INFLUENCE OF MAXIMUM AGGREGATE SIZE ON STRENGTH DEVELOPMENT OF HIGH-STRENGTH CONCRETE AND SELF-COMPACTING CONCRETE [+]

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Abstract :

The main purpose of this research is to evaluate the effect of maximum size of coarse aggregate (MSCA) on the development of strength (compressive and tensile) of high strength concrete (HSC) and self compacting concrete (SCC) using locally available materials. Two sets of mixes, one for HSC and the other for SCC were prepared. Each set includes three mixes with same materials; fixed mix proportion and different MSCA (20, 14 and 10) mm. Fresh concrete properties were evaluated using slump test for HSC and slump flow, V-funnel and L-box tests for SCC. 72 cubes, 48 cylinders and 48 prisms for determination of cube compressive strength (f_{cu}); splitting tensile strength (f_s) and flexural strength (f_r) respectively were fabricated from 6 batches. Concrete specimens after (7, 28, 56 and 90) days were investigated. The results indicated that it is possible to produce HSC and SCC with satisfied fresh and hardened properties from locally available materials by using coarse aggregate (CA) with (20, 14 and 10) mm as maximum size. Based on the results of this work, workability of HSC increased as MSCA increase with using a fixed water to cement ratio and a fixed rate of superplasticizer (SP) while the fresh properties of SCC increased as MSCA reduced with using an optimum SP dosage for each mix. The results showed that f_{cu}, f_s and f_r for HSC and SCC increased with the decreasing MSCA and observed as maximum at 10 mm MSCA when compared to 20 mm and 14 mm size at all ages of concrete. Based on the results, decreasing MSCA from 20 mm to 10 mm increased f_{cu} by (11-16) %, f_s by (5-8) % and f_r by (6-9) % for HSC and f_{cu} by (8-12)%, f_s by (4-7)%, and f_r by (5-8) %, for SCC for ages between 7 to 90 days. The results also indicated that the ratios of 7- day to 28- day of f_{cu} values for HSC were higher than that of SCC and there was notable gain in f_{cu} values after 28 days age for all mixes. Hardened HSC & SCC specimens in splitting and flexure showed similar pattern of strength development to those corresponding in compressive strength with a lower rate.

Keywords: High strength concrete, Self compacting concrete, Coarse aggregate, Concrete strength

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تأثير المقاس الأقصى للركام على تطور المقاومة للخرسانة عالية المقاومة والخرسانة ذاتية الرص

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المستخلص :

إن الغرض الرئيسي من هذا البحث هو تقييم تأثير المقاس الأقصى للركام الخشن على تطور المقاومة (الانضغاط و الشد) للخرسانة عالية المقاومة والخرسانة ذاتية الرص باستخدام مواد محلية متاحة. تم تحضير مجموعتين من الخلطات واحدة لكل نوع, تتضمن كل مجموعة ثلاث خلطات من نفس المواد ونسبة خلط ثابتة واختلاف المقاس الأقصى للركام الخشن (20, 14, 10) ملم. تم تقييم خواص الخرسانة الطرية باستخدام فحص الهطول للخرسانة عالية ألمقاومة وفحص الانسياب و قمع في و صندوق ال للخرسانة ذاتية الرص. تم إعداد 72 مكعب , 48 اسطوانة و 48 موشور من ستة خلطات وتم إنضاجها وفحصها بعد(7, 28, 56, 90) يوم لإيجاد مقاومة الانضغاط, مقاومة شد الانشطار و مقاومة الانثناء على التوالي. بينت النتائج إمكانية إنتاج خرسانة عالية المقاومة و خرسانة ذاتية الرص مقبولة من ناحية الخواص الطرية والمتصلبة باستخدام مواد محلية و بمقاس أقصى للركام الخشن (20, 14, 10) ملم. كما بينت النتائج ازدياد قابلية التشغيل للخرسانة عالية المقاومة بزيادة المقاس الأقصى للركام الخشن عند استخدام نسبة ماء/سمنت وجرعة ملدن ثابتتان بينما ازدادت خواص الخرسانة الطرية الذاتية الرص بنقصان المقاس الأقصى للركام و باستخدام نسبة ماء/سمنت ثابتة وجرعة ملدن مناسبة. ان النتائج بينت بان مقاومة الانضغاط, مقاومة شد الانشطار و مقاومة الانثناء للخرسانة عالية المقاومة و الخرسانة ذاتية الرص تزداد بنقصان المقاس الأقصى للركام وتبلغ أعلى قيمة لها عند استخدام المقاس 10ملم عند مقارنته بالمقاس 20 ملم و 14 ملم ولجميع الأعمار. كما بينت النتائج بان نقصان المقاس الأقصى من 20 ملم إلى 10 ملم أدى إلى زيادة مقاومة الانضغاط, مقاومة شد الانشطار ومقاومة الانثناء للخرسانة عالية المقاومة بنسبة (11-16)%, (5-8)%, (6-9)% والخرسانة ذاتية الرص بنسبة (8-12)%, (4-7)%, (5-8)% للأعمار بين 7 و 90 يوم. كما أشارت النتائج إلى إن نسبة مقاومة الانضغاط بعمر7 أيام إلى مقاومتها في عمر 28 يوم كانت اعلى في الخرسانة عالية المقاومة مقارنة بالخرسانة ذاتية الرص. وهنالك زيادة محسوسة في مقاومة الانضغاط بعد العمر 28 يوم وفي جمع الخلطات الخرسانية . أظهرت النماذج المتصلبة للخرسانة عالية المقاومة والخرسانة ذاتية الرص في اختبارات مقاومة شد الانشطار والانثناء سلوكا مماثلا لسلوك نظائرها في اختبار مقاومة الانضغاط وبنسب تغاير اقل.

الكلمات الدالة: الخرسانة عالية المقاومة، الخرسانة ذاتية ألرص، الركام ألخشن، مقاومة الخرسانة.

1. Introduction :

High strength concrete (HSC) and self compacting concrete (SCC) are two types of high performance concrete (HPC). Both are often considered a relatively new, their development has been gradually achieved over many years due to advances in concrete technology. The new generation of superplasticizers (SP) has taken both types a wide step forward**.** There are no set definitions for HSC and SCC yet, however HSC relates to its compressive strength measured at a given age, while SCC is concrete with the special property of the fresh concrete "self compacting". SCC is also called self-consolidating concrete, self-leveling concrete, flowing concrete or high-workability concrete. The use of HSC and SCC becomes more popular in many parts of the world with successful application so understanding these technologies are becoming more and more important. In order to produce high HSC and SCC, many factors must be investigated, coarse aggregate (CA) is one of these factors.

2. Literature Review :

2.1. High Strength Concrete (HSC) :

The definition of HSC has changed over the years so there is no precise point of separation between high strength concrete and normal strength concrete (NC). However, ACI-Committee 363 defined HSC in 2011 as, a concrete that has a specified compressive strength of (55 MPa) or greater. HSC has emerged as a viable material to use as an alternative to conventional normal-strength concrete in infrastructure systems to reduce member cross section, extend member span length, reduce the number of system members, or enhance system sustainability [1]. The relatively higher compressive strength per unit volume, per unit weight will also reduce the overall dead load on foundation of a structure with HSC. Also, the inherent techniques of producing HSC generate a dense microstructure making ingress of deleterious chemicals from the environment into the concrete core difficult, thus enhancing the long-term durability and performance of the structure [2]. A significant information regarding historical background, material selection, mixing and placing, inspection and testing, physical properties, structural design, economics, and examples of applications for HSC was reported by [3]. HSC material selection and mix proportioning are a more critical process than that of NC. Each material, namely cement, sand, CA, concrete admixtures, and pozzolans must be evaluated as to type, strength characteristics, grading, fineness, and interaction in combination with each other [4]. HSC mixes have usually used high cement contents, low water cement ratios, normal weight aggregate, and chemical and pozzolanic admixtures. Laboratory trial batches have been required in order to generate necessary data on mix design [3]. HSC is characterized by lower bleeding than NC and appears require more effort to compact than NC. Tensile strength of HSC which is characterized by high ultimate strength increases as compressive strength rises. [5]. HSC can gain considerable strength after the normally specified 28-day age. To take advantage of this characteristic, many specifications for compressive strength have been modified from the typical 28-day criterion to 56 days or later ages [4]. A comprehensive experimental program was undertaken to determine the short-term mechanical properties of HSC with different target compressive strength different specimen sizes, and different curing conditions by Logan, et-all [6].

2.2. Self Compacting Concrete (SCC) :

There are as yet no standard definitions or specifications for SCC [7]. However, SCC has been defined as a concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for any additional compaction [8]. The Prototype of SCC was first completed in 1988 in order to achieve durable concrete structures by improving quality in the construction process [9]. The history of the created SCC from its origins in Japan to its development in Europe was outlined by [10]. Okamura and Ouchi cited that SCC can greatly improve construction systems and can be succeeded in creating durable and reliable concrete structures requiring very little maintenance work. When SCC becomes so widely used, it will be seen as the "standard concrete" rather than as a "special concrete" [11]. Many literatures investigate the technology behind creating SCC, including its components and mix proportioning techniques. It highlights numerous benefits in using SCC and refers to the various tools used to parameterize its properties such as [7][8][12]. SCC differs from conventional concrete (CC) in that its fresh properties are vital in determining whether or not it can be placed satisfactorily. The various aspects of workability which control its filling ability, its passing ability and its segregation resistance, all need to be carefully controlled to ensure that its ability to be placed remains acceptable [12]. Many projects dealing with fresh SCC properties have been carried out and reported such as [8][12][13][14]. The highly flowable nature of SCC is due to very careful mix proportioning, usually replacing much of the CA with fines and cement, and adding chemical admixtures. [7]. In general, the hardened properties of SCC are similar or superior to those of equivalent CC. At similar water/cement ratios the characteristic strength of SCC is at least equal to that of CC, and has a similar strength development for the same grade. The tensile strength is also comparable to the same grade of CC and drying shrinkage is also similar [10]. An extensive database of more than 175 papers from all over the world with results on fresh and hardened properties of SCC reported between 1990 and 2011, originating from numerous journal and conference papers devoted to SCC was developed by Desnerck, et-all[15]. A database focused on the properties of fresh SCC with regards to some MSC and PhD researches that conducted in Iraq was developed by Al-Mishhadani & Al-Rubaie [16].

2.3. Coarse Aggregate (CA) :

One way of viewing concrete is that the CA are held together by a mortar [17]. During the early years of concrete technology it was sometimes assumed that the smallest percentage of voids (greatest density of aggregates) was the most suitable for concrete**.** It is now known that is not the best target for the mix designer [18]**.** From economical point of view, one way to reduce the cement content is to fill as much of the volume of concrete as possible with aggregate. Larger sized CA can accomplish this objective rather easily. Increasing the maximum size of coarse aggregate (MSCA) lowers the water demand for any desired level of workability**.** Lower water demand decreases the water/cement ratio (W/C), thereby increasing strength [19]. Increasing the aggregate size excessively may lead to several detrimental effects and cause a decrease in strength. Such effects include a decrease in the bond area between the CA and the cement paste, It can be expected that there is an optimum MSCA that balances positive and negative effects and leads to a peak value of strength [20]**.** The structure of concrete can be described as three phase system consisting of hardened cement paste, aggregate and the interfaced between aggregate and cement paste, the smaller nominal maximum size has a larger surface compared with the larger nominal maximum size and results therefore a high bonding strength at the interface zone around the aggregate particles when concrete is under loading [21]**.** Al-Attar concluded from his study that the bond between cement paste and aggregate depends largely on the interface zone characteristics. The effect of the transition zone on the mechanical properties of concrete is still obscure [22]. In general, it is found that the CA will influence significantly the strength and structural properties of the concrete. CA properties also affect aggregate-mortar bond characteristics and mixing water requirements [4]. Many studies have shown that in HSC, the MSCA should be kept to a minimum, at (12.7 mm) or 9.5 mm. Maximum sizes of 19.0 mm and 25.4 mm also have been used successfully. Crushed stone produces higher strengths than rounded gravel. Accentuated angularity is to be avoided. The ideal aggregate should be clean, cubical, angular, 100 percent crushed aggregate with a minimum of flat and elongated particles. The mineralogy of the aggregates should be such as to promote chemical bonding [3]. In SCC the normal MSCA is generally 16-20 mm and particle sizes up to 40 mm or more have been used, however SCC test methods and values are stated for MSCA of up to 20 mm. Crushed aggregates tend to improve the strength, while rounded aggregates improve the flow because of lower internal friction [12]. Mehta and Monteiro in 2006 stated that aggregate characteristics, such as size, gradation, shape, surface texture and volume fraction, all have significant effects on concrete rheology [23].

3. Research Significance :

Although the applications of HSC & SCC had been increased all around the globe, locally this applications has had quite limited .So there is a much need for developing a data about properties of locally producted HSC and SCC to be established by experimental work and analysis. The main aim of this work is to study the influence of MSCA on the development of f_{cu}, f_s and f_r of HSC & SCC using locally available materials. Also this research aims to provide some information about fresh properties of these two types of concrete. Other properties of hardened HSC & SCC were also investigated such as the rate of development of f_{cu} with age of concrete and the factors influencing theme. An experimental program was arranged and the results of this study were reported and discussed, beside that necessary conclusions were outlined.

4. Experimental Program :

In order to achieve the scope of this study**,** after the selection of suitable materials, the experimental work was divided into two sets mixes (HSC and SCC) mixes. Each set includes three mixes with different MSCA {20, 14, and 10} mm. Same materials for both the HSC and SCC mixes were used .Same materials with fixed mix proportion were used in each set for obtaining comparable results across the mixes**.** Experimental investigations were carefully planned with controlling of several basic factors to get a representative comparison between investigated mechanical properties of each set. All concrete mixes were made under controlled laboratory conditions. The aggregates were used in saturated surface dry condition (SSD) so aggregate moisture content was not changed and mixing water quantities were not needed to be adjusted. Fresh concrete properties were evaluated using suitable tests for each set. A total number of 36 cubes of (150*150*150) mm for f_{cu} determination, 24 cylinders of (150*300) mm for f_s determination and 24 prisms of (100*100*400) mm for f_r determination were cast in 3 batches for each set with different MSCA. Concrete specimens after (7, 28, 56 and 90) days were investigated according to the standard methods. The materials used in this experimental work are as below:

4.1. Materials Selection and Properties :

4.1.1. Cement :

Ordinary Portland cement (Tasluja) available in local market was used. It was conforming to Iraqi Standard Specifications [24]. Tables (1) and (2) show the physical and chemical properties of this cement.
The choice of Portland cement for HSC is extremely important [3]. In SCC, C_3A content higher than 10% may cause problems of poor workability retention [12]

Table (1): Physical properties of cement

Test	Result	Limits of (IQS No. 5/1984)
Initial Setting Time	145	>=45min.
Final Setting Time	7:20	<=10hrs.
Compressive Strength at (3days)	22.8	>=15Mpa.
Compressive Strength at (7days)	31.2	>=23Mpa.

Table (2): Chemical properties of cement

Oxide	Result %	Limits of (IQS No. 5/1984)	Compound Composition	Result %
(CaO) %	63.43		(C_3S) %	47.82
(SiO_2) %	21.62		(C_2S) %	25.99
(Al_2O_3) %	5.18		(C_3A) %	7.65
(Fe_2O_3) %	3.60		(C_4AF) %	10.96
(MgO) %	2.25	<=5		
(SO_3) %	2.13	<=2.5% if C_3A <5% <=2.8% if C_3A >5%		
Loss on Ignition (L.O.I)	1.35	<=4%		
Free Lime	0.62			
Insoluble Residue (I.R)	1.33	<=1.5%		
Lime Saturation Factor	0.91	0.66-1.02		

4.1.2. Fine Aggregate :

Natural sand from Al-Ekhaider region was used as fine aggregate with specific gravity ,fineness modulus , sulfate content and absorption of **(**2.65**)**, (2.89), **(**0.36**)** % and (1.3) % respectively .The grading of the sand was compatible with zone (2) of fine aggregate grading according to Iraqi Standard [25].
Fine aggregates with a fineness modulus in the range of 2.5 to 3.2 are preferable for HSC and fine aggregates with a smooth texture have been found to require less mixing water [4]. Particles size fractions of less than 0.125 mm should be include the fines content of the paste and should also be taken into account in calculating the water powder ratio In SCC [12].

Table (3): Gradation of fine aggregate

Sieve Size (mm)	Passing (%)	Limits of (IQS No.45/1984) (%) zone(2)
10	100	100
4.75	94	90-100
2.36	79	75-100
1.18	64	55-90
0.6	43	35-59
0.3	27	8-30
0.15	4.5	0-10

Materials finer than 75 µm sieve 1% **< =5%**

4.1.3. Coarse Aggregate (CA) :

Crushed gravel from Al-Nibaee region was used with three different maximum sizes (20, 14, and 10) mm. Its average specific gravity, sulfate contents, absorption and the dry rodded unit weights were (2.64), (0.042) %., (0.8) **%** and (1610) kg/m^3 respectively**.** Tables (4), (5) and (6) show the gradation of these aggregates, which were conforming to Iraqi Standard [25]. These selected sizes of CA were recommended to be used in HSC and SCC by many literatures such as [3][4][8][12].

Table (4): Gradation of coarse aggregate size (20) mm

Sieve Size (mm)	Passing (%)	Limits of (IQS No.45/1984) (%)
37.5	100	100
20	100	85-100
10	18	0-25
5	3	0-5

Table (5): Gradation of coarse aggregate size (14) mm

Sieve Size (mm)	Passing (%)	Limits of (IQS No.45/1984) (%)
20	100	100
14	100	85-100
10	11	0-25
5	6	0-10

Table (6): Gradation of coarse aggregate size (10) mm

Sieve Size (mm)	Passing (%)	Limits of (IQS No.45/1984) (%)
14	100	100
10	100	85-100
5	16	0-25
2.36	2	0-5

4.1.4. Water :

The tap water was used for both mixing and curing of concrete. The same requirements on the quality of water as for NC had been respected.

4.1.5. Superplasticizer (SP) :

For the production of HSC as well as SCC, a water-reducing admixture is needed. In this work a high range water-reducing admixture (HWRA) was used, it has the trade mark (Glenium 51) SP. Its composition is based on polycarboxylic ether; it conformed to the requirements of types A and F of ASTM C494 standard [26]. Table (7) shows the technical properties of this SP.
Glenium 51 had the best tendency to give a stable mix with high slump flow values. It has the highest earlier compressive strength and final compressive strength [14]**.** The optimization of the cement-admixture system is important. The exact effect of a water reducing agent on water requirement, for example, will depend on the cement characteristics [3].This SP had been used successfully by many researchers with Iraqi cement in producing HSC and SCC such as [27][28].

4.1.6. Limestone Powder (LSP) :

A crushed limestone which is locally named as "Al-Gubra“(LSP) available in local market was used as a filler powder for SCC mixes (100% passing sieve 0.075mm). The chemical composition of LSP is shown in Table (8).
In SCC, the tendency to segregation can be reduced by the use of a sufficient amount of fines (< 0,125 mm) [12]. Calcium carbonate based mineral fillers are widely used and can give excellent rheological properties and a good finish. The most advantageous fraction is that smaller than 0.125 mm and in general it is desirable for >70% to pass a 0.063mm sieve [8].

Table (7): Technical properties of (Glenium 51) (From manufacture catalog)

Main Action	**Form**	**Color**	**Viscosity**	**Specific gravity**	**Chloride content**	**pH**
Concrete Superplasticizer	Viscous liquid	Light brown	128 cps @20ºC	1.1 @ 20ºC	Nil	6.6

Table (8): Chemical analysis of limestone powder

Oxide	**CaO**	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**SO_3**	**L.O.I**
Content (%)	52.76	1.62	1.2	0.79	0.30	2.91	40.3

<u>4.2. Concrete Mixes :</u>

Initially, one mixture proportioning for HSC was fabricated to be used with the different MSCA within the requirements of HSC and according to the recommendations of (ACI Committee 211.4R-93**)** guide [4]**.** Many trial batches were carried out in the laboratory with properties of the initial mix. Several adjustments were performed in order to identify optimum proportions for the different mixes with different MSCA to have an even consistency and uniformity and to determine the suitable dosage of SP for each mix. After many trial mixes the dosage of the SP was kept to 0.85% of cement weight which satisfies workability of all mixes with slump value at least around10cm. Finally, HSC mixes with Cement: Sand: Gravel ratio of (1:1.33:2.26) by weight, were found to be most suitable, with W/C ratio of (0.35) and SP

(0.85%) by cement weight. After determining the suitable mixture proportioning materials, no changes were made to all materials except the size of CA. Accordingly, three HSC mixes shown in Table(9) namely (H20,H14,H10) were arranged. The first letter in mix designation refers to the type of concrete HSC; the digits that follow refer to the MSCA (20 mm, 14 mm, and 10 mm). Mix proportional of SCC must satisfy the criteria of filling ability, passing ability and segregation resistance. Initial mix composition was prepared by volume according to indicative typical ranges of [12]. After the powder, water, and CA content had been estimated, the sand content which balances the volume of the other constituents was calculated by the method of absolute volumes. Numerous trials were performed in the laboratory to verify properties of the initial mix with different MSCA and to determine the suitable dosage of SP for each mix. Necessary adjustments to the mix composition had then been made until obtaining a satisfactory self-compact ability by evaluating fresh concrete tests. Trials mixes showed that SP must be added in range of (1.71-1.84) % by cement weight depending on the MSCA to satisfy the requirement of achieving SCC. The usage of large MSCA causes a small reduction in the SP dosage from small MSCA due to the increase in surface area with smaller size. This trend is consistent with founding from previous research carried out by Salman and Hussian [29]. Hu and Wang concluded that larger size CA generally results in concrete with lower yield stress and viscosity [23]**.** However the most suitable mix proportions which can be used with different MSCA are (1:2.06:2.31) Cement: Sand: Gravel by weight with W/C ratio of (0.48), LSP (160kg/m^3) and SP (1.71-1.84) % by cement weight depending on the MSCA .In this mix Water/powder ratio by volume was (1); total powder content was 180 liters per cubic meter and CA content was 33 per cent by volume of the mix. After determining the suitable mixture proportioning materials for SCC, no changes were made to all materials except the size of CA and the dosage of SP to maintain the required workability. Accordingly, three SCC mixes shown in Table (9) namely (S20, S14, S10) were arranged.

Table (9): Mixes contents

Concrete type	**HSC**			**SCC**		
Mix Designation	H20	H14	H10	S20	S14	S10
coarse aggregate size (mm)	20	14	10	20	14	10
Water (l/m^3)	170			180		
Cement (Kg/m^3)	486			375		
Limestone powder (Kg/m^3)	0			160		
Gravel (Kg/m^3) (SSD)	1100			867		
Sand (Kg/m^3) (SSD)*	648			775		
Superplastisizer % of cement weight	0.85			1.71	1.79	1.86
Water/Cement (ratio)	0.35			0.48		

***SSD: saturated surface dry**

4.3. Mixing, Casting, Compacting and Curing of Concrete :

A laboratory mixer was used to mix the concrete. The mixing sequence consisted of homogenizing cement, coarse and fine aggregate (and LSP for SCC mixes) in dry stat, then half of the mixing water was added and the whole materials were mixed well. The superplasticizer was added to the remaining water and was introduced to the mixture then the concrete was mixed for at least 3 minutes.. After the mixing procedure was completed, tests were conducted on the fresh concrete to determine workability parameters. From each concrete mix, 12 cubes, 8 cylinders and 8 prisms were cast. HSC fresh concrete was cast into the molds in two layers for cubes and prisms and three layers for cylinders and the poured concrete was fully compacted. SCC fresh concrete specimens were cast in one layer without any compaction .The upper surfaces of fresh concrete were leveled for all specimens by hand trawling. The molds were stripped after 24 hour, and then concrete specimens were placed in a water curing tank at room temperature according to BS. 1881: Part 111 [30].

4.4. Concrete Tests :

4.4.1. Fresh Concrete Tests :

4.4.1.1. High Strength Concrete :

The fresh properties of HSC mixes were tested by the standard slump test with the procedures of BS. 1881: Part 102 [31].

4.4.1.2. Self Compacting Concrete (SCC) :

A concrete mix can only be classified as SCC, if the requirements (filling ability, passing ability and segregation resistance) are fulfilled [12], There are a number of methods existed for testing fresh SCC properties, but there was no agreement on which was the most suitable for general purposes, and there was certainly no immediate prospect, anywhere, of a standardized test [13]. Also there is no single test capable of assessing all of the key parameters, and a combination of tests is required to fully characterize SCC mix [8][12][13][32]. So the following tests were selected as recommended by [12]: slump flow (D and T_{50cm}) and T_v with V-funnel for filling ability; (H_2/ H_1) by L-box for passing ability (blocking resistance) and T_{5min} by V-funnel, with visual test for segregation resistance. Accordingly, each mix was tested with different workability parameters by the procedures of. [12]. The filling ability of fresh concrete was described with slump flow test investigated with Abrams cone. The diameter of the concrete flowing out of the slump cone was obtained by calculating the average of two perpendicular measured diameters for determining the slump-flow diameter (D). Slump flow time (T_{50cm}) which represent the time for concrete to reach 50 cm spread circle. The filling ability of the fresh concrete was also tested with V-funnel by measuring (T_v) whereby funnel flow time after filling the funnel with concrete. Further (T_{5min}) was also measured with V-funnel, which indicates the tendency for segregation. (T_{5min}) values represent the ability of the concrete to flow out of the funnel but after refilling the funnel and allowing the concrete to discharge after 5 minutes from the refilling. The homogeneity of SCC was also assessed by visual observations during the slump flow test to find if there is any color variation in the mixes or on the base plate, any evidence of separated cement paste or bleeding and the pattern of aggregates distribution. The passing ability was determined using the L- box test and the ratio B_r was found as (H_2/ H_1), where H_2, H_1 are the heights of the concrete at both ends of horizontal section of L-box after allowing the concrete to flow as illustrated in Table (10).

4.4.2. Testing of Hardened Concrete :

4.4.2.1. Compressive Strength Test :

This test was carried out according to BS.1881: part 116 [33], using a digital testing machine of 2000 kN maximum capacity. Three cubes were tested for each mix at each age and the average value of the three specimens was reported.

4.4.2.2. Splitting Tensile Strength Test :

The splitting tensile strength test was performed according to BS.1881: part 117 [34]. Two cylinders were tested for each mix at each age and the average value was reported.

4.4.2.3. Flexural Strength Test :

This test was carried out according to BS.1881: part 118 [35] to find the flexural strength f_r using a two-point load test method: Two prisms were tested for each mix at each age and the average value was reported. The f_r usually referred to as the modulus of rupture (Mr). In all the specimens, the fracture initiates in the tension surface within the middle third of the span length, so f_r (MPa) was calculated from the simple beam bending formula.

5. Results and Discussion :

5.1. Fresh Concrete :

Table (10) shows the results of fresh concrete tests for HSC and SCC mixes. From the results it can be seen that:

1- Slump values of HSC were increased with the increasing size of CA when using a fixed W/C ratio and a fixed rate of SP. This is due to the fact that as aggregate size increases, the surface area to be wetted decreases so that slump values were increased. Neville [19] stated that increasing the MSCA lowers the water demand for any desired level of workability.

2- It is clear from the results that all the mixes of SCC satisfy the requirements of SCC as illustrated in (EFNARC)[12]**.** Also visual observations from the slump flow test show that there were no any color variation in the mixes or on the base plate and there is no any evidence of separated cement paste or bleeding with even distribution of the aggregates. The fresh concrete properties of these mixes were improved due to suitable mixture proportioning, optimum SP dosage and addition of lime powder. Thus, all the mixes are within good consistency and workability at fresh state (good filling ability and passing ability parameters without segregation).

The results show that D values increase with decreasing size of CA while T_{50cm} and T_v values decrease with decreasing size of CA. These parameters indicated that the smaller MSCA leads to an increase the filling ability with using an optimum SP dosage for each mix. This trend is probably related to the tendency of the mixes with smaller MSCA to flow more freely than that with larger MSCA. This result is compatible with the study carried out by Khaleei, O., 2007 and Rahim, J., 2005, cited by [36], they indicated that the flow ability of SCC decreases with the increase of the MSCA from 10 to 20 mm. The results also clearly show the effect of MSCA on the T_{5min} values, the mix with (20 mm) MSCA give values of (T_{5min}) higher than mix with the (14 mm) and (10 mm) MSCA. Thus, as the MSCA increases the tendency of the mix to segregate increases. This result is consistent with study carried out by Salman and Hussian [29], they used two sizes of aggregate (10 and 20) mm. The L-box test results indicated that mix contains 10 mm MSCA give value of (B_r) higher than mixes with the (14 mm) and (20 mm) MSCA and the lowers value with the mix containing 20 mm MSCA. This result indicated that the smaller MSCA leads to an increase the passing ability. This trend agrees with the previous research carried out by Salman and Hussian, they stated that smaller MSCA showed good deformability and flow ability without blockage near the obstacles [29].

Table (10): Results of fresh properties mixes

HSC		SCC						
Mix Designation	Slump (mm)	Mix Designation	Slump flow		V-funnel		L-box Br H_2/H_1 ratio
			D (mm)	T_{50cm} (sec)	T_v (sec)	$T_{5min.}$ (sec)	
H20	128	S20	690	4.5	10	+1	0.88
H14	114	S14	705	4.0	8.5	+0.5	0.90
H10	96	S10	715	3.5	7.5	+0.5	0.91
		EFNARC limit	650-800	2-5	6-12	0 - (+3)	0.8-1

D: final slump flow diameter (the average diameter of the concrete circle)
T_{50cm}: time taken for concrete to reach the 500 mm spread circle
T_v; funnel flow time after filling the concrete in the funnel
$T_{5\ min}$: V-funnel flow time after keeping the concrete in funnel for 5 min
$B_r = H_2/H_1$: Where H_2 is the mean depth of concrete at the end of the L- box after allowing the concrete to flow and H_1 is the depth of concrete immediately behind the gate of L- box after allowing the concrete to flow.

5.2. Hard Concrete :

5.2.1. Compressive Strength :

The results of the f_{cu} tests for HSC & SCC were shown in Table (11) & Figures (1 and 2). It was noticed that the f_{cu} of HSC and SCC increases with the MSCA decrease for all the ages. The highest strength was obtained from concrete made with 10 mm MSCA, followed by 14 mm size and the lowest strength was recorded with concrete containing 20 mm MSCA. This is because of smaller MSCA has a larger surface compared with the larger MSCA an results therefore a high bonding strength at the interface zone around the aggregate particles when concrete is under loading [21]. Smaller aggregate sizes are also considered to produce higher concrete strengths because of less severe concentrations of stress around the particles [3]. Moreover, small aggregate particles will contain less internal flaws and produce a higher concrete strength [5]. This result agrees with the study carried out by Yaqub and Bukhari [37] in studying HSC, and Al-Mishhadani, et all [36], they used two sizes of aggregate (10 and 20) mm in SCC.

From the results, it was observed that the percentages of increase in f_{cu} mix made of 10 mm MSCA to the f_{cu} of the mix made with 20 mm MSCA at (7, 28 , 56, and 90) days for HSC are (16) % , (13) % , (11) % and (11) % respectively ,while for SCC are (9) % , (12) % , (10) % and (9) % respectively. It is clear from these results that the percentages of increasing in f_{cu} as MSCA decreasing for HSC is higher than that for SCC for all ages. It seems likely that this is because of CA in HSC occupy larger percent of the volume than SCC and their characteristics play a major role in determining the properties of hardened concrete.

The results show that the average ratio of 7-day to 28-day f_{cu} for HSC is (0.72) and for SCC is (0.65). It can be seen that HSC which is characterized by low w/c ratio, and high cement contents has a higher rate of gain of strength than SCC at early ages. It can be said that this ratio 7-day to 28-day f_{cu} increases as the strength of concrete increased. This is in agreement with study carried out by Kheder, et-all [38], they concluded from their study for SCC and CC that the ratio of 150 mm cylinder f_c' at 7 day to that at 28 days increased from 0.553 to 0.725 as the strength of concrete increased from (20 to 80MPa.). Beside that there is notable gain in f_{cu} of HSC and SCC after 28 days strength. The average percentage rate of f_{cu} development for HSC mixes between 28-day to 56-day and to 90-day are (16)% and (21)% respectively while for SCC are (9)% and (12)% respectively**.** This is because the hydration of cement is a time dependent reaction, as time passes, there is higher gel/space ratio and, thus, higher strength**.** HSC with high cement contents has a higher strength development at later ages.

It is worth noting that ACI Committee 363 R- 92[3]**,** cited that high-strength concrete shows higher rate of strength gain at early ages as compared with normal strength concrete, but at later ages the difference is not significant and the ratio of 7-day to 28-day strength were found between 0.8 - 0.9 for HSC. It is clear that the ratio of 7 -day to 28-day compressive strength for HSC in this study is lower than that indicated by above literature and there is notable gain in compressive strength at later ages but this result is consistent with others researches such as [4, 5, and 27] and probably related to the difference in cement characteristics. ACI Committee 363 R-92 stated that, strength development will depend on both cement characteristics and cement content [3]. Some literature showed that the rate of early strength gain for HSC is similar to lower strength concrete and long term strength gain is dependent on the type and combination of cementitious materials in the concrete [5]. Others stated that HSC can gain considerable strength after the normally specified 28-day age [4]**.** AL- Mashhadi, et-all, concluded from their study that the Iraqi cement when it used in HSC experienced low compressive strength at early ages, whereas the compressive strength develops at higher rate at later ages. The main reason of this phenomenon according to their conclusions is the chemical composition of Iraqi cement such as the difference in percentages of C3S and C2S of Iraqi cement compared with the imported cement [27].

Table (11): Results of compressive strength cubes for HSC and SCC

Mix	**Mix Designation**	**Compressive strength- f_{cu}- (MPa.)**			
		7days	**28days**	**56days**	**90days**
HSC	H20	41.8	58.2	68.9	71.1
	H14	45.1	62.4	71.8	75.6
	H10	48.3	65.8	76.1	79.2
SCC	S20	24.4	37.5	41.0	42.5
	S14	25.7	39.7	43.1	44.9
	S10	26.6	41.8	45.0	46,2

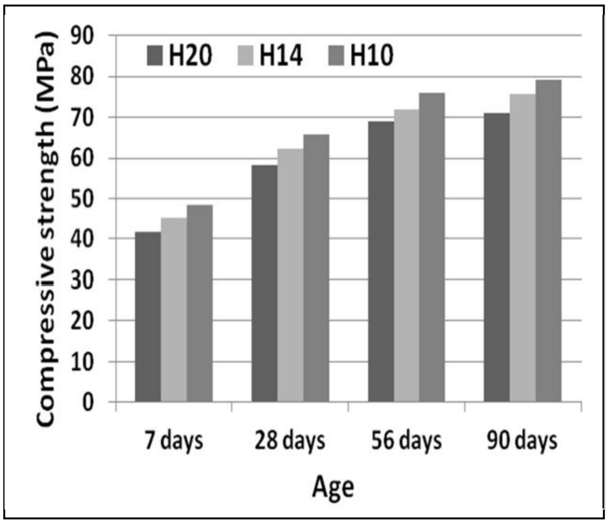

Figure (1): Development of compressive strength (f_{cu}) for different mixes of HSC

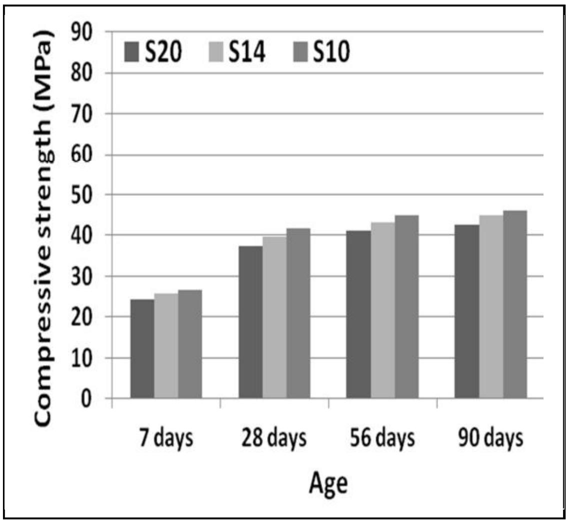

Figure (2): Development of compressive strength (f_{cu}) for different mixes of SCC

5.2.2. Tensile Strength (splitting tensile strength (f_s) and flexural strength (f_r)) :

Tensile strength of concrete may be measured by direct and indirect tensile tests. Direct tensile tests are difficult to perform due to testing limitations. Indirect tests include split-cylinder and flexure tests, are usually used to measure tensile strength of concrete [19].The simplest and the most reliable method, which generally provides a lower coefficient of variation, is the splitting tensile test [39]. The tensile strength of concrete in flexure (modulus of rupture) is a more variable property than the compressive strength [40].

The results of f_s & f_r tests for HSC and SCC at ages (7, 28, 56 and 90) days were shown in Tables (12 & 13) and plotted in Figures (3 to 6). If these figures are compared with their corresponding f_{cu} figures (1&2), it can be seen that f_s & f_r of HSC and SCC occurs at a much smaller pattern as that of their corresponding f_{cu}. f_s and f_r values are greatly affected by the level of the corresponding f_{cu}. This is due to the fact that the compressive and tensile strengths are closely related. According to (ACI 363R-92)[3], many researchers concluded that splitting and flexural strengths are proportional to the square root of the cylinder compressive strength (f_c') for wide ranges of concrete strength from 21 MPa to 83 MPa. Different other formulas for f_s and f_r with its corresponding compressive strength are proposed by National building codes. The results showed that f_s & f_r of HSC ranged between (3.23 – 4.55) MPa, (5.04 -6.98) MPa respectively and (2.57 – 3.62) MPa, (4.01 -5.67) MPa respectively for SCC. As in compressive strength, it was also noticed that f_s & f_r increases with the (MSCA) decrease for all the ages, the highest values of f_s & f_r were obtained from concrete made with 10 mm size of CA followed by 14 mm size and the lowest strength was recorded with concrete containing 20 mm size of CA. Decreasing MSCA from 20 mm to 10 mm increases f_s & f_r of HSC mixes with the ranges of (8-5) % and (9-6) % respectively and (7-4)%, and (8-5) %, respectively for SCC mixes. Also as in f_{cu}, it is clear that the increasing in f_s & f_r as MSCA decreasing for HSC is higher than that for SCC. It is clear from the results that hardened specimens of HSC & SCC in splitting and flexure showed similar pattern of strength development to those in compressive, as f_{cu} increases, f_s & f_r also increase with the lower ratio. So it is not needed to duplicate the result dissection of the compressive strength here again.

Table (12): Results of splitting tensile strength cylinders for HSC and SCC

Mix	Mix Designation	Splitting tensile strength (MPa.)			
		7 days	28 days	56 days	90days
HSC	H20	3.23	3.88	4.19	4.21
	H14	3.40	4.06	4.30	4.42
	H10	3.49	4.14	4.41	4.55
SCC	S20	2.57	3.28	3.40	3.48
	S14	2.68	3.37	3.47	3,53
	S10	2.75	3.46	3.55	3.62

Table (13): Results of flexural strength beams (modulus of rupture) for HSC and SCC

Mix	Mix Designation	Flexural strength (modulus of rupture) (MPa.)			
		7 days	28 days	56 days	90days
HSC	H20	5.04	6.07	6.46	6.60
	H14	5.31	6.29	6.67	6.83
	H10	5.49	6.42	6.82	6.98
SCC	S20	4.01	5.06	5.31	5.40
	S14	4.20	5.24	5.42	5.53
	S10	4.31	5.35	5.58	5.67

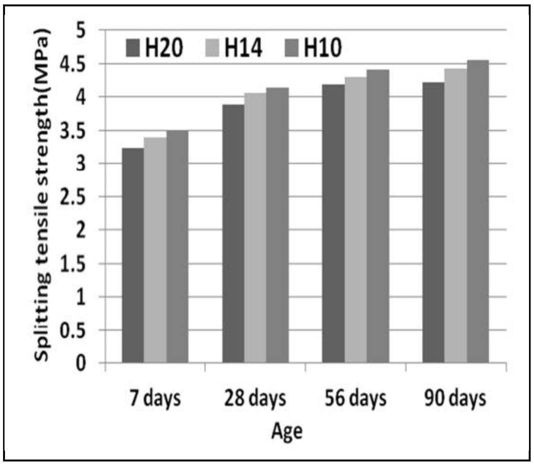

Figure (3): Development of splitting tensile strength for different mixes of HSC

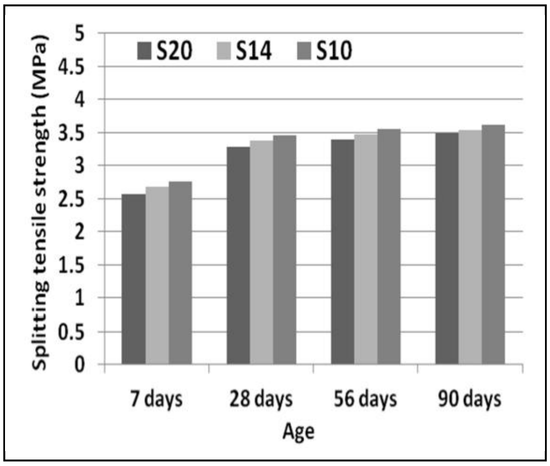

Figure (4): Development of splitting tensile strength for different mixes of SCC

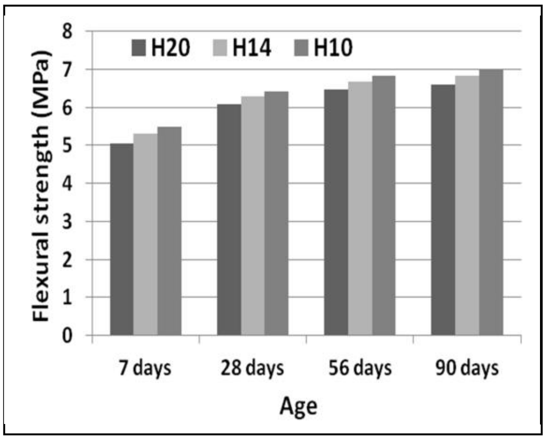

Figure (5): Development of flexural strength for different mixes of HSC

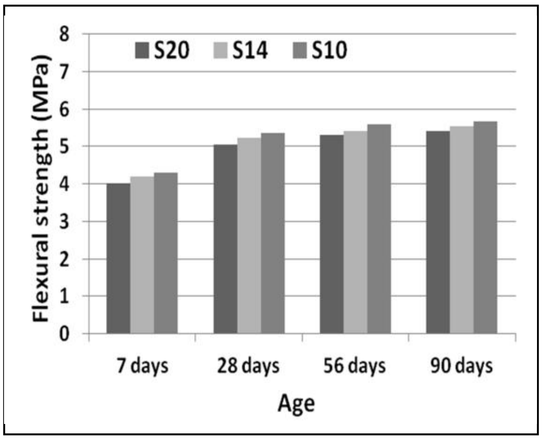

Figure (6): Development of flexural strength for different mixes of SCC

6. Conclusions :

Based on the results of this work, it can be concluded that:

1- HSC and SCC can be obtained with satisfied fresh and hardened properties from locally available materials by using coarse aggregate with 20 mm, 14 mm and 10 mm as maximum size.

2- The workability of HSC increases as MSCA increase with using a fixed water to cement ratio and a fixed rate of SP while the fresh properties (filling ability, passing ability and segregation resistance) of SCC increase as MSCA reduce with using an optimum SP dosage for each mix. The need of amount of superplasticiser slightly increases with the decrease size of coarse aggregate to satisfy the requirement of fresh concrete.

3- Compressive, splitting tensile and flexural strengths for HSC and SCC increase with the decrease maximum size of coarse aggregate and observed as maximum at 10 mm maximum size of coarse aggregate when compared to 20 mm and 14 mm size at all ages of concrete (7,28,56 and 90) days.

4- Decreasing maximum size of coarse aggregate from 20 mm to 10 mm increases compressive, splitting tensile and flexural strengths with the ranges of (16-11) %, (8-5) % and (9-6) % for HSC mixes and (12-8)%, (7-4)%, and (8-5) %, for SCC mixes for ages between 7 to 90 days.

5- The average ratios of 7 -day to 28-day compressive strengths for HSC is equal to (0.72) and for SCC is (0.65). HSC tends to gain strength quicker than SCC

6- There is notable gain in compressive strength of HSC and SCC after 28 days strength. Average values of 16-21% increase in strength is obtained at 56 days and 90 days compared to 28 days strength for HSC and 9-12% for SCC **.**

7- Hardened HSC & SCC specimens in splitting and flexure show similar pattern of strength development to those corresponding in compressive strength with a lower rate.

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Notations :

CA:	coarse aggregate
CC:	conventional concrete
f_c':	cylinder compressive strength
f_{cu}:	cube compressive strength
f_s:	splitting tensile strength
f_r:	flexural strength
MSCA:	maximum size of coarse aggregate
NC:	normal strength concrete
SP:	superplasticizer