

# Effects of recycled concrete aggregate on some mechanical properties of high strength concrete

S S Hassan<sup>1</sup>

<sup>1</sup>Asst. Prof. University of Technology, Baghdad, Iraq  
40045@uotechnology.edu.iq

**Abstract.** Aggregate is one of the essential ingredients for creating concrete, as it generally comprises 75% of the total for any concrete mixture. The strength of the concrete product is thus generally determined by the characteristics of aggregates used, which explains the need for a choice of alternative coarse aggregates. The goal for this study is to determine the strength properties of recycled aggregates for use in high strength concrete, to better understand the properties of concrete with recycled aggregates used as a substitution material for normal aggregates in concrete. The study thus compared the properties of high strength concrete with several percentage (22,40, 60,80, and 100%) of recycled aggregates. The investigation was done utilising a workability test that examined compressive, splitting tensile, and flexural strength. There is a possibility of utilising low cost recycled aggregates as an alternative material to normal aggregates in high strength concrete, as for these strength properties, the outcomes appear to suggest only a gradual reduction in compressive and splitting tensile strength as the level of recycled aggregates utilised in the specimens approaches the 100% replacement level.

**Keywords:** recycled aggregate, high strength, compressive, strength, splitting tensile, strength, slump, silica fume, sustainable material

## 1. Introduction

Concrete is the most frequently applied building material in the construction industry, and the main causes behind its popularity are its high strength and durability. Conventional concrete contains cement, gravel, and sand. The amount of building demolition has increased in Iraq in recent years, creating a need to recycle construction and demolition waste into something more useful and environmentally friendly. Research into modern and innovative uses of waste materials are thus being undertaken world-wide, and innovative projects are emerging that are significant to this substantial subject.

Using crushing concrete from construction debris and building demolition waste as recycled aggregate instead of natural aggregate can be of significant help in preserving natural resources and lowering the amount of demolition waste and construction debris that must be disposed of<sup>[1][2]</sup>.

In Iraq, efforts to utilise recycled aggregate in the manufacture of high strength recycled aggregate concrete have been relatively unsuccessful; thus, to date, the use of construction and building waste aggregate in concrete has been restricted.

## 2. Objectives and Significance of this Research

Utilising waste from demolished building in concrete production is useful both environmentally, and economically. Environmentally, it helps by allowing the substitution of a part of the virgin components generally required with demolition waste materials and by thus allowing clean disposal of those materials. Combining these advantages with the fact that these are locally obtained materials ultimately increases the environmental impact, allowing the development of novel sustainable building materials that use only locally available materials. The reuse of concrete as recycled aggregate may thus give rise to more sustainable practices of concrete production. The reuse of concrete from building demolition as aggregates began in practice many years ago, and from the beginning this green material has been considered to provide two main environmental benefits, namely resolving the increase in waste and protecting the natural sources of aggregates<sup>[3-5]</sup>. This research focuses on the development of high strength recycled aggregate concrete made more



sustainable by the utilisation of recycled concrete aggregate from Baghdad. The main variables in this research were the percentage replacement of natural coarse or natural coarse and fine aggregates with recycled concrete aggregates from waste concrete, and the concrete age of 7, 28, and 90 days. It also strives to check the hypothesis that partial or complete substitution of normal aggregates with recycled concrete aggregates from demolished buildings will not lead to important reductions in the strength properties of high strength recycled aggregate concrete.

### 3. Experimental programme

#### 3-1 Materials

##### 3-1-1 Cement

Ordinary Portland cement was utilised in this study, and Table 1 and Table 2 list the chemical and physical properties of this cement, which meets Iraqi specification No.5 /1984<sup>[6]</sup>.

**Table 1.** Chemical composition and main compounds of the cement

Oxide composition	CaO	SiO <sub>2</sub>	AlO <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	SO <sub>3</sub>	L.O.I	I.R
Content (percent)	60.8	19.9	5.69	3	1.5	2.3	1.5	1.1
Main compounds	C <sub>3</sub> S		C <sub>2</sub> S		C <sub>3</sub> A		C <sub>4</sub> AF	
Content (percent)	47.14		21.57		10		9.12	

**Table 2.** Physical properties of the cement used in this study

Physical properties	Specific surface area (M <sup>2</sup> /kg) (Blain)	Soundness (mm) (Autoclave)	Setting time Initial setting (hrs:min)	Setting time final setting (hrs:min)	Compressive strength (MPa) 3days	Compressive strength (MPa) 7days
Test results	318	0.22	2:10	3:45	24	30.5

##### 3.1.2 Normal Aggregate

- Fine aggregate: Normal sand (Al - Ukhaider) with a maximum particle size of 4.75 mm was utilised. Table 3 illustrates the sieve analysis, which conforms to Iraqi specification No. 45/1984<sup>[7]</sup> while Table 4 shows physical and chemical properties, which conform to the Iraqi specification No. 45/1984<sup>[8]</sup>.
- Normal coarse aggregate: Natural crushed aggregate of 10 mm ultimate size from Al-Nebai was utilised . its physical and chemical properties, which conform to the required Iraqi specification No. 45/1984<sup>[7]</sup>, as shown in Table 6.

##### 3.1.3 Recycled Aggregate

The recycled aggregate (fine and coarse) was gained from buildings demolition in the Baghdad area in Iraq. No data was obtainable on the age of the buildings; however, most old building in that region were dated 15 to 30 years ago. Large portions of construction debris were brought to the University of Technology Laboratory and broken up by a labourer into pieces with a size less than 50 mm. Those fragments were

crushed by hand with a hammer before being sieved in the laboratory. The fraction between 4.75 to 10mm was utilised as recycled coarse aggregate (RCA) and the parts passing through a 4.75mm sieve were utilised as recycled fine aggregate (RFA). The particle size distribution of recycled aggregate was thus similar to the particle size distribution of normal aggregate.

### 3.1.4 Silica Fume

Silica fume was utilised in this research as MS610, produced by the BASF Company. It contained about 98.87% SiO<sub>2</sub>, 0.01% Al<sub>2</sub>O<sub>3</sub>, 0.01% Fe<sub>2</sub>O<sub>3</sub>, 0.23% CaO, 0.01% MgO, 0.23% SO<sub>3</sub>, and 0.48% K<sub>2</sub>O. Its fineness and specific gravity were 16,000 m<sup>2</sup>/kg and 2.17, respectively.

### 3.1.5 Superplasticizer

Sulphonated melamine formaldehyde condensate superplasticizer, commercially known as Melment L-10, was utilised as a high-range water reducing agent. This superplasticizer is classified as type F according to ASTM C494 [9].

**Table 3.** Grading properties of normal fine aggregate.

Sieve size(mm)	Cumulative passing %	Limits of Iraqi specification NO. 45 /1984
4.75	95	90-100
2.36	79	75-100
1.18	59	55-90
0.6	39	35-59
0.3	15	8-30
0.15	6	0-10
Fine materials passing from % sieve (75 µm)=3.8		Max.=5%
Fineness modulus		3.06

**Table 4.** Physical and chemical properties of normal fine aggregate

properties	Sulfate content	Absorption %	Dry specific gravity	Relative specific gravity	Apparent specific gravity
result	0.12%	3.1%	2.4	2.5	2.6

**Table 5.** Grading of normal coarse aggregate

Sieve size(mm)	Cumulative % passing	Limits of Iraqi specification NO. 45 /1984
14	100	100
10	88.6	85-100
5	10.9	0-25
2.36	0	0-5

**Table 6.** Physical and chemical properties of normal course aggregate

properties	Sulfate content	Absorption %	Dry specific gravity	Relative specific gravity	Apparent specific gravity
result	0.06% (max0.1%)	3.6%	2.41	2.53	2.62

### 3.2. Mix proportions

Eleven mixes were prepared in the University of Technology's laboratory. A control mix containing natural aggregates was used as reference mix, and then ten additional mixes were prepared to examine the effects of replacing the normal aggregate with recycled concrete aggregate (crushed concrete) on the strength of the high strength concrete material. Table 7 shows the mix proportions for all mixes. In order to design the original high strength concrete without recycled concrete, the mix was determined to require high workability, high strength, and the lowest possible w/c ratio; thus, superplasticizer of 1.1% cement weight was added to obtain high workability, and 22% silica fume by cement weight was added to gain strength. The control mix (reference) had weights of 1 (cement): 1.21(sand): 1.82 (gravel) and did not include any recycled aggregate. In series 1 (mixes M1, M2, M3, M4, and M5), the normal coarse aggregate was replaced with 20%, 40%, 60%, 80%, and 100% by weight recycled coarse aggregate, respectively, while in series 2 (mixes M6, M7, M8, M9, and M10), the natural fine and coarse aggregate were both replaced with 20%, 40%, 60%, 80%, and 100% (by weight) recycled fine and coarse aggregate, respectively

**Table 7.** Details of mixes used throughout this investigation

Mix No.	Composition								Series No.
	C	NS	NG	RCS	RCG	SF	SP	replacement ratio (% by weight)	
1	reference	-*	-	-	-	-	-	0%	control
2	Mix1	-	-	-	-	-	-	20% of NG	series 1 partial replacement of normal gravel
3	Mix2	-	-	-	-	-	-	40% of NG	
4	Mix3	-	-	-	-	-	-	60% of NG	
5	Mix4	-	-	-	-	-	-	80% of NG	
6	Mix5	-	-	-	-	-	-	100% of NG	
7	Mix6	-	-	-	-	-	-	20% of NS (10% RCS+10% RCG)	series2 partial replacement of normal aggregate
8	Mix7	-	-	-	-	-	-	40% of NS (20% RCS+20% RCG)	
9	Mix8	-	-	-	-	-	-	60% of NS (20% RCS+40% RCG)	
10	Mix9	-	-	-	-	-	-	80% of NS (30% RCS+50% RCG)	
11	Mix10	-	-	-	-	-	-	100% of NS (30% RCS+70% RCG)	

\* :used in mix, blank: not used

## Notation:

C =cement, NS =normal fine aggregate NG = normal coarse aggregate sp= superplastisizer

RCS=recycled concrete sand (fine aggregate)

RCG=recycled concrete gravel (coarse aggregate)

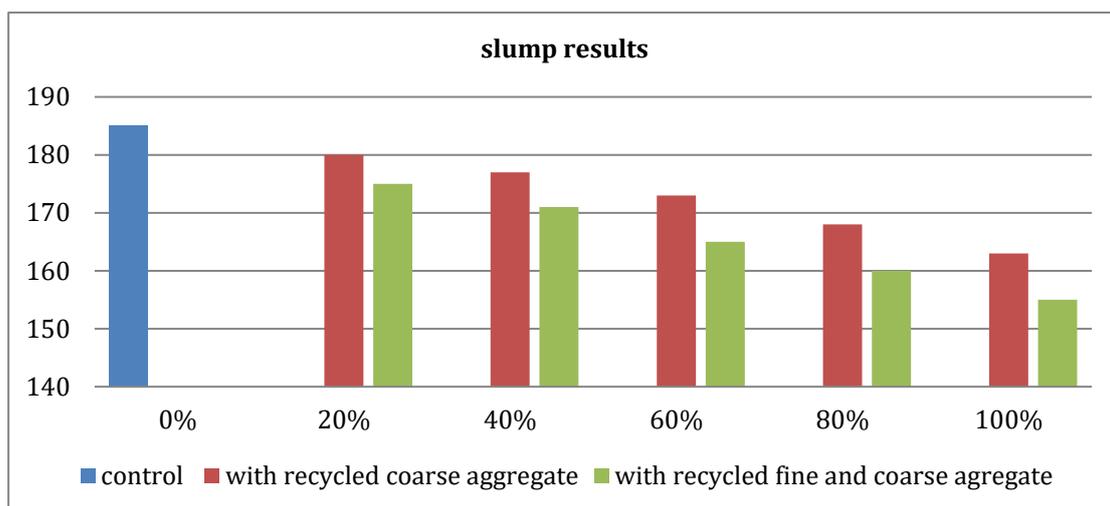
SF =silica fume

## 4. Results and discussion

### 4.1. Workability

Workability is influenced by replacing natural aggregate, and thus the slump test for all mixes was done after mixing and before casting according to the test method ASTM C143/C143 M<sup>[10]</sup>. The ratio of w/c was fixed for all concrete mixes. Figure 1 shows the influence of utilising recycled aggregate on the workability of all mixes. It was noticed that an increase in the recycled concrete percentage caused a decrease in slump, which is due to the increase in absorption of water by the recycled aggregate. The results also show that the workability was decreased compared with the reference concrete.

The reduction in slump is an indication of the increased amount of energy that would be required to cast the concrete. It is believed that this reduction in slump is due to the higher absorption ability of the recycled aggregates.



**Figure 1.** Slump for all mixes

### 4.2. Compressive strength

The average value of compressive strength of the hardened concrete was specified at the ages of 7, 28, and 90 days by using 100 x 100 x 100mm cubes. These cubes were taken from the moulds after one day and cured in water prior to testing. The test results are summarised in Tables 8 and 9.

In this study, comparative checking was conducted on two types of high strength recycled aggregate concrete; laboratory trials were carried out on two series of mixes with recycled aggregates gained from various sources in Baghdad as replacements for coarse or both (coarse and fine) forms of normal aggregate at levels of up to 100% by weight.

From Tables 8 and 9, the strength of the reference concrete is seen to be 72.23 MPa, while the compressive strength at 90 days of high strength recycled aggregate concretes containing recycled coarse aggregates are in the range of 68.59 to 58.34 MPa, and the compressive strength at 90 days of high strength recycled aggregate concrete containing recycled coarse and fine aggregate were in the range of 68.1 to 57.1 MPa. The reductions of compressive strength were observed as compared with normal concrete and are shown in Figures 2 and 3.

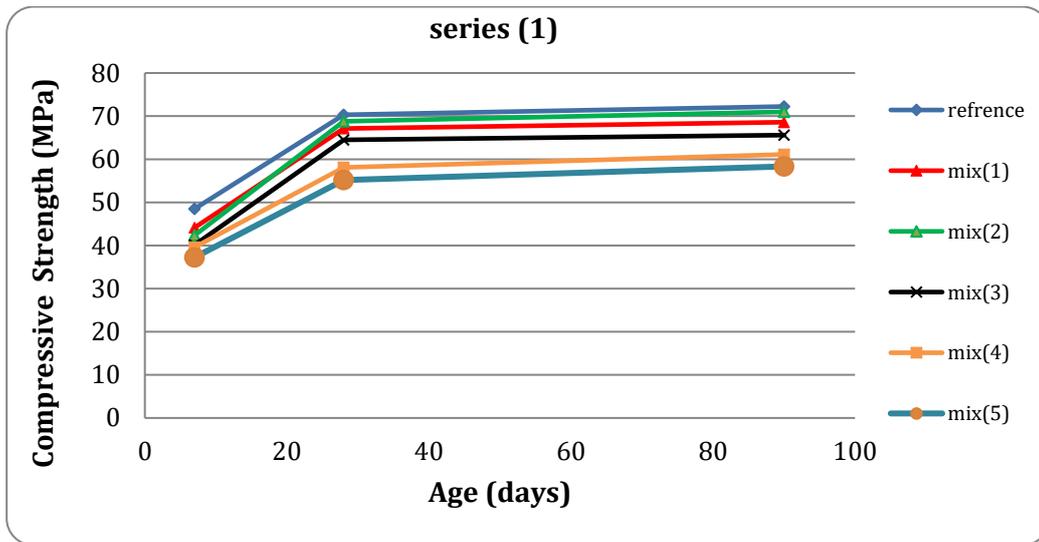
Figure 4 exhibits the growth of compressive strength for all mixes when tested at different ages. The test results showed that replacing normal coarse aggregate with recycled demolished concrete aggregate at the levels of 20%, 40%, 60%, 80, and 100% had only a slight effect on the compressive strength. However, the specimens' strength increased as the proportion of the replacement was raised, seen when using recycled concrete aggregate as are placement for normal coarse aggregate at a level of up to 100% concrete at 90days. The compressive strengths of the mixtures in series 1, which replaced the natural coarse aggregate with recycled coarse aggregate only were greater than those of the mixes in series 2, which replaced the natural fine and coarse aggregate with recycled coarse and fine aggregates. Compressive strength of not less than 57.1 MPa was produced, as shown in Figure 4. In general, the loss of compressive strength may have been due to the quality of recycled aggregate, as the recycled aggregate was obtained from destruction of unknown quality concrete. Similar results have been reported by other researchers [12-14].

**Table 8.** Compressive strength for series 1 (with crushed concrete as a partial replacement of normal gravel)

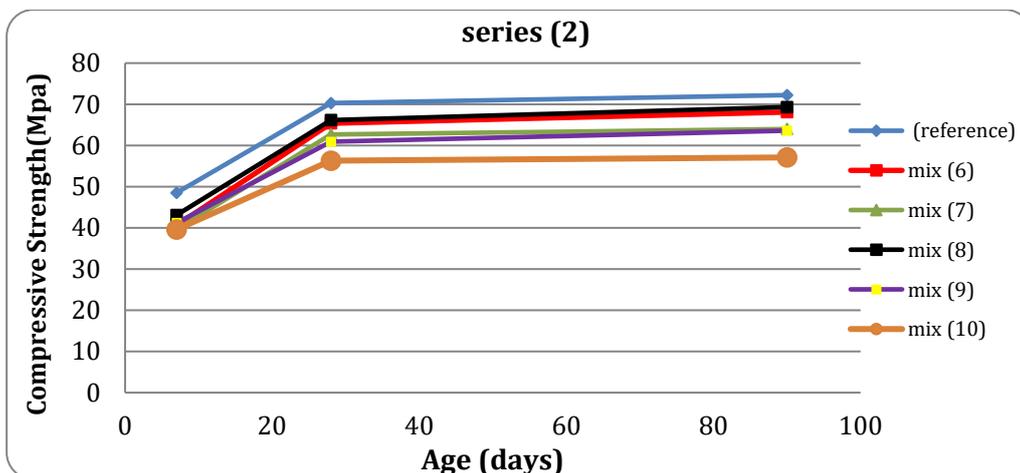
Mix No	Compressive strength (MPa)		
	7 days	28 days	90 days
(reference)	48.5	70.3	72.23
1	44.13	67.12	68.59
2	42.35	68.8	70.99
3	40.12	64.49	65.6
4	39.6	58.1	61.12
5	37.24	55.19	58.34

**Table 9.** Compressive strength for series 2 (with crushed concrete as a partial replacement of normal aggregate)

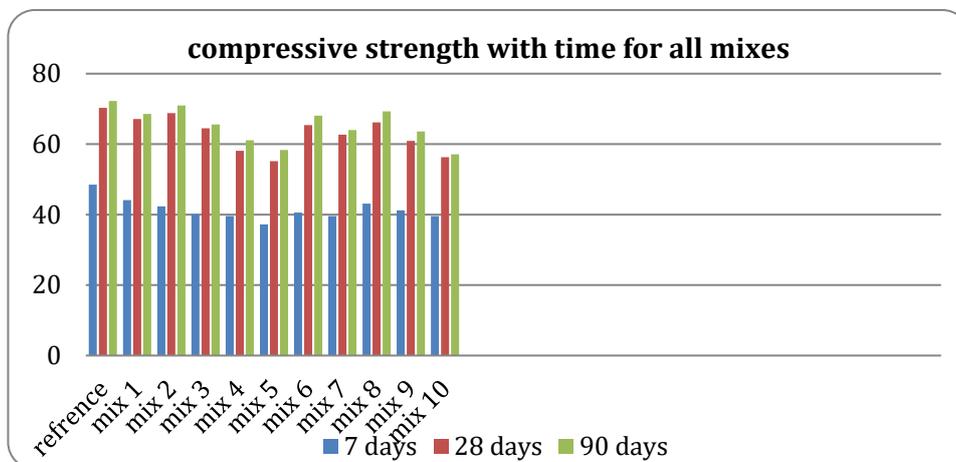
Mix No	Compressive strength (MPa)		
	7 days	28 days	90 days
(reference)	48.5	70.3	72.23
6	40.6	65.39	68.1
7	39.6	62.67	63.99
8	43.1	66.17	69.31
9	41.2	60.92	63.6
10	39.6	56.31	57.1



**Figure 2.** Compressive strength with time for series 1



**Figure 3.** Compressive strength with time for series 2



**Figure 4.** Compressive strength with time for all mixes

#### 4.3 Splitting tensile strength

The splitting tensile strength test is often utilised to obtain the tensile strength of concrete instead of a direct tensile strength test because the former is easier to perform. In practice, however, the tensile strength of concrete is often evaluated from the compressive strength<sup>[11]</sup>. The average value of splitting tensile of the hardened concrete was thus specified at different ages (7, 28, and 90 days) using 100 x 200 mm cylinders. These cylinders were taken from the moulds after one day and were treated in water before testing. The test results are summarised in Tables 10 and 11.

The splitting tensile strength of the recycled aggregate concrete is shown in Figure 5 and Figure 6. Although the results show considerable scatter, the tendency for the splitting tensile strength to increase as the compressive strength increases can still be recognised.

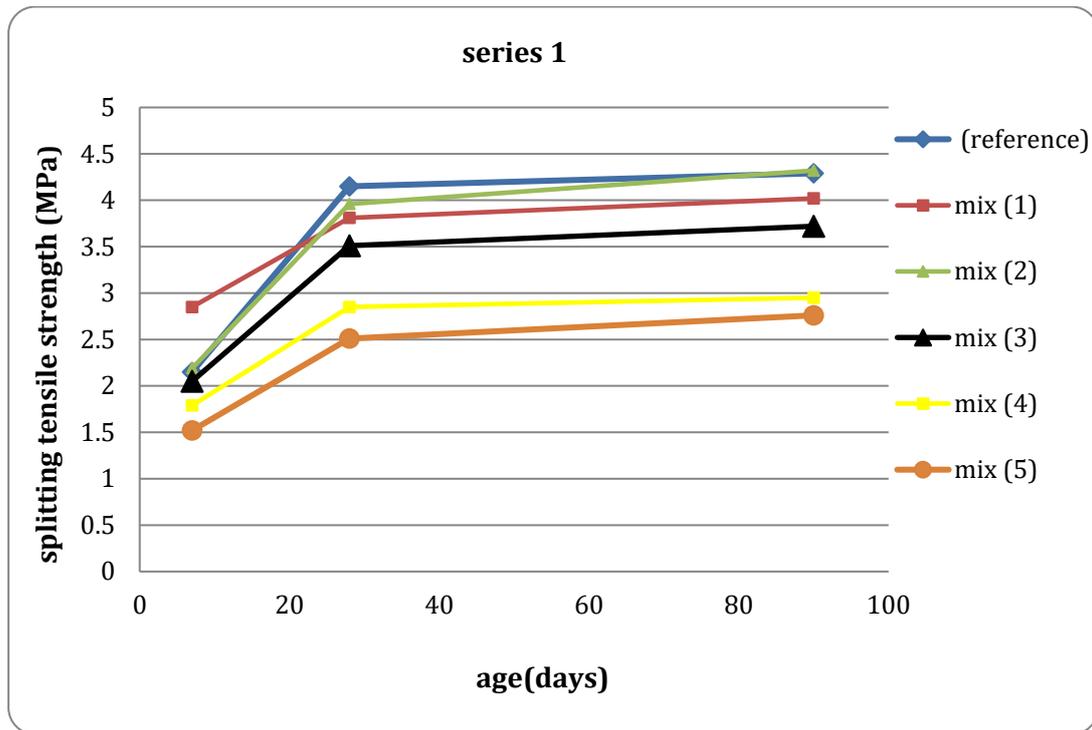
Compared with normal high strength concrete, splitting tensile strength values showed that strength was only a little lower for series 1 and series 2 high strength recycled concretes. The tensile splitting strengths of the mixes in series 1, which replaced the natural coarse aggregate with recycled coarse aggregate, were greater than those of mixes in series 2, which replaced the natural fine and coarse aggregate with recycled coarse and fine aggregate, which may be due to the better properties of recycled aggregate with low porosity and powerful bonding between old mortar<sup>[12] [14] [15]</sup>.

**Table 10.** Splitting tensile strength for series 2 (with crushed concrete as a partial replacement of normal gravel)

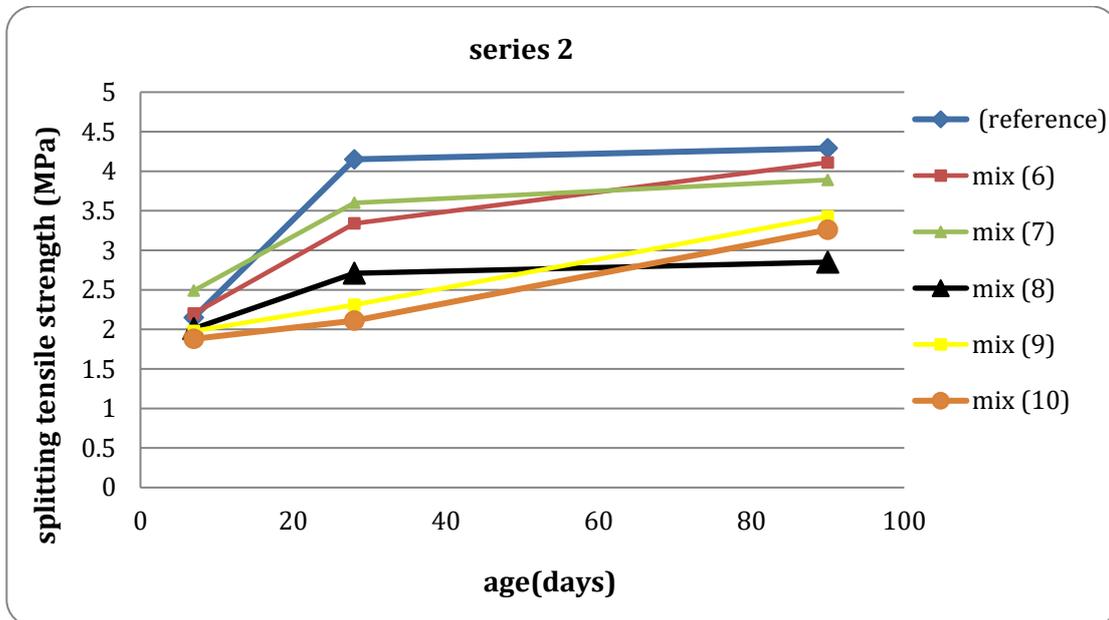
Mix No	splitting tensile strength (MPa)		
	7 days	28 days	90 days
(reference)	2.15	4.15	4.29
1	2.85	3.81	4.02
2	2.19	3.96	4.32
3	2.05	3.51	3.72
4	1.79	2.85	2.95
5	1.52	2.51	2.76

**Table 11.** Splitting tensile strength for series 1 (with crushed concrete as a partial replacement of normal aggregate)

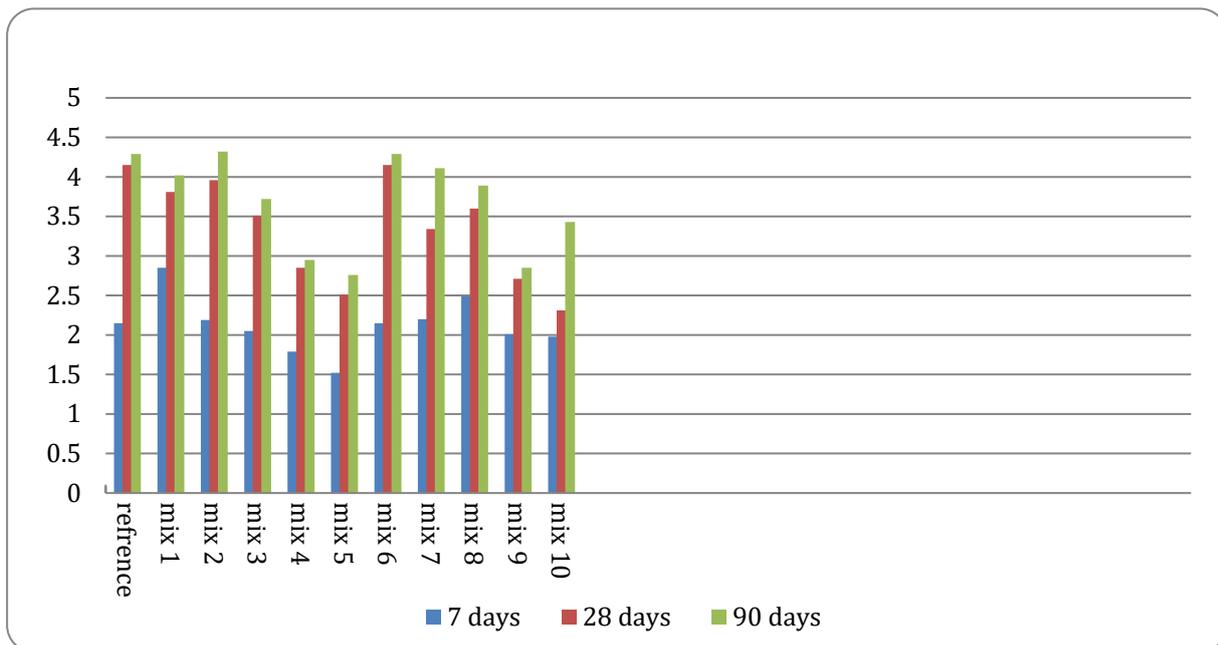
Mix No	splitting tensile strength (MPa)		
	7 days	28 days	90 days
(reference)	2.15	4.15	4.29
6	2.2	3.34	4.11
7	2.49	3.6	3.89
8	2.01	2.71	2.85
9	1.98	2.31	3.43
10	1.88	2.11	3.26



**Figure 5.** Development of splitting tensile strength with time for series1



**Figure 6.** Development of splitting tensile strength with time for series2



**Figure 7.** Splitting tensile strength with time for all mixes

## 5. Conclusions

From this research, the following conclusions can be drawn:

1. The effect of the use of recycled aggregate on the strength of high strength concrete depends on the percentage of recycled aggregate utilised.
2. For low percentages of substitution (less than 20%), any influence on the strength of the concrete is negligible in practical terms.
3. Concrete mixes designed with a combination of recycled aggregate as a partial replacement for natural coarse aggregate offered higher compressive and splitting tensile strengths than concrete mixes designed with a combination of recycled concrete aggregate used as partial replacement normal coarse and fine aggregate.
4. Recycling waste demolition aggregate in high strength concrete production may assist in resolving a vital environmental problem.
5. In general, replacing normal aggregates with recycled concrete aggregates shows comparable results with respect to compressive and splitting tensile strength; however, further studies to examine the effects on durability and other properties are necessary.

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