The Effect of Filler Types and Superplastizier on the Workability and Splitting Tensile Strength of Self-Compacting Concrete

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Abstract

Self-compacting concrete (SCC) is a special type of concrete that can flow through intricate geometrical configurations under its own mass without external or internal vibration or segregation. The objectives of the research work were to evaluate the effects of filler types (silica fume and limestone dust) and high- range water-reducing agent, (HRWRA, superplastizier-type Sikament -163) on the workability and splitting tensile strength of SCC. The experimental results showed the using silica fume and limestone dust in Self-compacting concrete led to a considerable improvement in splitting tensile strength. As the percentage of limestone powder and silica fume increases, the workability properties of SCC slightly decreased with increases in splitting tensile strength. The workability properties of SCC for all the replacements satisfy the recommended values given by specifications.

Keywords: self-compacting concrete, silica fume, limestone dust, fillers, strengths, splitting, super plasticizers

تأثير أنواع المواد المالئة والملدن الفائق على قابلية التشغيل ومقاومة الشد بالانشطار للخرسانة ذاتية الرص

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قسم التقنيات المدنية، المعهد التقني - الموصل

الخلاصة

الخرسانة الذاتية الرص هي نوع جديد من الخرسانة والتي يمكن ان تنساب خلال المقاطع الخرسانية المعقدة بتاثير وزنها دون الحاجة الى رصها بالاهتزاز وبدون حصول انعزال في مكوناتها. الغايات من مشروع البحث هذا هي لبيان تاثيرات أنوع المواد المالئة (غبار السيليكا ومسحوق الحجر الجيري) مع الملدن الفائق نوع (Sikament-163) على قابلية تشغيل ومقاومة الشد الانشطاري للخرسانة الذاتية الرص. تبين النتائج التجريبية, بان استخدام غبار السيليكا ومسحوق الحجر الجيري في الخرسانة الذاتية الرص ادى الى تحسن مميز في مقاومة الشد الانشطاري. عند زيادة نسبة مسحوق الحجر الجيري و غبار السليكا فان قابلية التشغيل للخرسانة الذاتية الرص قلت قليلا ولكن مقاومة الشد الانشطاري ازدادت. خواص قابلية التشغيل للخرسانة الذاتية الرص لجميع نسب الاستبدال كانت مرضية وضمن القيم المعطاة في المواصفات.

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Introduction:

Self-Compacting Concrete, started in Japan in the late 80's to solve problems of pouring and setting concrete in high rebar densities structures, has slowly spread all over the world, showing many other characteristics and attracting attention first in laboratories and then in application. The most relevant performances of SCC are already well known and have been confirmed in large scale applications. High filling capacity, no vibration needed, reducing noise and unhealthy tasks for workers, high flow for longer distance pouring, homogeneity due to absence of poor workmanship in casting, high strength and durability, excellent surface are the main performances recognized to the product [1].

Dehn F. et al. [2] have focused their research work on the time development of SCC compressive and splitting tensile strength and the bond behavior between the reinforcing bars and the self-compacting concrete compared to normal concrete. In order to ensure a good production of SCC, a mix design should be performed, so that the predefined properties of the fresh and hardened concrete would be reached for sure. All the components should be coordinated so that bleeding and segregation would be prevented. Because of these aspects, their mix design was based on experience from Japan, Netherlands, France, and Sweden. Experimental results showed higher compressive strengths (36%) and splitting tensile strengths (28%) of the SCC specimens compared to normal concrete specimens. Also, the bond behavior measured at 1, 3, 7 and 28 days after concreting was better for self-compacting concrete than that of normally vibrated concrete.

Cristian D. [3] showed, that the self-compacting concrete can be obtained in such a way, by adding chemical and mineral admixtures, so that it's splitting tensile and compressive strengths are higher than those of normal vibrated concrete. An average increase in compressive strength of 60% has been obtained for SCC, whereas 30% was the increase in splitting tensile strength. In addition, the SCC tensile strengths after 7 days were almost as high as those obtained after 28 days for normal concrete. Also, due to the use of chemical and mineral admixtures, self-compacting concrete has shown smaller interface microcracks than normal concrete, fact which led to a better bonding between aggregate and cement paste and to an increase in splitting tensile and compressive strengths. A measure of the better bonding was the greater percentage of the fractured aggregate in SCC (20-25%) compared to the 10% for normal concrete.

Muhammad I. K. [4] carried out tests in order to find the effects of silica fume on the workability of self-compacting concrete. The test results showed that, the inclusion of silica fume (SF) decreased workability of concrete. At higher dosage of SF superplasticizer usage is vital to maintain the workability at the required level. The major reduction in the permeability of concrete is achieved by incorporation of SF up to 10%, beyond this the reduction is not much efficient.

A combination of the slump flow and either the L-box blocking ratio (h2/h1), J-Ring, U-box, or V-funnel flow time can be used to assess filling capacity of SCC for quality control and design of SCC for placement in restricted sections or congested elements, typically encountered in structural applications. SCC designed for structural applications should have a slump flow of 670 ± 50 mm, an h2/h1 index greater than 0.70, a J-Ring flow of 650 ± 50 mm, a spread between slump flow and J-Ring flow lower than 50 mm, and a V-funnel flow time of less than 8 seconds [5].

Seshadri, T and Srinivasa, P. [6] studied the properties like Compressive Strength, Split Tensile Strength and Flexural Strength of SCC mix proportions ranging from M30 to M65 Grades of Concrete. An attempt also has been made to obtain a relationship between the splitting tensile strength, Flexural Strength and Compressive strength by the test results. The Split Tensile Strength Values are observed to be varied from 3.01 to 6.44 N/mm^2 for 28 days, 3.52 to 7.54 N/mm^2 for 90 days and 3.68 to 7.62 N/mm^2 for 180 days. The Split Tensile Strength for all the Grades of Concretes at 90, 180 days are observed to be varied from 15% to 25% when compared with 28 days Split Tensile Strength.

Mostafa A. Gzal [7] showed, that the type and time of curing had little effect on the properties of self-compacting concrete with limestone powder or clinker powder compared to the normal concrete, and the compressive strength and splitting strength were developed more rapidly than that of normal concrete for the same curing at (6-11) MPa for mix with 10% limestone powder, (1-8) MPa for mix with 8% limestone powder and (10-16) MPa for mix with 10% clinker powder.

A-Feel J. R. and Al-Saffar N. S.[8] in their research, carried out tests in order to study the effect of curing methods on the compressive, splitting, and flexural strengths (modulus of rupture) of self compacting concrete in comparison to those of normal concrete. The self compacting concrete consisted of Portland cement (P.C) limestone powder (L.S) (L.S 8% / 92% P.C), sand, gravel and super-plasticizer. The specimens were cured in the air and water, for the period of 7, 14, and 28 days. The results showed that the water cured specimens gave highest compressive strength, splitting tensile strength and flexural strength than specimens cured by air about 11%, 10% and 11% for self compacting concrete at 28 days respectively. The results indicated that the splitting tensile strength for SCC cured in water or air at 28 days is increased by 25% compared to that of normal concrete, this indicates that the type of curing is not so important for the development of tensile strength of SCC. A comparison of tensile and compressive strength indicates that the compressive strength is more sensitive to the curing method than the tensile strength.

Experimental Work

Materials

Cement

Locally manufactured Cement, conforms to IQS, No.5, 1984 requirements, was used in this investigation. Its physical properties used are presented in **Table (1)**.

Fine Aggregate

The fine aggregate used was uncrushed aggregate from Al-kanhash region in Mosul city. The sieve analysis of this aggregate is shown in **Table (2)**. It conforms to the Iraqi specification No. 45/1980, Zone (2). The specific gravity, absorption, fineness modulus and material finer than No. 200(75 μm) sieve of the used fine aggregate were (2.65, 0.9%, 2.9 and 0.2%) respectively.

Table (1): Physical Properties of Cement

Physical properties	Test result	Limits of Iraqi spec. No. 5/1984
Specific surface area Blaine method, cm^2/gm	2750	$\geq$ 2300 cm^2/gm
Standard consistence, %	27.5	-
Setting time, Vicat's method: **Initial setting, hrs: min.** **Final setting, hrs: min.**	 0:60 2:50	 $\geq$ 45 minutes $\leq$10 hour
Fineness on sieve No. 170, %	3	$\leq$ 22%
Compressive strength of 5 cm cubic mortar samples, N/mm^2: **3 days** **7 days**	 17.2 26.8	 $\geq$ 15 N/mm^2 $\geq$ 23 N/mm^2

Coarse Aggregate

Natural coarse aggregate of 10-mm maximum size was used for concrete mixes of this investigation. The sieve analysis of the used sand is shown in **Table (3)**. It conforms to the limits of Iraqi specification No. 45/1984. The specific gravity, absorption, and material finer than sieve No. 200 (75 µm) of the used fine aggregate were (2.62, 0.5%, and 0.8%) respectively.

Table (2): Grading of Fine Aggregates

Sieve size (mm)	Accumulated percentage passing (%)	Accumulated percentage retained (%)	Limit of Iraqi specification No. 45/1984, Zone (2)
4.75	94.65	5.35	90-100
2.36	78.83	21.17	75-100
1.18	65.98	34.02	55-95
0.60	49.62	50.38	35-59
0.30	13.78	86.22	30-8
0.015	6.79	93.21	0-10

Table (3): Grading of Coarse Aggregates

Sieve size (mm)	Accumulated percentage passing (%)	Accumulated percentage retained (%)	Limit of Iraqi specification No. 45/1984
14	100	0.0	100
10	87.80	12.20	85-100
5	11.60	88.40	0-25
2.36	0.0	100	0-5

Mixing Water

Ordinary potable water was used in this investigation for both mixing and curing purposes.

High-Range Water-reducing Admixtures (Superplasticizer) Type Sikament-163

Commercially available high performance superplasticizing admixture, Sikament-163, Type (F) according to ASTM C494-86 was used to maintain the slump of the concrete. It was produced by Sika Near East S.a.l Beirut- Lebanon. The properties, supplied by the manufacturer, are given in **Table (4)**.

Silica Fume

Silica fume type Sika Fume-HR used in this investigation was obtained in powder form with fineness 0.1µmm. It was produced by Sika Near East S.a.l Beirut-Lebanon**.** The technical data of this type are shown in **Table (5)**. The silica fume was incorporated in the self-compacting concrete at 0, 7.5 and 15% as a partial cement replacement by weight of cement content.

Table (4) Technical Data of Superplasticizer Type Sikament-163 Used

Property	Result
Type	Naphthalene formaldehyde sulphonate
Color	Dark brown
Density	1.2 kg/l
Storage	Sikament-63 must be stored free from frost
Shelf life	18 months from date of production if stored properly in original unopened packing
Dosage	0.8 – 3% by weight of cement
Packaging	5 kg and 20 kg pails, 250 drums

Table (5) Technical Data of Silica Fume Type Sika Fume-HR Used

Property	Result
Composition	A latently hydraulic blend of active ingredients
Appearance	Grey powder
Dry bulk density	0.05 – 0.1 kg
Storage	Sika Fume-HR is not affected by frost. It must be stored in dry conditions
Shelf life	24 months from date of production if stored properly in original unopened packing
Dosage	2 – 10% by weight of cement
Packaging	15 kg bags. Special packs and bulk silo deliveries also available on request

Limestone Dust

A limestone dust from north of Iraq with maximum size 0.075mm was used throughout this work, as a partial replacement 0%,7.5% and 15 % by weight of cement content.

The Experimental Program
Preparation of Concrete Specimens

Concrete Mixes

The details of mix proportions are presented in **Table (6**). The water to cement ratio was 0.52 for mixes without fillers and superplasticizer. While the water to cement ratio was 0.41 for mix contain superplasticizer only. The silica fume and limestone dust were incorporated in the concrete at 0, 5, and 15% as a partial cement replacement by weight of cement content.

Table (6): Details of the Mixes Used Throughout This Investigation

Mix designation	Mix Proportion	(W/C) or (W/Cm)*	Silica Fume (%)	Limestone dust (%)	Superplas-ticizer (%)
SCC1	1:2.2:1.8	0.52	0	0	0
SCC2	1:2.2:1.8	0.41	0	0	3
SCC3	1:2.2:1.8	0.41	0	7.5	3
SCC4	1:2.2:1.8	0.43	0	15	3
SCC5	1:2.2:1.8	0.42	7.5	0	3
SCC6	1:2.2:1.8	0.43	15	0	3

* W/Cm ratio: Water/ cementinous materials ratio

Mixing Procedure

The mixing of concrete is important to obtain the required workability and homogeneity. A mechanical mixer of (0.16) m^3 capacity was used. The interior surface of the mixer cleaned and moistened before placing the materials.

For self-compacting concrete without admixtures, the raw materials of gravel, sand were first mixed dry for about one minute then the cement was added to the mixer and mixed for one minute. After that mixing water was added gradually and mixed for about two minutes until a homogenous concrete mix was obtained.

For self-compacting concrete containing superplasticizer, the raw materials of gravel and sand were first mixed dry for about one minute then the cement was added to the mixer and mixed for one minute. After that mixing water with superplasticizer (Sikament-163) was added gradually and mixed for about two minutes until a homogenous concrete mix was obtained.

For self-compacting concrete containing superplasticizer and fillers (silica fume or limestone dust), the raw materials of gravel and sand were first mixed dry for about one minute then the cement and filler was added to the mixer and mixed for one minute. After that mixing water with superplasticizer (Sikament-163) was added gradually and mixed for about two minutes until a homogenous concrete mix was obtained.

Casting and Curing of Specimens

From each trial mix, a total of 3 cylindrical concrete specimens, 150 mm in diameter and 300 mm high, were cast for determining the splitting tensile strength after 28 days of moist curing. The moulds were oiled properly for easy demolding and then filled with self-compacting concrete. The concrete will flow under its own weight; therefore, the molds were not vibrated. After casting and finishing, the specimens were covered with plastic sheet to avoid loss of water due to evaporation. The specimens were demolded after 24 hours of casting and then they were transferred to a curing tank placed at the laboratory temperature of 18 to 20ºC. The specimens were cured in the water tank for 28 days.

Testing of Fresh Self-Compacting Concrete

Workability

Self-compacting concrete is not only designed to self-consolidate but also flow under its own weight. It provides a slick finished surface without vibration. SCC must satisfy the following workability performance criteria [9]:

(a) Filling ability – The property that determines how fast self-compacting concrete flows under its own weight and completely fills intricate spaces with obstacles, such as reinforcement, without losing its stability.

(b) Passing ability – the ability of self-compacting concrete to pass through congested reinforcement and adhere to it without application of external energy.

(c) Stability – the ability of self-compacting concrete to remain homogenous by resisting segregation, bleeding and air popping during transport, placing and after placement.

Various workability tests, as mentioned below, were carried out for the self-compacting concrete mixes, **Figure (1)** gives the Slump flow, J-ring and V-Funnel Apparatus used:

Figure (1): Slump flow, J-ring and V-Funnel Apparatus used [8]

Slump flow test:

Filling ability and flowability of the self-compacting concrete mixes were tested using the slump flow test. The 'slump flow' is the mean diameter of the horizontal spread of the concrete mass, after lifting the slump cone, as shown in **Figures (1).** For self-compacting concrete, the slump flow should be 650-800 mm, and T_{500} should be 2-5 seconds [10]. The following formula was used to calculate the Flow test:-

$$\text{Flow test (S)} = \frac{D_{max.} + D_{perp.}}{2} \qquad (1)$$

Where:

$D_{max.}$ = Maximum Diameter (mm)

$D_{perp.}$= Diameter perpendicular to Maximum Diameter (mm)

J-ring test:

Passing ability of the mix was tested using a J-ring apparatus as shown in **Figures (1),** with 16 bars (ø18 mm), to simulate actual congestion of reinforcement in the I-beam. J-ring test is performed by lifting the slump cone and allowing self-compacting concrete to flow radially outward through the J-ring. For self-compacting concrete, the J-Ring Blocking Step should be < 20 mm [10]. The following formulas were used to calculate the J-Ring Flow Spread and J-Ring Blocking Step:-

$$\text{J-Ring Flow Spread (Sj)} = \frac{D_{max.} + D_{perp.}}{2} \qquad (2)$$

Where:

$D_{max.}$ = Maximum Diameter (mm)

$D_{perp.}$= Diameter perpendicular to Maximum Diameter (mm)

$$\text{J-Ring Blocking Step (Bj)} = \frac{(\Delta h_{x1}+\Delta h_{x2}+\Delta h_{y1}+\Delta h_{y2})}{4} - \Delta h_0 \qquad (3)$$

Where:

$\Delta h_{x1}+\Delta h_{x2}+\Delta h_{y1}+\Delta h_{y2}$ = differences of level in the concrete outside J-Ring (mm)

Δh_0 = level in the concrete inside the J-ring (mm)

V-Funnel test:

Filling ability of self-compacting concrete was also tested using the V-funnel apparatus as shown in **Figures (1).** Filling ability was evaluated by measuring the time (T_0 in seconds) taken for the mix to completely empty-out through the V-funnel, The time recorded after the concrete was left standing for 5 minutes in the V-funnel was the T_5 time. For self-compacting concrete, the flow time T_0 should be 6-12 seconds, and T_5- T_0 should be 0-3 seconds [10].

Testing of Hardened Self-Compacting Concrete

Splitting tensile strength test

The splitting tensile strength (f_{ts}) was conducted on cylinders of (150 x 300 mm). The average of three test specimens was taken. The test was carried out in accordance with ASTM C 496-86. The following formula was used to calculate the splitting tensile strength;

$$f_{ts} = \frac{2P}{\pi DL} \qquad (4)$$

Where:

P = Maximum Load (N) D = Diameter of sample (mm) L = Length of sample (mm)

Results and Discussion

The superplasticizer (Type Sikament - 163) was used to reduce the water-cement ratios while maintaining equal workability to reference self-compacting concrete mix. The water reducing effect produced by superplasticizer was investigated with three different percent of limestone dust and silica fume contents (0%, 7.5% and 15% by weight of cement) as shown in Table (6). The results indicated that the dosage of 3.0% superplasticizer by weight of cement gave water reduction (21.15%, 21.15% and 17.30%) for self-compacting concrete with limestone dust of (0%, 5% and10%) by weight of cement respectively. While, the effect of (3%) superplastizier on the water reduction of self-compacting concrete containing silica fume (0%, 7.5% and 15%) by weight of cement were (21.15%, 19.23% and 17.30%) respectively.

The values of water reduction of self-compacting concrete mixes containing limestone dust or silica fume as a partial replacement by weight of cement in conjunction with 3% dosage of superplasticizer was found to be lower than that of the self-compacting concrete mixes containing superplasticizer only. This behavior may attribute to the very high surface area of limestone dust and silica fume powder which can be completely dispersed into individual particles.

Tables (7) to (9) presents the various workability test results of different self-compacting concrete mixes. Slump flow test results, J-Ring test results and V-funnel test results are presented in **Tables (7), (8) and (9)** respectively. All of the workability test results conformed to the criterion of self-compacting concrete (SCC).

Table (7): Slump Flow Test

Mix designation	T_{500} (sec)		Slump Flow (mm)	
	Results	Limits of specifications [10]	Results	Limits of specifications [10]
SCC1	3	(2-5) sec	745	(650-800) mm
SCC2	4		695	
SCC3	4		690	
SCC4	3		720	
SCC5	3		730	
SCC6	4		675	

Table (8): J-Ring Test

Mix designation	J-Ring Flow Spread (mm)		J-Ring Blocking Step (mm)	
	Results	Limits of specifications	Results	Limits of specifications [10]
SCC1	680	-	13	< 20 mm
SCC2	705		11	
SCC3	745		10	
SCC4	690		13	
SCC5	738		10	
SCC6	674		11	

Table (9): V-Funnel Test

Mix designation	T_0 (sec)		T_5 (sec)	T_5- T_0 (sec)	
	Results	Limits of specifications [10]	Results	Results	Limits of specifications [10]
SCC1	8	**(6-12) sec**	**9**	1	**(0-3) sec**
SCC2	10		13	3	
SCC3	8		10	2	
SCC4	11		13	2	
SCC5	9		12	3	
SCC6	10		11	1	

From **Table (7) to (9)**, it can be seen that the addition of 7.5% and 15% limestone dust or silica fume did cause any decrease in workability of self-compacting concrete. This behavior may attribute to the very high surface area of limestone dust and silica fume powder which can be completely dispersed into individual particles [7].

The splitting strengths development for various filler contents of all mixes of self-compacting concrete are presented in **Table (10)** and **Figures (2) and (3)**. Results demonstrated that in general, all self-compacting concrete specimens exhibited continuous increase in splitting strengths with increases of silica fume contents and limestone dust contents.

From **Tables (10) and (11) and Figures (4)**, it can be seen that the addition of 3% superplasticizer causes increase in the splitting strengths of self-compacting concrete at 28 days. The increase of splitting strength of self-compacting concrete with 3% superplasticizer by weight of cement was 21.8%.

Also, it can be seen that the addition of 7.5% and 15% limestone dust and 3% superplasticizer causes increase in the splitting strengths of self-compacting concrete without superplasticizer at 28 days. The increases of splitting strength of self-compacting concrete with 7.5% and 15% limestone dust by weight of cement were 37% and 47% respectively. While, the increases of splitting strength of self-compacting concrete with 7.5% and 15% silica fume by weight of cement and 3% superplasticizer were 50% and 58% respectively.

Table (10): Splitting Tensile Strength of Self-Compacting Concrete

Mix designation	Splitting Tensile strength (MPa)	
	Splitting Tensile strength Results (MPa)	Average Splitting Tensile strength (MPa)
SCC1	3.4,3.0,3.1	3.2
SCC2	3.7, 3.9, 4.0	3.9
SCC3	4.6, 4.2, 4.2	4.3
SCC4	4.8, 4.7, 4.5	4.7
SCC5	4.8, 4.7, 4.9	4.8
SCC6	4.8, 5.3, 5.0	5.0

Also, it can be seen that the effects of 7.5% and 15% limestone dust and 3% superplasticizer causes increase in the splitting strengths of self-compacting concrete with 3% superplasticizer at 28 days. The increases of splitting strength of self-compacting concrete with 7.5% and 15% limestone dust by weight of cement were 12% and 21% respectively. While, the increases of splitting strength of self-compacting concrete with 7.5% and 15% silica fume by weight of cement and 3% superplasticizer were 24% and 30% respectively.

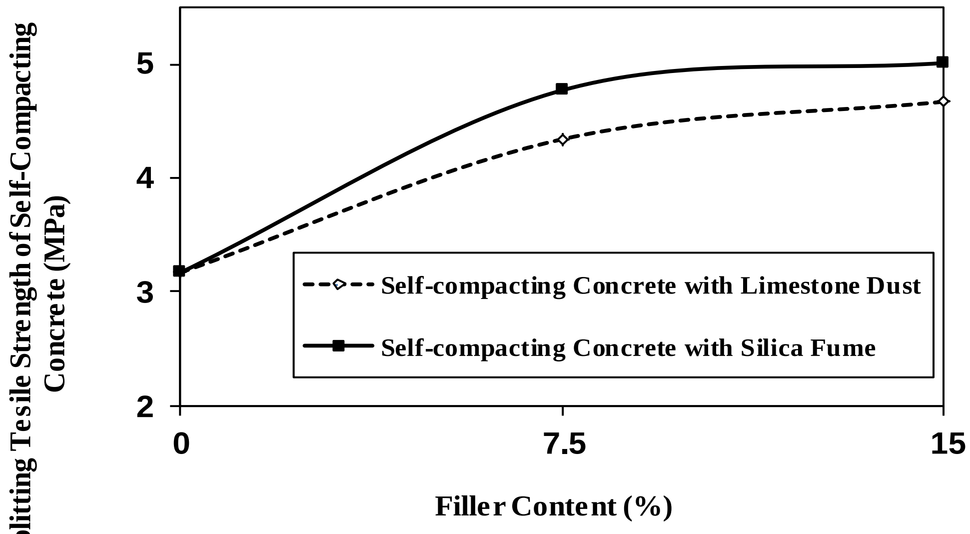

Figure (2): The Effect of Filler Contents on the Splitting Strength of Self-compacting Concrete (when the SSC1 without Admixtures)

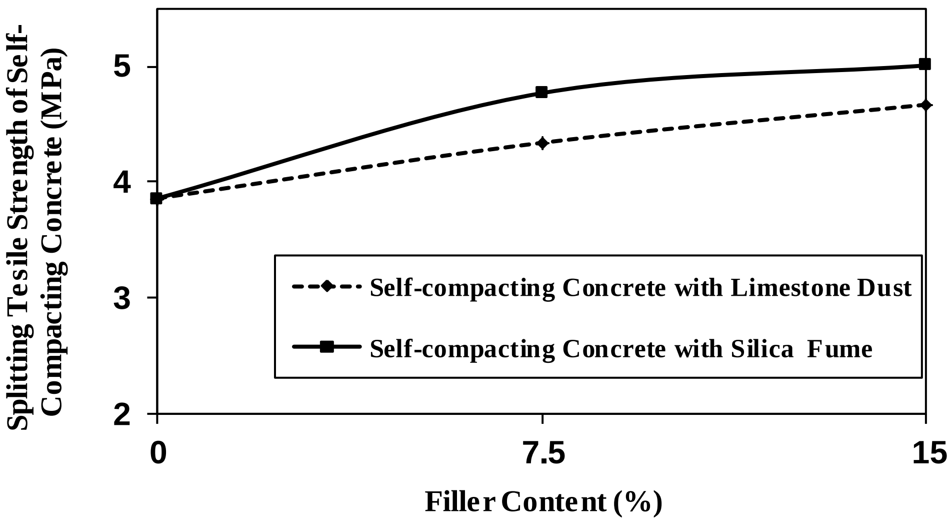

Figure (3): The Effect of Filler Contents on the Splitting Strength of Self-compacting Concrete (when the SSC2 with Admixtures)

Figures (2) and (3) show the results of the splitting strength. Self-compacting concretes with silica fume give better results than those with ground limestone. This behavior is due to the pozzolanic activity of the silica fume which increases when ground because of the higher reactivity related with the higher fineness.

This improve in the properties of superplastized silica fume self-compacting concrete is attributed to the reduction in capillary porosity caused by the reduction of the water content of the mix. In addition to deflection or dispersion of the cement agglomerates into primary particles. Further, the dispersion system will include particles spaced at a more uniform distance from one to another. Thereby on continuing hydration there is a greater statistical chance of intermeshing of hydration product with fine and coarse aggregates surface to produce a system of higher internal integrity. Also, this improve in properties is attributed to the pozzlanic reaction of the silica fume with calcium hydroxide, which was liberated during the hydration of cement. It contributed to the densification of concrete matrix, thereby strengthening the transition zone and reducing the microcracking leading to significant increase in strengths.

Table (11): Increasing percentage of splitting tensile strength of self-compacting concrete

Mix designation	**Increasing percentage of splitting tensile strength, after compared with:**	
	SCC1	**SCC2**
SCC2	21.8	-
SCC3	36.9	12.4
SCC4	47.3	21.0
SCC5	50.4	23.6
SCC6	58.0	29.8

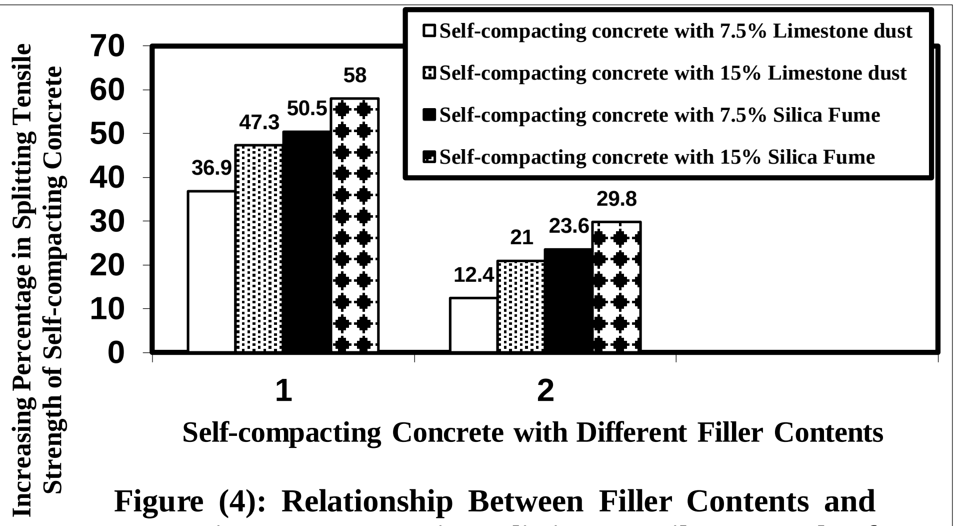

Figure (4): Relationship Between Filler Contents and Increasing Percentage in Splitting Tensile Strength of Self-compacting Concrete, (1: comparable with SSC1, 2: Comparable with SSC2)

Conclusions

Depending on the results of this investigation, the following conclusions can be drawn: -

1-The dosage of 3.0% superplasticizer by weight of cement gave water reduction (21.15%, 21.15% and 17.30%) for self-compacting concrete with limestone dust of (0%, 5% and10%) by weight of cement respectively. While, the effect of superplastizier (3%) on the water reduction of self-compacting concrete containing silica fume (0%, 7.5% and 15%) by weight of cement were (21.15%, 19.23% and 17.30%) respectively.

2- As the percentage of limestone powder and silica fume increases, the workability properties (flow ability, passing ability and filling ability) of SCC slightly decreased with increases in splitting tensile strength. The flow properties of all the replacements satisfy the recommended values given by specifications.

3- Self-compacting concretes with silica fume give better properties than those with ground limestone. This behavior is due to the pozzolanic activity of the silica fume which increases when ground because of the higher reactivity related with the higher fineness.

4- The increases of splitting strength of self-compacting concrete with 7.5% and 15% limestone dust by weight of cement and 3% superplasticizer were 36.90% and 47.31% respectively, when compared with self-compacting concrete without superplasticizer (SSC1). While, the increases of splitting strength of self-compacting concrete with 7.5% and 15% silica fume by weight of cement and 3% superplasticizer were 50.47% and 58.04% respectively.

5- The increases of splitting strength of self-compacting concrete with 7.5% and 15% limestone dust by weight of cement and 3% superplasticizer were 12.43% and 20.98% respectively, when compared with self-compacting concrete with superplasticizer (SSC2). While, the increases of splitting strength of self-compacting concrete with 7.5% and 15% silica fume by weight of cement and 3% superplasticizer were 23.57% and 29.79% respectively.

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