Table S.2 - MOVEMENT CAPACITY PARAMETERS

Mov No.	Arv Flow (veh /h)	Satn Flow 1st Grn	Satn Flow 2nd Grn	Flow Ratio 1st Grn	Flow Ratio 2nd Grn	Total Cap. (veh /h)	Prac. Deg. Satn xp	Prac. Spare Cap. (%)	Lane Util (%)	Deg. Satn x
10 T	3547	6800		.522		3400	.90	-14	100	1.043*
11 T	195	6800		.029		453	.90	109	100	.430
12 T	1814	6800		.267		1757	.90	-13	100	1.033
13 T	486	6800		.071		510	.90	-6	100	.953

1

Table S.3 - INTERSECTION PARAMETERS

Crit Mov No.	Green Period	Phases Fr	Phases To	Adjusted Lost Time, l	Adjusted Flow Ratio	Required Grn Time Ratio	Required Movement Time
10 T		1	2	3	.522	.580	72.5
11 T		2	3	11	-	-	11.0Min
12 T		3	4	3	.267	.296	38.6
13 T		4	1	3	.071	.079	12.5
		Total:		20	.860	.955	134.6

- Flow ratio not used for cycle time calculations and

  the adjusted lost time equals the required movement time

(=Min or Max as shown in Table S.1)

Cycle Time:

Minimum	Maximum	Practical	Chosen
44	120	120	120

(Cycle time specified by the user)

Degree of Saturation (Highest) = 1.043
Practical Spare Capacity (Lowest) = -14 %
Total Vehicle Flow = 6042
Total Vehicle Capacity (all lanes) = 6120

Table S.4 - PHASE INFORMATION

Phase No.	Change Time	Green Start	Displayed Green	Grn+Intgrn Secs	Grn+Intgrn Prop.
1	0	5	58	63	.525
2	63	68	6	11	.092
3	74	79	29	34	.283
4	108	113	7	12	.100

1

Cycle Time = 120

Table S.5 - MOVEMENT PERFORMANCE

Mov No.	Total Delay (veh-h/h)	Aver. Delay (sec)	Total Stops (veh/h)	Stop Rate	Longest Que per Lane (vehs)	Longest Que per Lane (m)	Perf. Index	Aver. Speed (km/h)	Fuel Rate (ml/km)
10 T	139.23	141.3	6031	1.70	55.8	335	455.22	17.9	148.7
11 T	2.91	53.8	169	.86	1.6	9	13.35	31.6	110.0
12 T	83.27	165.2	3223	1.78	29.8	179	250.79	16.0	157.3
13 T	22.14	164.0	852	1.75	7.9	47	66.51	16.1	156.4

Table S.6 - INTERSECTION PERFORMANCE

Total Flow (veh/h)	Total Delay (veh-h/h)	Aver. Delay (sec)	Total Stops (veh/h)	Stop Rate	Perf. Index	Aver. Speed (km/h)	FUEL Rate (ml/km)	FUEL Total (ml/h)
6042	247.56	147.5	10274	1.70	785.87	17.3	150.6	910042.9

1

Table S.7 - LANE PERFORMANCE

Mov No.	Lane No.	Short Lane (m)	Effective Red and Green Times (sec) R1	G1	R2	G2	Arv Flow (veh/h)	Cap (veh/h)	Deg. Satn x	Aver. Delay (sec)	Stop Rate	Back of Queue (vehs)	Back of Queue (m)
10	1 T		60	60	0	0	887	850	1.043	141.3	1.70	55.8	335
	2 T		60	60	0	0	887	850	1.043	141.3	1.70	55.8	335
	3 T		60	60	0	0	887	850	1.043	141.3	1.70	55.8	335
	4 T		60	60	0	0	887	850	1.043	141.3	1.70	55.8	335
11	1 T		112	8	0	0	49	113	.430	53.8	.86	1.6	9
	2 T		112	8	0	0	49	113	.430	53.8	.86	1.6	9
	3 T		112	8	0	0	49	113	.430	53.8	.86	1.6	9
	4 T		112	8	0	0	49	113	.430	53.8	.86	1.6	9

Table S.15 - CAPACITY AND LEVEL OF SERVICE (HCM METHOD)

Mov No.	Mov Typ	Green Time Ratio (g/C) 1st grn	2nd grn	Total Flow (veh/h)	Total Cap. (veh/h)	Deg. of Satn (v/c)	Prog. Factor	Aver. Delay (sec)	LOS
10 T		.500*		3547	3400	1.043*	1.00	141.3	F
11 T		.067*		195	453	.430	1.00	53.8	E
12 T		.258*		1814	1757	1.033	1.00	165.2	F
13 T		.075*		486	510	.953	1.00	164.0	F
Intersection:				6042	6120	1.043		147.5	F

Level of Service calculations are based on overall delay.

* Maximum v/c ratio, or critical green periods

- **Summary of Intersection Performance with best Alternate**

Table S.3 - INTERSECTION PARAMETERS

Crit Mov No.	Green Period	Phases Fr	Phases To	Adjusted Lost Time, l	Adjusted Flow Ratio	Required Grn Time Ratio	Required Movement Time
10 T		1	2	7	.484	.538	41.9
13 T		2	1	7	.135	.150	16.7
		Total:		14	.618	.687	58.7

Cycle Time:

Minimum	Maximum	Practical	Chosen
28	120	45	65

Cycle Time = 65

Table S.15 - CAPACITY AND LEVEL OF SERVICE (HCM METHOD)

Mov No.	Mov Typ	Green Time Ratio (g/C) 1st grn	2nd grn	Total Flow (veh /h)	Total Cap. (veh /h)	Deg. of Satn (v/c)	Prog. Factor	Aver. Delay (sec)	LOS
10 T		.615*		3145	4000	.786	1.00	11.5	B
11 T		.169		351	812	.432	1.00	24.2	C
12 T		.615		565	2954	.191	1.00	5.4	A
13 T		.169*		875	1100	.795*	1.00	36.8	D
		Intersection:		4936	8866	.795		16.2	B

Level of Service calculations are based on overall delay.

* Maximum v/c ratio, or critical green periods

Production of Self-Compacting Concrete by Using Fine Aggregate Not Conforming Local Specifications

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الخلاصة

يهدف هذا البحث إلى دراسة خصائص الخرسانة ذاتية الرص المنتجة من المواد المتـوفرة محليـا" ومحاولـة لتوسيع تدرج الركام الناعم وبمعامل نعومه يتراوح مابين (4.1-1.5) وتأثير المقاس الأقصى للركام الخشـن. وكذلك دراسة تأثير استبدال الميتاكاؤولين عالي الفعالية كجزء من وزن السمنت على الخصائص الطرية والصلبة للخرسانة الذاتية الرص. يتضمن البحث تصميم 24 خلطة مختلفة من الخرسانة الذاتية الرص تـم تحضـير 8 خلطات مرجعية لغرض المقارنة. أن الفحوصات المختبرية التي استخدمت لتقييم قابلية التشغيل هي فحص جريان الهطول، القمع على شكل حرف V، الصندوق على شكل حرف L والصندوق على شكل حـرفU. أوضـحت النتائج إن تأثيرات التدرج المختلفة للركام الناعم و المقاس الأقصى للركام الخشن ليست متساوية حيـث إن زيـادة المقاس الأقصى مع زيادة معامل النعومة يقلل من الانسياب وقابلية المـرور ومقاومـة الانعـزال. وان أسـتبدل الميتاكاؤولين عالي الفعالية بنسبة 10%من وزن الأسمنت تؤدي إلى تقليل الانسيابية وزيادة اللزوجة. إن معامـل النعومة(3.1) للركام الناعم يعطي نتائج أفضل من المعاملات الأخرى . أظهرت نتائج البحث انه يمكـن انتـاج خرسانة مرصوصة ذاتيا من المواد المحلية المكونة لهذا النوع من الخرسـانة وإمكانية استخدام تدرج مختلـف للركام الناعم وبمعامل نعومة يتراوح مابيـــن (4.1-1.5) وان تأثير اختلاف معامل النعومـة لـيس ذو أهميه على خواص الخرسانة المتصلبة بينما يكون أكثر أهميه على الخواص الخرسانة المتصلبة.

Abstract

This study aims to investigate the properties of SCC produced by locally available materials , and attempts have been made to increase the range of grading of fine aggregate, with fineness modulus ranging from (1.5 to 4.1) , and to study the effect of the maximum size of coarse aggregate . It also aims to study the influence of High Reactivity Metakaolin (HRM) as a partial replacement by weight of cement on the properties of fresh and hardened SCC, 24 different mixes of SCC are prepared .8 mixes are considered as Reference mixes which are used for comparison purposes. To determine the workability, different test methods were adopted such as slump flow, V-funnel, and L-box tests. When fineness modulus of fine aggregate and maximum size of coarse aggregate increase, flowability, passing ability and segregation resistance decrease as compared with small maximum size of aggregate and other fineness modulus. Further more, the inclusion of 10% HRM as a partial replacement by weight of cement leads to decrease flow ability and increase of viscosity. The fineness modulus (3.1) of fine aggregate gives better results than other fineness modulus. The results obtained from this study, also show that it is possible to produce SCC from local available materials which satisfy the requirement of this type of concrete. Moreover, the results show the possibility of using different grading of fine aggregate with fineness modulus ranging from (1.5 to 4.1) and the effect of change in fineness modulus is not significant on hardened concrete properties , while it is more significant on fresh concrete properties .

1.1: General: -

Self-Compacting Concrete (SCC), a recent innovation in concrete technology, has numerous advantages over conventional concrete. Self-compacting concrete, as the name indicates, a type of concrete that does not require external or internal compaction, because it becomes leveled and compacted under its self –weight. SCC can spread and fill every corner of the formwork purely by means of its self -weight, thus eliminating the need of vibration or any type of compacting effort [(1)].

The behind developing SCC was the concerns regarding the homogeneity and compaction of conventional cast-in-place concrete within intricate i.e. (heavily–reinforced structures) and to improve the overall strength, durability and quality of concrete [(2)].

The SCC concrete is highly flowable and cohesive enough to be handled without segregation .It is also referred to as self-consolidating concrete, self-leveling concrete, super-workable concrete, highly flowable concrete, non vibrating concrete, and other similar names. A highly flowable concrete is not necessarily self- compacting because SCC should not only flow under its own weight but also fill entire form and achieve uniform compaction without segregation [(3)].

1.2: Causes of Using Self – Compacting Concrete: -

Self - Compacting Concrete (SCC) was first developed in Japan as a mean to create uniformity in the quality of concrete by controlling the ever present problem of insufficient compaction by a workforce that was losing skilled labour and by the increased complexity of designs and reinforcement details in modern structural members. Durability was the main concern and the purpose was to develop a concrete mix that would reduce or eliminate the need for vibration to achieve consolidation. Self - compacting concrete achieves this characteristic by its unique fresh state properties. In the fresh state, it flows under its own weight and maintains homogeneity while completely filling any formwork and passing around congested reinforcement. In the hardened state, it equals or exceeds standard concrete with respect to strength and durability [(4)].

Insufficient compaction will lead to the inclusion of voids, which not only leads to a reduction in compressive strength, but strongly influences the natural, physical and chemical protection of embedded steel reinforcement afforded by concrete. Concrete is normally compacted manually using vibrators, often operated by untrained labour, and the supervision of the process is inherently difficult [(5)].

1.3: Significance of the Study:-

Considering the economy and the durability of present concrete structures, the quality and density of the concrete cover, as well as the compaction of the concrete are the main parameters. SCC offers new possibilities and prospects .As a result of the mix design, some properties of the hardened concrete can be different for SCC in comparison to normal vibrated concrete .Therefore, it is important to verify the mechanical properties of SCC before using. It is for practical applications, especially if present design rules are applicable or if they need some modifications [(6)].

The most important constituent of concrete of both freshly mixed and hardened concrete is the aggregate in addition to serving as inexpensive filler compared with cement .Usually specifications are followed for the materials used in concrete .These specifications are usually based on the local materials and requirements of various countries that may differ from Iraqi conditions.

According to the latest statistics of the Iraqi National Center for Construction Laboratories (NCCL) cited by **Ali** [7], most of the Iraqi sands do not conform to Iraqi specifications for grading which cause great economical problems in the country .This investigation is focused on the possibility of producing SCC with available local sands with high performance.

Therefore, there is a need to study the properties of available raw materials in Iraq in order to facilitate their use in producing SCC without an adversely effects on the main requirements of design and construction.

1.4: The aim of the Study: -

The following main points are the aims of this study:-

- The possibility of producing SCC using local available sand finer than the upper limit and coarser than the lower limit specified by Iraqi Specification (I .O. S 45 /1984) , the ACI (ACI 211.1-91) and British (BS 882 :1992) .
- The effect of maximum size of coarse aggregate on fresh and hardened properties of SCC.
- The possibility of using larger maximum size of aggregate (20 mm) in producing SCC.
- The effect of changing fineness modulus of fine aggregate on fresh and hardened properties of SCC.
- The possibility of producing SCC using poorly –graded fine aggregates.
- The effect of metakaolin as mineral admixture on the fresh and hardened properties of SCC.

2: Literature Review

2. 1: Coarse Aggregate: -

Most types of aggregates are suitable to produce SCC. The aggregate used should be selected in consideration of the performance required of fresh and hardened concrete [8, 9].

The content of coarse aggregate in SCC is a vital parameter in ensuring that the mix has excellent flow characteristics and proper mechanical properties **(Khayat et al., 1999, cited by Newman and Choo, 2003)** .A high coarse aggregate content can lead to a reduction in segregation resistance and also to blockage of the flow **(Okamura et al., 1998, cited by Newman and Choo, 2003)** [10].

In 2002 **EFNARC** [8] stated the determination of coarse aggregate volume. Generally, coarse aggregate content D> 4 mm should be between 50 % and 60 %. When the volume of coarse aggregate in concrete exceeds a certain limit, the opportunity for collision or contact between coarse aggregate particles increases rapidly and there is an increased risk of blockage when the concrete passes though spaces between steel bars.

In 2005, **Rahim** [11] concluded that the flowablity of SCC decreases with an increase in volume ratio and maximum size of coarse aggregate, segregation tendency for mixes with larger size (20mm) aggregate is significantly higher than small size (10mm) aggregate.

2.2: Fine Aggregate: -

The fine aggregate in SCC plays a major role in the workability and stability of the mix. The total fine in the mix is a function of filler and the fine aggregate content. The grading of fine aggregate is particularly important. The grading of fine aggregate in the mortar should be such that both workability and stability are simultaneously maintained [10].

In 1998 **Okamura** [1] had fixed the coarse aggregate content to 50% of the solid volume and the fine aggregate content to 40% of the mortar volume, so that, self-compatibility could be achieved easily by adjusting the water to cement ratio and superplasticizer .

In 2003**, Lahoud et al.** [13] concluded that the increase in the fine aggregate content increases the cohesion of self-compacting concrete.

In 2005 **EFNARC** [12] stated that the influence of fine aggregate on the fresh properties of the SCC is significantly greater than that of coarse aggregate. Particles size fraction less than 0.125 mm should include the fine content of the paste and should also be taken into account in calculating the water powder ratio. The high volume of paste in SCC mixes helps to reduce the internal friction between the sand particles but a good grain size distribution is still very important. Many SCC mix design methods use blended sands to match an optimized aggregate grading curve and this can also help to reduce the paste content. Some producers prefer gap-graded sand.

2.3: Fineness Modulus: -

The particle size distribution of fine aggregate can be often represented by the fineness modulus (F.M). The F.M is calculated from the sum of cumulative percentages retained on standard sieves ranging from 4.75mm to 150μm divided by 100.

Mindess (1981) [14] **and Neville (2005)** [15]**,** stated that, although the F.M is a crude depiction of aggregate grading, it can be used to check uniformity of grading if small changes are expected. It is possible that, aggregate of very different particle size distribution can have the same fineness modulus. The F.M of fine aggregate is used in mix proportioning as a convenient parameter describing aggregate grading which has a significant effect on the workability of concrete. The fineness modulus should be in a range between 2.3 and 3.2, where lower numbers represent a fine grading and higher numbers are representative of coarse grading of concrete sands. The F.M of fine aggregate is required for mix proportioning since sand gradation has the largest effect on workability. Fine sand (low F.M) has much higher paste requirements for good workability.

Newman and Choo, (2003), [10] stated that the standard concreting sands are suitable for use in SCC provided that standard procedures are adhered to sands with FM of between 2.4 – 3.0 fine and coarse aggregate with a grading similar to that used in conventional concrete.

In the method of proportioning concrete constituents recommended the **(ACI 211-91)** [16], the rang of approved F.M is (2.4 to 3.2). It is necessary to increase this rang, so that as wide variety as possible of fine aggregate can be used. This was successfully accomplished by **AL-Qassab** [17]; the range was widened from (1.3 to 4.2) using local Iraqi aggregate, and **AL-Dulaimy** [18]. The results obtained show the possibility of using different gratings of sand with F.M ranging from (1.4 to 3.7) , depending on the American Specification of concrete mix design which notices that these different grading of fine aggregate did not affect the slump or compressive strength .

2:4: Properties of Fresh Concrete: -

2:4.1: Workability: -

The workability of SCC is higher classes of consistence described within international standards, but a highly flowable concrete does not only flow under its own weight, but should also fill the entire form and achieve uniform consolidation without segregation [19].

The level of fluidity of the SCC is governed chiefly by the dosing of the S.P. however, over dosing may lead to the risk of segregation resistance and blockages. [12] SCC differs from conventional concrete in that its fresh properties are critical to its ability to be placed satisfactorily. There are three key properties of workability which need to be carefully controlled to ensure satisfactory performance during its wet phase and for successful classification as SCC.

EFNARC [8, 12] and all other researches agreed with the flowing statements.

"A concrete mix can only be classified as Self-compacting Concrete if the requirements for all three characteristics below are fulfilled:

- ***Filling ability*** of the concrete is to flow freely under its own weight: both horizontally and vertically upwards if necessary and to completely fill formwork of any dimension and shape without leaving voids.
- ***Passing ability*** is the ability of concrete to flow freely in and around dense reinforcement without blocking.
- ***Resistance to segregation*** during placement and while flowing, the concrete should retain its homogeneity and there should be no separation of aggregate from paste or water from solids, and no tendency for coarse aggregate to sink downwards through the fresh concrete mass under gravity.

EFNARC (2005) [12] added another property which is viscosity.

- ***Viscosity***: can be assessed by T50 time during the slump –flow test or assessed by the V-funnel flow time, the time value obtained does not measure the viscosity of SCC , but is related to it by describing rate of flow. Concrete with a low viscosity will have very quick initial flow and then stop. Concrete with a high viscosity may continue to creep forword over an extended time.

2:4:2 Test Methods of Fresh SCC: -

Many different test methods have been developed in attempts to characterize the properties of SCC .So far, no single method or combination of methods has achieved universal approval. Similarly, no single method has been found which characterizes all the relevant workability aspects. So, each mix design should be tested by more than one test method for the different workability parameters. Alternative test methods for the different parameters are listed in Table (2-5) below (8, 12).

Table (2-5): List of Test Methods for Workability Properties of Self-Compacting [(8)].

Method	Property
Slump-flow by Abrams cone	Filling ability
T50 cm Slump flow time	Filling ability
V-funnel	Filling ability
V-funnel at T5 minutes	Segregation resistance
L-box	Passing ability

Before the inception of any research, a number of methods existed for testing these properties. These had been developed to assess the key properties of SCC before it is placed, to ensure that the fresh concrete will indeed be "self-compactable" and will also when hardened, achieve the required uniformity in engineering properties. Much more is demanded of SCC in its fresh state than of conventional vibrated concrete; SCC, though it has to have flowing characteristics, it is not the same as conventional superplasticised concrete, and it is; therefore, more important to verify its properties (8, 20).

3: Materials used in Experimental Work: -

3:1 Cement: -

The cement used in this study is Lebanese ordinary Portland cement type (I). This cement is tested and checked according to Iraqi Standard Specification (I.O.S 5:1984) (21). Tables (3-1) and (3-2) show the chemical and physical properties of this cement and the limits of I.O.S 5:1984 for each one.

Table (3-1): Chemical Composition of Cement*.

Compound Composition	Chemical Composition	Percentage by weight	Limits of IOS 5:1984
Lime		61.27	_
Silica	SiO_2	21.36	_
Alumina	Al_2O_3	5.05	_
Iron Oxide	Fe_2O_3	3.12	_
Magnesia	MgO	2.06	<5
Sulfate	SO_3	2.07	<2.8
Loss on Ignition	L.O.I	3.21	<4
Insoluble residue	I.R	1.32	<1.5

Lime saturation factor	L.S.F	0.86	0.66-1.02
Main Compounds (Bogue's equation) percentage by weight of cement			
Tricalcium silicate (C_3S)		38.5	
Dicalcium Silicate (C_2S)		33.2	
Tricalcium Aluminate (C_3A)		8.39	
Tetracalcium Aluminoferrite (C_4AF)		10.8	

Table (3-2): Physical Properties of Cement*.

Physical Properties	Test Result	Limit of IQS 5:1984
Fineness using Blaine air permeability apparatus (cm^2/g)	4810	>2300
Soundness using Autoclave method	0.2%	<0.8%
Setting time using Vicat's instruments Initial (min.) Final (hrs:min)	 3:20 4:40	 >45 min <10 hrs
Compressive strength for cement paste cube (70.7 mm) at 3 days (MPa) 7 days (MPa)	 33.4 42.2	 >15 >23

* All chemical and physical tests were made by National center for construction laboratories and researches.

3:2 Fine Aggregate: -

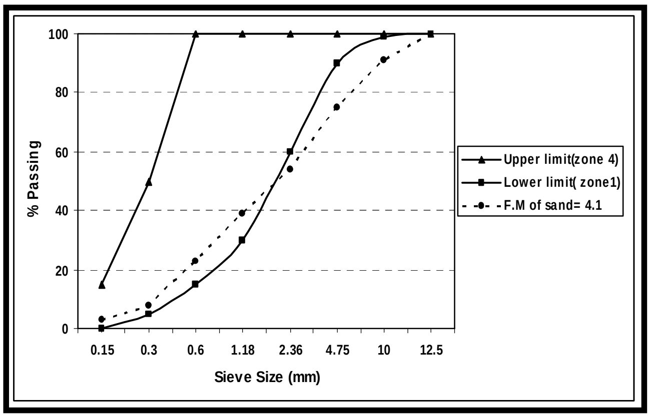
The grading, particle shapes and the amounts of fine aggregate are important factors in the production of SCC. Four types of natural sand from Al-Ukhaider region were used .The grading of the fine aggregate was out of the limits of the **Iraqi Specification No.45/1984** [22] . Table (3-3) and Figures (3-1) ,(3-2) ,(3-3) ,(3-4) show the grading ,and Table (3-4) shows the physical properties of the four type of fine aggregate that are performed by the National Center for Construction Laboratories and Researches (NCCLR).

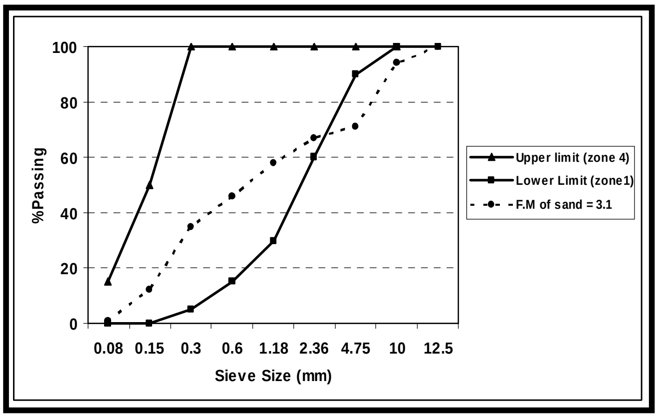
Table (3-3): Grading of Sand with Fineness Modulus (1.5, 2.7, 3.1 and 4.1).

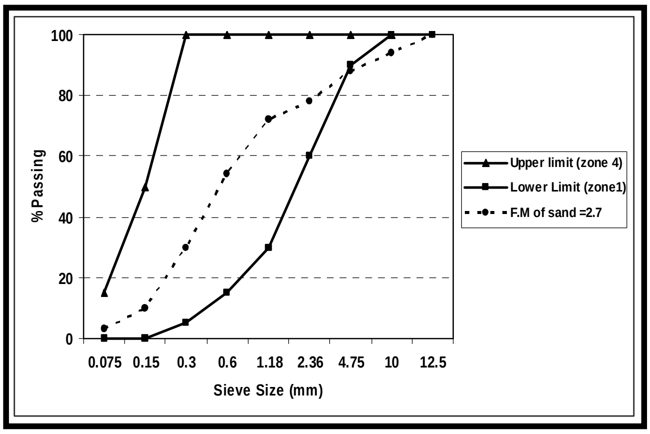
Set No.	Sieve size (mm)	F.M=1.5 %passing	F.M=2.7 %passing	F.M=3.1 %passing	F.M=4.1 %passing
1	12.5	100	100	100	100
2	10	100	94	94	91
3	4.75	100	88	71	75
4	2.36	100	78	67	54
5	1.18	96	72	58	39
6	0.6	70	54	46	23
7	0.3	60	30	35	8
8	0.15	24	10	12	3
9	Fine sand 0.075	7	3	1	0

Table (3-4): Physical Properties of Fine Aggregate.

Set No.	Physical Properties	F.M=1.5	F.M=2.7	F.M=3.1	F.M=4.1
1	Specific gravity	2.68	2.65	2.65	2.65
2	Sulfate content %	0.4	0.35	0.35	0.32
3	Absorption %	4%	3%	2%	2%
4	Moisture Content %	0.25	0.35	0.2	0.2







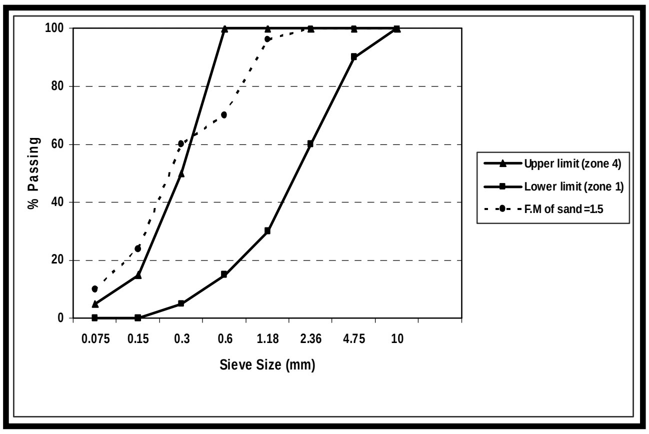


Figure (3-1): Grading of Sand with Fineness modulus of 4.1.

Figure (3-2): Grading of Sand with Fineness modulus of 3.1.

Figure (3-3) :Grading of Sand with Fineness modulus of 2.7.

Figure (3--4): Grading of Sand with Fineness modulus of 1.5

3:3 Coarse Aggregate: -

Crushed gravel of maximum size 20 mm and 10mm from Al-Niba`ee region is used. Table (3-5 show the grading of this aggregate, which conforms to the **Iraqi Specification No.45/1984** [22]. The specific gravity, sulfate content and absorption of coarse aggregate are illustrated in Table (3-6).

Table (3-5): Grading of Coarse Aggregate 20 mm and 10mm.

Set No.	Sieve Size (mm)	% Passing by weight	
		Coarse Aggregate	Coarse Aggregate
1	20	100	---
2	14	90	100
3	10	35	89
4	5	7	711
5	2.36	0	0

Table (3-6): Physical Properties of Coarse Aggregate 20 mm and 10mm.

Set No.	Physic Properties	Test Results	Test Results
1	Specific gravity	2.62	2.36
2	Sulfate content	0.09%	0.06%
3	Absorption	0.6%	0.63%

3:4: Superplasticizer: -

To achieve high workability needed to produce the self-compacting concrete, superplasticizer (high water reducing agent HWRA) based on polycarboxylic ether is used. One of a new generation of copolymer - based superplasticizer designed for the production of SCC is the usage of **Glenium 51**(23). The typical properties of Glenium 51 (according to the manufacturer editions) are shown in Table (3-7).

Table (3-7): Typical Properties of Glenium 51(23).

Form	Viscous liquid
Color	Light brown
Relative density	1.1 @ 20 °C
pH	6.6
Viscosity	128 ± 30 CPS @ 20 °C
Transport	Not Classified as dangerous
Labeling	Not hazard label required

3:5 Mineral Admixtures: -

High reactivity Metakaolin (HRM) is an aluminuosilicate pozzolan produced by clinking the kaolin (a fine, white, clay mineral that has been traditionaiiy used in the manufacture of porcelain) at temperatures of (700-900) °C locally available fine grain size kaolin clinks in laboratory using the burning kiln of clinkering ability up to 1200 °C. kaolin is burned at 700 °C for whole one hour then left to cool down .This procedure of clinking is based on the work of many researchers specially **Yassien** (24).

Strength Activity Index (S.A.I) of HRM with Portland cement is determined according to **ASTM (311-89)** [25]. HRM cement mortars that contain 10% HRM are tested, the W/P that satisfies flow 110m05mm is 0.40.The chemical and physical properties of HRM are listed in Table (3- 8).

Table (3-8): Chemical and physical properties of HRM*.

Chemical Properties		
Oxides	**Content %**	**Pozzolanic class N**
SiO_2	51.34	
Fe_2O_3	2.30	70 % Min.
Al_2O_3	33.4	
CaO	3.00	
MgO	0.17	
SO_3	0.15	4% Max.
L.O.I	7.8	10% Max.
Physical Properties		
Specific Gravity	2.62	---
Fineness (Blaine) cm^2/g	19000	---
Strength Activity Index	150	75

* Test was carried out at State Company of Geological Survey and Mining.

3:6 Mix Design: -

3:6 :1 Determination of Mix Design Method: -

Mix design of SCC must satisfy the criteria of filling ability, passing ability and segregation resistance. The mix design method used in the present study is according to **EFNARC 2002** [8], and then the proportions of materials are modified after obtaining a satisfactory self-compactability by evaluating fresh concrete tests. SCC mixes with Cement: Sand: Gravel ratio of (1:1.56:1.77) by weight, were used. The W/C ratio for each mix was adjusted taking into account the S.P and dosage. Superplasticizer is added in (1.1-2.9) liters per 100 kg of powder depending on the fineness modulus of fine aggregate and maximum size of coarse aggregate to satisfy the requirement of achieving SCC.

3:6:2 Concrete Mixes: -

In order to achieve the aim of the study, this work was divided into six sets .A total of 24 mixes based on the mix design method (EFNARC 2002) (8), has been prepared in this study. SCC mixes were divided into two groups , group 1, consisted of six sets, set one consisted of four reference SCC containing different fineness modules , named R1 , R2 , R3 and R4 without using admixture, with W/C ratios of (0.56, 0.53, 0.527 , 0.51) respectively. Set two included four mixes, Ref. mixes were used after adding superplastiser, named, G1, G2, G3 and G4. Set three includes set two mixed with HRM, and these mixes were named M1, M2, M3 and M4. For the above three sets of SCC mixes maximum size aggregate was 20mm. In group 2, the three above sets were used with the same mixes, using coarse aggregate with maximum size aggregate of 10 mm.

The twenty four self compacting concrete mixes described above have different fineness modulus with different dosages of superplasziser depending on the workability and SCC requirements of the mixes and their composition and addition. The details of mixes are shown in Table (3-11).

Table (3-11): Details of Mixes.

Mix	Water l/m^3	Cement kg^3	HRM kg/m^3	Sand kg/m^3	Gravel kg/m^3	S.P l/m^3	W/P ratio
R1	280	500	---	780	885	---	0.560
R2	265	500	---	780	885	---	0.530
R3	262	500	---	780	885	---	0.524
R4	255	500	---	780	885	---	0.510
G1	170	500	---	780	885	9.0	0.358
G2	170	500	---	780	885	6.8	0.353
G3	170	500	---	780	885	6.4	0.352
G4	170	500	----	780	885	5.5	0.351
M1	170	450	50	780	885	13.5	0.367
M2	170	450	50	780	885	9.0	0.358
M3	170	450	50	780	885	8.3	0.356
M4	170	450	50	780	885	7.5	0.355
E1	290	500	---	780	885	---	0.580
E2	270	500	---	780	885	---	0.540
E3	268	500	---	780	885	---	0. 530
E4	265	500	---	780	885	---	0. 536
S1	170	500	---	780	885	9.6	0.359
S2	170	500	---	780	885	7.3	0.354
S3	170	500	---	780	885	7.0	0.354
S4	170	500	---	780	885	6.1	0.352
H1	170	450	50	780	88	14.5	0.369
H2	170	450	50	780	885	9.8	0.360
H3	170	450	50	780	885	9.2	0.358
H4	170	450	50	780	885	8.4	0.357

Results and Discussions

4.1 Properties of Fresh SCC

4.1: Slump Flow and T50 cm Test: -

The consistency and workability of SCC were evaluated using the slump flow test. Because of its ease of operation and portability , the slump flow test is the most widely used method for evaluating concrete consistency in the laboratory and at construction site .Table (4-1) shows the slump flow (final diameter) values and T50 cm for SCC mixes .

Set No. 1 and Set No. 4 are reference mixes and their slump flow values were between (515 - 600) mm and (540 - 625) mm respectively. The results of T50 cm range between (1-2) sec both of them do not satisfy the requirement slump flow stated in **EFNARC** [(8)]. If any increase in the slump flow of these mixes is required higher water content should be added, leading to produce non homogeneous and segregated mixtures .Other negative effects are the reduced strength and durability as well as increased porosity of the concrete which are the results of the high water content.

The mixes in Set No. 2, G1 mix gave higher slump flow diameter from other mixes because of fineness of sand (F.M= 1.5), which leads to the increase in surface area of fine aggregate.

In Set No.3, mixes containing HRM exhibited lower slump flow values comparing with mixes Set No. 2. The percents of reduction in the slump flow compared with Set No.2 were 2.65 %, 2.74%, 2.77 %, 1.58 % .This may be attributed to the addition of HRM which has high fineness.

The T50 cm values reflect the viscosity of the mix and its speed of flow, T50 cm for all mixes (except G4, M4) is between (3-5) secs. This indicates a good deformability. This agrees with the **EFNARC 2002** [(8)],while mixes G4 and M4 show higher time of T50 cm , which is due to the large average particle size of sand (F.M= 4.1) and the maximum size of coarse aggregates .

Table (4-1): Results of Slump flow &T50 cm Tests.

Set No.	Mix Symbol	Slump Flow (mm)	T50 (sec.)
1	R1	600	2.0
	R2	580	1.5
	R3	565	1.0
	R4	515	1.0
2	G1	755	3.5
	G2	730	4.0
	G3	720	4.5
	G4	660	6.0
3	M1	735	4.0
	M2	710	4.5
	M3	700	5.0
	M4	650	7.0

Set No.	Mix Symbol	Slump Flow (mm)	T50 (sec.)
4	E1	625	2.0
	E2	600	1.5
	E3	580	1.5
	E4	540	1.0
5	S1	770	3.0
	S2	770	3.5
	S3	750	4.0
	S4	710	4.5
6	H1	750	3.5
	H2	735	4.0
	H3	720	4.5
	H4	690	5.0

Also, similar performance was observed in mixes Set No.5 and Set No.6 containing from 10 mm maximum size aggregate which gave slump flow diameters higher than Set No. 2 and 3 with maximum size aggregate (20mm).

More over, T50cm are lower than T50 cm values of the mixes containing 20 mm maximum size aggregate, and this agrees with the study carried out by Rahim (11).

Figures (4-1) and (4-2) show the effect of fineness modulus of fine aggregate on slump flow. The high value of fineness modulus and the large maximum size of coarse aggregate lead to decrease in the slump flow and to an increase in the flow time of (T50cm) .This trend agrees with the studies carried by Okammura and Ouchi (26) .

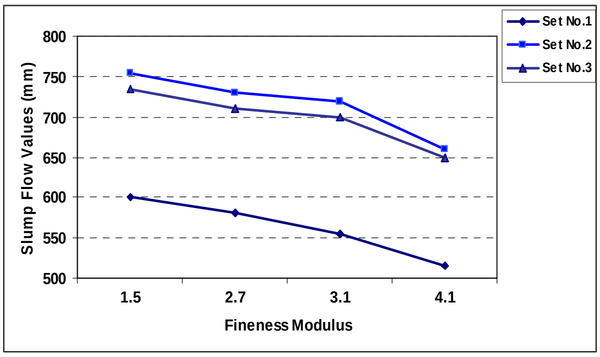


Figure (4-1): Slump Flow values of Mixes Set No. No. 1, 2 &3 with different F.M of fine aggregate.

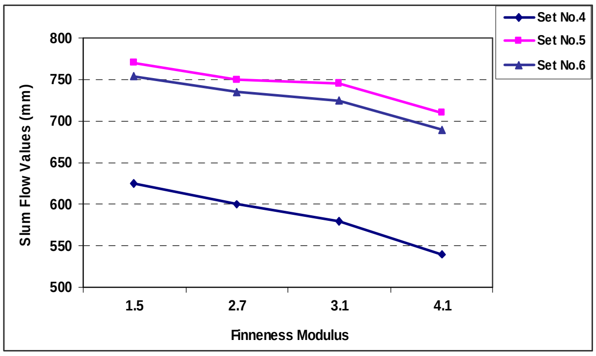


Figure (4-2):Slump Flow values of Mixes set 4, 5 &6 with different F.M of fine aggregate.

Figures (4-3) and (4-4) show the influence of grading of fine aggregate on (T50 cm) of SCC with different fineness modules of fine aggregate and maximum size of coarse aggregate. The figures illustrate that with the increase in the value fineness modulus and maximum size of coarse aggregate, the (T50 cm) increases and the fluidity of the mixes decreases .This agrees with studies carried out by Petersson (27). Also, shows that the incorporation of high HRM as a partial replacement by weight of cement leads to increase T50 values.

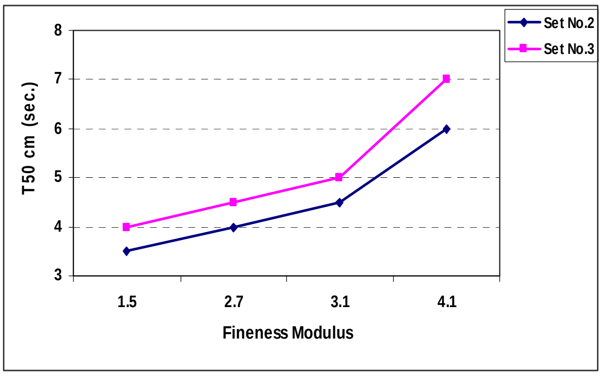


Figure (4-3): T50 cm Values of Mixes Set No.2&3 with Different F.M of fine **aggregate.**

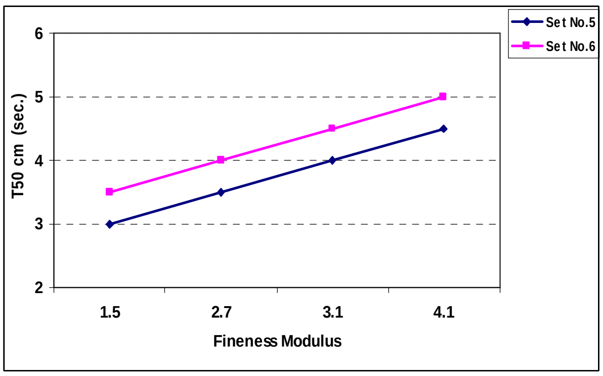


Figure (4-4): T50 cm values of Mixes Set No. 5 & 6 with Different F.M of fine **aggregate**

The empirical relationship between (D) and (T50) cm for all mixes in Set No. 2, 3 and Set No. 5, 6 is illustrated in Figs. (4-5) and (4-6) respectively. It can be seen that this relationship between these two parameters is linear and of high degree of correlation coefficient (R2 = 0.96) for maximum size aggregate 20 mm and correlation coefficient

(R2 = 0.95) for maximum size aggregate 10 mm. Thus, it can be inferred that for speed flow (T50 cm is low), there will be high flow spread (D).

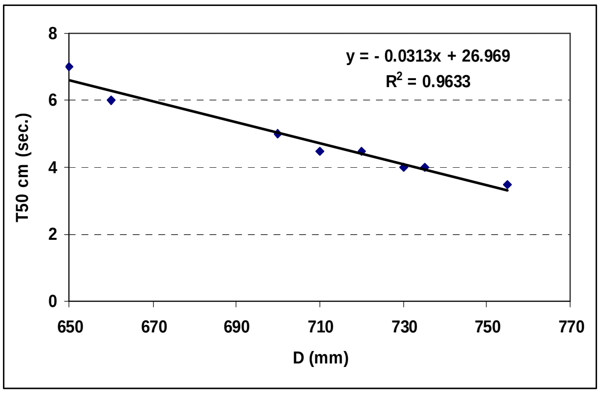


Figure (4-5): Relationship between Slump flow & T50 cm Of Set No.2&3.

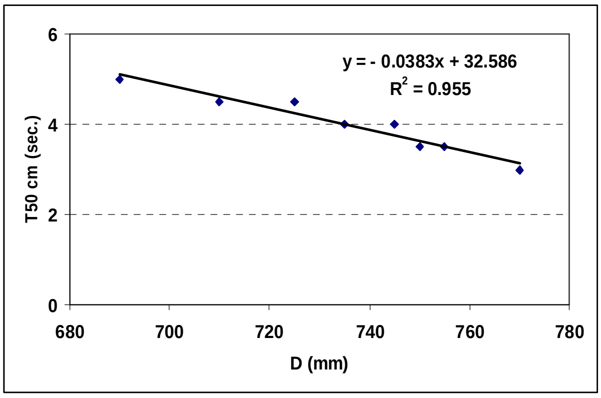


Figure (4-6): Relationship between Slump flow & T50 cm of Set No.5&6.

4:2: L- Box Test: -

The L-box test was used to measure the passing ability of the SCC mixes. The values of (H2/H1) represent the Blocking ratios (Br), while the values of T20 and T40 represent the time of the concrete to reach 20 and 40 cm flow respectively. The L- Box test results are listed in Table (4-2) as well as the values of T20 and T40 flow respectively. This table shows clearly that all the mixes containing fine aggregate with large fineness modulus as (G4 , M4) and large maximum size aggregate has blocking ratios out of limits specified by SCC EFNARC (8) . This means, for given mixes , the acceptable slump flow results can not necessarily lead to successful L-Box test .Also, the good flow ability of a mix does not indicate an accepted passing ability . For this reason, it is well known that the slump flow test is inadequate for passing ability evaluation.

The results obtained from (G4, M4) agree with the studies carried out by Hwang (2006) et al. (28) which allow the critical low limit (Br) values 0.75.

Table :(4-2): Results of L-Box Tests.

Set No.	Mix Symbol	Br	T20 (sec.)	T40 (sec.)
1	R1	---	---	---
	R2	---	---	---
	R3	---	---	---
	R4	---	---	---
2	G1	0.94	2.0	3.0
	G2	0.91	3.0	5.0
	G3	0.87	4.0	6.0
	G4	0.78	5.0	8.5
3	M1	0.92	3.0	4.5
	M2	0.88	4.0	5.5
	M3	0.84	4.5	6.5
	M4	0.77	6.0	9.0

Set No.	Mix Symbol	Br	T20 (sec.)	T40 (sec.)
4	E1	---	---	---
	E2	---	---	---
	E3	---	---	---
	E4	---	---	---
5	S1	0.96	1.0	2.0
	S2	0.93	2.0	3.5
	S3	0.90	2.5	4.5
	S4	0.84	3.5	6.0
6	H1	0.93	2.0	3.5
	H2	0.92	3.0	4.5
	H3	0.87	3.5	5.5
	H4	0.82	4.5	7.0

The values of Br are illustrated in Figs.(4-7) and (4-8) with different fineness modulus of fine aggregate and maximum size aggregate.

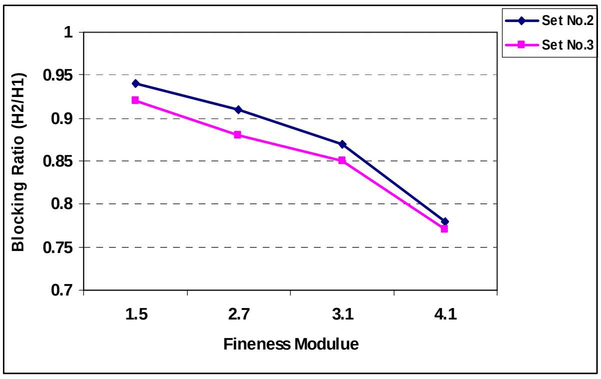


Fig (4-7): Blocking Ratio vs. Fineness Modulus of Mixes Set Set No. 2 & 3.

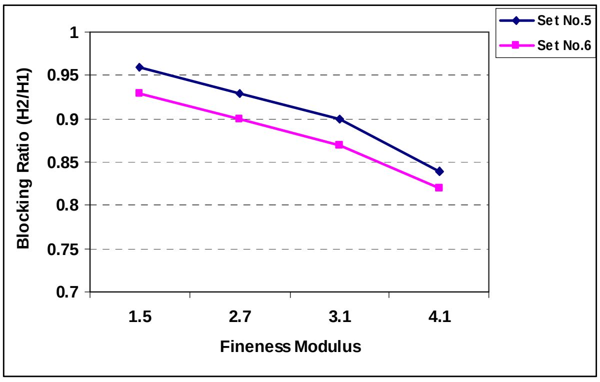


Fig (4-8): Blocking Ratio vs. Fineness Modulus of Mixes Set No. 5 & 6.

From Fig. (4-7), segregation can be noticed that mixes with fine aggregate higher fineness modulus segregation near the obstacles in mix G4 and M4 in Set No.2, 3, while from Fig. (4-8), it can be noticed that no segregation took place because of using smaller maximum size of aggregate which showed good deformability and flowability without blockage near the obstacles . Sets No. 3 and 6 which contain (HRM) had lower blocking ratio less than Set No.2 and 5 mixes due to the Ultra fineness of HRM which increases the requirement of mix to higher superplasticizer dosage to get the desirable results.

The empirical relationship between (D) and (L-Box) results (Br) for all mixes is illustrated in Figs. (4-9) and (4-10). It can be seen that, the relationship between these two parameters is linear , and high degree of correlation coefficient (R2 =0.97) for both of them .Therefore, it can be said that what have been inferred from the behavior of these mixes in slump flow tests seem to be adequate to explain the behavior of these mixes in L-Box test .

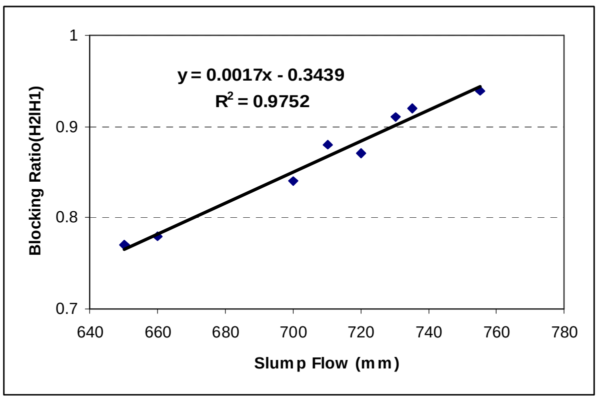


Figure (4-9): Relationship between slump flow & Blocking Ratio of Set No2&3.

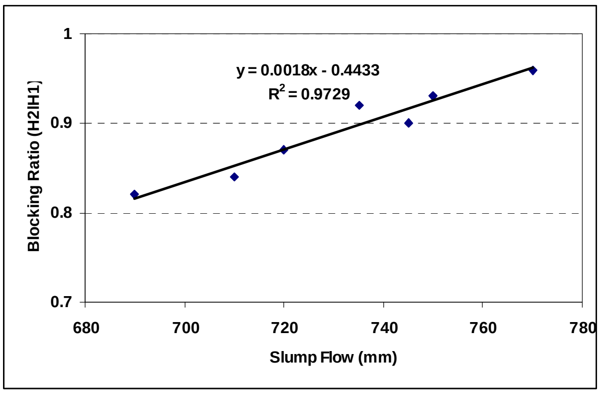


Figure (4-10): Relationship between slump flow &Blocking Ratio of Set No.5&6.

4.3: V- Funnel Test: -

The values of V-funnel test (flow time) represent the ability of concrete to flow out of the funnel and they are used to determine the filling ability of SCC. On the other hand, the flow time at (T5 minutes) value represents the same ability but after refilling the funnel and allowing the concrete to flow 5 minutes after the first filling. Table (4-3) shows the time of the concrete to pass through the V-funnel and shows that the time of flow through the V-funnel for all mixes (except M4) is (5.5 to 12) sec. which agrees with the acceptance criteria for SCC reported by **EFNARC 2002 (8).**

Table (4-3): Results of V-Funnel Tests.

Set No.	Mix Symbol	TV (sec.)	Tv5 (sec.)	Set No.	Mix Symbol	TV (sec.)	Tv5 (sec.)
1	R1	---	---	4	E1	---	---
	R2	---	---		E2	---	---
	R3	---	----		E3	---	---
	R4	----	---		E4	---	---
2	G1	7.0	9.0	5	S1	5.5	7.0
	G2	8.0	10.5		S2	6.5	9.0
	G3	8.5	11.0		S3	7.5	10.0
	G4	12.0	15.0		S4	9.0	12.0
3	M1	8.0	11.0	6	H1	7.0	9.0
	M2	9.0	11.5		H2	8.0	10.0
	M3	9.0	12.0		H3	8.5	11.0
	M4	13.0	16.0		H4	10.0	13.0

The results obtained from (M4) agree with the studies carried out by **Ouchi, 2003** [29] and **final report (2005)** [30] ,which allow the flow time up to 20 sec, but the time obtained from (S1) is less than the acceptance limits, because of the fineness sand and the smaller nominal maximum size of coarse aggregate .

Figures (4-11), (4-12) and (4-13), (4-14) show the time of flow immediately after mixing and the time after 5 minutes respectively. The results clearly show the effect of fineness modulus of fine aggregate and maximum size of coarse aggregate on the ability of concrete to flow. Also, it shows that the time sharply increases when fineness modulus of fine aggregate increases more than 3.1. The results obtained show that the V-funnel test is more sensitive to the change of the properties of the concrete mixes than the slump flow test.

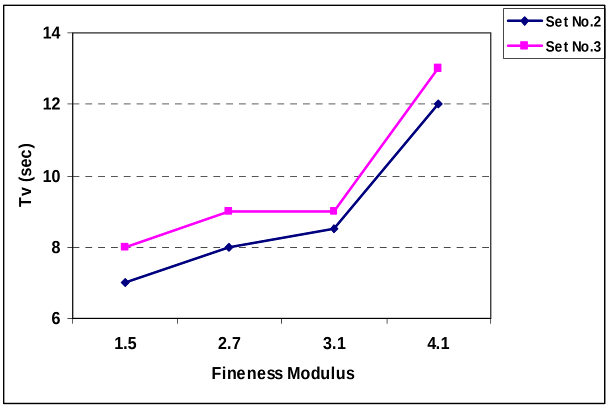


Figure (4-11): Relationship between Flow Time & Fineness Modulus of Set No.2&3

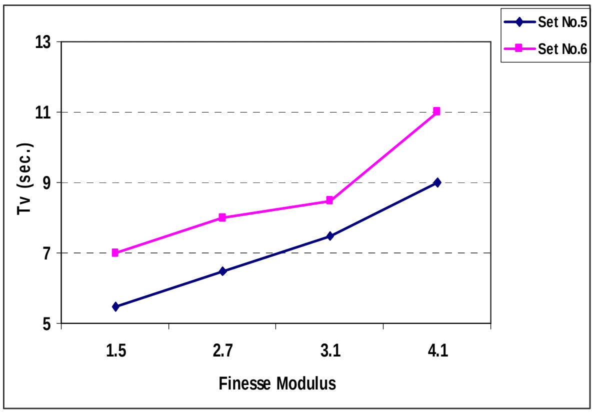


Figure (4-12): Relationship between Flow Time & Fineness Modulus of Set No.4&5.

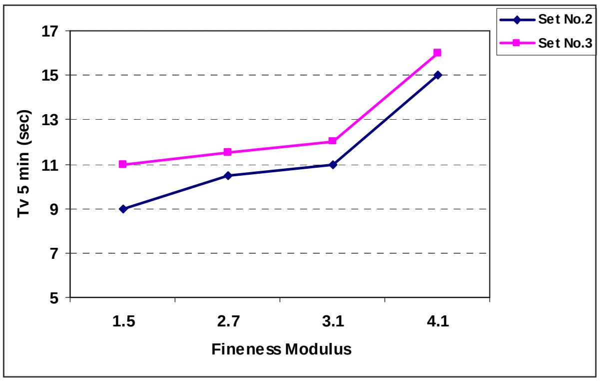


Figure (4-13): Relationship between Flow Time (T5 min.) & Fineness Modulus of Set No.2&3.

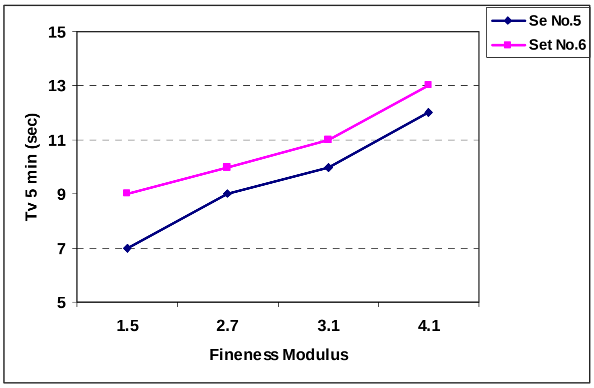


Figure (4-14): Relationship between Flow Time (T5 min.) Fineness Modulus of Set No.5&6.

Figures (4-15) and (4-16) gave an overview over the characteristic fresh concrete parameters of the tested mixes. The nature of the relationship between these two parameters is clearly defined by this figure. The high degree of correlation between the results (R^2 = 0.94 and 0.98 respectively), demonstrates that all mixes of this study are homogenous SCC mixes.

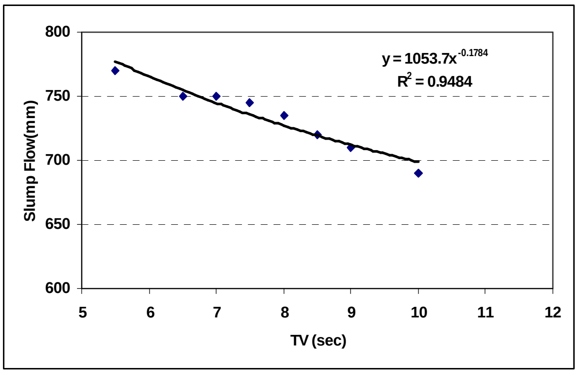


Figure (4-15): Relationship between V- Funnel & Slump flow of Set No. 2&3.

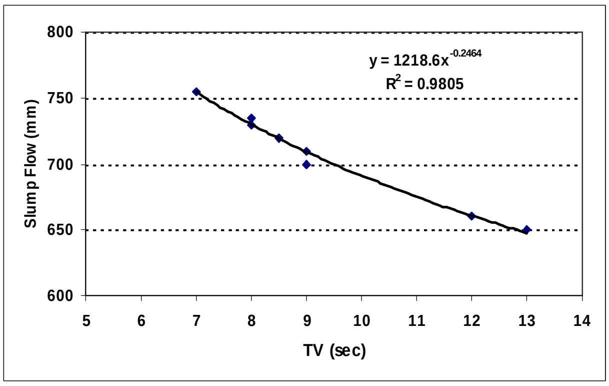


Figure (4-16): Relationship between V- Funnel & Slump flow of Set No. 4&5.

4.4: The Effect of Fineness Modulus of Fine Aggregate on Superplasticizer Dosages:-

Table (4-4) shows the dosage of superplasticizer required for each mix to achieve a satisfactory SCC that agrees with the acceptance criteria reported by **EFNARC 2002 (8).**

Table (4-4): Superplasticizer Dosage (% by weight of powder).

Set No.	Mix Symbol	S.P dosage % by weight of powder
2	G1	1.80
	G2	1.36
	G3	1.28
	G4	1.1
3	M1	2.70
	M2	1.80
	M3	1.66
	M4	1.50

Set No.	Mix Symbol	S.P dosage % by weight of powder
5	S1	1.92
	S2	1.46
	S3	1.40
	S4	1.22
6	H1	2.90
	H2	1.96
	H3	1.84
	H4	1.68

range of superplasticizer dosage for all mixes, as illustrated in Table (4-5), is (1.1 to 2.9) % by weight of powder. The dosage 2.9 % by weight of powder seems to be high, but as it was explained in the literature SCC need high dosages of superplasticizer. Also, this dosage is not higher than that used in SCC according to **AL- Jabri** [31]. The table that the increase in fineness modulus causes a small reduction in the superplasticizer dosage, except in case of mixes (F.M = 1.5) which contains finer sand and lead to increase surface area. So, it absorbs a large quantity of water and requires a higher quantity of superplasticizer. This agrees with the studies carried out by **Okamura and Ouchi** [26]. Also, it can be seen from table that the usage of maximum size of coarse aggregate, causes a small reduction in the superplasticizer dosage from small maximum size aggregate due to the increase in surface area. In addition, the table shows that the mixes that contain HRM require higher superplasticizer dosage than other mixes for example, superplasticizer dosage of G1 mix in Set No. 2 is (1.8 **%** by weight of powder), while superplasticizer dosage of M1 mix is (2.7**%** by weight of powder). This behavior is attributed to fineness of HRM used in this study which requires more superplasticizer dosage to achieve the required workability.

4.3: Hardened SCC Properties:-

4.3.1: Compressive Strength:-

To study the effect of fineness modulus of fine aggregate with maximum size of coarse aggregate on the compressive strength of SCC, standard cubes measuring 150 mm are used. Table (4- 6) shows the average of the results of compressive tested cubes 7, 28, 56 and 90 days.

From the test results shown in table (4-5), it is noticed that the compressive strength of the mixes in Sets No. 5 and 6 made of 10 mm with maximum size aggregate is higher than the compressive strength of the mixes in Sets No.2 and 3 made of 20 mm maximum size aggregate.

At 7, 28 , 56, and 90 days of curing percentages of increase in compressive strength of concrete are (4.4 -9.5) % , (3.78 – 18.18) % , (4.8 -10.6) % and (3.8- 6.85) % respectively ,while in Set No. 6 the percentages of increase in compressive strength of concrete mixes compared with Set No. 3 are about (4.8-7.8)% , (5.26 – 21.66) % , (7.1 -11.5) % and (6.2-11.9) % respectively . This is due to the smaller maximum size of coarse aggregate that has the larger surface area which results in a higher bonding strength at the interface transition zone (ITZ) around aggregate particles when concrete is under loading .This agrees with the studies carried out by Neville (15), **Mindess and Young. (14)**.

Table (4-5): Results of Compressive Strength (MPa) for 150mm Cubes (f_{cu}).

Set No.	Mix	7 days	28 days	56 days	90 days	Set No.	Mix	7 days	28 days	56 days	90 days
1	R1	24	33	41	45	4	E1	26	35	43	48
	R2	29	37	44	51		E2	32	39	46	52
	R3	33	39	46	54		E3	33	41	50	56
	R4	35	42	49	55		E4	37	45	52	58
2	G1	41	53	62	73	5	S1	44	55	65	78
	G2	44	58	70	80		S2	46	66	77	83
	G3	45	60	73	81		S3	47	68	79	86
	G4	42	55	66	77		S4	46	65	73	80
3	M1	38	57	70	78	6	H1	41	60	75	83
	M2	41	63	77	84		H2	43	74	85	94
	M3	43	65	78	88		H3	46	75	87	95
	M4	40	60	73	82		H4	43	73	80	87

From the test results shown in table (4-5), it is noticed that the compressive strength of the mixes in Sets No. 5 and 6 made of 10 mm with maximum size aggregate is higher than the compressive strength of the mixes in Sets No.2 and 3 made of 20 mm maximum size aggregate.

At 7, 28 , 56, and 90 days of curing percentages of increase in compressive strength of concrete are (4.4 -9.5) % , (3.78 – 18.18) % , (4.8 -10.6) % and (3.8- 6.85) % respectively ,while in Set No. 6 the percentages of increase in compressive strength of concrete mixes compared with Set No. 3 are about (4.8-7.8)% , (5.26 – 21.66) % , (7.1 -11.5) % and (6.2-11.9) % respectively . This is due to the smaller maximum size of coarse aggregate that has the larger surface area which results in a higher bonding strength at the interface transition zone (ITZ) around aggregate particles when concrete is under loading .This agrees with the studies carried out by **Neville** [15], **Mindess and Young.** [14].

Table (4-5) shows that, the compressive strength increases with the used superplastizer compared to Ref. concrete due to the decrease in water to cementations. The effect of incorporation of HRM as a partial replacement of cement weight. The results show that the compressive strength values of mixes with HRM at age of 7 days are lower by about (4.7 – 7.3) % and (2.12 –6.8) % than those without HRM. This agrees with the studies carried out by **AL-jabri** [31]. At age 28 , 56 and 90 days compressive strengths of mixes Sets No. 3 and 6 are larger than those without HRM Set No. 2 and 5 about (7.5 – 9.1)% , (6.8 – 12.9) % , (5.4 -8.6) % and (8.8 -21.16) % ,(9.6 – 15.38) %and (6.8 – 13.25) % respectively .

This behavior is due to the pozzolanic activity of HRM on hydration of cement, where HRM reacts with calcium hydroxide .This reaction leads to augmentation in the densification of transition zone and thus increases the bonding strength at the interface zone and the formation of microcracking is decreased. Hence, the microcracking initiation occurs at a higher stress level [32]. From the results of compressive strength test, it can be noticed that the effect of fineness modulus of SCC mixes is rather different from the others , thus the mix with F.M (3.1) gave higher compressive strength between (3.4 – 13.2)% and (3.17-14.0)% for Sets No.2 and 3 at age 28 days .Also, Sets No. 5and 6 gave higher compressive strength between (3.0 – 4.6)% and (1.35 -25)% at age 28 days compared with other mixes in same set . This result may be attributed to the good interlocking between the paste of cement and aggregate particles which lead to higher density and lower voids ratio.

4.3.2: Static Modulus of Elasticity:-

As it is known, the modulus of elasticity of concrete depends on the proportion of Young's module of the individual components and their percentages by volume. Thus, the modulus of elasticity of concrete increases for high contents of aggregates of high rigidity, whereas it decreases with the increase in hardened cement paste content and porosity [33].The determined according to ASTM C 469-87 a . The results of Modulus of Elasticity for all mixes are given in Table (4-6).

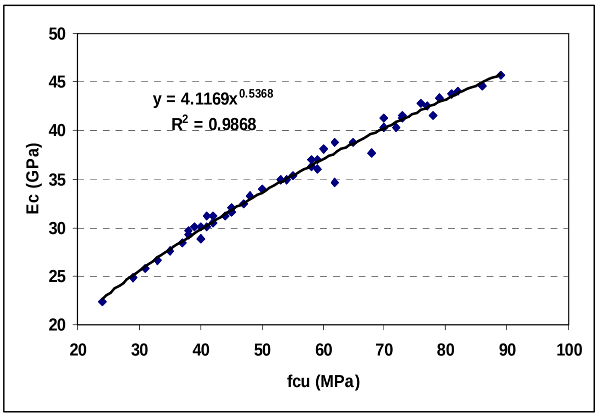
Table (4-6): Results of Modulus of Elasticity E_c (GPa).

Set No.	Mix	7 days	28 days	56 days	90 days
1	R1	22.39	26.68	30.06	31.64
	R2	24.85	28.41	31.25	33.90
	R3	25.78	29.25	32.03	34.98
	R4	27.56	30.46	33.16	35.34
2	G1	30.06	34.62	37.74	41.60
	G2	31.25	36.38	40.35	43.42
	G3	31.64	37.07	41.29	43.72
	G4	30.46	35.34	39.07	42.52
3	M1	28.83	36.04	40.35	41.60
	M2	30.10	38.08	42.52	44.60
	M3	31.26	38.74	42.83	45.76
	M4	29.70	37.07	41.29	44.02

Set No.	Mix	7 days	28 days	56 days	90 days
4	E1	25.30	29.61	33.03	35.01
	E2	28.23	31.36	34.23	36.53
	E3	28.71	32.20	35.78	37.99
	E4	30.50	33.83	36.53	38.71
5	S1	33.43	37.69	41.13	46.81
	S2	32.71	42.14	44.98	46.80
	S3	34.62	41.45	45.58	47.69
	S4	35.78	41.12	43.74	45.90
6	H1	30.93	39.41	44.36	46.85
	H2	33.03	43.72	47.69	50.00
	H3	33.83	44.36	47.41	50.28
	H4	33.03	43.72	45.90	47.00

The table (4-6) shows that, the modulus of elasticity of mixes having different fineness modulus of fine aggregate, the modulus of elasticity increases with the increase in the fineness modulus of fine aggregate up to 3.1. This agrees with the studies carried out by **Mindess and Young** [(14)], and **Aulia, et al**. [(32)]. Also, it appears from the figures that, the smaller nominal maximum size for Sets No. 5 , 6 has larger modulus of elasticity about (8.87 – 16.35)% and (9.35 – 17.9)% compared with Sets No. 2 , 3 which have the larger nominal maximum size because concrete with smaller nominal maximum size has larger compressive strength than concrete with larger maximum size. This leads to higher static modulus of elasticity of those mixes .This agrees with results obtained by **Holschemacher and Klug** [(33)].

The table (4-6) shows that, the compressive strength of concrete and the elastic modulus of concrete are related; the increase in one is similarly reflected in an increase in the other. This agrees with the results obtained by **Mindess and Young** [(14)].



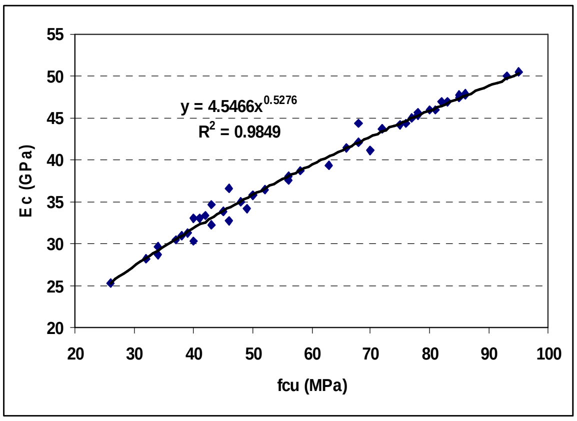


Figure (4- 17): Relationships between Compressive strength Static Modulus of Elasticity of Set No. 1, 2 &3.

Figure (4- 18): Relationships between Compressive strength & Static Modulus of Elasticity of Set No. 4, 5 &6.

$E_c = 4.11\, f_{cu}^{\;0.53}$ for SCC mixes in Set No. 2&3 (4 – 3)

$E_c = 4.54\, f_{cu}^{\;0.52}$ for SCC mixes in Set No. 5&6 (4 – 4)

In comparison with the following relationship stated by **ACI (ACI-318-08)** [(34)], the SCC relationship seems to be somewhat close.

$E_c = 4.7\, f_c^{\;0.5}$ ACI -318 Code [(34)] (4 – 5)

5.1: Conclusions:-

1. .It can be concluded that, it is possible to produce SCC with satisfied fresh and hardened properties by using fine aggregate having fineness modulus ranging between 1.5 to 4.1 and coarse aggregate with 20 mm and 10 mm as maximum size.
2. Self-compacting concrete can be obtained by adding suited Superplastizer and very fine mineral admixture (metakaolin) .These two materials provide a sufficient balance between the yield stress and viscosity of the mix .The inclusion of 10 % HRM as a partial replacement by weight of cement needs (1.5 - 2.9) %

Superplastizer to produce SCC , compared with (1.1- 1.92)% for concrete mixes without HRM .

3. It is possible to produce self- compacting concrete without using mineral admixture and by using only a suitable dosage of superplastizer.
4. The workability of all studied mixes and the ranges of slump flow are between (650-770) mm, T50 cm times for all mixes are between (3- 5) sec. The time of the concrete to pass through the V –funnel time is still less than (5.5 - 13) sec. while L-box results are in the ranges of (0.77 – 0.96), for blocking ratio. The filling height range is between (0-30) mm.
5. All mixes show good deformability without segregation except mixes G4 (mix has fineness modulus 4.1), M4 (mix has fineness modulus 4.1with HRM) which show somewhat blockage behavior in L- box with large maximum size aggregate.
6. The flowability of SCC decreases with an increase of fineness modules of sand and maximum size of coarse aggregate
7. The mix has fineness modulus equal to 3.1 and superplastizer with dosage range (1.28-1.4) % is considered as best mix.
8. The effect of the change in fineness modulus of sand is not clear on hardened concrete , but its effect is more clear on the properties fresh concrete .At suitable coarse sand with small maximum size aggregate pass the to tests of fresh concrete with high content of cement.
9. Due to Self - Compatibility, all studied mixes show compressive strength, splitting tensile strength, modulus of Rupture and static modulus of elasticity with the ranges of (38 - 90) MPa, (3.89 - 7.40) MPa,(5.81 -9.79) MPa (29.70 - 50.28) GPa respectively.
10. The mechanical properties of SCC mixes containing 10 mm maximum size of coarse aggregate are higher than mixes with 20 mm maximum size of coarse aggregate in the mixes.
11. The addition of HRM as a partial replacement of cement increases significantly the mechanical properties of SCC mixes as compared with mixes without HRM for all ages of test.

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