Investigation of Mechanical Properties of Recycled Concrete and the Amount of Recycled Aggregate in Concrete Design

Shahriar Shahabi, Behzad Farahmand, Mojtaba Majlessi and Tabasom Moradi

Abstract**—** Today saving natural sources and using sustainable methods has become an important issue. Because the importance of concrete as a key material in constructions and its wide usage, using concrete, containing recycled aggregate is considered an essential topic. Buildings reaching the end of their design life, demolition of them, and also problems involved in discarding construction wastes, encouraged us to investigate properties of recycled aggregate concrete (RCA) especially compressive strength. Specimens were created by an appropriate mix design. Each time 0,20,40,60,80 and 100 percent of normal aggregate replaced respectively, once by recycled aggregates acquired from a 35MPa compressive strength concrete(Mix.11) and the other time with recycled aggregates of a 56MPa one(Mix.2). Specimens cured in ASTM situation and the compressive strength was measured after 14, 28,56 days and 90days. Finally, no significant compressive strength decrease in concretes made with the high ratio of RA were observed, while there was a noticeable difference between the results from the specimens containing Mix.1(35Mpa) and Mix.2(56Mpa).

Keywords**—** Recycled Aggregate, Recycled Concrete, **Compressive Strength**

I. Introduction

THE environmental impact of producing raw ingredients of concrete (such as coarse aggregate, fine aggregate and concrete) is considerable [1-4]. Many structures created with reinforced concrete are reaching the end of their design life. Though they are yet resistance enough and available to use. The order of the problem makes it cautious to explore the source of raw materials in order to reduce the waste of energy and more available natural sources to achieve and produce a more "green" concrete.

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Crushing concrete to create coarse aggregate for producing new concrete is a common way to achieve a more environment-friendly concrete. This will reduce the consumption of natural resources as well as the consumption of the landfills required for waste concrete.

Concrete rubbles generated from demolition works constitute a substantial proportion of waste quantity. They yields fragment in which the aggregate is contaminated with hydrated cement paste, gypsum and minor quantities of other substances.

The major difference between natural aggregate and recycled coarse aggregate is the adhered mortar at the surface of Recycled aggregate concrete. [5]

There were some activities carried out by researchers to investigate the important properties of this Recycled aggregate concrete such as compressive, flexural and tensile strength, elastic modules and workability. The increase in concrete porosity and presence of weak interfacial bonding between aggregate, and binder matrix are mainly attributed to the situation.[6] in terms of the flexural strength, it has been reported that RAC content has insignificant influence on that [7]

In this study, it is tried to investigate the effect of recycled aggregate percentage in recycled aggregate concrete's mechanical properties such as compressive and tensile strength with a variable amount of water and a constant workability.

II. Experimental Work

As the large percentage of recycled concrete available for the experimental work, could be made of the concrete used in old or new crushed buildings, we decided to use 2 buildings with the proximate age of 20 years with known compressive strength of 35 and 56Mpa.

After breaking the concretes by a crusher and removing the unwanted materials like steels in an independent laboratory, the outcome was a mix of both fine and coarse aggregates, but as the few fine aggregates that were produced.

Coarse aggregates were in (SSD) conditions before using them.

The first issue was the high water absorption of Recycled Aggregates (RA) instead of Natural Aggregates (NA), and that's because of rough surface of cement paste presence.

There was not a big deference in specific gravity of NA and

RA used.

By analyzing the broken concretes, it was considered that the kind of available NA used in this experiment was so similar to the main aggregates used in old concrete buildings. All the aggregate properties are shown in Table I.

Concrete mixes

Here we were supposed to make 6 different mixes for comparison, and 6 mixes with (0% RA,100% NA), (20% RA,80%NA),(40% RA,60%NA), (60% RA,40%NA), (80% RA, 20%NA),(100% RA,0%NA) as coarse aggregates were made.

The 100% NA mixture was made as the control mix to benchmark the results in comparison.

This study employed ordinary Portland cement with a density of 3.14 g/cm^3.

TABLE.I
PROPERTIES OF AGGREGATE

	Fine agg	RA.1 (30Mpa)	RA.2 (55Mpa)	NA
Materials	sea sand	Usual building	Mall concrete	Andesite
Density	2.56 g/cm3	2.69 g/cm3	2.81 g/cm3	2.73
Size (max.min)	5-0 mm	20-5 mm	20-5 mm	20-5 mm
Absorption	1.33%	1.44%	1.51%	1.30%

For each of these mixes, 8 specimens were made.4 cubic ones (150×150mm) for compressive tests and 4 cylinders (150×300mm) for tensile strength test and 3 dog-bone-shaped ones for each (100% RA Mix.1,100% RA Mix.2,Control mix)due to direct tension test in order to have an approximate number for modulus of young.

At last 105 specimens were made for all compressive, tensile, young's module test.

The compressive strength test was carried out according to ASTM C39, while tensile strength test was conducted following ASTM C496.

The control mix proportions were written for a 30 Mpa compressive strength as shown in Table II.

Though using all aggregates in (SSD) conditions the water absorption of mixtures had an increasing slop as shown in Fig1.

All the concrete mixtures were blended for 5 minutes in the mixer and were consolidated using an internal vibrator for cylinders and vibrator table for cubic ones.

After casting, all the specimens were covered with plastic sheets and water-saturated burlap.

III. RESULTS AND DISCUSSION

Compressive Strength

Compressive strength test was carried out on the specimens at the age of 14, 28, 56 and 90 days.

Table. III presents the results of compressive strength test in cubic specimens.

Also diagrams of strength development up to 90 days are shown in Fig.3 to display the process of strength development in RAC and NAC.

(The diagrams in Fig.3 are drawn for NAC,100% RA in Mix.1 and 100% RA in Mix.2)

TABLE.II- (A)
MIXTURE PROPORTIONS OF MIX.2. CONCRETE

ID	W/C (%)	Water (kg/m3)	Cement (kg/m3)	Air (%)	Slump (cm)	SP (gr/m3)
0% RA	34	140	410	3.6	10	510
20% RA	35	144	410	3.7	10	510
40% RA	38	155.8	410	3.7	10	510
60% RA	40	164	410	3.8	10	510
80% RA	44	180	410	4.1	10	510
100% RA	46	188.6	410	4.5	10	510

TABLE.II-
(B). MIXTURE PROPORTIONS OF MIX.1. CONCRETE

ID	W/C (%)	Water (kg/m3)	Cement (kg/m3)	Air (%)	Slump (cm)	SP (gr/m3)
0% RA	31	127	410	3.2	10	510
20% RA	33	135	410	3.4	10	510
40% RA	35	143	410	3.5	10	510
60% RA	38	155	410	3,7	10	510
80% RA	41	168	410	3.8	10	510
100% RA	43	176	410	4.1	10	510

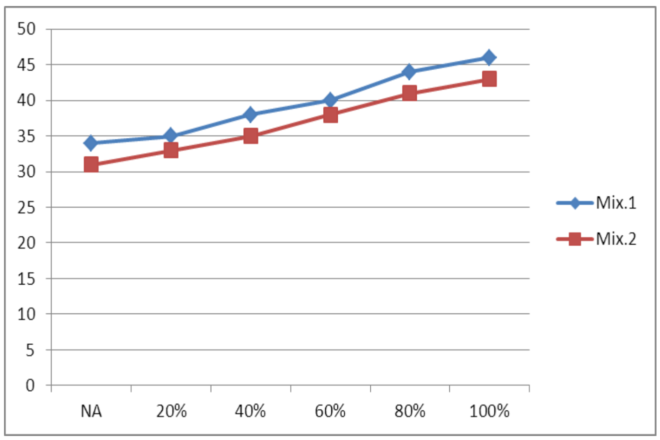

Fig.1 water/cement ratio due to RA percentage

TABLE.II
COMPRESSIVE STRENGTH RESULTS

	Mix.1				Mix.2			
compressive strength (MPa)	14 day	28 day	56 day	90 day	14 day	28 day	56 day	90 day
0% RA	25.4	30.4	32.4	34.1	25.5	31.5	32.6	34.4
20% RA	23.0	27.4	28.3	29.5	24.8	30.3	30.9	32.9
40% RA	22.3	26.5	28.0	28.5	24.1	28.9	29.9	31.0
60% RA	21.6	25.2	26.7	27.1	22.8	27.5	29.4	29.9
80% RA	19.6	23.8	25.2	26.3	20.4	26.8	27.9	28.7
100% RA	17.1	21.3	23.9	25.1	19.1	25.0	26.2	27.4

For having a same workability in 3 mixes, a 10cm slump was decided to be accomplished.

The diagrams of 90 day compressive strength for Mix.1 and Mix.2 are presented in Fig.2.

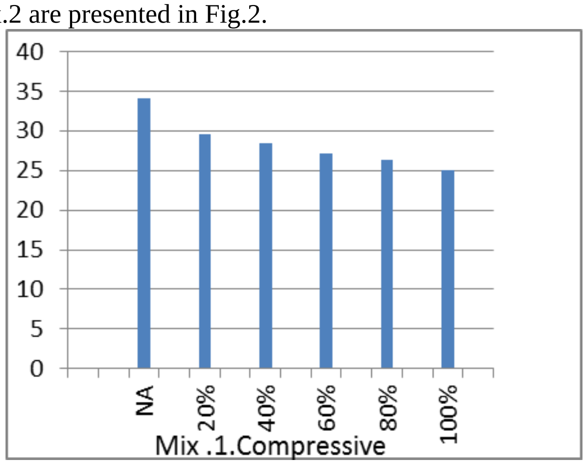

Fig. 2 90 day compressive strength for Mix.1

According to Table.3 and Fig.2 the compressive strength of RAC was slightly lower than the conventional concrete made from similar mix proportions. On the average, a 20% of strength loss in Mix.1 and a 13% in Mix.2 observed.

Also results show a reverse relation between the amount of RA used and compressive strength.

The results indicate, that for concretes with equal amount of coarse aggregate, the loss of compressive strength caused by the use of recycled aggregate is more significant in the mix with weaker RA (Mix.1).

Tensile Strength

The diagrams of 90 day tensile strength for Mix.1 and Mix.2 are presented in Fig.4.

Fig.4 shows that as in compressive strength, the tensile strength of RAC is slightly lower than NAC. Also there is a reverse relation between the amount of RA used and concrete's tensile strength.

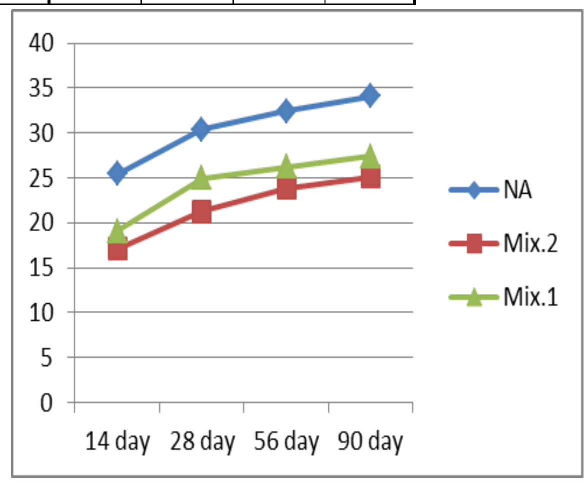

Fig.3 NAC and RAC's strength development

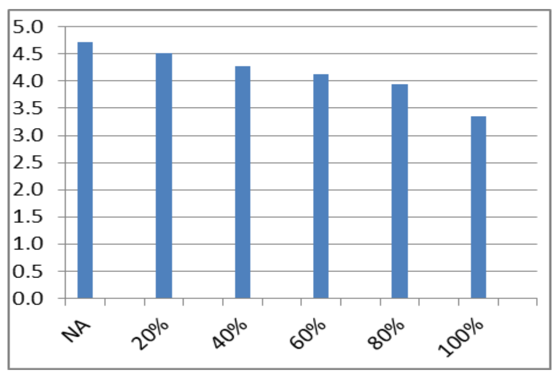

Fig.4- (a) Tensile strength of Mix.1

For equal amounts of RA used in mixes the tensile strength loss is more noticeable in the concrete containing weaker RA (Mix.1). Result in concrete built with the 56 MPa RA(Mix.2) were close to NAC's tensile resistance.in average, a 14% and 7% tensile strength reduction in Mix.1 and Mix.2 was observed respectively.

Fig.5 shows the 90 day tensile strength loss in both mixes due to the percentage of RA used, compared to NAC.as it's clear strength reduction in Mix.1 with the 35 MPa RA is faster and has a higher slope.

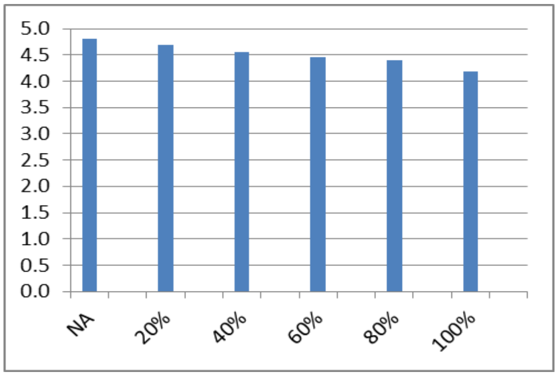

Fig.4- (b) Tensile strength of Mix.2

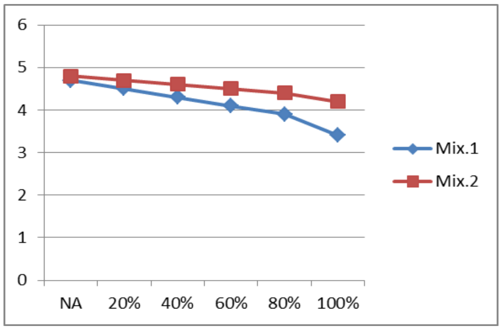

Fig.5 Tensile strength loss

Modules of Young

The 9 dog-bone-shaped specimens were tested in 1, 2, 3 and 7 days of age and the average of test results are presented in the time-dependent tensile Young's moduli in Table.IV.

TABLE. IV
YOUNG'S MODULE TEST RESULTS

	E (GPa)	E (GPa)	E (GPa)
age	Mix1	Mix2	Control Mix
1	26	23	19
2	31	28	22
3	32	31	25
7	36	32	27

For final comparison in effects of RA addition instead of NA as coarse aggregate, the 7day specimen results are shown in Fig.6.

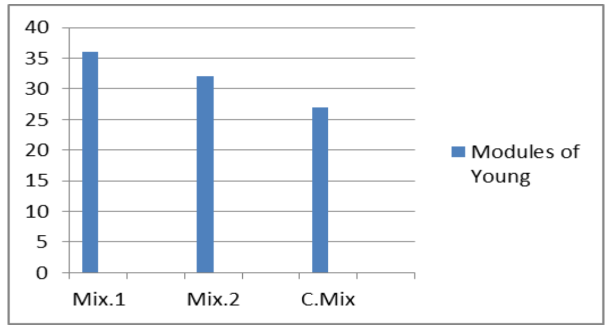

Fig. 6 7day young module test results

IV. CONCLUSION

Use of recycled aggregate concrete can be a good solution for the problem of construction wastes and it also can save many natural sources by recycling old building's concrete and prevent using new materials.

-As seen in final results it would be more appropriate using known and high strength recycled concrete for receiving a dependable strength near the strength which our proportion mix is written for.

For example in this test the 56MPa recycled aggregate had shown much better results than 35MPa one.

-Another cause of strength reduction in RAC's could be the w/c ratio increment in which it could be controlled by adding Superplasticizers instead of water, to have a same workability.

-From the young's modulus charts it could be understood that by replacing RA in concrete mixture instead of NA, the concrete would get much softer and showing more Obeisance in high pressures.

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