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Key words: *recycled concrete, crushed red brick, ceramic aggregate, ceramic powder, SCC*

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EFFECT OF RECYCLED MATERIALS AND HYBRID FIBERS ON THE PROPERTIES OF SELF-COMPACTING CONCRETE

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Self-compacting concrete (SCC) has many properties comparing to conventional concrete and represents a good choice towards sustainability. The use of different recycled materials contributes to seize the negative impact of huge amount of waste on the ecosystem. In this study, locally available materials have been used as partially cement replacements. Such materials including ceramic waste powder (CWP) and glass powder (GP) in addition to fly ash with total cement replacement of 30%(12%CWP+8%GP+12%Fly ash) have been found to increase the compressive strength by about 7% compared to the control SCC. Normal aggregate was replaced by recycled aggregate with different recycled aggregate which are Recycled Concrete (RC), Crushed red brick (REB) and Crushed ceramic (CER.) The percentages of replacements are: 25%, 50%, 75% and 100%, for each type of aggregate. The results show that the increase of the amount of recycled aggregates decreases the strength properties of SSC and effect on workability of SSC also the result show a reduction in oven dry density. The combination of different type of recycled aggregate shows a reduction in SSC strength. The use of fibers shows better performance of SSC compared to combination aggregate mix without fiber but reduce the workability of SCC. However, the fiber content of 1.0% shows the best result of the mechanical properties, whereas, fiber content up to 1.5% affects negatively on concrete properties. The use of hybrid fiber also increases the strength properties of concrete.

Key words: recycled concrete, crushed red brick, ceramic aggregate, ceramic powder, SCC

INTRODUCTION

Conventional concrete technology requires mechanical vibration for placing concrete, which is time- and energy-consuming, noisy and often dangerous. In order to overcome these issues, self-compacting concrete (SCC) is developed, However, facing growing demands related with a sustainable development, technology of self-compacting concrete becoming questionable for the reason of its relatively high content of cement which can cause high heat of hydration danger of quick setting, also that cause an increased value of carbon footprint also as we mention before there is huge quantities of construction and demolition waste which represent a real challenge to environmentalist so recycling this waste can effectively contribute to manage these waste Also there another problem related to the concrete which is brittleness nature of concrete the using of the fiber will help to overcome this problem because of the Abundance of raw materials the using of conventional building materials is more traditional so hope this research carried out and the using of recycled material become more acceptance.[1-6]

This study aimed to design self-compacting concrete reinforced with hybrid fiber (recycled plastic and sisal fiber) and study the effect of using different recycled material as partial replacement of cement and to investigate the effect of using different recycled aggregate on the behavior of concrete of both fresh and hardened properties.

EXPERIMENTAL PROGRAM

This section covers the materials used and the tests done.

Materials used

Cement: Ordinary Portland cement (OPC) Type I used in this study has been manufactured from Badoosh factory. Its physical characteristics and chemical compositions are illustrated in Tables 1 and 2, respectively.

Fine aggregate: The sand used in this study was the natural river sand from Kanhash region in Mosul city with specific gravity of 2.63.

Table 1: Physical characteristics of ordinary Portland cement

Test	Produced cement	ASTM C150 [7]
Initial setting time (minute)	143	min 45
Final setting time (minute)	175.5	max 600
Fineness Blain (cm^2/g)	3398	more than 2300
Compressive strength 3 days, N/mm^2 7 days, N/mm^2	 31.64 39.3	 ≥ 12 ≥ 19

Coarse aggregate (Gravel): The washed rounded aggregate of 12.5 mm maximum size was used, the specific gravity and absorption are 2.68 and 0.4 %, respectively.

Tap water: Normal tap water has been used for concrete mixtures.

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Table 2: Chemical composition of ordinary Portland cement

Constituent	Content Percent (%)	ASTM C 150 [7]
CaO	62.5	-
SiO_2	20.91	-
Al_2O_2	5.96	-
MgO	3.8	≥ 5.0 %
Fe_2O_2	2.53	-
SO_2	2.32	≥ 2.8 %
L.O.I	1.45	≥ 4.0 %
C_3S	33.37	-
C_2S	35.92	-
C_3A	11.5	-
C_4AF	7.7	-

Super plasticizer: High-range water-reducing (HRWR) admixture, super plasticizer from (Sika Visco Crete®–5930), was used to confirm the desired workability of mixes.

Recycled concrete aggregate (RC): Recycled concrete was collected from the demolition of ruined buildings in city with specific gravity of 2.22 and absorption of 5.12. Such aggregate has been crushed to appropriate size and the maximum aggregate size is 12.5 mm.

Waste clay brick aggregate: A waste of clay bricks has been crushed to an appropriate size with specific gravity of 1.90 and absorption of 3.8 % has been used in this study.

Crushed ceramic aggregate: Crushed ceramic aggregate was collected from ceramic storages in Mosul city. It has a specific gravity of 2.1 and absorption of 0.81%.

Figure 1: Recycled concrete aggregate

Figure 2: Clay brick aggregate

Ceramic waste powder (CWP): It was collected from damaged ceramic materials from the ceramic storages in Mosul city, then it has been crushed and grinded then sieved to be passing through sieve No.200.

Glass powder: The glass from residual broken glass in Mosul city was crushed and grinded then sieved to be passed through sieve No 200.

Fly ash: Fly ash was brought from DCP company in Erbil city. It conforms to ASTM C618 Class F [8]. The characteristics of such materials are shown in Table 3 to show the characteristics of it.

Figure 3: crushed ceramic aggregate

Figure 4: Waste ceramic powder

Figure 5: Glass powder

Table 3: Characteristics of fly ash

Appearance	Pale grey fine powder
Relative Density	2.12
PH in water	7_12
Theoretical surface area	200_700
Loss on Ignition %	5
SO_3 %	3.0
Moisture Content %	3
Fineness (Retained on 45μ)	5.0_25
Sum of Oxide (Al+Si+Fe)	70
Chloride %	0.1

Fiber

Sisal fiber: Natural sisal fiber was used with length of 20 mm and aspect ratio of 40.

Recycled plastic fiber: Recycled plastic from PVC factory where chopped into length of 20 mm and diameter of 2mm and aspect ratio of 10.

Figure 6: Sisal fiber

Figure 7: Plastic fiber

Mix proportion

The proper ties of SCC are affected by the material properties; the mix proportion was 1:1.60:1.40. The water to binder is 0.38 with total cementitious materials of 528kg/m^3. The cement content is 368 kg, fly ash is 52.8, ceramic waste powder (CWP) is 63.6 kg, and glass powder (GP) is 42.2 kg. The designation of the mixes and mix proportions are depicted in Tables 4 & 5. The SCC mixes reinforced with fibers are listed in Table 6.

Mixing procedure: mixing procedure for SCC is more sensitive to the time comparing to the conventional concrete, the following procedure where performed to obtain a SSC:

1. Fine and coarse aggregates are loading and mixing at the beginning for 1 minute
2. Cement and filler are added and mixed for 1 minute.
3. A half of mixing water in addition to Sika visco-crete 5930 have been added and mixed for 2 minutes
4. The residual water and fibers are carefully added (to avoid balling) an mixed with 3 minutes.

Casting and curing: After finishing the mix procedure the test of fresh concrete were done to conduct Slump and flow time v-funnel L-box tests.

Table 4: Details of SCC mixes

Mix name	Details	Remarks
R0	Reference mix with no cementitious materials	-------
R1	Reference mix with 30% cementitious materials	The percentages of each of fly ash, glass powder and ceramic powder are determined depending on mortar trial mixes to get the optimum percentages of combination
RC25	25% of coarse aggregate has volumetrically been replaced by recycled concrete.	Same cementitious materials combination as R1 have been considered
RC50	50% of coarse aggregate has volumetrically been replaced by recycled concrete.	Same cementitious materials combination as R1 have been considered
RC75	75% of coarse aggregate has volumetrically been replaced by recycled concrete.	Same cementitious materials combination as R1 have been considered
RC100	100% of coarse aggregate has volumetrically been replaced by recycled concrete.	Same cementitious materials combination as R1 have been considered
REB25	25% of coarse aggregate has volumetrically been replaced by red brick aggregate.	Same cementitious materials combination as R1 have been considered
REB50	50% of coarse aggregate has volumetrically been replaced by red brick aggregate.	Same cementitious materials combination as R1 have been considered
REB75	75% of coarse aggregate has volumetrically been replaced by red brick aggregate.	Same cementitious materials combination as R1 have been considered
REB100	100% of coarse aggregate has volumetrically been replaced by red brick aggregate.	Same cementitious materials combination as R1 have been considered
CER25	25% of coarse aggregate has volumetrically been replaced by crushed ceramic aggregate	Same cementitious materials combination as R1 have been considered
CER50	50% of coarse aggregate has volumetrically been replaced by crushed ceramic aggregate	Same cementitious materials combination as R1 have been considered
CER75	75% of coarse aggregate has volumetrically been replaced by crushed ceramic aggregate	Same cementitious materials combination as R1 have been considered
CER100	100% of coarse aggregate has volumetrically been replaced by crushed ceramic aggregate	Same cementitious materials combination as R1 have been considered

Table 5: Mix Proportions of SCC with recycled aggregate

MIXES	Cement Kg/m^3	Fly ash	Ceramic waste powder (CWP)	Glass powder (GP)	Sand Kg/m^3	Coarse agg. (gravel) (kg/m^3)	Volumetric replacement of coarse agg.	Sp.%
RO	528	---	---	---	844	739	0	0.8
R1	368	52.8	63.6	42.2	844	739	0	
RC25	368	52.8	63.6	42.2	844	554	25%	0.8
RC50	368	52.8	63.6	42.2	844	370	50%	0.85
RC75	368	52.8	63.6	42.2	844	185	75%	0.85
RC100	368	52.8	63.6	42.2	844	0	100%	0.88
REB25	368	52.8	63.6	42.2	844	554	25%	1.0
REB50	368	52.8	63.6	42.2	844	370	50%	1.2
REB75	368	52.8	63.6	42.2	844	185	75%	1.25
REB100	368	52.8	63.6	42.2	844	0	100%	1.35
CER25	368	52.8	63.6	42.2	844	554	25%	0.9
CER50	368	52.8	63.6	42.2	844	370	50%	0.95
CER75	368	52.8	63.6	42.2	844	185	75%	1.0
CER100	368	52.8	63.6	42.2	844	0	100%	1.2

The molds were used steel and plastic mold were lubricated and the specimens were cast only in one layer without any compaction. All specimens were kept in laboratory for (24±2) hours then demolded and immersed in water until the specific testing time.

Test procedure: The tested fresh properties of SSC includes methods used for Filling ability, Passing ability and Segregation resistance (slump flow, L-box and V -funnel tests), respectively.

Whereas, the hardened SCC tests includes compressive strength test which was carried out on 100x100x100 mm cube specimens based on BS 1881: part 5 [9]. The average of three specimens was recorded and considered for each age test (7, 28 and 90 days).

The splitting tensile strength was performed in accordance with ASTM C496 [10] and conducted on cylinders of 100 * 200 mm. The average of three test specimens has been taken at 7, 28 and 90 days.

Also, the flexural strength test was done according to ASTM C78 [11]. The flexural strength was carried on 100*100*400 mm prisms. The flexural value was taken as the average value of three specimens at 7, 28 and 90 days. The dry density concrete for SCC in a hardened state at age 28 days was carried out in accordance with ASTM C 642 [12]. Lastly, the Ultrasonic Pulse Velocity (UPV) Test was performed on specimens at age of 28 day. The test was carried out in accordance with ASTM C597 [13].

RESULTS AND DISCUSSIONS

This section deals with the analysis of the results which were obtained after testing all the specimens and their dis-

Table 6: Mix proportions of SCC with recycled aggregate with fibers

MIX	Sisal	Plastic	NA Kg/m^3	RC Kg/m^3	CER Kg/m^3	REB kg/m^3	SP%
F0	----	----	293	162.7	152	131	1.0
F1	0.5	----	293	162.7	152	131	1.0
F2	1.0	----	293	162.7	152	131	1.0
F3	1.5	----	293	162.7	152	131	1.2
F4	----	0.5	293	162.7	152	131	1.0
F5	----	1.0	293	162.7	152	131	1.0
F6	----	1.5	293	162.7	152	131	1.0
F7	0.5	0.5	293	162.7	152	131	1.5
F8	1.0	1.0	293	162.7	152	131	1.6
F9	0.5	1.0	293	162.7	152	131	1.5
F10	1.0	0.5	293	162.7	152	131	1.5

cussion. The results show the effect of different recycled aggregate and different type of fibers and hybrid fibers on both fresh and hardened properties of SCC mixes.

Fresh properties: The fresh properties include workability tests which are: slump test, V-funnel and L–box. Table 7 shows the results of different SCC mixes prepared by various recycled aggregates. From this Table, it can be noticed that the slump value ranges from 630 mm to 733mm. While the T500 ranges from 2.57 to 4.0 sec, the v –funnel ranging from 7.5 sec to 11 sec and L-box varies from 0.72 to 0.9. From the results, it can be observed that amount of recycled aggregate would reduce the workability. This may return to the shape of this aggregate and the reduction of free water in SSC which is the main dominant of the recycled aggregate. The lowest value of flow has been obtained when the normal aggregate was completely replaced by crushed ceramic. Whereas, the crushed clay bricks aggregate show the best value among the recycled aggregate. Adding CWP, GP, Fly ash show a slight decrease in flow diameter and this may be related to the SSC become more viscous. The Table 8 shows the test results of workability for the fiber mixes of sisal fiber, plastic fiber and hybrid fiber. It can be seen that the increase in Vf of fiber reduces the slump value from 681mm to 640mm for the mixes SF1 and SF2, while the v-funnel result ranges from 11 to 13 sec and the L-box ranging from 0.77 to 0.

Hardened properties

Compressive strength

Table 9 shows the compressive strength of mixes of recycled concrete aggregate in addition to the reference value. From such Table, it can be observed that the use of RC reduces the compressive strength of SCC and this may be due to the low property of RC aggregate compared with normal aggregate. Also, it can be noticed that the increase of the crushed clay brick amount, reduces the compressive strength at all age of concrete. This reduction is related to the reduction in adhesive strength between surface of particle of crushed clay brick and cement paste also may related to the difference of shape and size between natural aggregate also the reduction may also related to low strength properties of clay brick [14]. The incorporating of ceramic aggregate causes a reduction in compressive strength and this reduction may attributed to the weak bond between CER aggregate and cement paste and the shape of CER aggregate make a continues path of porosity which led to un dense concrete the reduction was at all age of concrete [15].

Table 7: Workability tests for SCC mixes prepared by various recycled aggregates

Mixes	T500(sec)	Slump(mm)	L-box h2/h1	V-funnel (sec)
R0	2.57	733	0.72	7.5
R1	2.63	712	0.75	8.0
RC25	2.70	690	0.79	8.62
RC50	2.71	675	0.83	9.0
RC75	2.75	655	0.86	10
RC100	2.78	650	0.88	10.5
REB 25	2.88	705	0.77	9
REB50	2.96	695	0.80	9.5
REB75	3.11	690	0.80	9.0
REB100	3.5	683	0.82	9.5
CER25	2.95	680	0.81	10
CER50	3.25	677	0.83	10.5
CER75	3.5	650	0.86	10.8
CER 100	4.0	630	0.9	11.0

Table 8: Workability test of fiber mixes

Mixes	T500 (sec)	Slump (mm)	L-box h2/h1	V-funnel sec
F0				
F1	3.15	681	0.75	11
F2	3.5	677	0.78	12
F3	3.7	665	0.83	12.5
F4	3.5	675	0.77	12
F5	4.0	655	0.8	11.5
F6	4.1	652	0.85	11.8
F7	4.3	668	0.86	12.0
F8	5.2	640	0.98	13
F9	4.7	645	093	12.3
F10	4.53	640	0.91	11.5

Table 9: Compressive strength for SCC with recycled aggregate

MIXES	7 Days	28 Days	90 Days
R0	36.74	43.505	50.02
R1	34.2	44.74	53.52
RC25	32.9	41.70	51.15
RC50	31.5	40.8	49.3
RC75	30.1	37.9	47.8
RC100	27.73	35.29	45.35
REB 25	33.71	40.95	50.86
REB 50	30.2	39.167	48.8
REB 75	29.22	38.46	47.32
REB 100	27.73	36.45	45.02
CER25	28.20	33.701	41.981
CER50	26.77	32.31	40.08
CER75	25.39	39.93	44.18
CER100	23.16	28.7	38.905

Table 10: Compressive strength for SCC reinforced with fibers

MIXES	7 Days	28 Days	90 Days
F0	28.29	37.34	44.285
F1	27.33	36.51	43.49
F2	26.23	35.38	42.89
F3	24.88	33.88	41.23
F4	30.34	39.45	47.13
F5	30.87	40.05	48.13
F6	29.88	38.98	46.56
F7	31.44	42.10	46.58
F8	30.77	40.45	44.88
F9	29.73	38.12	42.15
F10	30.25	39.77	44.56

Splitting tensile strength

From Table 10, it can be seen that the recycled concrete aggregate increase, may reduce the splitting tensile strength of SCC. The reduction is related to low strength properties of recycled aggregate and that super poses with most results of global research. From fig 4.16 and table 4.16 we find that the adding sisal fiber increase the splitting tensile strength the increasing was up to 1.0% while increasing fiber to 1.5% show slight reduction the increasing was (2%, 1%, 7%) for vf of 0.5 at the ages of 7, 28. 90 day while vf of 1.0% caused increasing of (22.1%, 11.5%, 9) at ages of 7, 28, 90 day respectively. It can also be found that the addition of plastic fiber enhances the splitting tensile strength of SCC. Vf of 1.0 % caused an increase by about 1.7%. While Vf of 1.5 caused an increase by about 14.9% at age of 90 day. It can also be noticed that the use of 0.5S+0.5P causes an increase by about 6%. Whereas, the use of 1P+1S causes an increase by about 1.7% using 0.5s+1p causes a reduction by about 2% while using 0.5p+1S causes an increase by about 4%.

Table 11: Splitting tensile strength for SCC with recycled aggregate

MIXES	7 Days	28 Days	90 Days
R0	6.413	6.577	6.63
R1	6.505	6.72	6.78
RC25	5.53	5.67	5.95
RC50	5.41	5.45	5.62
RC75	4.65	4.68	5.05
RC100	4.48	4.51	4.8
REB 25	5.89	6.03	6.15
REB 50	5.68	5.33	5.55
REB 75	5.21	5.25	5.41
REB 100	4.84	5.15	5.27
CER25	5.91	6.11	6.21
CER50	5.53	5.85	5.92
CER75	4.95	5.20	5.25
CER100	4.70	4.73	4.85

Table 12: Splitting tensile strength for SCC reinforced with fibers

MIXES	7 Days	28 Days	90 Days
F0	2.25	2.79	3.3
F1	2.3	2.81	3.56
F2	2.89	3.15	3.67
F3	2.71	2.98	3.25
F4	2.77	3.1	3.25
F5	3.17	3.33	3.42
F6	3.35	3.66	3.88
F7	2.78	3.16	3.53
F8	2.56	2.99	3.36
F9	2.54	2.86	3.23
F10	2.87	3.11	3.88

Flexural strength

From figure (4.7) and table (4.8) we found adding of SCM show slight increment in flexural value with (1.4%, 2.1%, 1.7%) at the ages (7, 28, 90) day respectively while incorporating the RC aggregate caused in flexural reduction the value of reduction increased with increasing amount of RC content the reduction was (13.7%, 7.9%) and 10% at ages of (7, 28, 90) respectively for RC25 while for RC50 the reduction was 15.6%, 17%, 15.2% at ages of (7, 28, 90,days) for RC75 the reduction was (27%, 28,8%, 23%) for RC100 the reduction was (30.4%,

Table 13: Flexural strength for SCC with recycled aggregate

MIXES	7 Days	28 Days	90 Days
R0	6.413	6.577	6.63
R1	6.505	6.72	6.78
RC25	5.53	5.67	5.95
RC50	5.41	5.45	5.62
RC75	4.65	4.68	5.05
RC100	4.48	4.51	4.8
REB 25	5.89	6.03	6.15
REB 50	5.68	5.33	5.55
REB 75	5.21	5.25	5.41
REB 100	4.84	5.15	5.27
CER25	5.91	6.11	6.21
CER50	5.53	5.85	5.92
CER75	4.95	5.20	5.25
CER100	4.70	4.73	4.85

Table 14: Flexural strength for SCC reinforced with fibers

MIXES	7 Days	28 Days	90 Days
F0	4.15	4.38	4.75
F1	4.16	4.39	5.12
F2	4.2	4.45	5.20
F3	4.05	4.27	4.92
F4	4.25	4.55	4.67
F5	4.33	4.50	4.71
F6	4.22	4.45	4.66
F7	4.25	4.37	4.78
F8	4.56	4.96	5.23
F9	4.43	4.89	5.13
F10	4.61	5.11	5.56

30.1%, 27.6%) the low strength value may return to the low strength properties of RC comparing to normal aggregate. The CER aggregate mixes show reduction in flexural strength the reduction was 7.8%, 6.8%, 7,2% at ages of 7, 28, 90 day for CER25 for CER50 the reduction was 13.7%,11.7%, and for CER75 22.8%, 20.6%, 23.8% for CER 100 the 26.7%, 28.8%, 26,8%. From Table (4.10) and Figure (4.9) the (REB mixes) show that reduction in flexural strength value for REB25 the reduction was (8.1%, 8.7%, 7.2%) for REB50, the reduction was (11.4%, 19%, 16.2%). For REB75 the reduction was (18.7%,19.9,%, 20.5) for REB100 the reduction was (24.5%, 21.4%, 20.5%) at the ages of 7, 28, 90 day respectively. From figure 4.20 and table 4.20 we find that adding sisal fiber mixes increasing the flexural strength the increasing at vf of 0.5% was 4% and for vf of 1.0 the increasing was 4.8% while 1.5% vf show slight reduction at the age of 90 day. Table 4.21 and figure 4.21 we observed that adding 1.0 of plastic fiber cause slight decreasing in flexural value the reduction was 1.6% for 0.5% and 1.8 for 1.5% at age of 90 day. From figure 4.22 and table 4.22 we find that using 0.5s+0.5p cause increasing about 0.6% and using 1S+1p cause increasing about 9% while using 0.5S+1.0P cause increasing about 7% while using 0.5P+1.0S cause increasing about 13%.

Density and ultra pulse velocity (UPV)

From Table 15, it can be found that the UPV values depend on the density. Hence, the increase in UPV values was comparable with the increase in density values for SCC prepared from recycled aggregate with or without fibers.

Table 15: Density and UPV TEST

MIXES	Density (Kg/m^3)	UPV Test (km/sec)
RO	2340	5.5
R1	2331	5.35
RC25	2310	5.2
RC50	2300	5.12
RC75	2285	5.005
RC100	2280	4.95
REB25	2284	4.93
REB50	2196	4.88
REB75	2095	4.5
REB100	1995	4.0
CER25	2285	4.25
CER50	2277	4.11
CER75	2270	4.1
CER100	2265	3.99
F0	2210	3.75
F1	2213	3.78
F2	2210	3.72
F3	2215	3.67
F4	2215	3.55
F5	2208	3.34
F6	2215	3.26
F7	2216	3.41
F8	2225	3.21
F9	2212	3.33
F10	2213	3.78

CONCLUSIONS

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

1. There is ability to replace normal aggregate with recycled aggregate (recycled concrete aggregate, crushed ceramic, crushed clay brick) up to 25% without significant influence of concrete properties.
2. The crushed ceramic aggregate gives the lowest strength values compared with other types of aggregate.
3. The increase in recycled aggregate reduces the workability, oven dry density and strength.
4. Sisal fiber can be used to improve splitting and flexural strength. However, the plastic fiber can be used up to 1% to give best result and the hybrization of two type fiber improves strength properties.

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