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Efficiency of the Use of Set-Retarding Superplasticizers in Hot Climates

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ABSTRACT. This paper examines the efficiency of the use of set-retarding superplasticizers in concrete and cement mixes for the purpose of reducing water content. Water-cement ratio was reduced from 0.6 to 0.5 for the concrete mixes and from 0.27 to 0.205 for cement pastes. Five different tests were performed: setting times, workability, compressive strength, porosity and water absorption. With the exception of workability batches, all samples were cured at 20°C, 35°C and 50°C. Three different curing regimes were employed; air curing, 3-day water curing and continuous water curing. Workability was measured both indoors (20°C + 65% RH) and or outdoors (38°C + 50% RH). Results indicate that high temperatures accelerate setting, workability loss and strength development but 28-day strength results were lower when compared to normal temperatures. The inclusion of superplasticizers improved the hardened concrete properties due to the lower w/c ratio but these improvements were smaller at high temperatures.

Set-retarding superplasticizers are widely used in hot-climate regions. The need for high workability, low w/c ratios, and prolonged setting necessitate the need for such admixtures (Alshamsi *et al.* 1992, ACI Committe 212 1990). However, the amount of published data on the influence of the use of such admixtures in hot climates on various concrete properties remains small. The scientific ground on which these admixtures are marketed are mainly based on information gathered at normal climatic conditions.

Hot climate factors (high ambient temperatures, low relative humidities, solar radiation and persistently high wind speeds) influence the properties of both fresh and hardened concretes. High temperatures accelerate setting of cements whether set-retarders are used or not (Alshamsi *et al.* 1992, Scrivener and Weiker 1992). The efficiency of some types of these admixtures in delaying setting have been found to be lower at high temperatures when compared to normal temperatures (Alshamsi *et al.* 1993). Workability on the other hand is influenced, among other factors, by water content, amount and type of admixtures, climatic conditions and time from the start of mixing. It is usually lost in two ways (Alshamsi *et al.* 1992, Alamri 1988):

1. Increase in stiffening rate of cement paste.
2. Increase in loss of mixing water as a result of evaporation or absorption by the aggregates.

The accelerated stiffening rate of cement pastes due to high temperatures results in stronger samples early in age (Alshamsi *et al.* 1992, Collepardi and Ramachandran 1992) but long-term strength (28 days or later) is hindered (Alshamsi *et al.* 1992, Alamri 1988, Price 1951). This has been attributed by some researchers to the production of weak and badly dispersed hydration products (Alamri 1988, Neville 1983). Alteration to the pore structure of such concretes also results in higher porosities, and higher permeability and water absorption characteristics (Alamri 1988, Goto and Roy 1981).

The need for proper early moist curing is paramount in hot climates for the prevention of plastic cracks and loss of essential water required for the continuation of hydration. Lack of curing reduces strength (Skanska 1981) and increases porosity (Alamari 1988) permeabilities, (Shanska 1981) and water absorption (Alamri 1988). In addition to this, the addition of superplasticizers allows the reduction of w/c ratios, hence increases strength and reduces permeability and water absorption (ACI Committee 212 1990, Klieger 1958). The amount of improvement at high temperatures needs to be highlighted in relation to that achieved at normal temperatures.

Experimental Details

1. Materials:

Cement: The cement used was ordinary portland cement conforming to BS12:1989. The fineness of the cement used was 3430 cm^2/g.

Aggregates: Both coarse and fine aggregates were used in the preparation of concrete samples. The maximum size of aggregate was 10mm. The grading of both aggregates was in accordance with BS882:1983.

Admixture: A naphthalene-based superplasticizer with mild retardation effect was used to compensate for the decrease in workability resulting from lowering w/c ratio. This admixture was based on modified lignosulfonates and polyoxycarbon acids and conformed to ASTM C494-80 types A,B, and D (chloride free).

2. Mixing and Curing:

Mixing was performed in the laboratory at 20°C ± 2°C + 65% ± 10%RH. A Pan-type mixer, vibrating table, and British standard 10 cm cubes were used in the preparation of the concrete samples. The specimens were immediately placed after mixing in the respective environments. With the exception of uncured samples, all specimens were covered with polythene sheet to minimize evaporation of mixing water. At the age of one day, samples were demoulded and placed either in water tanks at different temperatures (20°C, 35°C and 50°C) or at: 1) 20°C + 70%RH, 2) 35°C + 70%RH and 3) 50°C + 20%RH, using either normal laboratory environment or environmental chambers in which samples were either uncured or water cured for 3 days only. In the case of cement pastes, the surface was covered with plastic lid to minimize evaporation of water. Workability tests on concrete were carried out indoors (22°C ± 2°C + 65% ± 10%RH) and outdoors (35°C + 50%RH approximately). The influence of the use of set-retarding superplasticizers was manifested by adding 470 ml of it per 100 kg of cement in order to reduce the w/c ratio from 0.6 to 0.5 while maintaining a constant workability. Aggregate to cement ratio was 4.5 with 45% fines. Details of mix proportions are shown in Table 1.

Table 1. Mix proportions of both pastes and concretes

	Pastes		Concrete	
	Paste 1	Paste 2	Concrete 1	Concrete 2
Cement	400 g	400 g	400 kg	400 kg
Sand	—	—	800 kg	800 kg
Coarse aggregates	—	—	1000 kg	1000 kg
Water	108	83	240 kg	200 kg
Superplasticizer	—	4 ml	—	1.88 liters

3. Tests:

The tests that were used to assess the efficiency of the use of superplasticizers in cement Mixes are as follows:

1. Setting times of pastes using the Vicat apparatus according to BS4550: part 3: 1978.

2. Workability of concrete was assessed using the standard slump test described in BS1881: part 102: 1983. Measurements of slump were taken at 10 minutes intervals from the start of mixing. Mixes were thoroughly remixed before each test time.
3. Compressive strength using 10 cm cubes according to British Standards BS1881.
4. Total porosity: Porosity of the concrete samples was measured using small pieces (approximately 500 g) of cubes tested for strength. The equation used for the calculation of total porosity is:

   Total Porosity = $[(W_{sa}-W_d)/(W_{sa}-W_{sw})]^*$ 100% where;

   W_{sa} = weight of saturated sample in air.
   W_d = weight of oven dry sample.
   W_{sw} = weight of saturated sample in water.

5. Water Absorption: this test was performed in accordance with BS1881: part 5: 1970 with the exception that samples were 10 cm cubes. The samples, at 28 days of ages, were placed in an oven at 105 °C for three days. They were then placed in an air-dry container for one day to reach room temperature before performing the test. Water absorbed by concrete samples after immersion in water for 30 minutes ± 30 seconds were recorded.

Results and Discussion

The results of all the tests are presented in Figs. 1 to 5 and Table 1.

Setting Times:

High temperatures accelerate setting of cement (Alshamsi *et al.* 1992, Alshamsi *et al.* 1992, Scrivener and Weiker 1992, Alshamsi *et al.* 1993). Figure 1 indicates that initial and final setting times were reduced by about 50% as temperature increased from 20°C to 50°C for both pastes; with and without superplasticizers. Because of the fact that set-retarding superplasticizers increase setting times, the addition of such admixture retarded setting at all temperatures. Nonetheless, the general trend of the result indicates that the effectiveness of such admixtures decreases with increasing temperature.

Workability:

Workability loss of concrete is mainly influenced by environmental conditions as well as setting rates (Alshamsi *et al.* 1992, Alamri 1988). The results presented here clearly confirm this (Fig. 2). In addition to the accelerated rates of setting observed at high temperatures, the lower relative humidity accelerates evaporation (Alshamsi *et al.* 1992), resulting in rapid reduction in workability.

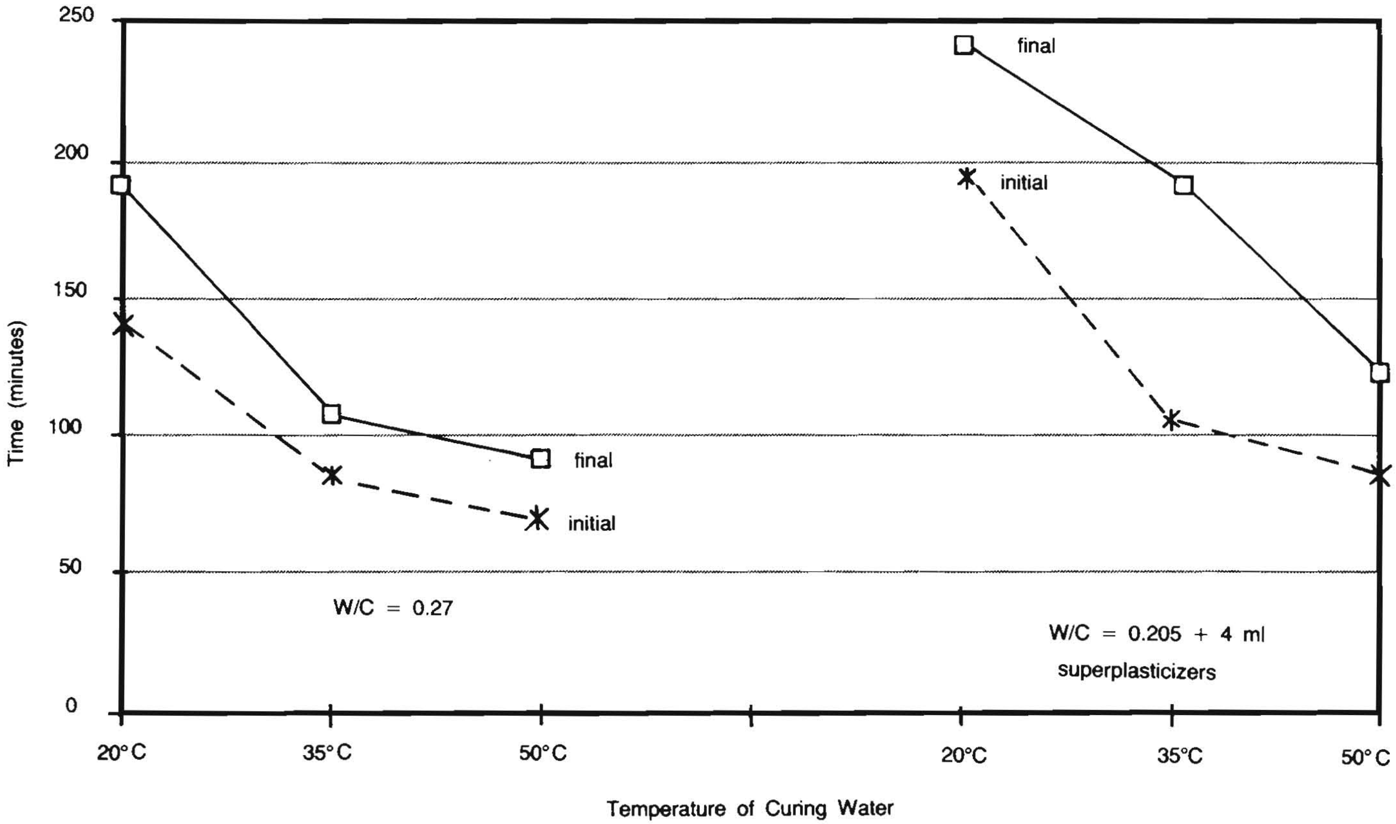

Fig. 1. The influence of curing temperature on initial and final setting times of cement pastes.

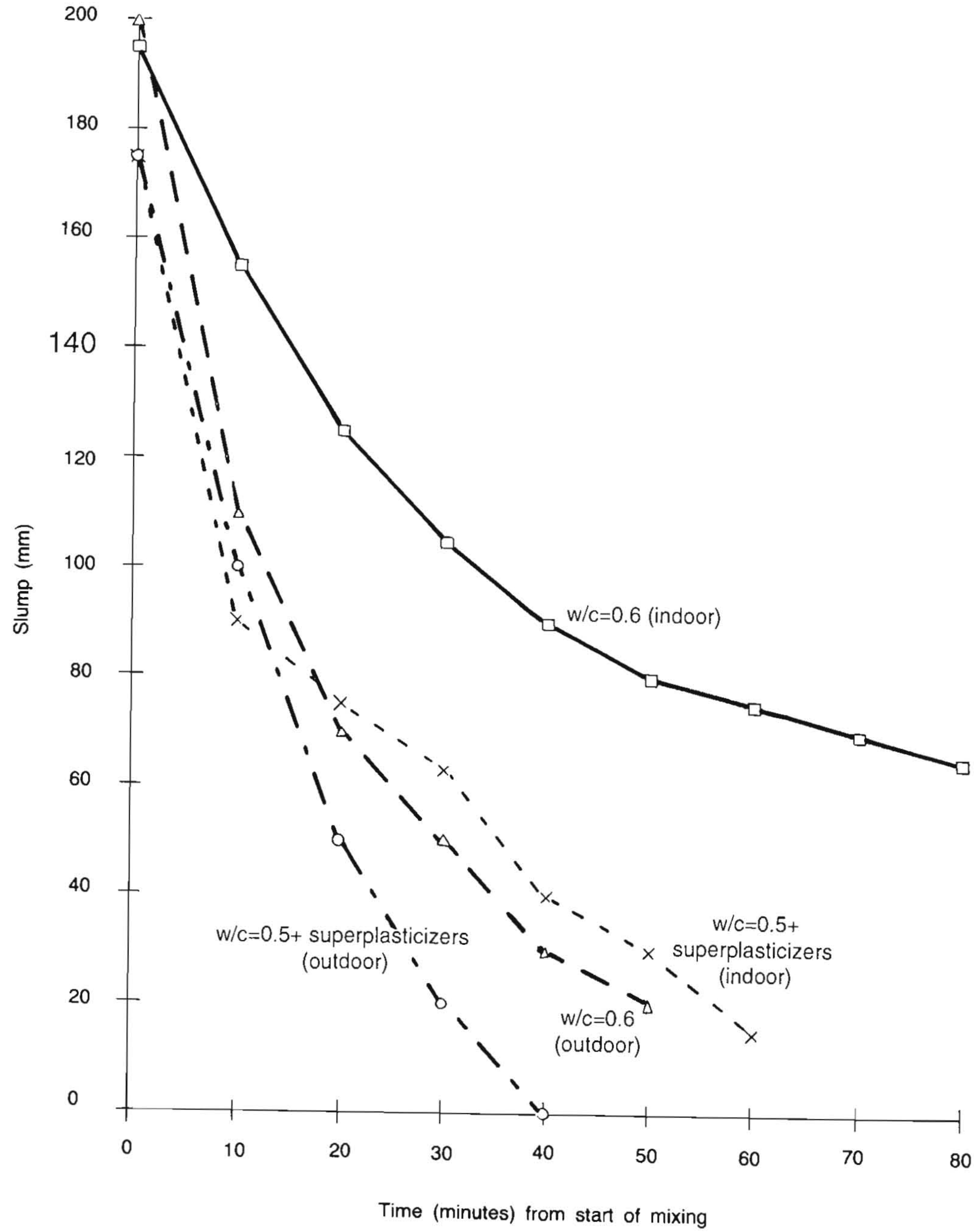

Fig. 2. The influence of ambient climatical conditions and the use of set-retarding superplasticizers on slump loss of concrete.

However, it is significant to note that mixes containing set-retarding superplasticizers were more vulnerable to the environmental condition, both indoors and outdoors, (Fig. 2), despite the fact that this type of admixture delays setting. This may be explained by either or both of the following:

1. Both water and admixture evaporate and due to the fact that mix 2 (w/c = 0.5 + superplasticizer) has less liquid substance than mix 1 (w/c = 0.6), evaporation affects mix 2 more than mix 1.
2. The efficiency of this superplasticizers at high temperatures decreases as shown earlier and as reported by Alshamsi *et al.* (1993).

Compressive Strength:

The compressive strength results are consistent with many published reports (Alshamsi *et al.* 1992, Alamri 1988, Skanska 1981). The use of superplasticizers to compensate for the reduction in workability due to the lower w/c ratio resulted in stronger samples at all ages and for all curing regimes, (Figs. 3 and 4). The rate of strength devlopment of the samples was affected by ambient temperature. High temperatures accelerated hydration resulting in stronger samples early in age (Fig. 3). However, it has been reported that high temperatures produce weak hydration products which are also poorly dispersed (Neville 1983, Goto and Roy 1981). This results in weaker samples at later ages. The results of this work confirm this whether superplasticizers are used or not.

The influence of curing type on strength was seen to be small (Fig. 4). Although these results may be seen to be in conflict with some published reports (*e.g.* Neville 1983), other reports illustrated similar trends; for example Popovics (1986) showed that when 7-days and 14-days cured samples were tested at 28 days of age, strength exceeded those of continuously cured samples. Similar behaviour has also been reported by others (Alamri 1988). A suggested explanation of such behaviour has been given by Popovis (1986) as follows:

1. Confined water within the pores of the samples exerts a internal hydrostatic pressure on hydration products when an external load is applied.
2. Drying decreases the volume of hardened cement pastes. These volume reductions result in smaller distances between surfaces in cement gel. Strength is then increased due to the increased bond between the surfaces.

In addition to this, the fineness of the cement used was relatively high (minimum required for ordinary portland cement and rapid hardening cement by BS12: 1989 are 2750 and 3500 cm^2/g respectively whereas the fineness of this cement is 3430 cm^2/g).

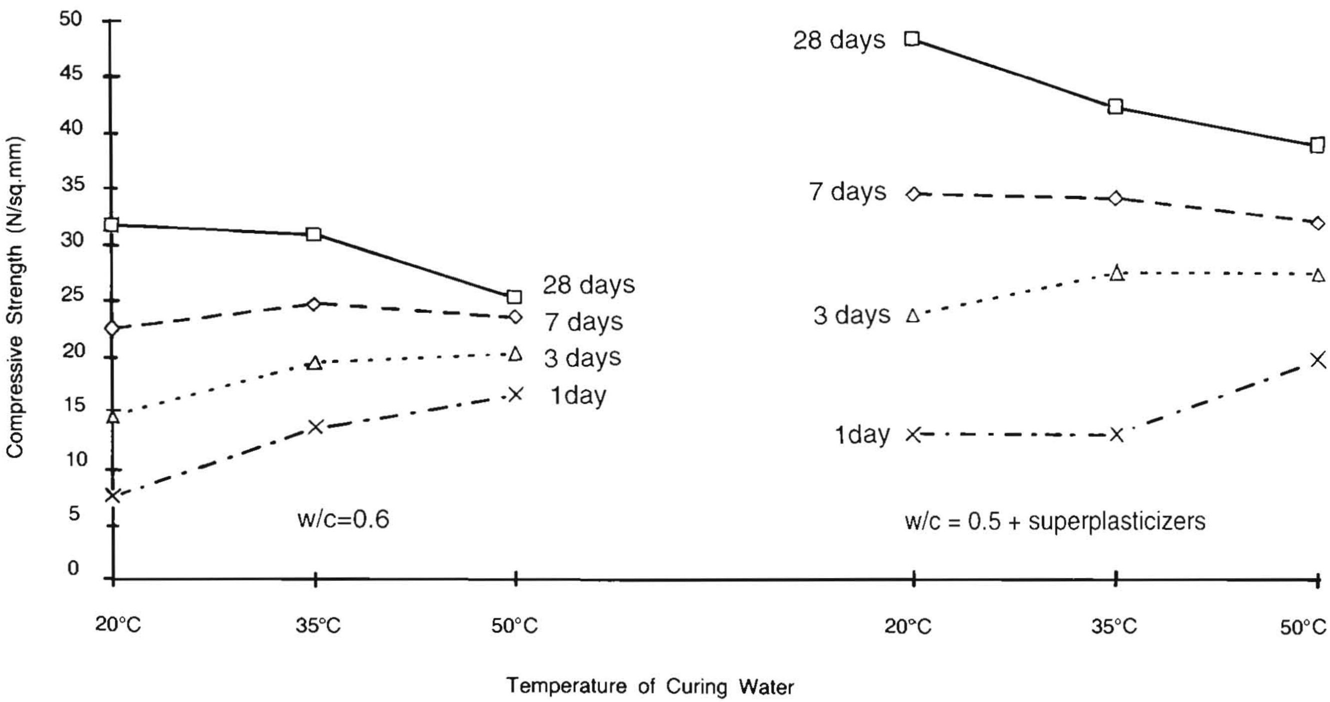

Fig. 3. Compressive strength results of water cured samples.

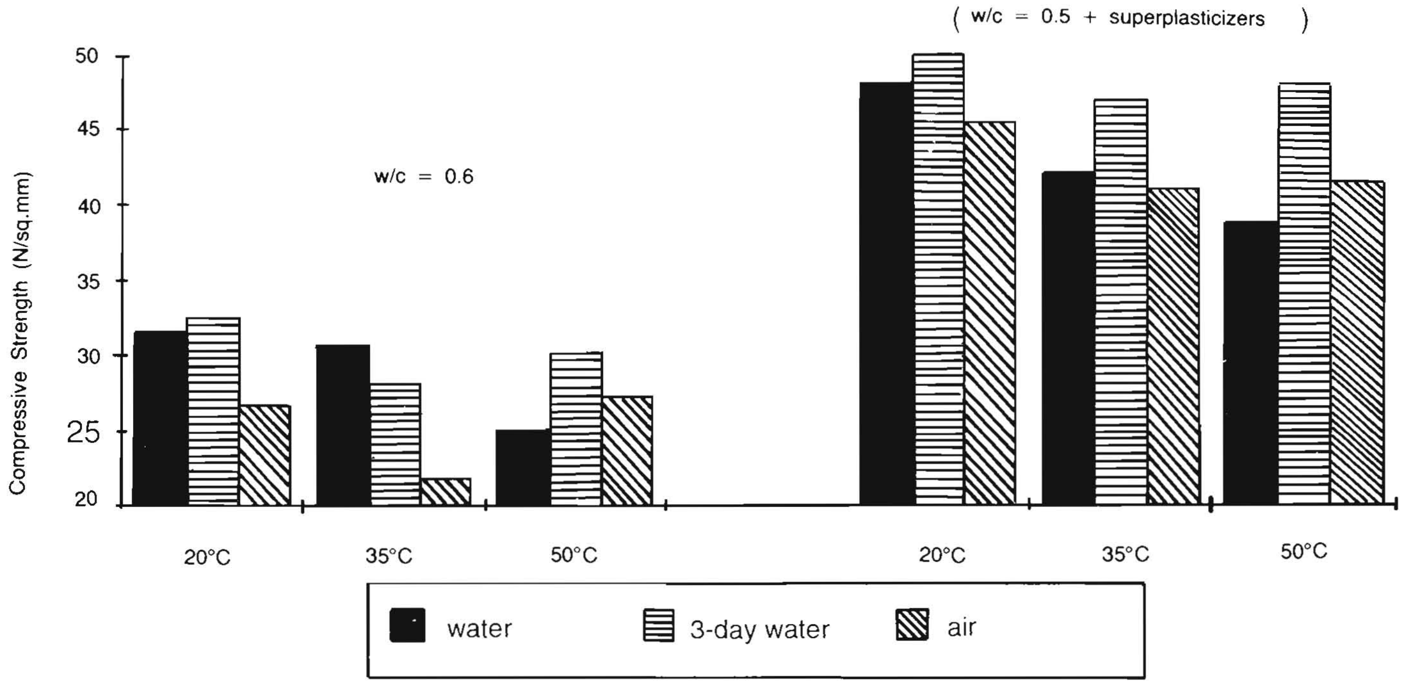

Fig. 4. The influence of curing regime on compressive strength of concrete (Testing was carried out at 28 days of age).

Fast hydration results from the increased surface area in contact with water especially when curing at high temperatures (Alshamsi *et al.* 1992). Curing for 7 days produced samples having 71%, 80%, and 93% of 28-days water cured samples respectively for mix 1. Similar results are also seen for mix 2.

Total Porosity:

The term total porosity is used to express the total pore volume in concrete. This includes the volume of gel pore, capillary pores and entrapped air. Curing temperature and the availability of sufficient moisture affect porosity as a result of the effects on the degree of hydration and the uniformity of the dispersion of the hydration products. Longer durations of moist curing lower porosity, (Table 2). On the other hand, the influence of temperature on total porosity is not always clear. This may be attributed to the fact that high temperatures may decrease the total porosity due to the increase in hydration rate whereas at the same time, it increases the total porosity due to the badly dispersed hydration products (Neville 1983, Goto and Roy 1981).

Table 2. Total porosity results (% of volume)

Mix	**W/C = 0.6**			**W/C = 0.5 + Superplasticizers**		
Environment	20°C+70RH	35°C+70%RH	45°C+20%RH	20°C+70RH	35°C+70%RH	45°C+20%RH
Water-cured	10.69	11.50	11.44	08.47	09.84	09.85
3-day cured	10.92	11.61	12.31	10.40	11.16	11.79
Air-cured	12.06	12.69	12.51	11.43	12.05	12.36

Superplasticizers reduce the total porosity when it is used to reduce w/c ratio. Furthermore, the addition of this type of admixtures disperses cement particles more uniformly throughout the mix resulting in lower total porosity for mix 2 as opposed to mix 1.

Water Absorption:

Lower w/c ratios lower porosity (Alamri 1988, Neville 1983) and reduces pore sizes (Alamri 1988, Roy and Idron 1982) resulting in more blocked pores and lowering water absorption. Fig. 5 indicates a reduction in water absorption when comparing mix 2 (w/c = 0.5 + superplasticizers) to mix 1 (w/c = 0.6).

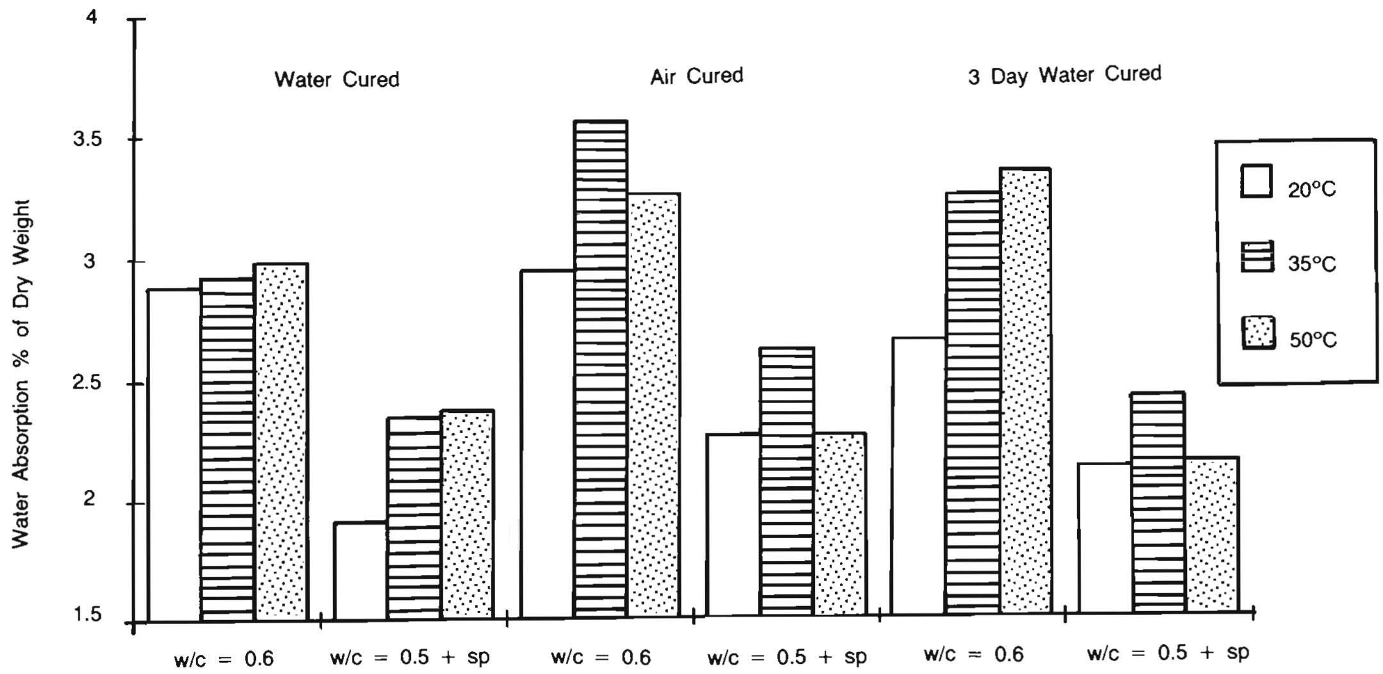

Fig. 5. The influence of curing regimes on water absorption results cured at three different environmental conditions. Testing was carried out at 28 days of age (sp = superplaticizers).

High temperatures influence the dispersion of the hydration products (Goto and Roy 1981). The high permeability reported by many researchers at high temperature has been attributed to the poor pore structure resulting from hydration at high temperatures (Alamri 1988, Goto and Roy 1981). The results presented here support this observation. It is interesting, however, to note that the reduction in water absorption experienced by lowering the w/c ratio was smaller at high temperatures (35°C and 50°C as opposed to 20°C).

Conclusions

The following conclusions can be drawn from the results presented here (based on tests using a single set-retarding superplastisizers).

1. Setting of cement is accelerated by curing at high temperatures. The amount of retardation experienced at high temperature due to the use of a set-retarding superplasticizer was less than that observed at normal temperatures.
2. The inclusion of a set-retarding superplasticizers in concrete accelerates workability loss. This loss is even more accelerated when casting occurs in a hot-dry environment.
3. Compressive strength, total porosity and water absorption of hardened concrete were improved by the use of this type of admixture (when used to reduce the w/c ratio). The improvements were smaller at high temperatures than at normal temperatures.

Acknowledgements

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تأثير استخدام مؤجلات الشك مقللات الماء في الأجواء الحارة

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قسم الهندسة المدنية ـ كلية الهندسة ـ جامعة الامارات العربية المتحدة
العين ـ ص. ب (١٧٥٥٥) ـ دولة الامارات العربية المتحدة

يهدف هذا البحث إلى دراسة مدى كفاءة استخدام اضافات الخلط المؤجلة للشـك المقللة للماء (Set-retarding Superplastiaeses) لغـرض تقليـل كميـة مـاء الخلطات الاسمنتيـة حيث تم تخفيض نسبـة المـاء إلى الاسمنت من 0.600 إلى 0.500 للخلطات الخرسانية مع المحافظة على قيمة ثابتة لهبـوط الخرسـانة (Slump of Concrete) ومن 0.270 إلى 0.205 لخلطات عجائن الاسمنت مع المحافظة عـلى قيمة القوام (Consistency) القياسية حسب المواصفات البريطانيـة عند استعمـال هذا النوع من المحـاليل، وقـد تم تقييم هذه الكفـاءة بواسـطة خمسة اختبـارات مختلفة كالتالي:

١ ـ زمن الشـك الابتـدائي وزمن الشـك النهـائي (Initial and Find Setting Times) وقد تم قياسهما بواسطة جهاز فيكات (Vicat Apparatus) بما يتوافق مع المواصفة البريطانية BS 4550:Part 3:1978 .

٢ ـ امكانية التشغيل: وقد تم قياسها بواسطة اختبار هبوط الخرسانة (Concrete Slump Test) حسب المواصفة البريطانية BS 1811:Part 102:1983 كل (١٠) دقائق لهدف إيجاد علاقة بين امكانية التشغيل وعمر الخلطة.

٣ ـ مقاومة الخرسانة للضغط بإستخدام مكعبات ١٠سم × ١٠سم × ١٠سم
٤ ـ المسامية حيث تم قياسها بواسطة عينات خرسانية تم أخذها من لب المكعبات التي تم اختبارهما لقياس مقاومة الضغط ـ بإستخدام المعادلة التالية :

$$\text{Total Porosity} = \frac{W_{sa} - W_d}{W_{sa} - W_w}$$: المساحية

علماً بأن :

W_{sa} = وزن العينة في الهواء وهي مشبعة بالماء .
W_{sw} = وزن العينة في الماء – وهي مشبعة بالماء .
W_d = وزن العينة بعد تجفيفها تماماً بواسطة فرن عند ١٠٥م° .

٥ ـ امتصاص الماء وقد تم اجراء هذا الاختبار بما يتوافق مع المواصفة البريطانية BS 1811:Part 5:1970 وبإستخدام مكعبات ١٠سم × ١٠سم × ١٠سم كعينات للإختبار حيث تم عند ٢٨ يوم تجفيف العينات بواسطة فرن درجة حرارته ١٠٥°م لمدة (٣) أيام ، وبعد تبريد العينات بوضعها في إناء مغلق لمدة يوم واحد في بيئة المختبر العادية تم قياس وزن الماء الممتص بواسطة العينات وذلك بغمرها في ماء درجة حرارته ٢٠°م لمدة ٣٠ دقيقة ± ٣٠ ثانية .

وبإستثناء الخلطات المستخدمة لقياس امكانية التشغيل فقد تم حفظ جميع العينات في ٣ بيئات مختلفة كالتالي : ٢٠°م + ٧٠٪ رطوبة نسبية ، ٣٥°م + ٧٠٪ رطوبة نسبية و٥٠°م + ٢٠٪ رطوبة نسبية في حين تم تقسيم العينات في كل بيئة الى (٣) أقسام حسب ظروف المعالجة كالتالي :
١ ـ عينات لم يتم معالجتها اطلاقاً .
٢ ـ عينات تمت معالجتها لمدة الأيام الثلاثة الأولى من عمرها .
٣ ـ عينات تمت معالجتها بصورة مستمرة .

أما فيما يتعلق بإمكانية التشغيل بـواسطة اختبـار الهبوط فقـد تم قياسهـا في بيئتين هما :

١) بيئة المختبر الداخلية (٢٠°م + ٧٠٪ رطوبة نسبية) .
٢) البيئة الطبيعية الخارجية لمدينة العين (٣٨°م + ٥٠٪ رطوبة نسبية) .

وقـد دلَّت النتائـج على ان درجـات الحرارة المـرتفعة تعجـل معدل الشـك ومعدل فقدان امكانية التشغيل (الهبوط) وتقلل مقـاومة الخـرسانـة للضغط عند (٢٨) يوم لجميع الخلطات المستخـدمة بـالرغم من ان درجـات الحرارة المـرتفعة تزيد من مقـاومة الخـرسانـة للضغط عند يـوم واحد أو (٣) أيـام ، وعند مقـارنة الخلطات الخرسانيـة المحتويـة على مؤجـلات الشك مقللات المـاء مع الخلطات الأخرى غير المحتوية على هذا النوع من اضافات الخلط فقد تبين من النتائـج ان هذه الاضافات تطيل زمن الشك في جميع البيئات وتحسن من خواص الخرسـانة المتصلبـة بسبب انخفاض نسبـة الماء إلى الاسمنت ، أمـا فيـما يتعلق بـإمكـانيـة التشغيل فإن استخدام هذا النوع من الاضافات كان لـه أثراً سلبيـاً على معـدل فقدان الهبوط حيث تسببت في معدل فقدان أسرع .