

## Improving the Quality of Recycled Aggregate Concrete to Meet Construction Standards: A Case Study in Euphrates Basin in the Eastern Region of Syria

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**Abstract:** This study aims at exploring the way of decreasing effects of impurities (such as clay and dust) of recycled aggregates on concrete quality in the Eastern area, Syria by excluding the detrimental materials retained on the pan. After that, properties of concrete have been investigated to test its conformity to structural requirements. For that, about 30 specimens collected from different mixes of recycled aggregates were casted and tested. Portland cement (290-510) kg/m<sup>3</sup>, water/cement ratio (0.33-0.66) and tap water were used. The compressive strength values of concrete cubes varied between 25-5 MPa, noting that strength development was monitored under continuous curing in tap water, up to 91 days. Within 28 days, modulus of elasticity of the specimens varied from 25-40 GPa which refers to good quality concrete. The flexural strength of these concretes was around 6 MPa. Also, the workability of concrete batches was good because of using plasticizers. Based on results, the properties of recycled aggregate concrete are able to produce concrete which meets construction standards after discarding the impurities through the pan.

**Key words:** Demolition, impurities, pan, quality, recycled aggregate concrete, strength

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### INTRODUCTION

Recycling of concrete agglomerates from damaged buildings as a coarse and fine aggregate in new construction can distribute in supporting infrastructure works (Brandes and Kurama, 2016). This aggregate can be used as a replacement of natural aggregates for a concrete production to reserve the natural resources and also to decrease amounts of demolition waste which has to be landfilled (Novakova and Mikulica, 2016).

Recycling Concrete Aggregate (RCA) can be directly used in a new concrete works. And because the aggregate forms around 65% of concrete volume, the use of recycled aggregate as a replacement of natural aggregate in the producing of concrete has become a widespread practice (Seo and Lee, 2015). Buildings are demolished due to war, natural disasters, reconstruction, etc. Waste concrete has been managed through its landfilling and recycling. Landfilling has become a major problem, especially in countries where land is scarce. Thus, the recycling of waste concrete has main environmental benefit, the conservation of natural sources, since, the recycled aggregate mainly including concrete was continued for last two decades in India (Awchat and Kanhe, 2008).

The feasibility of using different groups recycled coarse and fine aggregate in structural concrete was completely evaluated by studying the performance of the recycled aggregates, so, several studies revealed a positive movement of such recycled concrete aggregate. However, a lot of researches have been conducted for improving the quality of recycled aggregate concrete by using different qualities of recycled aggregate and some studies referred that recycled aggregate concrete is generally lower than that of conventional concrete, mainly due to the quality of material used (Xiao *et al.*, 2006). This problem attributed to a lot of admixtures which take place between impurities and concrete agglomerates, especially, during demolition processes (Bury *et al.*, 2006; Moon and Moon, 2002). So, processing centres of construction and demolition waste, segregate and sort all blemished materials from concrete agglomerates before crushing, grinding and converting it into different size aggregates to use it in the civil projects but this process is generally incomplete as required (Florea and Brouwers, 2013; Koshiro and Ichise, 2014). Here, the problem follows the geographic area and the kind of demolished or constructed structures (Ulsen *et al.*, 2013; Pun *et al.*, 2006). And the problem becomes bigger when materials

come from disintegrating of structures in case of war and natural disasters such as earthquakes or sand storms (Zega *et al.*, 2010).

In the Eastern region of Syria, structures are exposed to both cases either war or sand storms. So, dust and rain sometimes falling together makes cleaning process useless. This case leads to accumulative layers of mud stuck to concerts that may become an essential constituent of concrete itself (BMPs., 2000; Hendriks and Janssen, 2001).

More problems appear in the old wastes at land fills which have not been processed yet as layers of impurities are bigger which needs more care and awareness regarding to this issue (USEPA., 1973). Impurities which mixed to aggregates affect negatively the engineering properties such as absorption, specific gravity, bulk density and other physical properties and consequently the quality of produced concrete (Brand *et al.*, 2015). Hence, the rate of these materials should be determined to check up the conformity of recycled aggregates to construction standards (Song and Ryou, 2014).

Because of war in Syria, especially in the Eastern region and depleting of natural sources of river aggregates, a lot of debris has to be processed in the same areas. Hereafter, it is necessary to look for applicable procedures to decrease the rate of harmful materials in the recycled aggregates according to tolerance limits (Dryzek, 1997). This study is an attempt to develop the conformity of recycled aggregate concrete to the quality needs for construction uses in the Eastern Region, Syria.

## MATERIALS AND METHODS

The recycled coarse and fine aggregates used in this study were collected from the western area of Euphrates River, exactly near Mayadeen city (Fig. 1). The following tests have been achieved on specimens of recycled aggregates:

- Sieve Analysis (SA)
- Sand Equivalent (SE)
- Crushing Strength Value (CSV)
- Water Absorption Value (WAV)
- Specific Gravity Value (SGV)

According to ASTM D2419 the methodology of this test is to take limited amount from the sand passed from sieve No. 4\* (4.75 mm), The specimens were mixed with separation liquids such as calcium chloride and glycerin, the mixture of each type mixed together inside graduated



Fig. 1: Part of sieving processes

Table 1: Physical properties of the aggregates used

Aggregate properties	Coarse (RCA)	Fine (RCA)	Natural coarse	Natural sand
SGV	2.43	2.41	2.65	2.66
CSV-KN	123	--	--	--
WAV%	4.2	6.3	0	0

vertical glassy cylinder manufactured for this test, the mixtures were left in cylinders for 30 min, the sand particles will deposit as a layer in the bottom of each cylinder while other light material layers in the top. After taking the measures of layers in each cylinder and apply calculations according to the following equation:

$$SE = \frac{H_2}{H_1} \times 100$$

Where:

SE = The Sand Equivalent value

H<sub>1</sub> = The Height of soft materials upon the bottom of cylinder (total height of materials)

H<sub>2</sub> = The Height of sand in the cylinder

It was clearly that most of soft materials passed through sieve No. 4\* (4.75 mm) and all fine materials retained on the pan were excluded from the whole concrete mixtures of the five samples asmost of harmful materials (clay and dust) retained on the pan Fig. 2 while Table 1 shows the sand equivalent values resulted in this test.

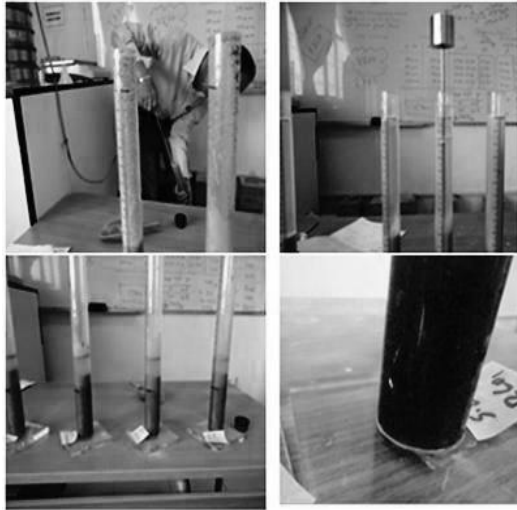


Fig. 2: Part of sand equivalent test

Actually, this practical method can develop the quality of recycled aggregate to meet construction standards. Moreover, it decreases the effects of soft material, especially the dust resulted from sand storms that beating the area continuously.

After that, to make sure the sand (both recycled or natural) become clean by removing the harmful materials from the pan, around 30 concrete batches collected from different mixtures of coarse and fine recycled aggregates (taken from demolition waste in Euphrates Basin area) were casted and tested. Recycled coarse aggregates of maximum diameter size 19 and 12.5 mm were used. Recycled fine aggregate as well as conventional fine aggregates were used for different mixes. Plasticizer was used in mixes to improve work ability at a lower water-cement ratio. Normal portland cement was used in addition to tap water, a lot of mixtures 25, 30, 35, 40, 45 and 50 MPa nominal compressive strength were designed. Some of batches were made from both recycled aggregate (coarse and fine) while others were made from recycled coarse and natural fine aggregate. Some mixtures were casted by replacing 50% recycled fine aggregate with natural sand. Two mixtures were casted with natural coarse aggregates, one with natural sand. Mixes are designated by the target strength of 25, 30, etc., signed by CC or CN. In CC mixtures both coarse and fine aggregates are recycled (Mixes 1-6). CN mixes are cast with recycled coarse aggregates and natural sand. Mixes where fine aggregate are a 50:50 combination of both natural and recycled sand are designated by CN 0.5, eventually, the mixtures with only natural aggregates are designated by NN or NC. Quantities were in kg, used to produce a cubic meter of various concretes are included in Table 2. All the

Table 2: Sand equivalent values before discarding the harmful materials from the pan

Sand Equivalent value (SE)					
Samples	Natural	RCA1	RCA2	RCA3	RCA4
S.E	46.41	58.83	69.18	72.12	64.48

mixes in Table 3 were cured in water tanks stored in temperature at 15°C while air-cured specimens were placed outside the control room on the roof of the laboratory.

The water/cement ratio used in this study varied between 0.33-0.67 and the slump varied from 7-20 cm. It can be seen in Table 3 and 4 that for mixes with 440 kg/m<sup>3</sup> cement even lower water/cement ratios produced more workable mixes (Mixes 7, 9, 10, 11, 13). The concretes made were easy to handle and compact. The use of the super-plasticizer facilitates more workable concretes at low water content. All concretes lose slump with time due to the process of ongoing hydration. It was observed that most of the mixes lost about 5 cm slump in the first 35 min after mixing. This shows that temperature monitoring is important while casting concrete.

Compressive strength values change but losses in strength of up to 10% are common when RCA is used as the only aggregate with respect to concrete made with only comparable natural aggregates (Dhir, 2009). The reasons for the loss in strength is usually associated with the weaker inter facial change area between aggregate and mortar, due to the aggregate having a coat of weak mortar already attached (Otsuki *et al.*, 2003; Etcheberria *et al.*, 2006) and this attached mortar raising the porosity of the concrete (Gomez-Soberon, 2002; De Juan and Gutierrez, 2009). The resultant bond between coarse RCA and mortar is not strong as it is in virgin aggregates. In order to overcome this problem, most mixes were cast with a super-plasticizer. Concretes of this series with both coarse and fine RCA were made using 295-440 kg of cement for a cubic meter of concrete. The water-cement ratio used varied between 0.3-0.67. Concrete made with cement content >300 kg/m<sup>3</sup> did not show any change in strength between 28 and 91 days (mix 1). This could be due to the lack of the interface between the cement paste and aggregate. These results suggest that up to 300 kg/m<sup>3</sup>, cement hydrated suitably in the first 28 days and there was not an excess of cement to keep hydrating after 28 days, hence, develop extra strength.

The maximum strength achieved by using 100% recycled aggregates is about 40 MPa. In the other hand, the recycled coarse and fine aggregates are able to producing 40 MPa compressive strength concrete.

Table 3: Mixture quantities of the concrete samples

Mixture No.	Specimens designation	Cement (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	RC coarse (kg/m <sup>3</sup> )	RC fine (kg/m <sup>3</sup> )	Natural sand (kg/m <sup>3</sup> )
1	25 CC	290	190	1209	623	-
2	30 CC	310	195	1046	621	-
3	35 CC	372	212	1045	601	-
4	35 CC	442	225	1044	533	-
5	40 CC	440	195	1047	534	-
6	30 CC	346	232	1002	683	-
7	35 CN	440	137	1045	-	580
8	40 CN	372	150	1046	-	655
9	40 CN	440	168	1046	-	578
10	40 CN	440	165	1046	-	579
11	45 CN	440	156	1046	-	577
12	40 CN	370	210	1046	-	654
13	45 CN	444	145	1046	-	580
14	50 CN	472	144	1046	-	579
15	50 CN	510	175	1043	-	513
16	50 CN	427	148	1047	-	653
17	50 CN	425	209	1045	-	653
18	30 CN 0.5	312	138	1045	310	337
19	45 CN 0.5	371	155	1045	300	327
20	45 CN 0.5	372	150	1045	299	326
21	50 CN 0.5	442	165	1045	266	290
22	50 CN 0.5	440	162	1045	266	290
23	30 CC	346	195	1001	682	-
24	40 CC	440	179	1045	533	-
25	40 CN	371	134	1045	-	653
26	50 CN	427	147	1045	-	579
27	30 CN 0.5	311	169	1045	310	337
28	45 CN 0.5	371	144	1045	299	326
29	50 CN 0.5	425	147	1045	265	290
30	40 NC	371	171	1045	-	-
31	50 NN	440	168	1210	598	579

CC: Concrete batches were casted from cycled aggregates(coarse and fine both); CN or NC: Concrete batches were casted from cycled aggregates and natural aggregate; CN0.5: Concrete batches were casted from cycled aggregates and natural aggregates in proportion 50:50; NN: Concrete batches were casted completely from natural aggregate

Table 4: Properties of different concrete batches\*

Mixture No.	Specimens designation	W/C	Slump (cm)	Air content (%)	Compressive strength (MPa)		
					7 (days)	28 (days)	91 (days)
Group 1							
1	25 CC	0.650	10.9	2.1	22.1	27.10	29.0
2	30 CC	0.622	14.2	2.2	25.5	32.90	39.0
3	35 CC	0.571	9.1	1.9	28.6	35.70	40.5
4	35 CC	0.502	20.0	2.0	32.0	35.50	40.0
5	40 CC	0.452	19.9	2.1	33.0	40.30	46.0
6	30 CC	0.671	12.1	2.2	23.5	32.60	33.5
Group 2							
7	35 CN	0.322	9.2	2.0	36.0	36.50	50.0
8	40 CN	0.412	14.1	1.4	35.5	42.50	37.0
9	40 CN	0.386	10.0	1.8	26.4	39.70	45.0
10	40 CN	0.365	12.0	1.9	42.5	44.30	46.0
11	45 CN	0.353	16.1	1.7	40.5	45.70	49.0
Group 3							
12*	40 CN	0.568	9.0	1.9	18.5	27.00	29.0
13	45 CN	0.328	10.6	1.8	35.0	49.00	50.0
14	50 CN	0.303	10.0	2.2	42.7	50.00	52.0
15	50 CN	0.347	7.1	2.5	46.5	51.30	50.0
16	50 CN	0.345	11.0	1.9	46.5	51.50	52.0
17*	50 CN	0.491	4.5	2.0	31.0	36.55	36.8
Group 4							
18	30 CN 0.5	0.446	8.0	1.8	32.5	35.50	44.0
19	45 CN 0.5	0.418	8.1	2.1	31.0	47.00	52.0
20	45 CN 0.5	0.405	11.1	2.5	35.5	41.00	44.0
21	50 CN 0.5	0.373	7.1	2.2	31.0	50.00	50.5
22	50 CN 0.5	0.367	7.6	2.6	45.0	51.00	51.6

\*Concrete patches were casted without adding plasticizer

## RESULTS AND DISCUSSION

The grain size distribution of the aggregates is shown in Fig. 3 while the physical figures are included in Table 1. Parameters of the first group models (1-6), the second group (7-11), the third group (12-17) and other groups are shown in the Table 3-6. In Table 3, designated as CC, belong to this group.

From Table 1, it was noticed that SEV of natural sand is decreased (46.41) whereas it is increased in RCA1 (58.83), RCA2 (69.18), RCA3 (72.12) and RCA4 (64.48). According to American standards ASTM, SEV of normal strength concrete it should be 75 and more than 80 for the high strength concrete (Sarkis, 2000). After we exclude the pan materials from concrete mixtures, the compression test values met the international standards and specifications, Table 4 shows that compression test values after 28 days varied between 27 and 53 MPa. When recycled fine aggregate was replaced by natural sand, the purpose is to develop compressive strength of the concrete. For example, mixes 3 and 8 are comparable in terms of total cement content of 372 kg/m<sup>3</sup> of concrete. The replacement of recycled sand by natural sand achieved to lower the w/c ratio and hence, develop the strength for the same slump. Again, there does not seem to be an considerable development in strength of this groups of concrete between 28 and 91 days. The longterm strength seems to be limited by the amount of cement and the strength capacity of there cycled coarse aggregates as well. Using a higher cement content of 440 kg/m<sup>3</sup>, a maximum

strength of 49 MPa was achievable (mix 11). The use of both 19 and 12.5 mm of aggregates in same weight with natural sand has further developed the strength potential of these concretes compared to those using 19 mm aggregates only. This is attributed to more desirable packing of the resultant aggregate solid structure (compare mixes 10 and 13). However, there is no remarkable change in strength between 28 and 91 days (only 3% increase) even with a considerable higher amount of total cement (mixture 15 with 510 kg/m<sup>3</sup> of cement).

This indicates the use of coarse recycled concrete aggregate in combination with natural sand tested in this study can produce concrete of no more than 50 MPa compressive strength. Two mixes in this series were cast without plasticizer (mixes 12 and 17).

Similar mixes cast with plasticizer (mix 12 with 8 and mix 17 with 16) clearly indicates that, the w/c ratio had to be increased to sustain work ability, which decreased the strength considerably (38.8% reduction for mix 12 and 28.8% reduction for mix 17 in 28 days strength). This indicates that the use of super-plasticizer in the recycled aggregate concrete will play a dynamic character.

Concretes made with 19 mm recycled aggregates and 50% natural sand and 50% recycled fine aggregate have considerably enhanced strength than concretes made with 100% recycled (compare mix 3 with 19 and mixes 4, 5 with 22). Concretes made with 50:50 are as good as those with 100% natural sand. Except mixes 19 and 21 all other mixes were cast with coarse aggregate of 19 and 12.5 mm size in

Table 5: Compressive strength development of concretes

Mixture No.	Specimens designation	W/C	Cement (kg/m <sup>3</sup> )	Slump (cm)	Air content (%)	Cube strength (MPa)			
						Normal curing (days)		Without curing (days)	
						<b>28.0</b>	<b>91</b>	<b>28.0</b>	<b>91.0</b>
5	40 CC	0.4150	440	17.9	1.6	39.0	45	49.0	44.5
6	30 CC	0.5510	346	7.9	3.2	32.0	34	28.0	29.5
8	40 CN	0.3480	372	10.3	2.7	42.5	36	23.5	35.5
16	50 CN	0.3450	425	17.7	1.5	51.5	51	36.5	41.5
18	30 CN 0.5	0.5412	311	14.1	2.5	32.0	34	28.5	27.5
19	45 CN 0.5	0.3760	371	9.2	2.6	47.0	52	45.5	40.5
21	50 CN 0.5	0.3470	424	10.5	2.1	51.5	51	53.5	46.5
30	40 NC	0.4620	372	11.1	1.7	49.0	51	33.0	39.5
31	50 NN	0.3800	440	7.3	2.1	48.0	51	43.0	55.5

Table 6: Flexural strength and E values of samples

Mix No.	Specimens designation	28 days flexural strength (MPa)	Density (kg/m <sup>3</sup> )	28 days comp. strength (MPa)	Experimental (GPa)	Values as/AS3600 (GPa)	Values as/ACI 318 (GPa)
1	50CN	5.6	2343	53.5	35.8	35.6	34.6
2	40CN	5.4	2332	33.0	33.6	27.5	26.9
3	30CC	5.2	2227	32.5	29.2	25.4	26.8
4	45CN 0.5	5.5	2310	47.4	34.8	32.8	32.1
5	40CC	5.1	2322	41.2	25.0	30.7	30.6
6	50CN 0.5	4.7	2359	44.5	26.1	32.7	31.3
7	30CN 0.5	3.7	2275	28.0	27.8	24.9	25.2
8	50NN	5.3	2526	51.5	39.4	39.2	33.2
9	50NC	6.2	2460	43.6	33.4	34.2	31.8

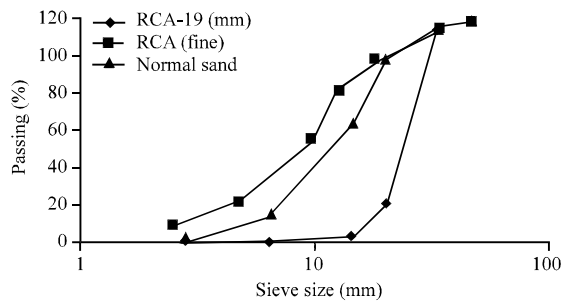


Fig. 3: Grain size distribution of aggregates used

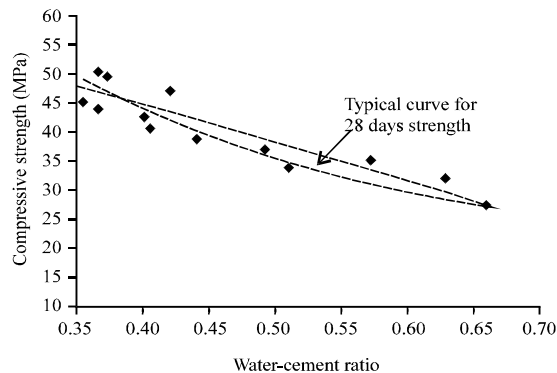


Fig. 4: Variation of compressive strength for RCA concrete with w/c ratio

equal proportion. This further improved the compressive strength development. Again, the maximum compressive strength achievable using these recycled concrete aggregates appears to be around 50 MPa. The results show that using normal practices, the recycled concrete aggregates from the present source can produce 50 MPa concrete. Figure 4 shows a plot of water-cement ratio versus compressive strength (28 days) of the concretes produced. The data is close to the distinctive 28 days strength curve (Mehta and Monteiro, 2006) based on Abram's cone rule.

A straightline best fit is drawn through the plotted points for comparison. This suggests that Abram's water-cement ratio is applicable to the concretes produced using recycled concrete aggregates.

Modulus values have been determined both experimentally and calculated from the results of strength and density. Cylinders of 150×300 mm size were used to determine the E values. Modulus of elasticity was calculated according to Australian Standard AS 3600-2009, while the modulus of elasticity was also calculated using ACI 318. The cylinders were tested for modulus of elasticity according to ASTM C469-02 at 28 days, after curing in tap water. The values of E

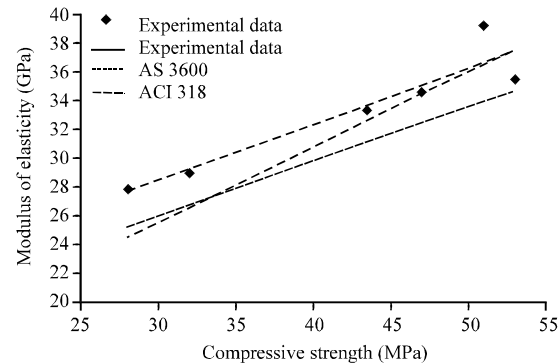


Fig. 5: Modulus of elasticity against compressive strength relationship for RCA concrete

obtained and calculated are listed in Table 6. The experimentally determined values of E for all the recycled concretes varied approximately between 24-39 GPa. These results suppose that these concretes are satisfactorily firm and further these values are similar to those of virgin aggregate concretes. The variation of E with the concrete compressive strength are similar to those of the virgin aggregate concrete (Neville, 1995). Figure 5 shows the variation of E with compressive strength. Plots of E-values calculated as per AS 3600 and ACI 318 equations are also included in Fig. 5. The experimental E-values are slightly higher than those of ACI 318 equation but follow a similar pattern. However, the E-values determined are very close to the E-values calculated by AS 3600 equation as six out of nine specimens showed a good correlation of 0.97.

Concrete beams of size 100×100×500 mm were cast and tested for flexural strength according to ASTM C 78-02 after 28 days of tap water curing. As indicated in Table 6, the results show that RCA gave equal performance to that of natural aggregate concrete (compare flexural strength of 50 CN, 50 NN and 50 NC mixes).

Figure 6 shows the plot between flexural strength and compressive strength of some samples tested in this study. The relationship shown is very similar to that between the flexural strength and the compressive strength of concretes made with virgin aggregates (Neville, 1995). For the concretes plotted in Fig. 6, the flexural strength is about 12% of the compressive strength which again is similar to that reported for natural aggregate concretes (Neville, 1995). Further, the variation of flexural strength showed a reasonably good correlation of 0.78 with the compressive strength for the plotted specimens. However, this correlation is only an approximation, because the relationship between flexural and compressive strengths is affected by the mix components and their proportions.

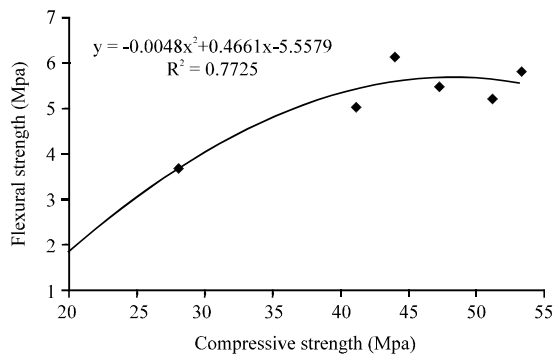


Fig. 6: Variation of flexural strength with compressive strength for RCA concrete

Commonly, the properties of recycled aggregate concrete have been established and demonstrated through several experimental and field projects. It has been concluded that RCA can be easily used in construction of low rise buildings, concrete paving blocks and tiles, flooring, retaining walls, approaching lanes, sewerage structures, subbase course of pavement, drainage layer in highways and dry lean concrete, etc. Recycling and reuse of construction and demolition waste is the appropriate solution to the environmental problems caused due to the dumping of enormous quantity of debris and the substantial depletion of natural resources.

Eventually, there was not remarkable change in compressive strength between 28 and 91 days even with a considerable higher amount of total cement (mix 18 with 510 kg/m<sup>3</sup> of cement). This indicates that the continued curing after 28 days declines the porous mortar attached to aggregates and thus, prevent further enhancement of strength. In such case, the RCA can meet the quality requirements for construction in the East of Syria.

### CONCLUSION

Simply, It can be said that most of harmful soft materials can easily be separated from concrete agglomerates and grinded in different recycling processes, then they passed through sieve (75  $\mu$ ) and retained in the pan. So, experimental results have proved that soft materials (clay and dust) in recycled and natural aggregates in Euphrates River basin can be detached from aggregate mixtures through the pan, this could be a practical procedure in processing centres. After this method a structural concretes of 27-50 MPa cube compressive strength can be produced using the recycled coarse (100%) and fine aggregate produced locally in East of Syria.

Other physical properties like bulk density, surface texture, particle size distribution and absorption are suited to some concrete production. The compressive strength values in the range of 35-50 MPa, the modulus of elasticity values 24-39 GPa and flexural strength 3.7-6.2 MPa suggest that recycled aggregate concrete produced can be used in structural applications.

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