Fresh Properties Of Self-Compacting Concrete With Time

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Abstract

Most studies on self-compacting concrete (SCC) reported in the literature deal with mixture proportioning and characterization of fresh and hardened concrete properties with limited information on the change of workability characteristic of SCC with time. The fundamental objective of this study is to evaluate the effect of time and environmental temperatures on fresh properties (filling ability, passing ability and segregation resistance) and compressive strength of self compacting concrete. In this study, one SCC mix designed according to ACI Committee 237 and mixed under two different environmental temperatures (22 and 43 ^{o}C). Fresh properties of self compacting concrete were determined by slump flow, J-ring, column segregation and visual stability index and repeated at intervals of 15 minutes after brief remixing. The results showed that the slump flow and passing ability of SCC mixtures were significantly lost within 30 minutes and beyond after mixing. Except the segregation resistance of SCC increased as the elapsed time was increased. The results also showed that the addition of 0.5% by weight of powders superplasticizer after 30 minutes, from the end of mixing, brought the SCC mix back to its initial fresh properties and maintaining a further workability period of about 15 minutes. Furthermore, the compressive strength of SCC decreased when the slump flow less than 550 mm.

Keyword: SCC, slump flow, J-ring, column segregation, visual stability index, Elapse time, Environmental temperatures

الخلاصة:

اغلب الدراسات التي تناولت الخرسانة ذاتية الرص قد تعاملت مع نسب خلط المواد والخواص الطرية والمتصلبة للخرسانة مع معلومات محدودة عن تغير قابلية التشغيل للخرسانة ذاتية الرص نتيجة الزمن ودرجة حرارة المحيط. تهدف هذه الدراسة إلى بيان تأثير كل من الزمن ودرجة حرارة المحيط على الخواص الطرية ومقاومة الانضغاط للخرسانة ذاتية الرص. تم استعمال خلطة خرسانية واحدة مصممة حسب لجنة المعهد الامريكي للخرسانة 237 وتم خلطها تحت درجة حرارة محيط مختلفة 22 و 43 ^{o}س ومن ثم فحص الخواص الطرية وإعادتها كل 15 دقيقة مع اعادة خلط الخرسانة قبل الفحص. أظهرت النتائج بان هناك فقدان كبير في انسياب الهطول وقابلية المرور للخرسانة ضمن 30 دقيقة وما بعدها من نهاية الخلط. في حين إن مقاومة الانعزال للخرسانة قد ازدادت مع مرور الزمن المنقضي. كذلك أظهرت النتائج بان اضافة 5% ملدن متفوق (نوع كيلينيوم 51) من وزن المواد الاسمنتية بعد 30 دقيقة من نهاية الخلط ادى الى رجوع الخرسانة الى خواصها الطرية الاولية والاحتفاظ بها لفترة حوالي 15 دقيقة. اضافة الى ذلك لوحظ انخفاض في مقاومة الانضغاط للخرسانة عندما يكون انسياب الهطول اقل من 550 ملم.

Introduction

Self-compacting concrete (SCC) represents one of the most outstanding advances in concrete technology during the last decade. Due to its specific properties, SCC may contribute to a significant improvement of the quality of concrete structures and open up new fields for the application of concrete. SCC, as defined by **ACI Committee 237 (2007)** is "highly flowable, nonsegregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation"

At first developed in Japan in the late 1980s, SCC meanwhile is spread all over the world with a steadily increasing number of applications. The use of SCC offers many benefits to the construction practice: the elimination of the compaction work result in reduced costs of placement, a shortening of the construction time and therefore in an improved productivity. The application of SCC also leads to a reduction of noise during casting, better working conditions and the possibility of expanding the placing times in inner city areas. Other advantages of SCC are an improved homogeneity of the concrete production and the excellent surface quality without blowholes or other surface defects.

Fresh SCC must possess the key properties including filling ability, passing ability and resistance to segregation at required levels. The filling ability is the ability of the SCC to flow into all spaces within the formwork under its own weight. Without vibrating the concrete, SCC has to fill any space within the formwork and it has to flow in horizontal and vertical directions without keeping air entrapped inside the concrete or at the surface. Passing ability is the ability of the SCC to flow through tight openings such as spaces between steel reinforcing bars, under its own weight. Passing ability is required to guarantee a homogenous distribution of the components of SCC in the vicinity of obstacles. The resistance to segregation is the resistance of the components of SCC to migration or separation and remains uniform throughout the process of transport and placing **Venkateswara Rao et al., (2010)**.

A concrete mix can only be classified as self-compacting concrete if the requirements for all three characteristics are fulfilled.

Research Significance

Most studies on SCC reported in the literature deal with mixture proportioning and characterization of fresh and hardened concrete properties with limited information on the change of workability characteristic of SCC with time. The fundamental objective of this study is to evaluate the effect of time and environmental temperatures on fresh properties (filling ability, passing ability and segregation resistance) and compressive strength of self compacting concrete.

Materials

1- Cement

Ordinary Portland cement manufactured by the new cement plant of Kufa was used throughout the experimental work. This cement complied with the **Iraqi specification (I.O.S.) No.5/1984.** The chemical and physical properties are given in Tables (1) and (2) respectively.

2-Fine Aggregate

Natural sand from AL-Akhaider region was used throughout this work. Table (3) shows the grading of the fine aggregate and the limits of the **Iraqi specification No.45/1984**. Table (4) shows the physical and chemical properties of fine aggregate.

3- Coarse Aggregate

Crushed gravel with maximum size of 20 mm from AL-Nibaee region was used. The gravel used conforms to the Iraqi specification **No.45/1984.** Table (5) shows the grading of the coarse aggregate. Table (6) shows the physical and chemical properties of the coarse aggregate.

4- Water

Tab water was used throughout this work for both mixing and curing concrete

5- High Range Water Reducing Admixture (HRWRA)

A copolymer based superplasticizer which is known commercially (GLENIUM 51) was used throughout this investigation as a (HRWRA). It is a third generation of superplasticizers and it complies with ASTM 494-2003 Type F. Table (7) indicates the technical description of the aqueous solution of superplasticizer used throughout this study.

6- Limestone Powder

Finely crushed limestone which has been brought from local market with specific gravity 2.69 was used. It is used in the concrete mixes after passing a 75 µm sieve (No. 200). According to **EFNARC (2002),** the fraction less than 0.125 mm will be of most benefit. The chemical composition of this limestone is shown in Table (8).

Mix Design:

The method of mixture design for SCC used in this study is based on ACI committee 237 (2007) guideline for SCC mixture proportions, as seen in Table (9).

Tables (10) and (11) show the mix proportions by weight and volume, respectively, used in this study.

Mixing Sequence:

The following are examples of three mixing sequences that can be adopted for SCC, **Khayat and Mitchell, (2008).**

Mixing sequence A

1-water+coarse aggregate+sand

2-cement+supplementary cementitious materials of filler

3-HRWRA with some delay between stages

Mixing sequence B

1-water+ cement + supplementary cementitious materials of filler

2- coarse aggregate+sand

3- HRWRA with 20 sec. delay between stages

Mixing sequence C

1-aggregate+water+1/2 HRWRA and any other admixtures

2- cement+supplementary cementitious materials of filler

3-remaining HRWRA with 5-10 sec. between stages 1 and 2 and 30 sec between stages 2 and 3.

Tests:

Fresh Concrete Tests:

Many different test methods have been developed in attempts to characterize the properties of SCC. In this study, the fresh properties of SCC were evaluated according to ASTM test methods.

Slump Flow Test:

A sample of freshly mixed concrete is placed in a slump mold in one lift, without tamping or vibration. The mold is raised and the concrete is allowed to spread. After the concrete stops spreading, diameter of the concrete is measured in two directions approximately perpendicular to each other. The average of the two diameters is the slump flow, **ASTM C 1611**.

Visual Stability Index (VSI):

The VSI test ranks the dynamic stability of the SCC on a scale of 0-3, with 0 indicating highly stable SCC and 3 indicating unacceptable SCC. The rating is based on the visual inspection of the slump flow patty immediately after it stops flowing. ASTM is working on selecting photographs to be representative of each ranking as will be mentioned latter, **GRACE, 2005**.

J-Ring Test:

A sample of freshly mixed concrete is placed in a slump mold that is concentric with the J-ring in one lift without tamping or vibration. The mold is rised and the concrete is allowed to pass through J-ring and spread. The diameter of the concrete is measured in two directions approximately perpendicular to each other. The average of the two diameters is the J-ring flow. The test is repeated without the J-ring to obtain the slump flow using the slump mold in the same manner as the associated J-ring test. The difference between the slump flow and J-ring flow indicates the passing ability of the concrete, **ASTM C 1621**.

Column Segregation Test:

A sample of freshly mixed concrete is placed in a cylindrical mold (column) without tamping or vibration and allowed to stand undisturbed for a specified duration. The mold has three sections representing different levels of the mold. Concrete samples from the top and bottom section and washed on a No. 4 (4.75 mm) sieve . The masses of saturated-surface dry (SSD) coarse agreggate in the top and the bottom sections are determined. Static segregation is calculated using the following equation, **ASTM C 1610**.

Percent static segregation, $$S\% = 2\left[\frac{M_{bottom} - M_{top}}{M_{bottom} + M_{top}}\right] \times 100 \quad \text{if } M_{bottom} > M_{top} \qquad \text{------(1)}$$

$$S\% = [0] \qquad \text{if } M_{bottom} < M_{top} \qquad \text{------(2)}$$

Where:

M_{bottom}= mass of aggregate retained on No.4 sieve from bottom coloumn section

M_{top} = mass of aggregate retained on No.4 sieve from top coloumn section

Hardened Concrete Test:

Compressive Strength Test:

For the hardened SCC, the compressive strength test was carried out according to **BS. 1881: part 116:1983.**

Results and Discussion:

Visual Stability Index (VSI):

The appearance of the test mixture was compared to pictures shown in **Fig.(1)** and descriptions of the surface bleed, mortar halo, and segregation distribution. Results show that VSI for SCC mixes varied between 0 and 1. A VSI rating of 0 or 1 was given to a stable SCC mixture with no evidence of segregation. **Fig. (2)** shows the SCC mixture with a given VSI of 0. This mix exhibits high quality with no indication of bleeding, segregation or separation. Very good aggregate distribution and materials carried to the outer edge of the slump flow.

Fresh Properties:

The fresh properties tests of SCC mixes were repeated every 15 minutes after brief re-mixing.

From the results shown in Tables (12) and (13) and Figs. (9), (10) and (11) it can be seen that, when the test age were 0 and 15 minutes, the slump flow, J-ring and column segregation tests varied from 580 to 610 mm , 10 to 20 mm and 13 to 15 % respectively. These results show that the self compacting concrete used was complied with the requirements of ACI Committee 237 as seen in Table (14). When the test age was 15 minutes, the slump flow and passing ability of SCC mixtures were slightly lost**.** However, the slump flow and passing ability of SCC mixtures lost significantly within 30 minutes and beyond after mixing. Except the segregation resistance of SCC increased as the elapsed time was increased due to gradual stiffening process. Figs. (3) and (4) show the flowability of SCC mixtures after 0 and 30 minutes from the end of mixing respectively. Figs. (5) and (6) also show the passing ability of SCC mixtures through an obstacle after 0 and 30 minutes from the end of mixing respectively. The decrease in slump flow, within

30 minutes and above after mixing, has also been observed by **Petersson, (1998),** and **Aarre and Domone (2004)**.

Test results also showed that the environmental temperatures had a notable effect on the fresh properties of SCC. Figs. (9) and (10) show that the slump flow and passing ability of 43 ^{o}C seriously lost more than 22 ^{o}C.

The results shown in Fig. (12) indicated that the addition of 0.5% by weight of powder superplasticizer in concrete after 30 minutes, from the end of mixing, brought the SCC mix back to its initial fresh properties and maintaining a further workability period of about 15 minutes.

Compressive Strength:

Fig. (13) shows the compressive strength for SCC as a function of the elapse time and environment temperatures. At the test ages of 0 minute and 15 minutes after the end of mixing with environment temperature of 22 ^{o}C, slump flow greater than 550 mm, there was no difference in the compressive strength because SCC mix should fully consolidate without the need for vibration. Beyond 15 minutes, the compressive strength drop significantly and at 30 minutes and 45 minutes, the reduction in compressive strength were 16 and 34 percent respectively. The drop in the compressive strength of SCC is due to the fact that the mix has lost its ability to self-compact. Furthermore, at the test age of 0 minute with environment temperature of 43 ^{o}C, slump flow greater than 550 mm, the compressive strength value was about 33.6 MPa. As the elapse time was increased to 15 minutes, slump flow 500 mm, the reduction in strength was 11 percent. Beyond 15 minutes, the strength continued to drop significantly and at 30 and 45 minutes, the reduction in strength were 23 and 42 percent. It is obvious from these results and Fig.(14) that the compressive strength of SCC decreased when the slump flow less than 550 mm. This is attributed to the fact that the SCC mixes with a slump flow of less than 550 mm has lost some of its ability to flow into all spaces within the molds under its own weight and may require minor vibration.

Conclusions and Suggestions:

With the limitations of materials and testing program employed in this study, some important conclusions can be described in the following sections,

1) The slump flow and passing ability of SCC mixtures were slightly lost between 0 minute and 15 minutes after the end of mixing. However, when the test age were 30 minutes and beyond, the slump flow and passing ability of SCC mixtures were significantly lost.
2) Segregation resistance of SCC increased as the elapsed time was increased.
3) The environmental temperatures had a notable effect on the flowability and passing ability of SCC.
4) The addition of 0.5% by weight of powder superplasticizer after 30 minutes, from the end of mixing, brought the SCC mix back to its initial fresh properties and maintaining a further workability period of about 15 minutes.
5) The compressive strength of SCC drop significantly when the mix has lost its flowabilty.
6) SCC mixes with a slump flow of less than 550 mm may require minor vibration.
7) The change in time of fresh properties of the SCC is an important criterion which will be needed further researches.

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Table (1): Chemical Composition of Cement

Oxide	%	I.O.S. 5:1984 Limits
CaO	60.79	—
SiO_2	20.75	—
Fe_2O_3	3.00	—
Al_2O_3	5.20	—
MgO	4.11	5.0 max.
SO_3	2.32	2.8 max.
L.O.I	1.90	4.0 max.
L.S.F	0.88	0.66-1.02
I.R	1.1	1.5 max.
Compound Composition %		
C3S	47.26	----
C2S	21.39	----
C3A	11.35	----
C4AF	9.12	----

Table (2): Physical Properties of Cement

Physical Properties	Test Results	I.O.S. 5:1984 Limits
Fineness, Blaine, cm^2/gm	2810	2300 min.
Setting Time: Vicat apparatus Initial hrs: min. Final hrs: min	 2:10 3:30	 00 :45 min. 10 :00 max.

Soundness (Autoclave expansion),%	0.22	0.8 (Max.)
Compressive Strength MPa 3-days 7-days	 18 27	 15 min. 23 min.

Table (3): Grading of Fine Aggregate

Sieve Size (mm)	Passing %	I.O.S. 45:1984 Limits Zone (3)
10	100	100
4.75	98	90-100
2.36	89	85-100
1.18	82	75-100
0.60	69	60-79
0.30	28	12-40
0.15	5	0-10

Table (4): Physical and Chemical Properties of Fine Aggregate

Physical Properties	Test Results	I.O.S. 45:1984 Limits
Specific gravity (S.G)	2.65	—
SSD loose density (kg/m^3)	1595	—
Absorption %	1	—
Sulfate content (SO3)%	0.4	≤ 0.5
Clay %	2	≤ 3.0

Table (5): Grading of Coarse Aggregate

Sieve Size (mm)	Passing %	I.O.S. 45:1984 Limits
37.5	100	100
20	100	95-100
10	60	30-60
5	6	0-10

Table (6): Physical and Chemical Properties of Coarse Aggregate

Physical Properties	Test Results	I.O.S. 45:1984 Limits
Specific gravity (S.G)	2.61	—
SSD loose density (kg/m^3)	1520	—
Absorption %	0.6	—
Sulfate content (SO3)%	0.08	≤ 0.1
Clay %	0.6	≤ 1.0

Table (7): Typical Properties of Superplasticizer

Form	Viscous liquid
Colour	Dark brown
Relative density	1.1 @ 20c°
Viscosity	128 ± 30 CPS @ 20c°
pH	6.6

Table (8): Chemical Analysis of Limestone Powder

Oxide	%
CaO	52.76
Al2O3	0.70
Fe2O3	0.17
SiO2	1.40
MgO	0.10
Na2O+K2O	—
L.O.I	40.60
SO3	0.91

Table (9): Mixtures Proportions Given by ACI 237 Committee

Absolute volume of coarse aggregate	28 to 32%
Paste fraction	34 to 40 % (total mixture volume)
Mortar fraction	68 to 72 %(total mixture volume)
Typical cement (powder content)	383 to 470 kg/m^3

Table (10): Mix Proportions of SCC (kg/m^3)

Mix	C	FA	CA	LSP	W	SP	W/p
MI	375	874.5	783	100	214	9.5	0.45

C: cement **FA:** fine agg. **CA:**coarse agg. **LSP:** limestone powder **W:** water
SP: superplasticizer **W/P:** water/powder ratio

Table (11): Mix Proportions of SCC by Volume (m^3/m^3)

Mix	C	FA	CA	LSP	W	SP	W/p
MI	0.12	0.33	0.3	0.037	0.214	0.0086	1.36

Table (12): Results of Fresh Properties of SCC (Environmental Temperature at 22 ^oC)

mix	Test age	Slump flow	J-Ring		Column segregation
		D (mm)	DJ (mm)	(D-DJ) mm	S%
MI	**0 minute**	610	600	10	15
	15 minutes	550	510	40	12
	30 minutes	400	310	90	10
	45 minutes	310	300	-	7

	Addition of superplasticizer of 0.5% by weight of powder				
	30 minutes	600	570	30	14
	45 minutes	560	510	50	13

Table (13): Results of Fresh Properties of SCC (Environmental Temperature at 43 ^{o}C)

mix	**Test age**	**Slump flow**	**J-Ring**		**Column segregation**
		D (mm)	**DJ (mm)**	**(D-DJ) mm**	**S%**
MI	**0 minute**	580	560	20	13
	15 minutes	500	450	50	10
	30 minutes	360	300	60	8
	45 minutes	300	300	-	6
	Addition of superplasticizer of 0.5% by weight of powder				
	30 minutes	570	540	30	14
	45 minutes	505	465	40	11

Table (14): Requirements of ACI Commettee 237

Property	**Requirements**	**Tests methode**
Slump Flow	Less 550 mm, 550 to 650 mm and greater than 650 mm. The required slump flow value will vary depending on the workability needed for a certain application or project.	ASTM C1611
J-Ring	The difference between J-ring flow and the slump flow must not exceed 50mm	ASTM C1621
Column Segregation	Static Segregation must not exceed 15%	ASTM C1610

Table (15): Results of Compressive Strength Test for SCC

Mix	**Environmental temperature**	**Compressive Strength (MPa) -28 days**			
		0 minute	**15 minutes**	**30 minutes**	**45 minutes**
MI	**22 ^{0}C**	31.3	31.5	26.5	20.9
	43 ^{0}C	33.6	29.9	25.6	19.3

Fig. (1) VSI test ranks the stability of the SCC on a scale of 0-3

Fig.(2) Stable SCC mixture, no evidence of segregation neither water bled can be seen in the picture (VSI of 0).

Fig.(3) Slump flow of SCC– 0 minute after mixing

Fig.(4) Slump flow of SCC– 30 minutes after mixing

Fig.(7) Column segregation resistance test of SCC

Fig.(8) SCC lost its ability to flow into all spaces within the mold

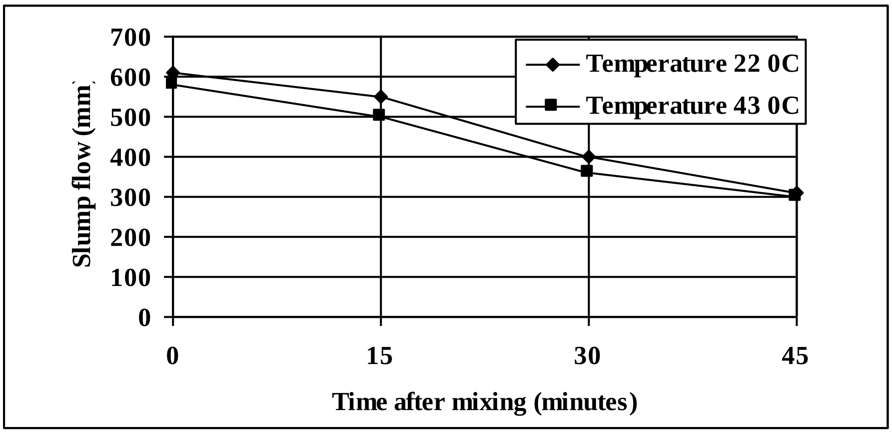

Fig.(9) Effect of elapsed time and environmental temperatures on slump flow of SCC

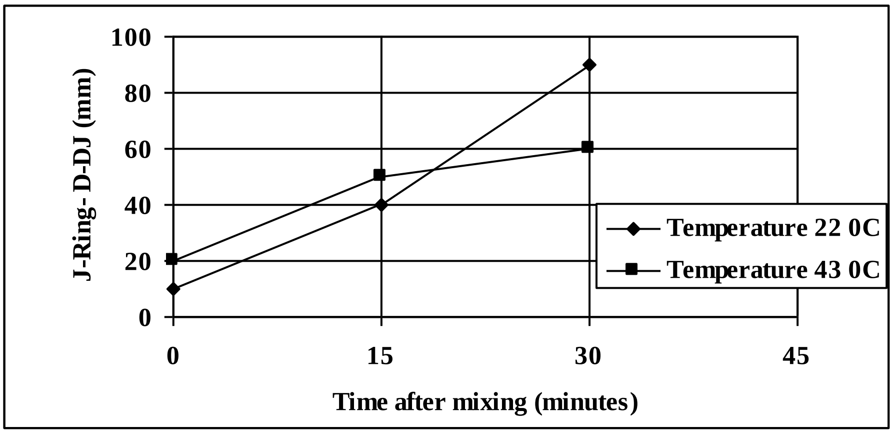

Fig.(10) Effect of elapsed time and environmental temperatures on passing ability of SCC

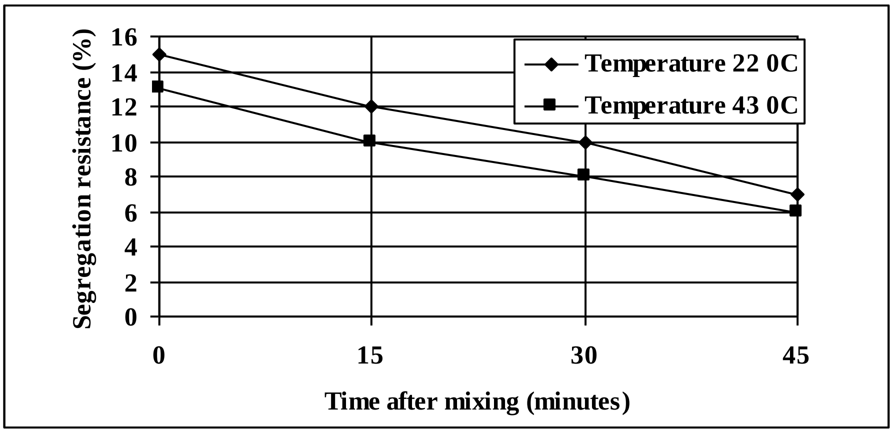

Fig.(11) Effect of elapsed time and environmental temperatures on segregation resistance of SCC

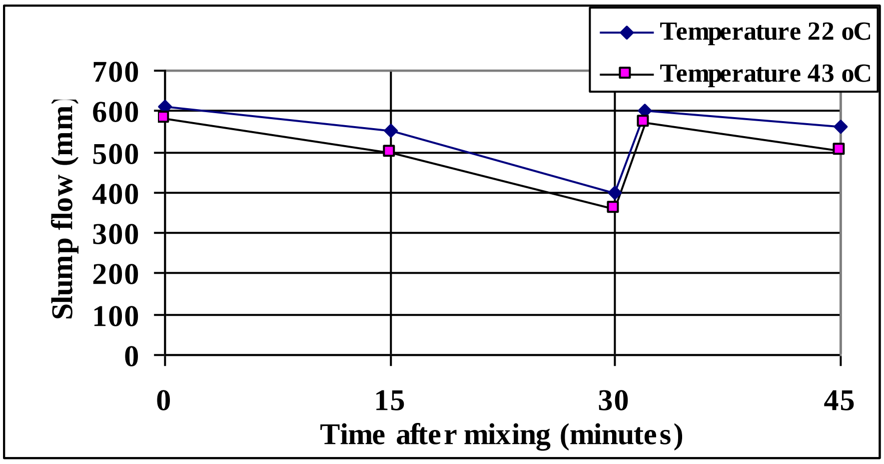

Fig.(12) Effect of additional dosage of superplasticizer after 30 minutes on slump flow of SCC

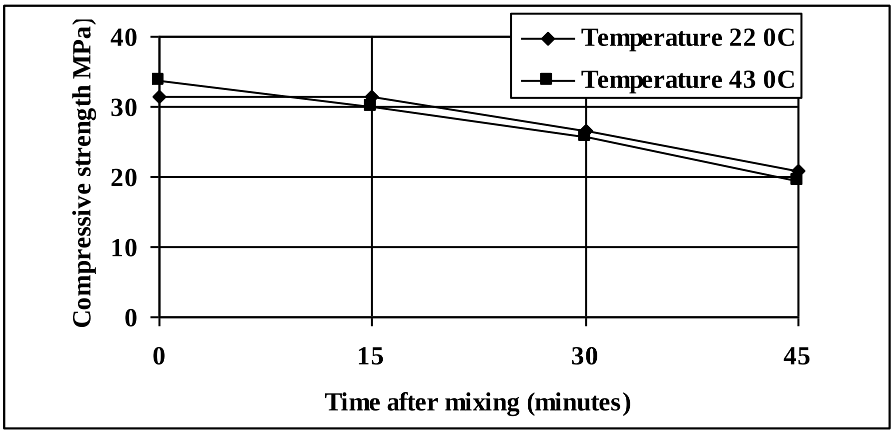

Fig.(13) Effect of elapsed time and environmental temperatures on compressive strength of SCC

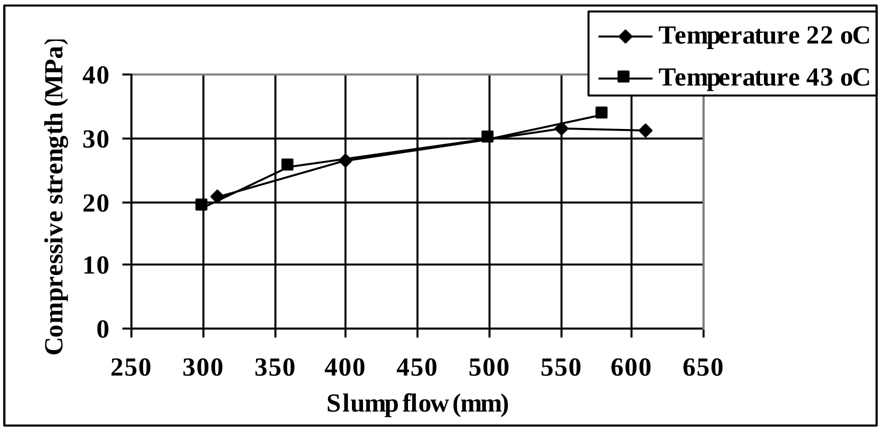

Fig.(14) Relationship between compressive strength and slump flow of SCC with environmental temperatures of 22 ^{o}C and 43 ^{o}C .