Behavior of Self-Compacting concrete Produced from recycled aggregate

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ABSTRACT

The project deals with studying the fresh and hardened properties of self-compacting concrete (SCC), using two types of fine materials (silica fume and limestone powder as 10% each by weight of cement. Also, the uses of crushed bricks aggregate and recycled concrete aggregate with different percentages of replacement from aggregate (coarse & fine). The effect of each type on the fresh and hardened properties of SCC has been studied.

The fresh properties of SCC are measured by using Slump Flow, J-Ring Tests. While hardened properties included compressive strength, splitting tensile strength & flexural strength tests as well as fresh density, dry density and water absorption.

The results show that adding recycled materials to the SCC will reduce the workability and have different effect on the hardened properties of concrete according to the replacement percentage of aggregate. The fresh and hardened properties of SCC containing 25% crushed brick shows better enhancements than that of SCC containing the same percentage of recycled concrete aggregate. Also, the combination of 25% crushed bricks aggregate + 15% recycled concrete aggregate facilitate the uses of significant percentages of these ruined buildings to be recycled with the production for the construction of new buildings.

Steel nails fibers have been used to enhance the ductility of SCC. Thus, the Percentage of 1% and 1.5% of such fibers were used. The flexural strength of self-compacting fibers reinforced concrete (SCFRC)Has been increased by about 33% to 35% due to 1.5% of steel nail fibers for the mix 25 crushed brick+15% recycled aggregate concrete and mix contain 25 %crushed brick, respectively

Introduction

Normal concrete, has many advantages such as an ability to be cast, low cost, good durability, fire resistance…etc. But it also has many disadvantages including a low tensile strength, and low ductility, therefore many types of concrete were developed to improve the performance of concrete, such as (high strength concrete, fiber reinforced concrete, and self-compacting concrete…etc.). High strength concrete has an improved compressive strength , durability and it is also extremely brittle. Self-compacting properties include a good flowability in the fresh state, and a good cohesiveness against segregation. It can also be high strength to improve its durability compared to the normal concrete **[1].** self-compacting concrete (commonly abbreviated to SCC) is a concrete mix which has a low yield stress, high deformability, good segregation resistance and moderate viscosity SCC was conceptualized in 1986 by Prof. Okamura at Ouchi University, Japan, at a time when skilled labor was in limited supply, causing difficulties in concrete-related industries. The first generation of SCC used in North America was characterized by the use of relatively high content of binder as well as high dosages of chemicals admixtures, usually superplasticizer to enhance flowability and stability. Such high-performance concrete had been used mostly in repair applications and for casting concrete in restricted areas. **[2]**

In today's world "going green" has become a top priority in our society, and sustainable buildings and design are at the forefront of this green revolution. While many designers are focusing on passive and active energy systems, the reuse of recycled materials is beginning to stand out as an innovative, highly effective, and artistic expression of sustainable design. Reusing materials from existing on site and nearby site elements such brick block and the concrete demolishing Demolition (both end-life buildings and parts of buildings for refurbishment) , structures, these materials can be used as recyclable building materials. Materials and projects featured after the break. Most common building materials today have recyclable alternatives. Concrete, metals, glass, brick and plastics can all be produced with some form of the previously used material, and this process of production lowers the energy requirement and emission **[3]** Also, to improve the performance of concrete, other types of concrete have been developed, such as fiber reinforced concrete (FRC),Where adding fiber reinforcement to the concrete to increases the ductility and improves the hardened properties of concrete, but it also reduces the workability of fresh concrete, therefore, the effort is directed to the study of the combining effect of (SCC) and fiber reinforced where this type of concrete is known as self-compacting fiber reinforced concrete (SCFRC).

Problem statement

The main issue that is required to solve in this project is the use of recycled materials which is a very common problem facing the city of Mosul after the war with ISIS.

Thus, the rubble of crushed bricks and demolished concrete have been used as aggregate to get rid of all these waste martials that may affect on the environment. The uses of such materials may greatly reduce the cost of new buildings, reduce the use of fresh raw materials , have less impact on the environment and most importantly clean the city of the after war remains.

Besides, the inclusion of these waste materials in the production of Self-Compacting Concrete (SCC) can be considered as a new approach for the use of this advanced and special type of concrete. The use of SCC has a great effect on the reducing segregation when the mix is casted especially in heavy steel reinforcements members or sections or complex shapes of formwork . In such cases, there will be great difficulties for compactions and vibrations of concrete and the use of SCC might be the optimum selection to overcome this problem. Furthermore, Main role of fibers is to bridge the cracks that develop in concrete and increase the ductility of concrete elements.There is considerable improvement in the post-cracking behavior of concrete containing fibers due to both plastic shrinkage and drying shrinkage.

Objective

- Design of control SCC using silica fume as a partial replacement of cement and superplasticizer to get the best flowability and suitable high strength concrete.
- Prepare different mixes of SCC using crushed brick aggregate and/or crushed concrete aggregate to compare them with control mix.
- Study the fresh properties followability by way of slump test , j-ring and hardened properties compressive strength , tensile strength , splitting , absorption , , density for all these different mixes.
- Characterizing the behavior of steel nail fibers on the fresh and hardened properties of self - compacting concrete

3-1 Materials

3-1-1 Cement: The cement used throughout this work was Ordinary Portland Cement produced by kar Cement Factory.

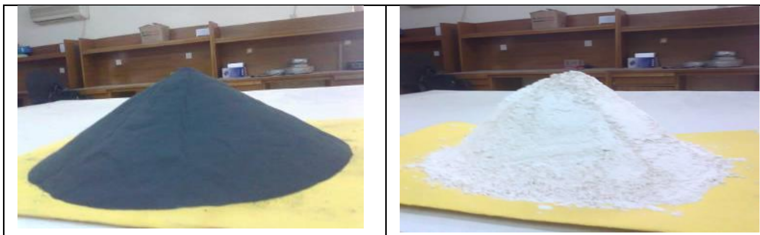
The physical Properties and chemical analysis of the used cement are shown in Tables **(3-1)**. It conforms to the Iraqi specification ,(IQS , No. 5/1984).

Table (3-1): Chemical Analysis of Cement

Compound Composition	(%)
Al_2O_3 Aluminum Oxide	5.8
SiO_2 Silicon Dioxide	21.35
Fe_2O_3 Iron Oxide	2.6
CaO Lime	62.3
SO_3 Sulphur Trioxide	2.5
MgO Magnesium Oxide	3.33
C_3S	41.5
C_2S	30
C_3A	10.9
C_4AF	7.9

3-1-2 fine material : two types of fillers, (silica fume) imported material and (limestone powder) local material in Mosul city, were used in this research**, Figure (3-1)** shows these fillers. The dosages of used fillers were 10% by weight of cement.

The fineness of silica fume (megaadd ms.) was (12630) cm^2/gm with specific gravity (2.178) , while limestone powder were passing from sieve No. 200 (75 μm) ,specific gravity 2.72 and absorption 67%



Silica Fume	**Limestone Powder**

Figure (3-1) : Silica fume and Limestone powder

3-1-2 Fine aggregate: Rounded natural sand of (4.75) mm maximum size, was used for concrete mixes in this investigation.

The sieve analysis of the used sand is conforms to the limits of B.S: 882:1992 The specific gravity (2.6)

Table (3-2): Sieve Analysis of Fine Aggregate

Sieve Size (mm)	Accumulated Percentage Retained (%)	Accumulated Percentage Passing (%)	Limits of B.S: 882:1992 Specification			
			Specific. Limits	Fine	Medium	Coarse
4.75	0.0	100.0	89-100	-	-	-
2.36	11	89	60-100	80-100	65-100	60-100
1.18	25.5	74.5	30-100	70-100	45-100	30-90
0.60	44.5	55.5	15-100	55-100	35-80	15-45
0.30	78.5	21.5	5-70	5-70	5-48	5-40
0.15	96.5	3.5	0-15	-	-	-

3-1-3 Coarse aggregate: The washed rounded aggregate of (12.5) mm maximum size was used, the specific gravity (2.6 5) respectively. The sieve analysis of this aggregate is conforms to the limits B.S: 882:1992 limit (5-14 mm - Fine)

Table (3-3): Sieve Analysis of Coarse Aggregate

Sieve Size (mm)	Accumulated Percentage Retained (%)	Accumulated Percentage Passing (%)	Limit of B.S: 882:1992 Specification		
			5-14 mm (Fine)	5-20 mm (Medium)	5-40 mm (coarse)
14	0.0	100	90-100	40-80	25-55
10	12.20	76.0	50-85	30-60	10-40
4.75	88.40	0.9	0-10	0-10	0-5
2.36	100	0.0	-	-	-

3-1-5 Chemical Admixtures: Chemical Admixture type ViscoCrete 5930 used as high range water reducing admixture (HRWRA).The dosage used was 1.5% by weight of cement.

3-1-6 Tap Water: Ordinary tap water was used in this investigation for both mixing and curing purposes.

3-1-7 recycled material: two types of recycled materials are used

the first type is crushed brick blocks with specific gravity (1.7) and

the second type is demolition concrete with specific gravity (2.1)

demolition concrete	crushed brick

were used in this research **,** the Figure below shows the recycled material used the **figure (3-2**) show a sample of the materials

figure (3-2)

3-1-8 <u>Fibers:</u> Steel nails fibers were used in this research. The properties and shape of such fibers are shown in **Table (3-4)** and **Figure (3-3).**

Table (3-4) The properties of Steel nails fibers

Properties	**Steel nails Fibers**
Length(mm)	**25mm**
Diameter (mm)	**1.6mm**
Aspect ratio	**16**
Density (kg/m ^{3})	**6900**

Figure (3-3) the shape of steel nails fiber

3-2 Mix Design & Mix proportion of recycled aggregate

compacting concrete can be largely affected by the characteristics of materials and the mix-proportion. A rational mix design method for self-compacting concrete using a variety of materials is necessary.(Okamura and Ozawa) have proposed a simple mix proportioning system assuming general supply from ready-mixed concrete plants [**7**]. The coarse and fine aggregate contents are fixed so that self-compact ability can be achieved easily by adjusting the water/binder ratio and superplasticizer dosage only and by trial and error method it has been found that the suitable mix proportion for this project is mix B shown in Table (3-4). and use in the project different proportion of recycled aggregate mix1 (25% of crushed brick) mix2 (40% crushed brick) mix3 (25% recycled aggregate concrete) MIX4 (25% brick + 15% recycled concrete aggregate), MIX 5(15% brick + 15% recycled concrete aggregate), MIX 6(20% brick + 10% recycled concrete aggregate)

Table (3-4) Mix Design.

	cement	**Sand**	**Gravel**	**Water /binde**	**Super-plasti-**	**Limestone powder**			**Compressive**

MIX Type				r	cizer		silica fume	Slump flow (mm)	strength 28 days (Mpa)
A	1	1.5	1.5	37%	1.5%	10%	10%	730	47.1
B	1	1.55	1.45	37%	1.5%	10%	10%	1000	61.4
C	1	1.45	1.55	37%	1.5%	10%	10%	840	37.2

3-3 Laboratory Tests

3-3-1 Slump of Hydraulic Cement Concrete (ASTM C 143/C 143M-05a)

A sample of freshly mixed concrete is placed in a mold shaped as the Frustum of a cone. The mold is raised, and the concrete allowed to subside. The vertical distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as the slump of the concrete.

3-3-2 Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring (ASTM C 1621/C 1621M1)

This test method covers determination of the passing ability of self-consolidating concrete by using the J-Ring in combination with a slump cone mold..

3-3-3 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C 496/C 496M)

This test method consists of applying a diametral compressive force along the length of a cylindrical concrete specimen at a rate that is within a prescribed range until failure occurs. Tensile failure occurs rather than compressive failure because the areas of load application are in a state of triaxial compression, thereby allowing them to withstand much higher compressive stresses than would be indicated by a uniaxial compressive strength test result.

3-3-4 Standard Test Method for Flexural Strength of Concrete (ASTM C 78 – 02)

A nominal (100 * 100 * 400 mm) concrete beam, molded and cured the test specimen shall be placed in the machine correctly centered with the longitudinal axis of the specimen.

3-3-5 Compressive strength: (BS 1881:1992)

For test three cubes of 100mm X 100mm x 100mm The concrete is poured in the mould. These specimens are tested by compression testing machine after 7 days curing and 28 days curing. Load should be applied gradually at the rate of 14 N/mm^2 per minute till the Specimens fails. Load at the failure divided by area of specimen gives the compressive strength of concrete.

3-3-6 Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes (ASTM C 1585 – 04)

This test method is used to determine the rate of absorption (sportively) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water.

4-1 Results and Discussion

4-1-1 Fresh properties of self – compacting concrete

The results of fresh concrete tests are shown in **Tables (4-1)** & **(4-2)**. These Tables present the various workability test results for all self-compacting concrete mixes. They include the slump flow diameter and J-Ring test. From the results shown in the Tables, the slump flow diameters for all mixtures are in the range of 1000 – 740 mm. The slump flow times (T500) are in the range of 2.21 – 3.4 seconds. Whereas, the J-Ring test values are in the range of 8.5 – 27.5 mm. From the results of **Tables (4-1)** to **(4-2)**, all concrete mixtures are conformed to the criteria on of self-compacting concrete (SCC) and the MIX 1 (25% crushed brick) has shown the best results in workability without showing signs of segregation. On the other hand, the MIX 3 (25% recycled concrete aggregate) has shown a clear segregation. However, the combination of the two recycled materials shows that the best results in workability is 25% crushed brick + 15% recycled aggregate concrete without noticeable segregation .

Table (4-1): J-Ring and Fresh Density Test Results of SCC

MIX No.	Fresh Density (Kg/m^3)	J-Ring		
		D max. (mm)	Dav. (mm)	Minimum Limit (D)
Reference	2490	980	960	**650** mm
MIX 1(25% crushed brick)	2395	860	830	
MIX 2(40% crushed brick)	2230	725	700	
MIX 3(25% demolition)	2460	770	750	
MIX 4(25% brick & 15%demolition)	2350	710	690	
MIX 5(15% brick & 15%demolition)	2400	715	700	

MIX 6(20% brick & 10%demolition)	2380	730	720	

Table (4-2): Slump Flow Results of SCC

MIX TYPE	**Slump Flow**				
	T_{500} Sec	**Limit (T500)**	**D max. mm**	**Dav. mm**	**Limits minmum**
Reference	2.21		1004	1000	
MIX 1(25% crushed brick)	2.93		871	850	
MIX 2(40% crushed brick)	3.1		840	830	
MIX 3(25% recycled concrete aggregate)	2.98		810	790	
MIX 4(25% brick & 15%demolition)	3.3	**(2-5)** sec	775	760	**(650)** mm
MIX 5(15% brick & 15%recycled concrete aggregate)	3.4		760	740	
MIX 6(20% brick & 10%demolition)	3.3		780	750	

Figure (4-1) J-Ring

Figure (4-2) Slump Flow

4-1-2 Hardened Properties of Self–Compacting Concrete:

The compressive, splitting and flexural strengths of Self-compacting concrete are shown in **Table (4-3**) for mixes containing silica fume and limestone as fillers.

It can be noticed from this Table (each results was the average of three specimens test), that there are significant reductions in compressive, splitting and flexural strength values due to recycled materials use.

Table (4-4) shows variable results regarding to the seven different mixes tested under the same test conditions. The use of 25% of crushed bricks as a partial replacement of total aggregate boosts the best performance among other mixes without showing any sign of segregation. This behavior can be attributed to the stored water in the crushed brick aggregate that may enhance the hydration of cement[2, 7]. Thus, the increase percentages of compressive, splitting tensile and flexural strengths are about 18%, 4 and 21% , respectively compared with reference mix. However, the use of recycled aggregate concrete does show significant decrease in these properties. However, the most useful combination is MIX 4 (25% crushed brick + 15% recycled concrete aggregate). This combination uses total of 40% of waste materials and record acceptable ranges of (compressive, splitting and flexural strengths.

Table (4-3). Compressive, Splitting and Flexural Strength for SCC mixes.

MIX No.	Compressive Strength f_{cu} (MPa)		Splitting Strength MPa)(f_{sp} at 28 days	Flexural Strength MPa)(σf at 28 days
	7 days	28 days		
MIX 1 (Ref.)	50.4	61.5	3.6	8.1
MIX 2(25% crushed brick)	66.5	72.5	3.75	9.8
MIX 3(40% crushed brick)	32.9	40.1	2.75	6.6
MIX 4(25% recycled concrete aggregate)	35.3	36.1	2.6	6.3
MIX 5 (25% brick + 15% recycled concrete aggregate)	39.5	54.2	3.1	7.8
MIX 6(15% brick + 15% recycled concrete aggregate)	30.2	41.8	2.7	6.7
MIX 7(20% brick + 10% recycled concrete aggregate)	32.3	45.4	2.85	6.8

4-1-3 Dry Density and Water Absorption of SCC: In order to characterize the effect of volume fraction of the replacement material and the material type on the density and water absorption, these tests were done for all mixes and their results are shown **in Table (4-4).**

Table (4-4). Dry Density and Water Absorption

Mix No.	Crushed brick	Recycled Concrete aggregate	Dry Density (Kg/m^3)	Absorption (%)
Mix 1	0%	0%	2390	2.51
Mix 2	25%	0%	2265	3.11
Mix 3	40%	0%	2090	4.84
Mix 4	0%	25%	2310	2.87
Mix 5	25%	15%	2190	3.97
Mix 6	15%	15%	2290	3.17
Mix 7	20%	10%	2270	3.2

In Table (4-4), the fresh density was in the range of 2230 to 2490 kg/m^3, while the results of dry density were in the range of 2090-2390 kg/m^3, for all types of replacement material. it can be seen that the SCC containing recycled concrete aggregate of 25% has more density than that containing crushed brick aggregate as 25 % or 40%. This is because of the higher density of recycled concrete aggregate which has higher specific gravity than that of crushed brick aggregate which will make the mix more dense Continuously, the mix with lower density is MIX 3 (40% crushed brick) but such mix has a higher absorption than other mixes and suffer from segregation. However, the combinations of 25% crushed concrete + 15% recycled concrete aggregate reduces the density from 2390 kg/m^3 (Ref. Mix) to 2190 kg/m^3 and without noticeable segregation.

4-1-4 fresh and Hardened Properties of (SCCRSNF): From the previous result two different mixes have been selected to study the effect of steel nails fibers on the compressive and flexural strength of SCC produced by recycled aggregate, thus the mixes with 25% crushed brick and 25% crushed brick + 15% recycled concrete aggregate have been used. The inclusions of 1 % and 1.5% of steel nails fibers have been tested on mentioned proportion mixes

Test	Compressive strength Mpa	Flexural strength Mpa
SCC1SNF1%	71.4	14.3
SCC1SNF1.5%	69.6	16.7
SCC2SNF1%	52.8	9.4
SCC2SNF1.5%	50.7	11.6

It can be noted that there is an increase in the values of flexural strengths with fibers addition (1, 1.5) % in SCC compared to control mixes (0% fiber), but there is a reduction in the compressive strength because of fiber incorporation which decreases the fresh properties of concrete. And this decrease the self -compaction ability of concrete, then led to increasing the voids ratio in concrete

5- Conclusions

Some conclusions are revealed for this study which deals with the production of Self Compacting Concrete (SCC) as follows:

1-The incorporation of 10% silica fume, 10% limestone powder and 2% of superplasticizer enable the engineers to produce excellent properties of SCC without segregations.

2-The use of 25% crushed bricks aggregate as a partial replacement of the total aggregate may enhance the mechanical properties of the SCC. The increase percentages of compressive, splitting tensile and flexural strengths are 18%, 4 and 21% , respectively compared with control SCC.

3-The use of 25% recycled concrete aggregate as a partial replacement of the total aggregate may dramatically decrease the compressive, splitting tensile and flexural strengths of the SCC.

4-The combination uses of 25% crushed bricks aggregate + 15% recycled aggregate concrete, give suitable ranges of strengths for SCC. Thus, the use of significant percentages as 40% of these waste materials encourage the engineers to reconstruct the buildings from such materials.

5-The use of crushed bricks aggregate reduces the density of SCC higher than that reduction obtained by the use of recycled aggregate concrete. However, the combination of 25% crushed bricks aggregate + 15% recycled aggregate concrete also gives acceptable ranges for all physical and mechanical properties of SCC.

6- The incorporation of fibers in concrete decreases the fresh properties of all concrete mixes containing steel nail fibers compared with the control mixes .

7- The addition of 1.0% steel nails fibers in the self-compacting concrete, produced by 25% crushed brick and 25% crushed brick + 15% recycled concrete aggregate, promotes the values of flexural strength by about 24.43% and 20.51%, respectively.

8- The addition of 1.5% steel nails fibers in the self-compacting concrete, produced by (25% crushed brick) and 25% crushed brick + 15% recycled concrete aggregate increases the values of flexural strength by about 35.1% and 33.58%, respectively

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