack widths of plain concrete. On the other hand, samples with two types of polypropylene fibers at 0.1% content by volume showed reduced shrinkage and total crack area when subjected to drying in a wind stream chamber at 31 °C & 50% RH for 16 hours [7]. Naaman et al. [8] found that at 0.2% volume fraction, most fine diameter fibers tested provided a reasonable control on plastic shrinkage cracking, reducing it to approximately 10% of the control. Yet there is controversy with regards to the influence of fibers on the drying shrinkage in the hardened stage. Balaguru and Shah [9] reported that polymeric fibers reduce the maximum and total crack widths under restrained conditions. However, Sanjuan et al. [10] found that the increase in sand content may be more effective in reducing shrinkage than adding fibers to a low sand mix.

Unfortunately most shrinkage studies were conducted in controlled laboratory conditions, where the temperature ranged between 20 and 30 °C. Few investigations have been cited on shrinkage studies carried out on samples stored in natural environments (Vandewalle, [11] in Belgium and Barr et al., [12] in Northern Iran). However, these investigations were conducted in moderate climate countries. Okba et al. [13] examined the surface cracks in fresh concrete slabs, with and without polypropylene fibers, cast at the Touska district. However, in their study no shrinkage or moisture loss measurements were made. Whereas in the out door shrinkage studies of Alsayed [14] and Fattuhi and Al-Khaiat [15], which were carried out in the Gulf region, no polypropylene fibers were used in the mixes. Balaguru [16] reported that at temperatures above 32 °C the Young's modulus of the fibers may be reduced, and therefore fiber deformation especially for thin fibers, may increase. It can be argued that there is a need to investigate the effect of high ambient temperatures on the drying shrinkage cracking tendency of polypropylene fibers concrete. In the current investigation, the moisture loss of samples subject to simulated desert climate was investigated, as an indicator to shrinkage, since Barr and El-Baden [17] found that the relationship between shrinkage and moisture loss during the first 100 days of drying was linear for all grades of concrete.

One other major problem with concrete in hot climates is its decreased durability (El-Dieb, [5]). Dhir et al. [18] considered that the absorption of concrete could be used to specify its durability irrespective of curing, grade or mix constituents. Limited data on the absorption and permeability of fiber concrete has been cited in the literature. Bayasi and Zeng [19], studied w/c=0.4 mixes having polypropylene fiber volumes 0, 0.1, 0.3 and 0.5%. They found that for ½ in long fibers, slightly longer than those used in the current investigation, there was a small increase in rapid chloride permeability with the use of fibers. With longer fibers (¾ in) the increase was significant. Sanjuan et al. [20] found that the use of 0.1 to 0.2% fibers in mortars reduced the water absorption if the w/c was less than 0.5, but the effect was reversed with higher w/c ratios. They also reported that CO_2 diffusion was increased with the increase in fiber volume. Ibrahim [21] tested the permeability of concrete with various fiber volumes, but all less than 0.1%, using Autoclam. She reported that the air cured samples at 45 °C exhibited very high permeability regardless of the fiber volume. However, the permeability was reduced with the increase of fiber volume for the water cured samples. No data has been cited in the literature on the effect of heat cycles on absorption of fiber concrete.

In this investigation, the effect of simulated desert climate on some properties of concrete is studied. The tested properties include moisture loss (as it is related to drying shrinkage), ultrasonic pulse velocity (internal cracking or discontinuity detector), absorption (durability index) and compressive strength (mechanical properties pointer). Concrete mixes having w/c ratios of 0.35, 0.45 and 0.55 and fiber volumes of 0, 0.1, 0.2 and 0.3% were prepared. Samples were water cured for 14 days. After that, three cubes from each mix were kept in laboratory air and then tested for the studied properties. Another three samples were placed in an oven operating two daily temperature cycles between 75 °C and room temperature. Whereas the last three samples were placed in a continuous heating oven at the same temperature to examine if the heat cycles are more or less damaging than sustained heating (which concrete sometimes encounters in industrial applications). The samples were conditioned for 16 days before testing for the studied properties.

MATERIALS, MIX PROPORTIONS, SAMPLE PREPARATION AND TEST PROGRAM

Materials

Ordinary Portland cement conforming to ESS 373/1991 [22] was used in preparing the test samples. The fine aggregate was natural sand, whereas the coarse aggregates was crushed dolomite which was supplied in two sizes 5-10 mm and 10-20 mm. Both conformed to ESS 1109/2002 [23]. Tap water was used in mixing and curing the test specimens. The fibers used were polypropylene monofilament crimped fibers having a length of 12 mm and a diameter of 18 μm.

Mix Proportions

The mix proportions for the twelve mixes prepared for the current investigation are shown in Table 1. The w/c ratios of the mixes were 0.35, 0.45 and 0.55. The mixes were without fibers or had a fiber content of 0.1%, 0.2% or 0.3% by volume. A superplasticiser complying with ASTM C494, Type F [24] was used to maintain the slump of the mixes between 10 – 15 cm.

Preparation of the Test Samples

The dry cement and aggregates were first mixed in a laboratory mixer. Half the water was added and mixing resumed. The mix was left undisturbed for few seconds after which the remaining water and superplasticiser were added. When uniformity of the mix was observed the fibers were evenly sprinkled by hand on to the fresh concrete whilst keeping the mixer running. Finally the slump was measured and nine standard 15 cm cubes were prepared from each mix giving 108 samples in total. .

Test Program

The test program is shown in Figure 1. Cast samples were kept in their moulds for 24 hours under wet burlap. After demoulding, they were water cured for 14 days. At that point the cubes were weighed and ultrasonic pulse velocity (UPV) measurements [25] were taken for each cube (stage 1). Samples from each mix were divided into three groups, each having three cubes to be subjected to the different conditioning regimes. The first group was kept in laboratory air undisturbed, the second group was placed in an oven operating a heat cycle, 6 hours of heating at 75 ºC followed by 6 hours in which the oven was automatically switched off by a timer, and thereafter this cycle was repeated. The third group, however, was placed in an oven which was continuously heated to the same temperature. The different groups remained in these conditions for a further 14 days. At that time the samples from the first group were weighed to evaluate their moisture loss then they joined their counterparts in the constant heating oven for drying for 48 hours. After these conditioning treatments, all cubes were taken out of the ovens and weighed to evaluate their moisture loss, and again the UPV was measured (stage 2). All samples were immersed in water for 48 hours and then weighed to evaluate their absorption and finally the compressive strength test [26] was carried on all samples.

RESULTS AND DISCUSSION

Moisture Loss

The moisture loss results are shown in Figures 2 and 3. It can be seen that the moisture loss of samples placed in both ovens was significantly higher than those stored in laboratory air. The moisture loss values of the heated samples were 4.23 - 29.96 greater than those for the samples kept in air. This reflects the drastic dehydrating effect, and hence drying shrinkage tendency, which desert climate may have on concrete subject to this environment.

Table 1 Mix proportions for concrete mixes (kg/m³)

Mix / Materials	Mix (1)	Mix (2)	Mix (3)	Mix (4)	Mix (5)	Mix (6)	Mix (7)	Mix (8)	Mix (9)	Mix (10)	Mix (11)	Mix (12)
	0% Fibers			0.1% Fibers			0.2% Fibers			0.3% Fibers		
w/c	0.35	0.45	0.55	0.35	0.45	0.55	0.35	0.45	0.55	0.35	0.45	0.55
Water	117.5	153.5	189.5	112.5	149.5	186.5	107.5	145.5	183.5	102.5	141.5	180.5
Cement	350	350	350	350	350	350	350	350	350	350	350	350
Fine Aggregates	670	640	609.3	670	640	609.3	670	640	609.3	670	640	609.3
Coarse Aggregates	1245	1188.5	1130.5	1245	1188.5	1130.5	1245	1188.5	1130.5	1245	1188.5	1130.5
Admixture	5	4	3	10	8	6	15	12	9	20	16	12
Fiber	0	0	0	0.9	0.9	0.9	1.8	1.8	1.8	2.7	2.7	2.7
Slump (cm)	10.5	11.5	12	13.5	12.5	13.5	12.3	13	14.3	10.5	11.3	13

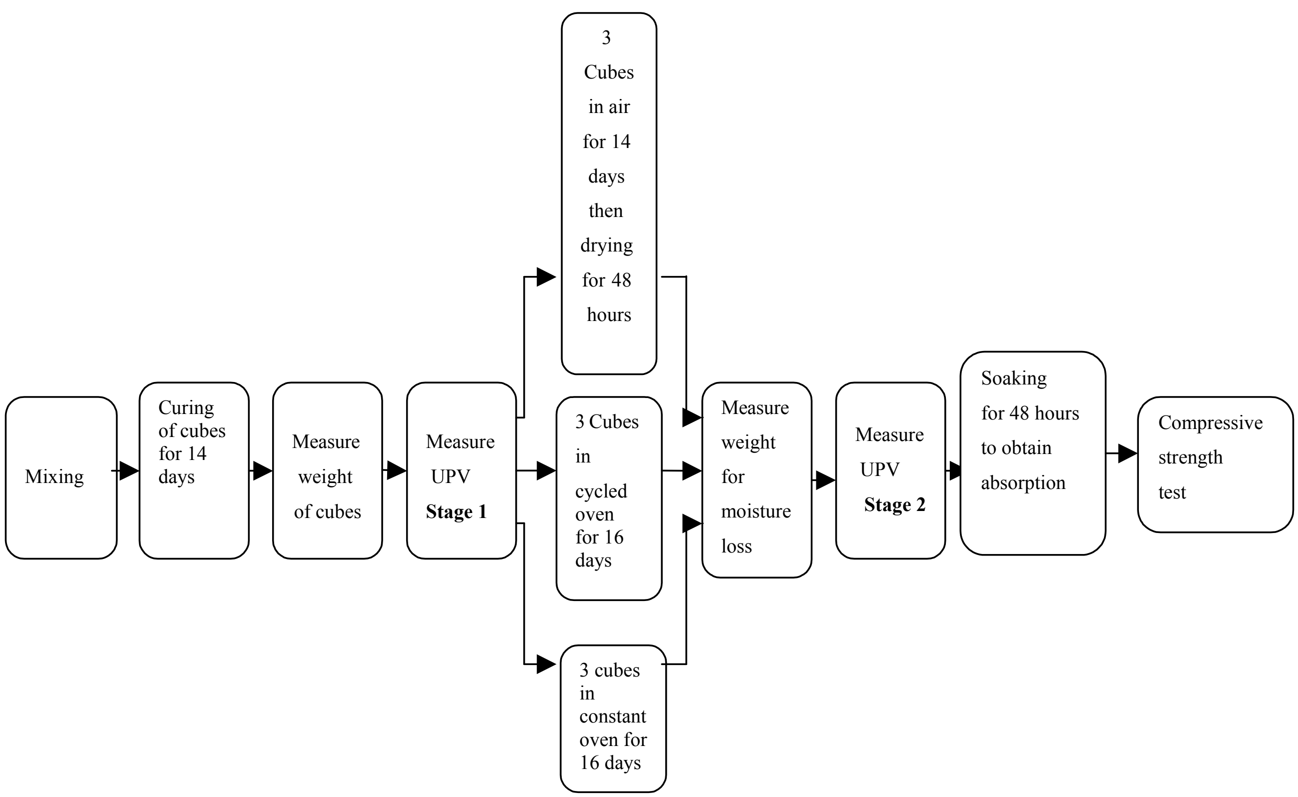

Figure 1 Test program

It is clear from the figures that the moisture loss values for samples placed in the cycled heating oven were slightly lower than those from the constant heating oven. As expected, constant heating caused more moisture to be lost from the concrete samples.

In general, the moisture loss increased with the increase in w/c ratio. This agrees with the fact that concrete with low water content shrinks less than that with high moisture content [27]. The moisture loss was also reduced with the increase in fiber volume. However, with the 0.3% fiber volume and w/c 0.45 and 0.55 mixes, the moisture loss was slightly higher than the corresponding mixes with 0.2% fiber volume. This is probably because of the ease of moisture evaporation from the 0.3% mixes as it was reported that in some cases with higher fiber volumes large amounts of air can be incorporated in the matrix ([28] and [19]). Others [29] argued that the presence of fibers increase the size and volume of pores, therefore the evaporation is increased.

The effectiveness of the fibers in moisture loss reduction depended on the conditioning regime to which the samples were subjected. Moisture loss reduction, for samples with fibers compared to those without fibers and stored in air, was 62.2–85.1%. The corresponding values for heat cycled and constantly heated samples were 16.2-30.7% and 14.2-27.1%, respectively. In addition, it should be noted that for samples stored in the laboratory, the effectiveness of the fibers in reducing the moisture loss depended on the w/c of the mix, the fibers were less effective in w/c = 0.55 mix (see Figure 3). For samples subject to heating, better control on moisture loss was exhibited by the inclusion of 0.3% fibers in the w/c=0.35 mix, whereas with w/c=0.45 or 0.55 mixes, 0.2% fibers mixes showed the highest moisture loss reduction. Therefore, it may be argued that from the moisture loss point of view in hot climates, 0.2-0.3% fiber contents are beneficial depending on the w/c ratio of the mix.

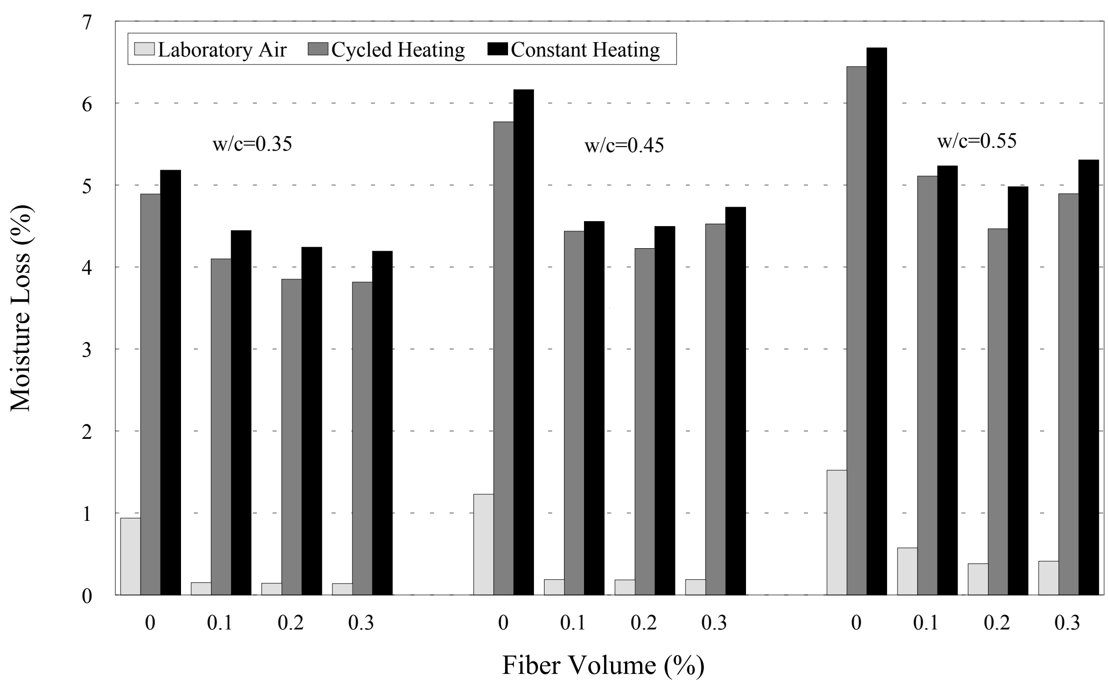

Figure 2 Moisture loss of different mixes after the conditioning regimes

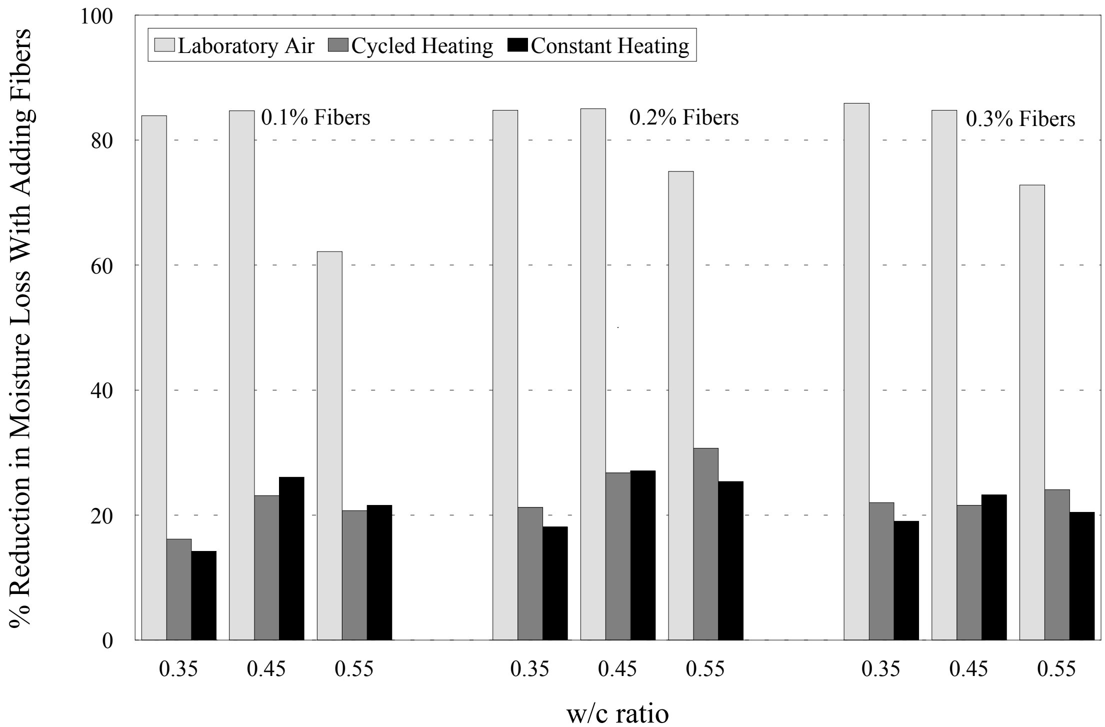

Figure 3 Effectiveness of fibers in moisture loss reduction

Ultrasonic Pulse Velocity

The percentage loss of UPV, e.g. difference between readings at stages 2 and 1 as a percentage of readings at stage 1 (see Figure 1), is plotted in Figure 4 for the different mixes in the current investigation. It can be seen that the UPV loss for heated mixes was higher than those kept in laboratory air, partially because the UPV of concrete is reduced by drying [30] and mainly because of the cracking induced by the temperature. There was no general trend in the data to indicate which heat treatment caused more damage to the samples (cyclic or continuous heating). In spite of the fact that the inclusion of fibers reduced the moisture loss (see Figure 3), the UPV loss seemed to increase with the increase in fiber content (see Figure 4) .

Pulse velocity measurements were carried out on concrete samples with polypropylene fiber volumes of up to 1.5% by Katwan et al. [31]. Their results showed that the pulse velocity is reduced as the fiber volume is increased. They argued that ultrasonic waves tend to travel in straight paths, however, the presence of fibers, which can be considered as a low density inhomogeneity in the matrix, results in scattering of the wave and this prolongs the time taken by the wave to cross the medium. Similar observations were made by Leung et al. [32] when studying the resonant frequency of fiber concrete. The effect of heat on this phenomenon has not been cited in the literature, but the current data, which shows higher UPV loss for heated mixes with high fiber volumes, may point out that the wave scattering may be increased when the fiber concrete had been subject to heating. Therefore, it can be argued that the UPV loss of heated samples shown in Figure 4 was not purely the result of dehydration and internal cracking.

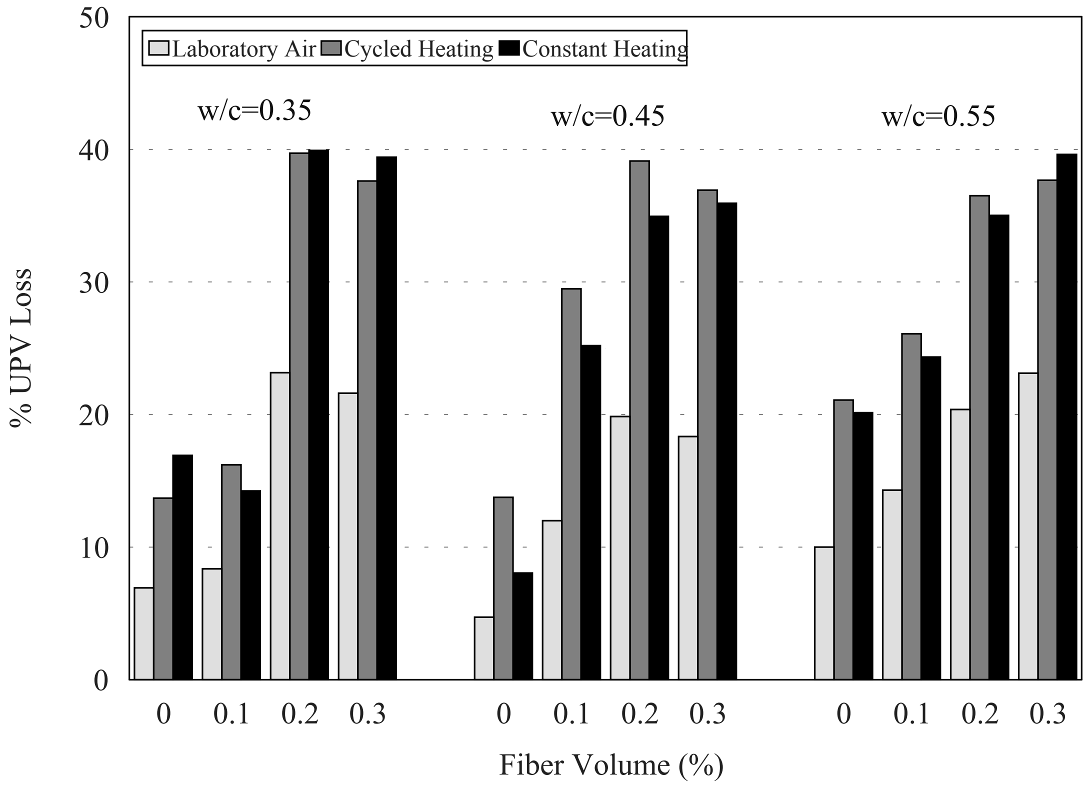

Figure 4 Effect of type of mix and conditioning regime on ultrasonic pulse velocity

Absorption

The absorption values of concrete with different fiber volumes, subject to the conditioning regimes, are shown in Figure 5. It can be seen that the conditioning regime had a profound effect on the absorption results. Heating increased the absorption values by a factor ranging between 2.84 – 18.76 compared to the samples kept in laboratory air. It is also clear that, the w/c = 0.55 samples exhibited a lower increase in absorption due to heating compared to the w/c = 0.35 and 0.45 mixes. For example, the absorption of the mix with w/c = 0.55 and 0.1% fibers, subject to either cyclic or constant heating, was 7.79 times greater than that for the same mix kept in laboratory air. The corresponding increases for the w/c = 0.35 and 0.45 mixes were 16.61 and 18.76 for cyclic heating or 16.54 and 18.67 for constant heating, respectively. However, higher fiber contents (0.2 and 0.3%) resulted in a lower increase in absorption leading to a maximum increase by a factor of 4.36 due to heating.

It can be seen from Figure 5 that the inclusion of 0.1% fibers in samples kept in laboratory air resulted in a reduction in absorption by a factor of 0.65, 0.41 and 0.84 for the w/c = 0.35, 0.45 and 0.55 mixes. Higher fiber volumes lead to an increase in absorption, i.e. the absorption of the w/c = 0.35 mix with 0.3% fibers was triple that without fibers. This trend was not observed in the heated samples, which almost all exhibited reductions in absorption (factor = 0.71-0.98) relative to the no fibers samples. The single exception for that observation was in the w/c = 0.35 mix with 0.3% fibers which exhibited a small increase in absorption in the order of 1.1 relative to the no fibers sample in the case of constant heating. It is also clear that, for samples subject to cyclic heating, 0.2% fibers seemed to give the lowest absorption values, whereas with the constant heating 0.1-0.2% fiber contents gave low absorption results. It seems that the inclusion of 0.2% fibers in concrete subject to desert environment would offer some improvement to its absorption, relative to the samples without fibers.

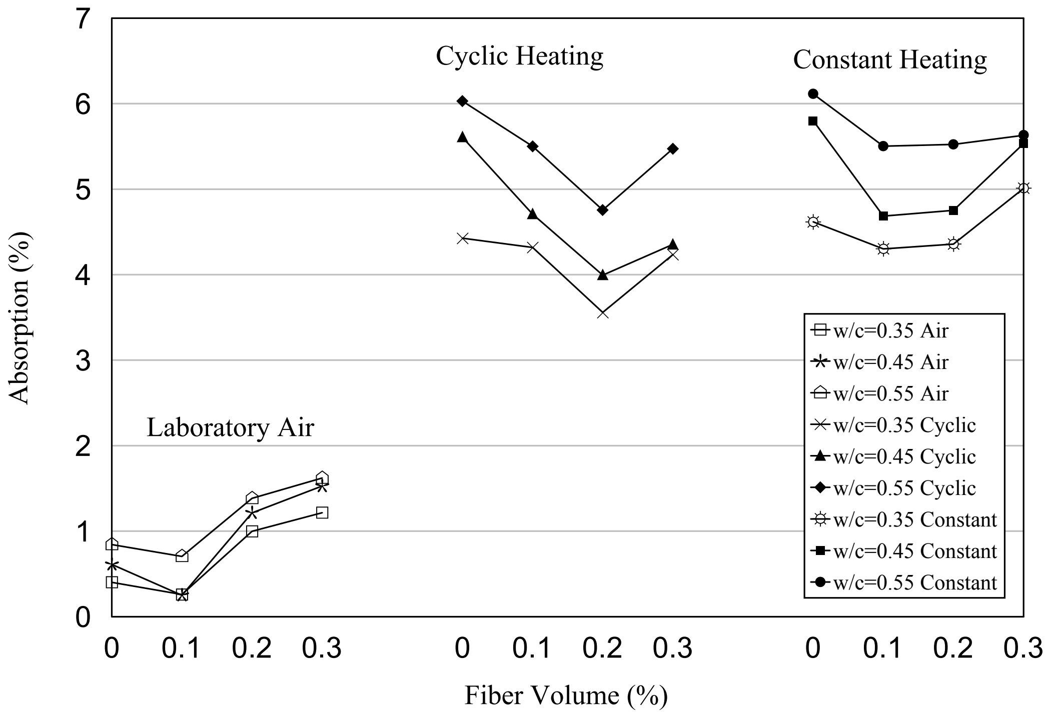

Figure 5 Effect of fiber inclusion and conditioning regime on absorption

Compressive Strength

The compressive strength results are shown in Figure 6. It can be seen that the trend lines for the different conditioning regimes followed the same pattern. Soroushian et al., [33] reported that the inclusion of 0.1% polypropylene fibers in a w/c = 0.39 mix that was moist cured for 7 days then air dried till the age of 28 days resulted in a reduction of 23% in the compressive strength values compared to the control mix without fibers. In the current investigation, the w/c = 0.35 mix, which was kept in the laboratory, exhibited a small increase in strength (2.15%) due to the inclusion of 0.1% fibers. Mixes with w/c = 0.45 and 0.55 benefited more from the use of 0.1% fibers (11.54 and 23.81% increase in strength, respectively, compared to samples with no fibers).

Samples with no fibers and subject to cyclic heating lost 5.4, 15.4 and 33.8% of their compressive strength values compared to those kept in air, for w/c = 0.35, 0.45 and 0.55, respectively. This confirms the findings of Rasheeduzzafar and Al-Kurdi [3] who reported that low w/c samples are less damaged by cyclic heating. The inclusion of 0.1% fibers increased the compressive strength, but with higher fiber volumes, the strength started a downward trend regardless whether the samples were heated or not. The combined effect of fiber inclusion at a volume of 0.1% and heating resulted in a higher increase in the percentage of compressive strength relative to that for the samples kept in laboratory air. For example, w/c = 0.35 and 0.55 samples with 0.1% fibers exhibited an increase of 24.3 and 40.0% in strength with the constant heating regime, but the increase was only 2.2 and 14.7% when the samples were kept in air, respectively. However, in all cases, the heated samples exhibited a lower strength compared to the samples left in air. It is also clear that the compressive strength of w/c = 0.35 samples suffered the most from the combined effect of the inclusion of high fiber volumes (0.3%) and heating. For example, cyclic heating of these samples reduced their strength by 37.5% compared to the no fiber samples. However, the w/c = 0.55 samples, with the same fiber volume and subject to the same heating regime, exhibited a slight increase in strength of 2.2% compared to the sample without fibers. The samples kept in laboratory air did not show such a difference in compressive strength change, as the strength of w/c = 0.35, 0.45 and 0.55 with 0.3% fibers was reduced by 22.6, 20.5 and 23.5%, respectively. Therefore, a small fiber volume of 0.1% is beneficial from the strength point of view in all cases, but higher fiber volumes can be used with high w/c mixes only, if required for the enhancement of other properties. High fiber volumes are not recommended for low w/c mixes in desert climates as the strength can be impaired.

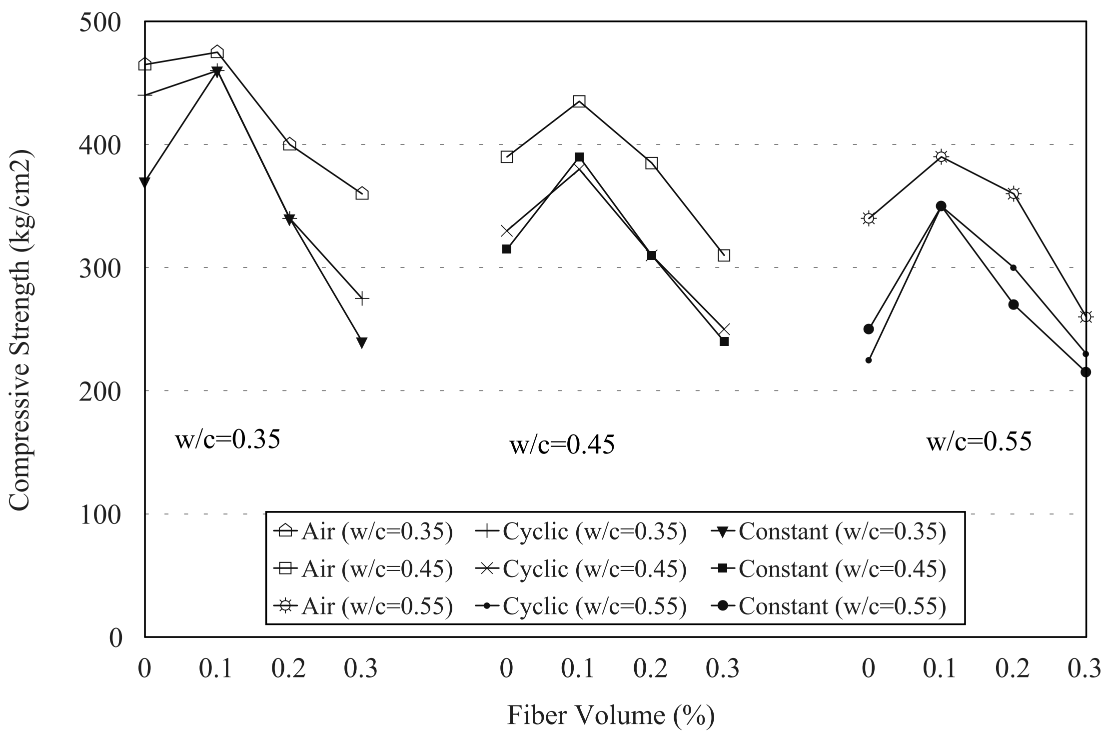

Figure 6 Effect of fiber inclusion and conditioning regime on compressive strength

CONCLUSIONS

Based on the tests carried out in this investigation, the following conclusions can be drawn:

1) Heating (either cyclic or constant to 75 °C) caused severe damage to the investigated properties of concrete, but no definite conclusion can be drawn regarding whether cyclic or constant heating is more damaging to concrete.

2) The moisture loss values due to heating were increased by a factor that ranged between 4.23 and 29.96 relative to the values for samples kept in air.
3) The inclusion of fibers reduced the moisture loss. However, the effectiveness of the fibers in moisture loss reduction depended on the conditioning regime to which the samples were subjected. Moisture loss reduction, for samples with fibers compared to those without fibers and stored in air, was 62.2–85.1%. The corresponding values for heat cycled and constantly heated samples were 16.2-30.7% and 14.2-27.1%, respectively.
4) The presence of polypropylene fibers interferes with the elastic waves traveling through concrete and hence reduces the pulse velocity. Heating of fiber concrete seems to magnify this interference and therefore ultrasonic pulse velocity readings could not be used as internal crack indicators in the current study.
5) Heating increased the absorption values by a factor that ranged between 2.84 – 18.76 compared to the samples kept in laboratory air. It seems that the inclusion of 0.2% fibers in concrete subject to desert environment (cyclic heating) would offer some improvement to its absorption (factor = 0.71-0.98), relative to the samples without fibers.
6) Samples with no fibers and subject to cyclic heating lost 5.4, 15.4 and 33.8% of their compressive strength values compared to those kept in air, for w/c = 0.35, 0.45 and 0.55, respectively. The inclusion of 0.1% fibers increased the compressive strength, but with higher fiber volumes, the strength started a downward trend regardless whether the samples were heated or not. In all cases, the heated samples exhibited a lower strength than the un heated ones.
7) A small fiber volume of 0.1% is beneficial from the strength point of view in all cases, but higher fiber volumes can be used in high w/c mixes only, if required for the enhancement of other properties. High fiber volumes are not recommended for low w/c mixes in desert climates as the strength can be impaired.

REFERENCES

1) Abu-Tair, A. I., Burley, E. and Rigden, S. R., 1997, "**Heat cycling of epoxy mortar repaired beams**", ACI Materials Journal, Vol. 94, pp. 129-133.
2) El-Menshawy, G., 2004, **Private communication**, Consultant Engineer, Edepco, Toushka pump station project.
3) Rasheeduzzafar and Al-Kurdi, S. M. A., 1993, "**Effect of hot weather conditions on the microcracking and corrosion cracking potential of reinforced concrete**", ACI SP 139, pp. 1-20.
4) Al-Tayyib, A. J., Baluch, M. H., Sharif, A. M. and Mahamud, M. M., 1989, "**The effect of thermal cycling on the durability of concrete made from local materials in the Arabian Gulf countries**", Cement and Concrete Research, Vol. 19, pp. 131-142.
5) El-Dieb, A. S., 1994, "**Concrete in hot weather: A Review**", Fifth International Colloquium on Concrete in Developing Countries, Egypt, pp. 1119-1130.
6) Grzybowski, M. and Shah, S. P., 1990, "**Shrinkage cracking of fiber reinforced concrete**", ACI Materials Journal, Vol. 87, pp. 138-148.
7) Pardon, I. and Zollo, R. F., 1990, "**Effect of synthetic fibers on volume stability and cracking of Portland cement concrete**", ACI Materials Journal, Vol. 87, pp. 327-332.
8) Naaman A. E., Wongtanakitcharoen, T. and Hauser, G., 2005, "**Influence of different fibers on plastic shrinkage cracking of concrete**", ACI Materials Journal, Vol. 102, pp. 49-58.
9) Balaguru, P. N. and Shah, S. P., 1992, "**Fiber-reinforced cement composites**", McGraw-Hill International Editions, page266.
10) Sanjuan M. A., Andrade, C. and Bentur, A., 1997, "**Effect of crack control in mortars containing polypropylene fibers on the corrosion of steel in a cementitious matrix**", ACI Materials Journal, Vol. 94, pp. 134-141.

11) Vandewalle, L., 2000, “**Concrete creep and shrinkage at cyclic ambient condition**”, Cement and Concrete Composites, Vol. 22, pp. 201-208.
12) Barr, B., Hoseinian, S. B. and Beygi, M. A., 2003, “**Shrinkage of concrete stored in natural environments**”, Cement and Concrete Composites, Vol. 25, pp. 19-29.
13) Okba, S. H., Abd El-latif, H., ElShafei, H. and Khafaga, S. A. M., 2004, “**Proposed solutions to minimize surface cracks of concrete slabs cast in Toska district, Egypt during hot weather**”, International Conference: Future Vision and Challenges for Urban Development, Cairo, Egypt, 20-22 December 2004, paper SG165F.
14) Alsayed, S. H., 1998, “**Influence of superlasticizer and silica fume on the drying shrinkage of high strength concrete subjected to hot dry field conditions**”, Cement and Concrete Research, Vol. 28, pp. 1405-1415.
15) Fattuhi, N. I. and Al-Khaiat, H., 1999, “**Shrinkage of concrete exposed to hot and arid climate**”, Journal of Materials in Civil Engineering, Vol. 11, pp. 66-75.
16) Balaguru, P., 1994, “**Contribution of fibers to crack reduction of cement composites during the initial and final setting period**”, ACI Materials Journal, Vol. 91, pp. 280-288.
17) Barr, B. and El-Baden, A., 2003, “**Shrinkage properties of normal and high strength fiber reinforced concrete**”, Structures and Buildings, Vol. 156, pp. 15-25.
18) Dhir, R. K., Jones, M. R., Byars, E. A. and Shaaban, I. G., 1994, “**Predicting concrete durability from its absorption**”, Third CANMET/ACI International Conference on the Durability of Concrete, 1177-1194.
19) Bayasi, Z. and Zeng, J., 1993, “**Properties of polypropylene fiber reinforced concrete**”, ACI Materials Journal, Vol. 90, pp. 605-610.
20) Sanjuan, M. A., Bacle, B., Moragues, A. and Andrade, C., 1990, “**Plastic shrinkage and permeability in polypropylene reinforced mortar**”, ACI SP 124, pp. 125-135.
21) Ibrahim, I. A., 2000 **“Effect of polypropylene fibers on concrete characteristics in hot climates**”, Proceedings of the eight^{h} Arab Structural Engineering Conference, Cairo, 21-23 October 2000 , pp. 1475- 1484.
22) ESS 373/1991, “**Specifications for Ordinary and Rapid Hardening Portland Cement**”.
23) ESS 1109/2002, “**Specification for Concrete Aggregates from Natural Sources**”.
24) ASTM C494, “**Specification for Chemical Admixtures for Concrete**” Annual Book of ASTM Standards.
25) Recommendations for Measurement of Ultrasonic Pulse Velocity in Concrete, 2003 “**Egyptian Code for the Design and Construction of Concrete Structures. Part 3 Laboratory Tests Guide for Concrete Materials**”.
26) Determination of Compressive Strength of Hardened Concrete Specimens. “**Egyptian Code for the Design and Construction of Concrete Structures. Part 3 Laboratory Tests Guide for Concrete Materials**”, 2003.
27) Babaei, K., 2005, “**Mitigating transverse cracking in concrete bridge decks**”, Transportation Research Board, Annual Meeting, January 2005, 9 pp.
28) Ramakrishnan, V., Wu, G. Y. and Hosalli, G., 1989,”**Flextural behavior and toughness of fiber reinforced concretes**”, Transportation Research Record, No. 1226, pp. 69-77.
29) Beddar, M. and Belagraa, L., 2004, “**Effect of Fiberous waste addition on free and restrained shrinkage of a mortar**”, International Conference: Future Vision and Challenges for Urban Development, Cairo, Egypt, 20-22 December 2004, paper SG139F.
30) Bungey, J. H. and Millard, S. G., 1996, “**Testing of concrete in structures**”, Blackie Academic & Professional, page 60.
31) Katwan, M. J., Abdulnoor, S. S. and Al Ani, Y. K., 2002, “**Interaction of elastic waves with fiber reinforced concrete**”, Composite Materials in Concrete Construction, Ed. Dhir, Paine and Newlands, Thomas Telford Publishing, pp. 255-264.
32) Leung, H. Y., Balendran, R. V., Nadeem, A, Maqsood, T. and Rana, T. M., 2003, “**Resonant frequency in fiber reinforced concrete: Effect of pozzolan and curing conditions**”, International Conference on Performance of Construction Materials in the New Millennium, Cairo, Egypt, 18-20 February 2003.
33) Soroushian, P., Khan, A. and Hsu, J., 1992, “**Mechanical properties of concrete materials reinforced with polypropylene and polyethylene fibers**”, ACI Materials Journal, Vol. 89, pp. 535-540.