The Production of Self-Compacting Concrete with Normal Cement Content

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Abstract

The main object of this work is to evaluate the possibility for using reasonable cement content and fine materials to reduce costs of expensive chemical admixtures needed for the manufacturing of self-compacting concrete (SCC). In this work, three values of cement content are used (rich, medium and lean mixes) with cement content of 400, 300 and 250 kg/m^3 respectively . Two maximum aggregate sizes of (10 and 20mm) for each cement content are used. The powder content material is (cementations + filler) is maintained constant (500kg/m^3) while the W/cm ratio ranges from 0.43 to 0.68. 10% Reactive Metakaolin Class N is used as a partial replacement by weight of cement. On the other hand, limestone dust was used as a partial replacement by weight of the powder content Tests were carried out on all mixes to obtain the properties of fresh concrete in terms of viscosity and stability. The results showed that increasing the percentage of filler (limestone dust) from 20% in rich mixes to50% in lean mixes of the total weight of the powder content reduces the amount of cement in SCC without significant effect on the fresh properties of the SCC mixes. This conclusion is significant from the economical point of view. The mechanical properties of hardened SCC mixes are also assessed. (compressive strength, modulus of elasticity). The results obtained from this work show that it is possible to produce SCC with different levels of cement content (250 to400kg/m^3) using local available materials which satisfy the requirements of this type of concrete .The test data collected indicate that these materials can be used in the manufacturing of economical SCC.

Keywords: SCC ,limestone dust ,compressive strength , static modulus of elasticity , L-box , V-funnel , J-ring , slump flow test

انتاج خرسانة ذاتية الرص ذات محتوى سمنت اعتيادي

الخلاصة

الهدف الرئيسي لهذا العمل هو تقييم امكانية الأستخدام المعقول لمحتوى السمنت و المواد الناعمة لتقليل الكلف الباهظة للمضافات الكيميائية التي نحتاجها في انتاج الخرسانة ذاتية الرص.في هذا العمل ، هناك ثلأثة قيم لمحتوى السمنت (الخلطات الغنية ، الخلطات المتوسطة ، الخلطات القليلة) مع محتوى السمنت(400 ، 300 و 250 كغم/م^3)على التوالي. و مقاسين من الركام الخشن 10، 20 ملم ، استعمل لكل محتوى اسمنت . محتوى المواد المسحوقة(500 كغم/م^3) بينما نسبة W/cm تتراوح بين(0.43 الى 0.68) . 10% ميتاكاؤلين عالي الفعالية صنف N استعمل كاحلال جزئي من وزن السمنت ، بينما مسحوق الحجر الجيري استعمل كاحلال جزئي من وزن محتوى المسحوق الكلي . النتيجة اظهرت بان الزيادة في نسبة الحجر الجيري المطحون من 20% في الخلطات الغنية بمحتوى السمنت الى 50% في الخلطات القليلة ، من الوزن الكلي لمحتوى المسحوق ادى الى نقصان في محتوى السمنت من غير تاثير يذكر في خواص الخرسانة الطرية ، هذا الأستنتاج مهم جدا من وجهت النظر الأقتصادية .الخواص الميكانيكية للخرسانة ذاتية الرص كانت ايضا تخمينية (مقاومة الانضغاط ،معامل المرونة الستاتيكي). النتائج في هذا العمل اظهرت امكانية انتاج خرسانة ذاتية الرص بمستويات مختلفة من السمنت من(250 الى 400 كغم/م^3) باستعمال مواد محلية متيسرة ، والتي تلبي متطلبات هذا النوع من الخرسانة . نتيجة الفحص التي جمعت بنيت بان تلك المواد يمكن استعمالها في تصنيع خرسانة ذاتية الرص لأغراض اقتصادية .

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Introduction

Self–compacting concrete (SCC) represents one of the most outstanding advances in concrete technology during the last decade. At first developed in Japan in the last 1980s, SCC meanwhile is spread all over the world with a steadily increasing number of applications [1].

Self–compacting concrete (previously called non–vibrated concrete) , which can be casted and compacted without the need of mechanical aid, is the concrete of future [2].It must fill the formwork completely, enclose the reinforcement, dearate only by the force of gravity and must not segregate [3] . Due to its specific properties, SCC may contribute to a significant improvement in the quality of concrete structures and open up new fields for the application of concrete [1].

Due to the highly flowable nature of self – compacting concrete, care is required to ensure excellent filling ability, passing ability and adequate stability [4].This ability is achieved by ensuring suitable rheological properties of fresh concrete: a low yield stress value associated with adequate plastic viscosity. The use of superplasticizer and optimization of fine – particles packing and flow behavior are those two of the central aspects of self–compacting concrete (SCC) mix proportioning . Fine particles including both cement and filler materials (Pozzolanic or non Pozzolanic) are used in mix proportioning . Among non Pozzolanic fillers,(limestone and dolomite) fines are the most frequently used to increase the content of fine particles in mixes [5].

Benefits of Self – Compacting Concrete (SCC)

Often the material costs of SCC will be higher than the equivalent material costs of a normal vibrated concrete. However, when SCC is sensibly utilized, the reduction of costs caused by better productivity, shorter construction time and in many cases, may result in more favorable prices of the final product [1]

The use of SCC offers many benefits to the construction practice : [6][7]

I. For the architect: it increases design flexibility and allows innovative techniques.

II. For the contractor: it reduces labor cost, reduces equipment on the jobsite, improves labor safety, shortens construction time

III. For the owners: faster construction time reduces cost, lowers maintenance cost in future with improved durability, and more design options.

IV. Better quality in the area of high reinforcement concentration.

V. High and very homogeneous quality of the concrete, very dense concrete-structure

VI. Better surface finishes

VII. Reduced noise levels

VIII. To assure compaction in the structure, especially in confined zones where vibrating compaction is difficult

Research Significance

In this study, an experimental work and statistical analysis have been carried out to achieve the following:-

I. Producing SCC according to the requirement for the fresh and mechanical properties of concrete by using different cement contents (low cement, medium cement and high cement content) with respect to current Japanese and European specifications.

II. Evaluating the effect of fillers (limestone and metakaoline) on the workability of the concrete in the fresh state and its hardened state properties

III. Evaluating the influence of the maximum size of coarse aggregate on the properties of SCC.

Experimental Work

Tests were conducted in order to view the differences in behavior during the fresh state as well as the hardened state. The slump flow, J- ring, L-box, and V-funnel were performed on concrete in the fresh state. After concrete has hardened, compressive strengths and static modulus of elasticity test were carried out to study the behavior of SCC mix with variable content of cement. For full description see reference NO. 8

Materials

1- Cement

The used cement was ordinary Portland cement. The cement was tested and checked according to IOS 5:1984[9]. Table (1) shows the chemical properties of this cement; and the physical properties are shown in Table (2). The chemical and physical tests were made by the National Center for Construction Laboratories and Research (NCCLR).

2- Fine Aggregate

Natural sand from Al-Ukhaider 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[10] .Table (4) shows the physical properties of the fine aggregate.

3- Coarse Aggregate

Crushed gravel with maximum size of 10 mm and 20 mm from Al-Niba'ee region was used .The tested characteristics of this gravel are given in Tables (5) and (6). Table (7) shows the physical properties of the coarse aggregate.

4- Water

Tap water was used for both mixing and curing of concrete.

5- High range water reducing

One of the new generations of copolymer-based superplasticizer, designed for the production of SCC was used (Glenium 51). Table (8) contains the property of this product.

6- Mineral Admixtures

Two locally available types of mineral admixtures were used for the purpose of this study. Limestone dust and high reactivity metakaolin to produce a SCC with reliable fresh concrete proprieties and moderate costs for the materials, and to reduce the amount of expensive chemical admixtures.

I- Limestone dust (Ld)

The fine limestone dust, was ground by blowing technique, to reach a specific surface of 3100 cm^2/g . The cost of grinding is very low, and the fineness of the gained material is very high. The chemical composition of Ld is listed in Table (9)

II-High Reactivity Metakaolin (HRM)

The used HRM was prepared by burning the kaolin clay at 700°C for whole one hour then left to cool down.The Chemical and physical properties of HRM are listed in Table (10) .

Strength Activity Index with Portland Cement (SAI)

I - S.A.I for HRM

According to the requirement of ASTM C311- 02 [11], the SAI test was made as follows:-

Strength activity index with Portland cement= (A/B) ×100 …… (1)

where:

A = average cube compressive strength of test mix, MPa

B = average cube compressive strength of control mix, MPa

Table (11) shows water/cement or water/ cementitious materials ratio and the strength activity index.

Concrete Mixes

In order to achieve the scope of this study**,** the work was divided into two sets,. Each set includes three mixes, {lean, medium, rich mixes}. Each mix contains cement, 10% HRM as a partial replacement by weight of cement and limestone dust. Table (12) shows the details of mixes.

I–Dosage of Superplasticizer (SPD)

A dosage of 7 liters per 100kg of the total weight of the powders was used for the first trial mixtures.

Fresh Concrete Properties

After preparing the six mixes, fresh properties of each mix were measured the workability tests were made on fresh concrete immediately after mixing including slump flow, J- ring, V-funnel and L-box tests. The tests were carried out to determine the effects of cement and filler content and maximum size of coarse aggregate on fresh properties.

Slump -flow Test

The flowing ability of fresh concrete is described by slump flow investigated with Abrams cone. Table (13) shows the slump spread values and T_{500} for the produced mixes.

L-box Test

The L- box test gives an indication about the filling ability and the passing ability of SCC. Table (13) shows the value of BL (H1/H2) which represents the blocking ratio and the value of T_{400}

represents the time of concrete to reach 400 mm flow .

J- ring Test

J- ring test measures the passing ability of SCC. Table (13) shows the value of BJ which represents the step of blocking {the difference in height between concrete inside and outside the ring} and the value of TJ_{500} mm represents the time of concrete to reach 500 mm flow.

V- funnel Tests

The values of Tv represent the ability of concrete to flow out of the funnel. Table (13) shows the results of V-funnel test. These results are within the limits pointed out in the literature, no blocking or segregation behavior was observed in all mixes.

The test method of segregation resistance is required for mixes when the slump flow is larger than 720mm and the blocking ratio smaller than 0.8(12).

Hardened Concrete Properties

Tow test were carried out on SCC mixes Compressive Strength and Static Modulus of Elasticity .

Results and Discussion

Compressive Strength

The Compressive Strength was measured in compliance with B.S.1881 (13) The compressive strength results of the different studied concrete mixes are shown in Table (14)

These results indicate that, the compressive strength increases with the decrease in percentage of Ld inclusion and with the decrease of w/cm material ratio . The relatively faster strength development for mixes particularly at early ages was believed to be mainly due to the inclusion of fine fillers powder, therefore, the interface zone becomes stronger, more homogenous and dense, and a new generation of copolymer – based superplasticizer leads to increase the ultimate compressive strength (14) . Fig. (1) shows the increase in strength compressive with time, with decrease in the percentage of W/cm ratio

Fig. (1) also shows the effect of maximum size of aggregate on the compressive strength of SCC mixes. In rich SCC mixes increasing the maximum size of aggregate leads to decrease the compressive strength, but in lean mixes the effect of maximum size of aggregate is not clear. However employing larger maximum size of aggregate would reduce the surface area and hence reduce the amount of required water to ensure a certain level of workability. While in rich mixes, this reduction in mixing water would improve the paste strength to an extent that makes the bond between the paste and aggregate as the critical point. The bond strength will be reduced when increasing the maximum size of aggregate, therefore, overall strength would be deceased. In lean mixes, the strength of the paste will be the crucial point. The reduced surface area of aggregate will require less paste and the reduction in mixing water will be more than sufficient to raise the paste strength and bond strength. Thus the concrete compressive strength would be increased.

Static Modulus of Elasticity

The static modulus of elasticity was measured in compliance with ASTM C 469 (15) .Table (14) showed the average result of this test. Fig. (2) showed the relationship between maximum size of aggregate and the static modulus of elasticity of the mixes. It appears from the figure that static modules of elasticity increases with the decrease in W/cm ratio and the richness of concrete mix. The effect of maximum aggregate size on the static modulus of elasticity also is shown in Fig. (2), where increasing the maximum aggregate size leads to decrease in the value of Ec. Fig. (3) showed empirical relationship between compressive strength and static modulus of elasticity for SCC mixes at 28 days age, The correlation factors of the studied relationship are high (R= 0.95).

Conclusions

1- Self-compacting concrete can be produced from locally available materials and reasonable cement contents. It has sufficient flowability and workability to make it self-compactable performance concrete. SCC needs careful proportion and batching. When it's properly proportioned and controlled, the fresh concrete will flow to great distance and remains homogeneous without segregation.

2- The workability of all studied mixes is good, with slump flow diameter greater than or equal to (650 mm), flow times range between (2.8 and 16)sec. while the step of blocking rangs between (0 and15)mm. of the fresh properties, medium cement content (300 kg/m^3) has the best influence, followed by rich mixes (400 kg/m^3) and lean mixes (250 kg/m^3) in descending sequence.

3- According to the result of testes in fresh state , it could be conclude that mixes 20MM ,10MM showed the optimum characteristics with respect to cementitions materials and limestone dust contents.

4- The addition of mineral admixtures (limestone dust and high reactive metakaoline), significantly affects the compressive strength of the SCC mixes. The gained strengths are range (54-75)MPa at 90 days. Thus it can be recommended that from the economical point of view it is more preferable to employ suitable mineral admixtures in producing SCC. with reasonable cement content .

5- It is required to increase the limestone dust content from 20% to50% of the total weight of the powder to produce SCC mixes with low cement content (250 kg/m^3) as compared with SCC mixes of (400 kg/m^3) content . On the other hand, it gives less compressive strength at the different ages of the test. The reduction was about (36% to26%) at 90 days for mix with maximum aggregate size of 10 and 20 mm respectively.

6- The static modulus of elasticity increases with decreasing the ratio of W/cm and the maximum aggregate size for all studied SCC mixes. At 28 days the static modulus of elasticity with W/cm ratio of (0.57) are (26 GPa) for 10 mm maximum aggregate size, while decreasing the ratio to (0.43) improves these properties to (36.94GPa)

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Table (1) Chemical composition of cement

Oxides	%	IOS 5:1984 requirements(9)
CaO	61.27	-
SiO_2	21.27	-
Fe_2O_3	3.12	-
Al_2O_3	5.05	-
MgO	2.06	<5
SO_3	2.07	<2.8
Loss on agent L.O.I%	3.21	<4
Insoluble residue I.R%	1.32	<1.5
Lime Saturation Factor, L.S.F	0.88	0.66 – 1.02
Main compounds (Bogue's equation)		
C3S	43.42	-
C2S	28.31	-
C3A	8.11	-
C4AF	9.48	-

Table (2) Physical properties of cement

Properties	Cement	IOS 5:1984 requirements[9]
Fineness Blaine method (m^2/kg)	481	≥ 225
Vicat set times(hr:min) Initial Final	3: 20 4; 40	≥45 min ≤10 hours
Mortar Compressive Strength (N/mm^2) at 3 days 7 days	33.4 42.2	>15 >23
Soundness: autoclave %	0.19	<0.8

Table (3) Grading of fine aggregate.

Sieve size (mm)	%Passing by weight	Limitations of the Iraqi SpecificationNo.45/1984 (zone 2) [10]
4.75	100	90-100
2.36	90.4	75-100
1.18	81.9	55-90
0.60	57.9	35-59
0.30	16.9	8-30
0.15	2	0-10

Table (4) Physical properties of fine aggregate Physical tests were made by the National Center Laboratories for Construction and Research (NCCLR)

Physical Properties	Test Results	Limit of the Iraqi specification[10]
Specific gravity	2.62	-
Sulfate content %	0.08	≤ 0.50 %
Absorption%	0.9	-
Materials finer than 75 µm sieve	1%	< 4%
Fineness Modulus	2.51	-

Table (5) Grading of coarse aggregate with maximum size (20) mm

Sieve size (mm)	%Passing by weight	Limitations of the Iraqi specificationNo.45/1984[10]
20.0	95	95 -100
14.0	-	-
10.0	59	30 - 60
5.00	1	0 - 10
2.36	-	-

Table (6) Grading of coarse aggregate of maximum size 10 mm

sieve size (mm)	%Passing by weight	Limitations of the Iraqi SpecificationNo.45/1984[10]
14.0	100	100
10.0	88	85 - 100
5.00	10	0 - 25
2.36	0	0 -5

Table (7) Physical properties of coarse aggregate

Physical Properties	Test Results	Limit of the Iraqi specification[10]
Specific gravity	2.62	-
Sulfate content %	0.06	$\leq$ 0.1 %
Absorption%	0.6	-

Table (8) Typical properties of (Glenium 51)

NO.	Main action	Concrete super plasticizer
1	Color	Light brown
2	PH. Value	6.6
3	Form	Viscous liquid
4	Subsidiary effect	Hardening
5	Relative density	1.1 at 20°C
6	Viscosity	128 $\pm$ 30 cps at 20°C
7	Transport	Not classified as dangerous
8	Labeling	No hazard table required

Table (9) Chemical composition and physical properties of Limestone dust*

Oxides	%
SiO_2	1.38
Fe_2O_3	0.12
Al_2O_3	0.72
CaO	56.1
MgO	0.13
SO_3	0.21
L.O.I	40.56

Table (10) Chemical and physical properties of HRM *

Chemical Composition		
Oxides	Content%	Requirements of class N pozzolans (ASTM 618-03) [16]
CaO	1.70	-
SiO_2	54.36	$\geq$70
Al_2O_3	32.9	
Fe_2O_3	1.10	
MgO	0.10	
SO_3	0.18	
Na_2O	0.23	
K_2O	0.43	
L.O.1	7.97	
Physical Properties		
Fineness (Blaine method m^2/kg)		1222
Specific gravity		2.55

Table (11) Strength activity index and w/c or w/cm ratio for tested mortars[8].

Index	w/c or w/cm ratio to give flow of 110±5	S.A.I
Control mix	0.484	-
HRM.mix	0.495	129

Table (12) shows the details of mixes. [8].

Mix	Water kg/m3	Cement kg/m3	HRM kg/m3	Ld kg/m3	Sand kg/m3	Gravel kg/m3	SP L/ m3	w/cm ratio	Ld/cm ratio	w/p ratio
10RM	170	360	40	100	788	890	9	0.43	0.25	0.34
20RM	170	360	40	100	788	890	9	0.43	0.25	0.34
10MM	170	270	30	200	788	890	9	0.57	0.67	0.34
20MM	170	270	30	200	788	890	9	0.57	0.67	0.34
10LM	170	225	25	250	788	890	9	0.68	1	0.34
20LM	170	225	25	250	788	890	9	0.68	1	0.34

Table (13) Result of fresh properties of SCC for all mixes(8).

Mix	Slump flow		J-ring			L - box		V-funnel
	T_{500} (sec)	D mm	TJ_{500} sec	DJ mm	BJ mm	BL H1/H2	T_{400} sec	Tv sec
10RM	4.5	670	6.0	667	10	0.89	3.5	15
20RM	4.0	675	6.5	665	14	0.88	3.3	14
10MM	3.4	710	4.5	710	0	0.96	3	11
20MM	3.0	720	4.5	720	0	0.95	2.8	10
10LM	5.4	660	6.7	650	15	0.86	4.5	16
20LM	4.3	670	6.2	665	13	0.85	3.9	15

Table (14) Results of compressive strengths test and static modulus of elasticity for deference SCC mixes(8).

Mix	Compressive Strengths test (MPa) for ages:				Static Modulus of Elasticity GPa.
	7 days	28 days	60 days	90 days	28 days
10RM	40.5	65	70	75	36.94
20RM	38	54	62	68	32.53
10MM	33	40.7	55	60	27.00
20MM	30	39	47	59	26.56
10LM	25	34.5	40	55	25.70
20LM	25.3	34	43	54	24.00

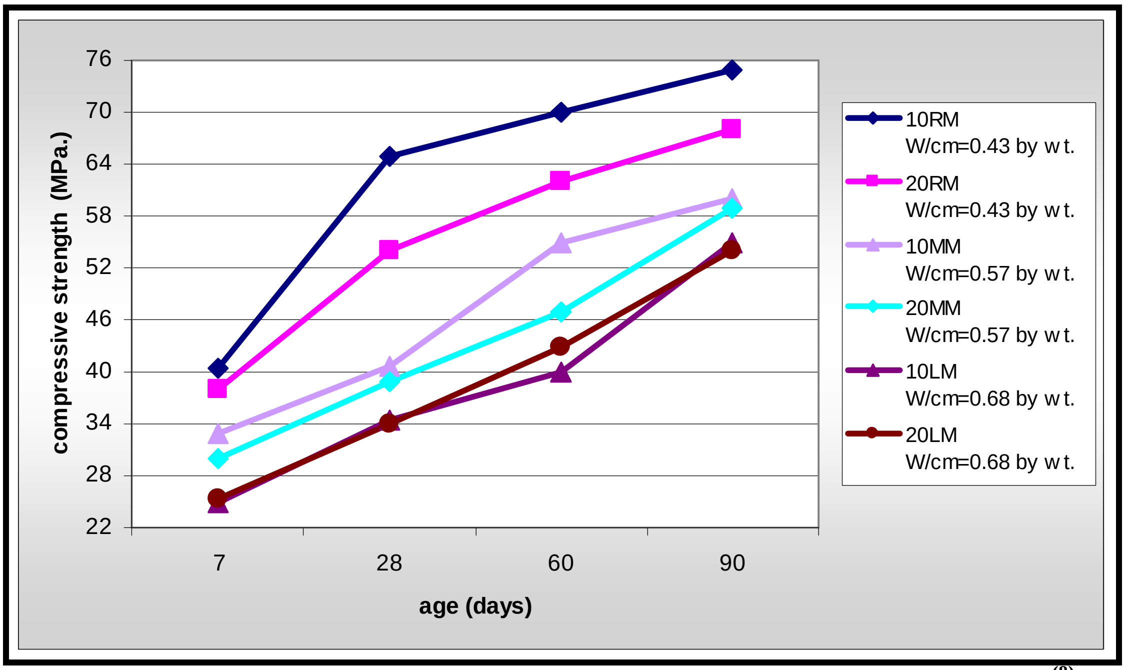

Figure (1) Relation between compressive strength and age for all studied mixes(8).

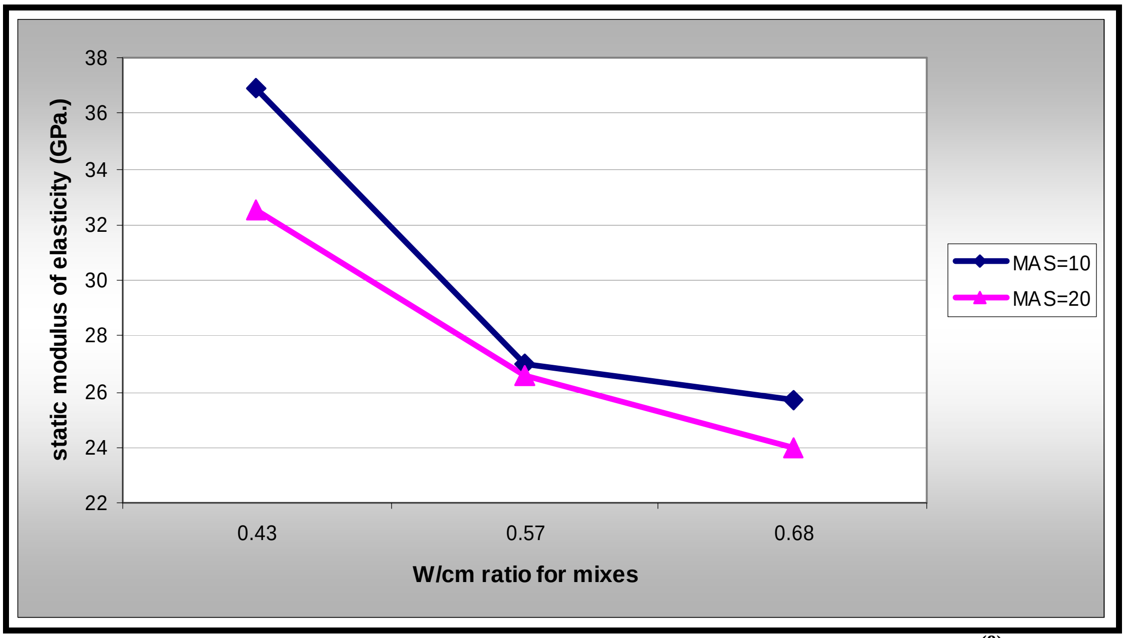

Figure (2) Static modulus of elasticity (Ec) for different SCC mixes [8].

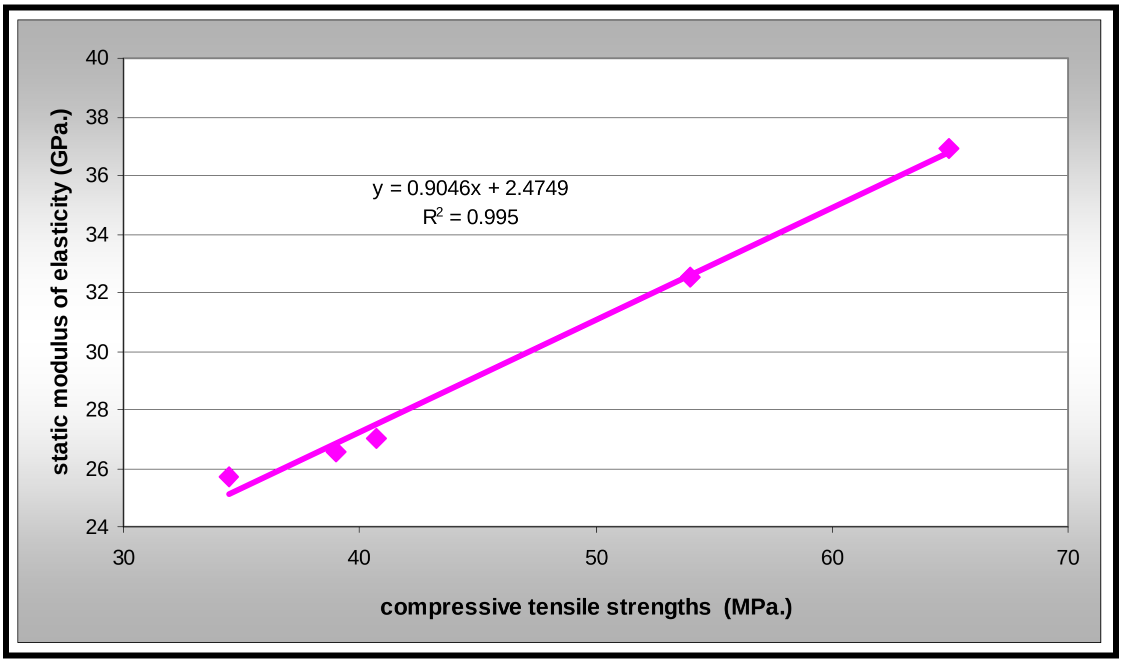

Figure (3) Relationships between f'_c and E_c for different SCC mixes