Production of Self-Compacting Concrete Using Limestone Powder

إنتاج خرسانة ذاتية الرص باستعمال مسحوق الحجر الجيري

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Abstract:

Self-compacting concrete (SCC) is a very important advance in the concrete technology in recent time. It is a new type of high performance concrete with the ability of flowing under its own weight and without the need of vibrations. Due to its specific properties, SCC may contribute to a significant improvement of the quality of concrete structures and open up new field for the application of concrete. This study aims to check whether the fresh properties of self compacting concrete mixed by the Nan Su et al., [1] method and using limestone filler comply with the requirements specified by the ACI Committee 237. In this study, four values of cement content 200, 250, 300 350 kg/m^3 are used. The maximum aggregate size of 20 mm was used. The contents of limestone powder for each cement content were 165, 139, 116, and 96 kg/m^3 respectively. Fresh performance of self compacting concrete was determined by slump flow, J-ring and column segregation. The results showed that the workability of all studied mixes is good, with slump flow diameter range between 570 to 630 mm. The difference between slump flow diameter and J-ring diameter is not exceed 50 mm, while the segregation resistance range between 10 and 15%. These results showed that the self compacting concrete used was complied with the requirements specified by the ACI Committee 237. The results also showed that the volume of coarse aggregate, paste fraction, mortar fraction and powder content were 0.294 m^3/m^3, 0.32 m^3/m^3, 0.69 m^3/m^3 and 446 kg/m^3 respectively, which meet the lower limits requirements of ACI Committee 237. Further, to obtain self compacting concrete with 15 to 30 MPa compressive strength, the content of cement required is only 200 to 350 kg/m^3.

Keywords: Self compacting concrete, Limestone powder, Slump flow, J-ring. Column segregation, Visual Stability Index, Compressive strength

الخلاصة:

تعتبر الخرسانة ذاتية الرص تطورا هام جدا في تكنولوجيا الخرسانة في الوقت الحاضر, وهي نوع جديد من الخرسانة عالية الأداء التي تكون لها القابلية على الانسياب تحت تأثير وزنها الذاتي دون الحاجة إلى استعمال الهزازات. إن الخرسانة ذاتية الرص وبسبب خواصها المميزة ربما تسهم بتحسين مهم في نوعية المشاءات الخرسانية وتفتح حقل جديد في تطبيقات الخرسانة. تهدف الدراسة إلى بيان فيما إذا كانت الخواص الطرية للخرسانة ذاتية الرص المنتجة من مسحوق الحجر الجيري تطابق متطلبات المواصفة الأمريكية للخرسانة ذاتية الرص والمصممة وفقا لطريقة Nan Su تم استعمال أربع قيم لمحتوى السمنت 200, 250, 300, و350 كغم/م^3, المقاس الأقصى للركام الخشن 20 ملم وأضيف مسحوق الحجر الجيري بمقدار 165, 139, 116 و 96 كغم/م^3 لكل محتوى من محتويات الاسمنت المذكورة على التوالي. أظهرت الدراسة بان نتائج فحوص قابلية التشغيل كانت مطابقة لمتطلبات المواصفة الأمريكية. إضافة إلى ذلك إن حجم كل من الركام, العجينة الإسمنتية والمونة وكذلك محتوى المسحوق كانت مطابقة للحد الأدنى من متطلبات المواصفة المذكورة. أظهرت النتائج أيضا بإمكانية إنتاج خرسانة ذاتية الرص مصممة بالطريقة المقترحة ذات مقاومة انضغاط من 15 إلى 30 نيوتن/ملم^2 وبمحتوى اسمنت من 200 إلى 350 كغم/م^3 .

Introduction:

Self-compacting concrete (SCC) is an advanced type of concrete that at the time of placement can flow and consolidate under its own mass without vibration, pass through intricate geometrical configurations, and resist segregation. Because of these unique workability characteristics, the use of SCC can result in increased construction productivity, improved jobsite safety, and enhanced concrete quality.

Self-compacting concrete was first developed in the late 1980s to achieve durable concrete structures. The creation of durable concrete structures required compaction by skilled workers. However, the gradual reduction in the number of skilled workers in japans construction has led to a similar reduction in the quality of construction work. Then, one solution to achieve durable concrete structures independent of construction work is the employment of self-compacting concrete [2].

The self-compacting concrete differs from conventional concrete in the following three characteristic features:

I-Filling ability: it is the ability of fresh concrete to flow into all spaces within the formwork under its own weight. To achieve filling ability [3]**:**

1-Improve shape and angularity to reduce interparticle friction; use finer grading to reduce harshness or coarser grading to reduce viscosity.

2-Ensure sufficient minimum paste volume to fill voids between aggregates and reduce interparticle friction between aggregates.

3-Ensure viscosity is not too high (sticky) or too low (instability); increase HRWRA dosage to increase slump flow.

II-Passing ability: which is described the capacity of the fresh concrete to flow through confined spaces and narrow openings such as, of congested reinforcement without segregation loss of uniformity or causing blocking. In defining the passing ability, it is necessary to consider the geometry and density of the reinforcement, the flowability /filling ability and the maximum aggregate size. To satisfy these requirements [3]**:**

1-Reduce amount of larger particles by reducing coarseness of grading or maximum aggregate size; improve shape and angularity to reduce interparticle friction.

2-Increase paste volume to reduce aggregate volume and interparticle friction between aggregates.

3-Reduce paste viscosity or increase HRWRA dosage to increase slump flow.

III-Segregation resistance: which is defined as the ability of fresh concrete to remain homogenous in composition during transport and placing. Due to the high fluidity of SCC, the risk of segregation and blocking is very high. Preventing segregation is therefore an important feature of the control regime, therefore, needs to be addressed, [3]**:**

1-Use more uniform grading (avoid gap grading); reduce coarseness of aggregate grading or maximum aggregate size.

2- Increase paste volume.

3-Ensure paste viscosity not too high or too low, reduce slump flow (lower HRWRA dosage); optimize workability retention (accelerate loss of slump flow in formwork); use VMA.

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

Because even with the existing of European guidelines and other international guidelines there are practical differences in how SCC is produced in each country. These differences primarily arise from the difference in cementitious materials available in each region. As example in Europe the ready availability of inert fine fillers such as limestone and dolomite allow the producers to design more economical SCC mixes with higher paste content as compared to their counterparts in Iraq. This difference and others lead to somewhat different design philosophies [4]. However, there are many commonalities in approaching SCC so valuable information can be gained from the international approaches and with some modifications it can be applied to approach SCC with Iraqi materials.

Research Significance:

The fundamental objective of this study is to provide information on the fresh and hardened properties of self compacting concrete produced using limestone powder to support the practical work in assessing the practicability of actually building with self compacting concrete. Furthermore, this study aims to check whether the fresh properties of self compacting concrete mixed by the Nan Su [1] method comply with the requirements specified by the ACI Committee 237[5].

Materials:

1- Cement

Throughout the experimental work, ordinary Portland cement confirming to Iraqi specification (I.O.S.) No.5/1984. was used. Its 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). The chemical composition of this limestone is shown in Table (8).

Mix Design:

The method of mixture design for SCC proposed and used in this study is based on a method developed in Taiwan by Nan Su [1]. The main objective of this method is to determine the amount of paste required to fill the opening between loosely piled aggregate. This method consists of the following steps:

Mixture Design Procedure:

A-Calculation of Coarse and Fine Aggregates Content

The content of fine and coarse aggregates can be calculated as follows:

$$W_{FA} = PF \times \rho_{FA}\left[\frac{FA}{TA}\right] ---------- (1)$$

$$W_{CA} = PF \times \rho_{CA}\left[1-\frac{FA}{TA}\right]-------(2)$$

Where:
W_{FA}=content of fine aggregate (kg/m^3)
W_{CA}=content of coarse aggregate (kg/m^3)
ρ_{FA} = unit volume mass of loosely piled saturated surface dry fine aggregate in air (kg/m^3)
ρ_{CA} =unit volume mass of loosely piled saturated surface dry coarse aggregate in air (kg/m^3)
PF= packing factor, which is the ratio of mass of aggregate of tightly packed state in SCC to that of loosely packed state in air. The volume ratio of aggregate in air is about 52-58%, in other words, the void in the loose aggregate is about 42-48% according to ASTM C 29. On the other hand, the value ratio of aggregate after lubrication and compaction in SCC is about 59-68%. In this study the PF values were selected to be 1.12, 1.14, 1.16 and 1.18.
FA/TA=volume ratio of fine aggregate to total aggregate which ranges from 50% to 57% [1] . In this study, the FA/TA ratio was selected to be 55%.

B- Calculation of Cement Content (C)

According to Nan Su [1], the compressive strength of SCC used in Taiwan is 0.138 MPa for each kilogram of Portland cement (C=f_{cu}/0.138). This relationship is based on empirical data and may vary for other regions. In this work, four values of cement content were used with cement content of 200, 250, 300 and 350 kg/m^3

C- Calculation of Mixing Water Content Required by Cement

According to Nan Su [1], the water-cement ratio is obtained from curves in ACI 211.1. In this study and after many trail mixes, four values of water/cement ratio were used, 0.55, 0.5, 0.45 and 0.4. The content of mixing water required by cement can then be obtained using Eq. (3).

$$W_{WC} = \left[\frac{W}{C}\right]C-------(3)$$

Where:
W_{wc}=content of mixing water (kg/m^3)
W/C= the water/cement ratio by weight
C= cement content (kg/m^3)

D- Calculation of Limestone Powder

This design method provides for the used of two different filler types (slag and fly ash). In this study only one filler (limestone) is used, so the option for the other is taken as zero.
The volume of limestone paste (V_{LSP}) can be calculated as follows:

$$V_{LSP} = 1-\frac{W_{CA}}{1000\times G_{CA}}-\frac{W_{FA}}{1000\times G_{FA}}-\frac{C}{1000\times G_{C}}-\frac{W_{WC}}{1000\times G_{W}}-V_a-------(4)$$

Where:
G_{CA}=specific gravity of coarse aggregate
G_{FA}=specific gravity of fine aggregate
G_C=specific gravity of cement
G_w=specific gravity of water
V_a=air content in SCC % (is about 1.5% depending on the construction method and the type and dosage of SP).

Test results show that the flow value (ASTM C 230) of the limestone powder paste is equal to that of the cement paste. Let W/W_{LSP} be the ratio of water-limestone powder by weight. Then the content of limestone powder (W_{LSP}) can be obtained using Eq.(5).

$$V_{LSP} = \frac{W_{LSP}}{[1000 \times G_{LSP}]} + \frac{W_{LSP}\left[\frac{W}{W_{LSP}}\right]}{1000 \times G_W} ------- (5)$$

Where:
W_{LSP}=content of limestone powder (kg/m^3)
G_{LSP} =specific gravity of limestone powder
W/W_{LSP} = water-limestone powder ratio

Mixing water content required by limestone powder paste can be obtained using Eq.(6).

$$W_{wp} = \left[\frac{W}{W_{LSP}}\right] W_{LSP} ------- (6)$$

E- Calculation of Mixing Water Content Needed in SCC

The mixing water content required by SCC is that the total amount of water needed for cement and limestone powder in mixing. Therefore, it can be calculated as follows:

$$W_W = W_{WC} + W_{WP} ------ (7)$$

F- Calculation of Superplasticizer Dosage (SP)

If dosage of superplasticizer used is equal to n% (2% is used in this study) of the amount of binders (cement+limestone powder) and its solid content of superplasticizer is m% (the solid content of SP is 40%), then the dosage can be calculated as follows:

Dosage of SP used, $W_{SP} = n\%[C + W_{LSP}] ------- (8)$

Water content in SP, $W_{WSP} = [1 - m\%]W_{SP} ------- (9)$

Tables (9) and (10) showed the mix proportions by weight and volume, respectively, calculated by the equations mentioned above.

Tests:

The Paste Flow Test:

To calculate the water/limestone powder ratio (W/W_{LSP}), the paste flow test was carried out, according to ASTM C230, to ensure flow value of limestone paste equal to that of the cement paste.

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[6].

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 [7] as will be mentioned latter.

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[8].

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 [9].

Percent static segregation, $$S\% = 2\left[\frac{M_{bottom} - M_{top}}{M_{bottom} + M_{top}}\right] \times 100 \quad \text{if } M_{bottom} > M_{top} \qquad \text{----(10)}$$

$$S\% = [0] \qquad \text{if } M_{bottom} < M_{top} \qquad \text{-----(11)}$$

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:

Slump Flow:

In the observation of the trail mixtures (not included in this study), it was found that there was sever segregation, bleeding and blocking. This problem was rectified with a change in the PF value from 1.14, 1.16 and 1.18 to 1.12. This means that a reduction in PF value would decrease the content of aggregates and increases the volume of paste, thus, enhancing the passing ability and segregation resistance of SCC. However, the results obtained in the slump flow test shown in Table (11) varied from 560 to 630 mm. These results show that the self compacting concrete used was complied with the requirements of ACI Committee 237[5]. ACI Committee 237 indicates that a common range of slump flow for SCC is 18-30 inches, (457-762) mm. The required slump flow value will vary depending on the workability needed for a certain application or project.

Visual Stability Index (VSI):

A visual stability index was applied to every mixture in order to examine the stability of SCC. 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 all 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 one of the SCC mixtures 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.

J-Ring:

According to Table (11), the results of J-ring range between 0-40 mm which is an acceptable limit, and complying with the requirements of ACI 237. Fig. (3) shows that the concrete used can be described as self compacting concrete due to the ability to flow through confined conditions, such as the narrow openings between reinforcement bars.

Column Segregation:

From the results shown in Table (11), it can be seen that the values of segregation resistance were between 10-15% for all mixes. The lower segregation resistance ratio means more segregation resistance. This give an indication for the segregation resistance of the self compacting concrete mixes, which complying with the requirements of ACI 237. Figs. (4) and (5) show the column segregation resistance test for self compacting concrete

Compressive Strength:

Although factors such as content of fine and coarse aggregate, material proportions, and curing age can effect the compressive strength of SCC, the ratio of water to binders is the most prominent determinant of compressive strength as shown in Fig.(6). Furthermore, the content of binders has great effect on the compressive strength of SCC. In this study, the maximum content of binders used is 446 kg/m^3, which is lower than 500 kg/m^3 powder as suggested by the Japanese mix design method [10]. On the other hand to obtain self compacting concrete with 15 to 30 MPa compressive strength (28-day), the content of cement required is only 200 to 350 kg/m^3. Al-Mishhadani et al., [11], stated that it is possible to produce SCC with 34 to 65 MPa compressive strength (28-day) using cement content of 250 to 400 kg/m^3. However, this is due to the high reactive metakaoline and limestone dust used in their study, while in this study only limestone powder was used.

The results also showed that with the proposed mix design method, the volume of coarse aggregate, paste fraction, mortar fraction and powder content were 0.294 m^3/m^3, 0.32 m^3/m^3, 0.69 m^3/m^3 and 446 kg/m^3 respectively, which meet the lower limits requirements of ACI Committee 237 as specified in Table (12).

Table (13) and Fig.(7) show the increase in the compressive strength with time. It is clear from the figure that the use of finely ground limestone filler can enhance compressive strength development at early age. This may be due to the fact that the inclusion of fine limestone powder may accelerate the hydration of C_3S and hence early strength development. This observation was also noticed by Khayat and Mitchell [12]. Furthermore, finely ground filler and supplementary cementitious materials can lead to a denser hardened cement matrix and a denser interfacial transition zone with aggregate. This can lead to greater strength and durability.

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) Self compacting concrete designed and produced with the proposed mix design method can be made with the materials used in this study. It is also possible to make SCC with lower binder content. Using lower binder content not only reduces the cost but can also have a positive effect on shrinkage.
2) The workability of all studied mixes is good, with slump flow diameter range between 570 to 630 mm. The difference between slump flow diameter and J-ring diameter is not exceed 50 mm, while the segregation resistance range between 10 and 15%. These results show that the self compacting concrete used was complied with the requirements specified by the ACI Committee 237.
3) In this design method, the optimal packing factor (PF) value was 1.12.

4) According to the results of tests in fresh state, it could be concluded that all mixes showed the optimum characteristics with respect to cement and limestone dust contents.
5) The aggregate packing factor (PF) determines the aggregate content and influences the flow ability, passing ability and segregation resistance.
6) To obtain self compacting concrete with 15 to 30 MPa compressive strength, the content of cement required is only 200 to 350 kg/m^3.
7) The MII to MIV mixes can be easily used as medium strength SCC mixes, which are useful for most of the constructions.
8) The volume of coarse aggregate, paste fraction, mortar fraction and powder content were 0.294 m^3/m^3, 0.32 m^3/m^3, 0.69 m^3/m^3 and 446 kg/m^3 respectively, which meet the lower limits requirements of ACI Committee 237.
9) The use of finely ground limestone filler can enhance compressive strength development at early age.
10) Further researches are required on SCC designed with the proposed mix design method and contains two locally available types of fillers (such as blast furnace slag + limestone, rice husk ash+ limestone, metakaolin+ limestone).

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Table (1) Chemical Analysis of the Used Ordinary Portland Cement

Chemical analysis	Percentage, by weight	Limit of I.O.S No.5/1984
Calcium oxide (CaO)	63.30	
Silicon dioxide (SiO_2)	20.81	
Aluminum oxide (Al_2O_3)	4.21	
Ferric oxide (Fe_2O_3)	2.68	
Magnesium oxide (MgO)	3.76	5.00 (Max.)
Sulfur trioxide (SO_3)	2.52	2.80 (Max.)
Potassium oxide (K_2O)	0.74	
Sodium oxide (Na_2O)	0.33	
Loss on ignition (L.O.I)	1.30	4.00 (Max.)
Insoluble residue (I.R)	0.35	1.50 (Max.)
Lime saturation factor (L.S.F)	0.88	0.66-1.02
Main compounds (Bogues equations)		
C_3S	60.17	
C_2S	14.35	
C_3A	6.63	
C_4AF	8.14	

Table (2) Physical Properties of the Used Ordinary Portland Cement

Physical property	Test results	Limit of I.O.S No. 5/1984
Specific surface area (Blaine method), m^2/kg	289	230 (Min.)
Setting time (Vicat apparatus), hr:min Initial Final	 2:15 4:50	 00:45 (Min.) 10:00 (Max.)
Soundness (Autoclave expansion),%	0.25	0.8 (Max.)
Compressive strength (70.7mm cube), MPa 3-day 7-day	 20 28	 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	55.76
Al2O3	0.70
Fe2O3	0.17
SiO2	1.40
MgO	0.10
Na2O+K2O	—
L.O.I	40.60
SO3	0.91

Table (9): Mix Proportions of SCC (kg/m^3)

Mix	PF	W/p	C	FA	CA	LSP	W_w	SP	Total*
MI	1.12	0.55	200	983	766	165	201	7.3	2322
MII	1.12	0.50	250	983	766	139	195	7.8	2340
MIII	1.12	0.45	300	983	766	116	187	8.3	2360
MIV	1.12	0.40	350	983	766	096	178	9.0	2382

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

Table (10): Mix Proportions of SCC by volume (0.001 m^3/m^3)

Mix	PF	C	FA	CA	LSP	W_w	SP	Total*
MI	1.12	63.5	370	294	62	201	6.6	997.1
MII	1.12	79	370	294	51	195	7.0	996.0
MIII	1.12	95	370	294	43	187	7.6	996.6
MIV	1.12	111	370	294	35	178	8.2	996.2

*Total = C+ FA+ CA+ LSP+ W_w+ SP

Table (11): Results of fresh properties of SCC for all mixes

mix	**Slump flow**	**Req. of ACI 237**	**J-Ring**		**Req. of ACI 237**	**Column segreg-ation**	**Req. of ACI 237**
	D (mm)		DJ (mm)	(D-DJ) mm		S%	
MI	570	457-762 (mm)	560	10	Not exceed, 50 (mm)	15	Not exceed, 15%
MII	590		550	40		10	
MIII	630		600	30		13	
MIV	610		610	0		15	

Table (12): 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 (13): Results of compressive strength test for different SCC mixes

Mix	**Compressive Strength (MPa)**			
	14-day	**28-day**	**60-day**	**90-day**
MI	12.5	15.0	16.8	18.4
MII	16.0	21.4	23.0	23.2
MIII	19.3	25.6	27.1	29.0
MIV	21.5	30.0	31.8	34.0

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

Fig.(3) Measuring passing ability of SCC through an obstacle

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

Fig.(4) Column segregation resistance test of SCC

Fig.(5) Concrete sample being washed over the No.4 sieve to remove all paste and fine aggregate

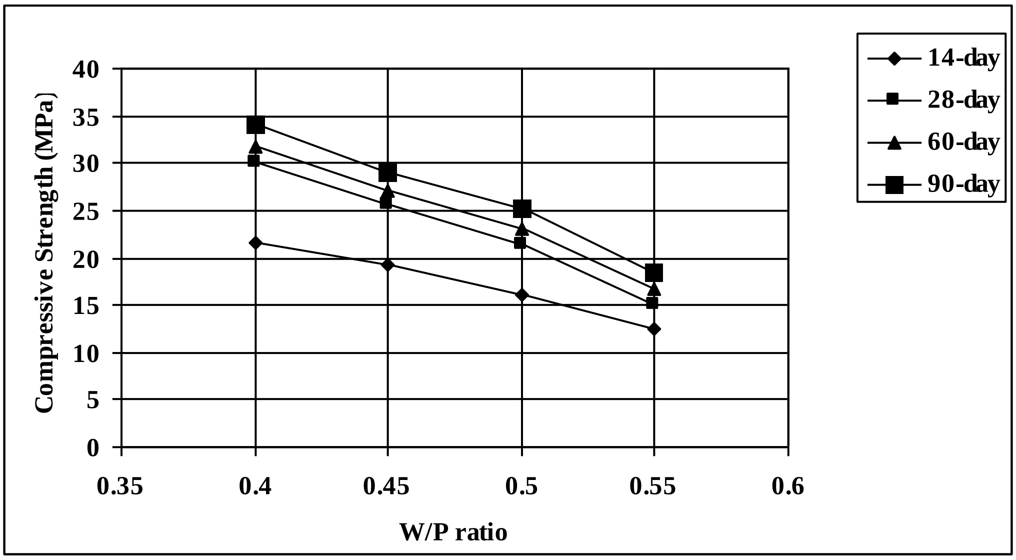

Fig.(6) Relationship between compressive strength and W/P ratio value for SCC with different ages

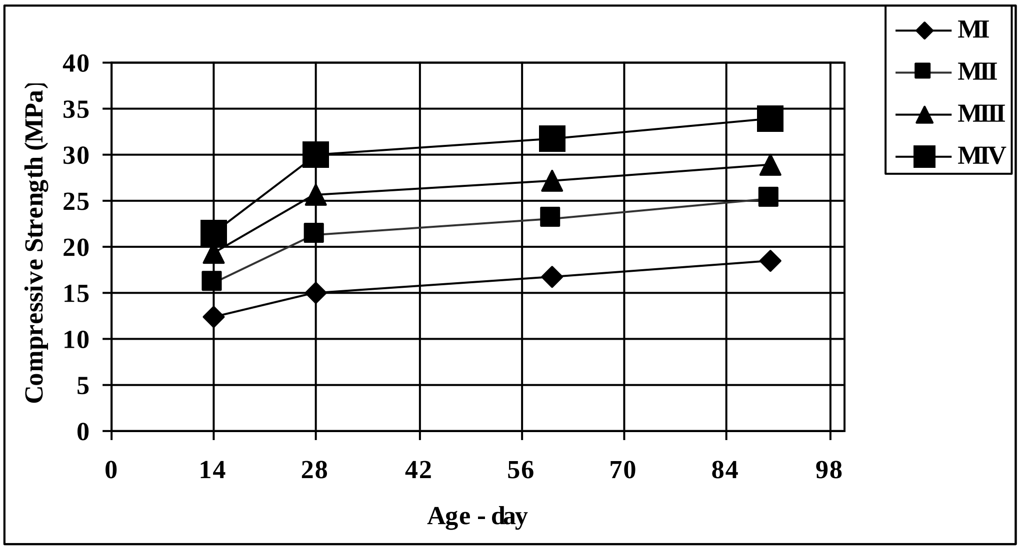

Fig.(7) Relationship between compressive strength and age for all mixes