



## Utilization of Demolished Waste as Coarse Aggregate in Concrete

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### Abstract

Demolishing concrete building usually produces huge amounts of remains and wastes worldwide that have promising possibilities to be utilized as coarse aggregate for new mixes of concrete. High numbers of structures around the world currently need to be removed for several reasons, such as reaching the end of the expected life, to be replaced by new investments, or were not built by the local and international standards. Maintaining or removal of such structures leads to large quantities of concrete ruins. Reusing these concrete wastes will help in saving landfill spaces in addition to more sustainability in natural resources. The objective of this study is to investigate the possibility of using old recycled concrete as coarse aggregate to make new concrete mixes, and its effect on the evolution of the compressive strength of the new concrete mixes. Core samples for demolished concrete were tested to determine its compressive strength. The core test results can be thought of as aggregate properties for the new concrete. Then, the compressive strength and splitting tensile strength of the new recycled aggregate concrete (RAC) were determined experimentally by casting a cubes and cylinders, respectively. It was found that the evolution of compressive strength of recycled aggregate concrete is similar in behavior to the concrete with natural aggregate, except that it is about 10% lower in values. It was also seen that water absorption for recycled aggregate is noticeably higher than that for natural aggregate, and should be substituted for in the mix design.

*Keywords:* Natural Aggregate; Compressive Strength; Recycled Aggregate; Concrete Waste; Tensile Strength.

### 1. Introduction

Recycling building concrete wastes as aggregates to make new concrete mixes is a modern trend for limiting ecological pollution by minimizing concrete waste and reducing the need for natural aggregates. Many studies investigated the feasibility of the use of demolished concrete as coarse aggregates [1–6]. The reuse of buildings waste is gaining more and more interest around the world, considering the production of significant quantities of buildings remains and the considerable changes in the applied environmental regulations [7]. The world consumes around ten to eleven billion tons of natural aggregate each year [8]. European Union countries consume about two billion tons of aggregates each year [9]. This puts huge pressure on the natural sources of good aggregates, which causes the reserves to considerably decline around the world. The goal of this study is to investigate the possibility of utilizing old concrete remains as a replacement for natural aggregates in new concrete mixes. Destructed concrete buildings generate huge amount of wastes worldwide, which can be used as a replacement for coarse aggregate for new concrete mixes. High numbers of structures around the world currently need to be removed for several reasons, such as reaching the end of the expected life, replacement by new investments, no more compliance to the local and international standards. For example, in Saudi Arabia, many buildings were demolished by the government for the expansion of two holy mosques,

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resulting in large amount of demolished waste concrete. The use of recycled concrete will not only contribute to the solution of waste disposal, but also to the conservation of natural resources, which are scarce in some regions, in addition to reducing the cost of newly constructed concrete.

Many concrete structures are demolished for various reasons, generating millions of tons of demolished wastes every year. Recent reports show that destructed concrete every year in European countries and United States is around 50 and 60 million tons, respectively [10]. Wardeh et. al. [11] studied fresh and hardened properties of concrete made with recycled aggregate. The results show that the tensile strength and the elastic modulus decrease while the compression peak strain increases in the new concrete mixes. In several states, different techniques for reusing old concrete wastes have been developed, and some recycling standards have even been set [12-14]. As a result of this process, various types of secondary materials are generated. Akhtar and Akhtar [15] carried out a study to investigate the effect of adding fibers and Class 'C' fly ash on the mechanical properties of concrete. Akhtar et al. [16] showed that behavior of recycled demolished concrete with partial replacement of cement by recycled remains is almost similar to that of conventional concrete. Recycling will not only preserve the natural resources, but will also obtain more economic use of such concrete, which is a good step toward sustainability around the world. Huda and Alam [17] discussed the use of recycled coarse aggregate in concrete, and investigated the fresh and hardened properties of sustainable concrete. Kubissa et al. [18] carried out a study to test the possibility of using aggregate obtained from crushed old concrete pavements in concrete manufacturing with addition of supplementary cementitious materials (SCM). They replaced 2 to 16 mm natural coarse aggregate with Recycled Concrete Aggregate (RCA) made of the low-quality old concrete pavement plates, and obtained concrete with similar strength values. The study investigated the different type of properties of recycled concrete with high percentages of RCA and crushed clay brick (CCB). High percentages of water absorption are noticed for CCB samples compared to RCA and natural aggregate samples. Zhou and Chen [19] studied the mechanical properties of recycled concrete prepared with two different types of coarse aggregate. The results indicate that different types of (RCA) cause considerable deviation in concrete properties. Changing in content of CCB (0-50%) affects physical and mechanical properties of concrete significantly, especially compressive and cylinder splitting strengths [20]. The recycled aggregates obtained from waste concrete are more angular and have higher absorption and specific gravity than natural coarse aggregates, and it results in increased strength and improved load carrying capacity [21]. This paper presents an experimental study on the mechanical properties of concrete containing recycled concrete used as aggregates, including compressive strength, stress-strain curve, elastic modulus, and Poisson's ratio. Many researchers around the world had conducted similar researches about this subject, but this will eventually lead to wider knowledge about it, and to establish international standards about concrete recycling.

## 2. Source of Materials

In present study, recycled concrete will be collected from old building remains in Tabuk city in Saudi Arabia, and crushed in the material lab at Fahad Bin Sultan University. This crushed concrete will be used as a coarse aggregate to produce new concrete, which will be compared with natural aggregate concrete. The target is to produce 30 MPa concrete compressive strength at 28 days. Natural sand is used as fine aggregate in the mixes of both natural concrete and recycled aggregate concrete. No recycled fine aggregate was used in this study. Recycled concrete was collected from demolished buildings in Tabuk city in Saudi Arabia. Any impurities were removed by screening, sieving, and washing of the crushed concrete. Recycled materials were sieved to discard particles with diameter less than 5 mm. The production process of recycled concrete is depicted in Figure 1. The coarse aggregates used throughout this experiment come from locally available crushed stone aggregate, with 19 mm maximum size.

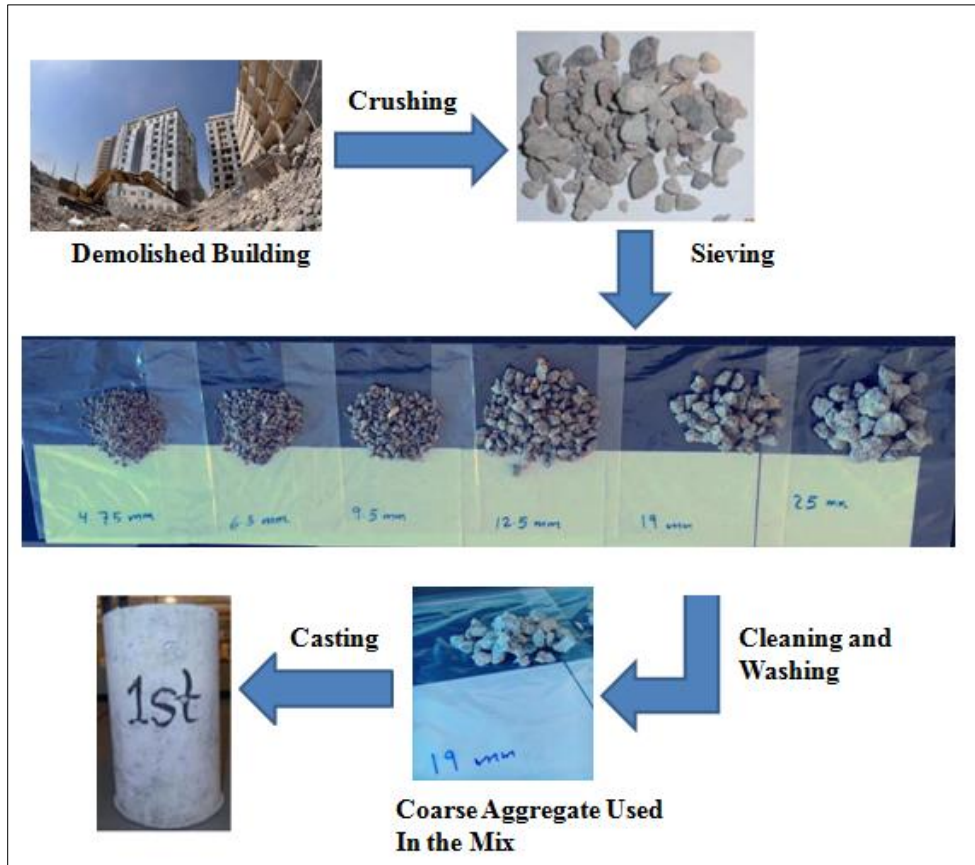


Figure 1. Preparation of recycled coarse aggregate

### 3. Materials and Properties

#### 3.1. Aggregates

Sieve analysis test was conducted to determine the grain size distribution of coarse aggregates according to (ASTM C136 / C136M – 14) [22]. From sieve analysis, fineness modulus F.M, maximum aggregate size (MAS) and nominal maximum aggregate size (NMA) were obtained. Table 1 shows typical values of F.M, MAS and NMA from the sieve analysis conducted on the natural and recycled aggregate. Figure 2 shows the gradation chart of natural and recycled aggregate.

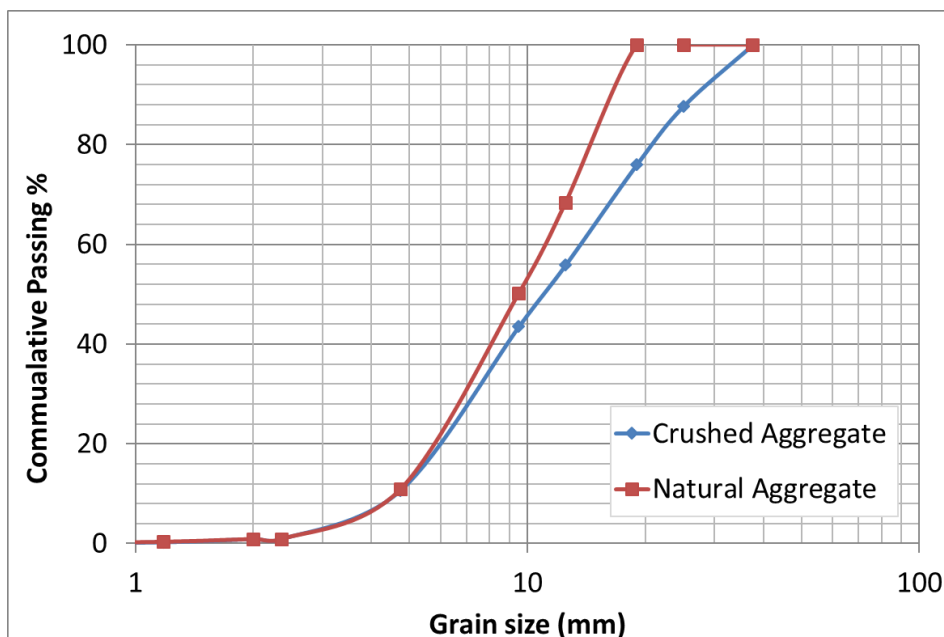


Figure 2. Grain size distribution for natural and recycled coarse aggregate

In order to confirm the use of demolished waste as coarse aggregates in concrete in newly constructed project, the mechanical properties for the recycle aggregate were determined, including specific gravity, water absorption, abrasion resistance, Aggregate Crushing Value (ACV), and Aggregate Impact Value (AIV). The results of these tests are summarized and compared with the results of the natural aggregates as shown in Table 1. It is seen that specific gravity and bulk density are almost identical, which means that the new concrete will have almost the same weight as the one with the natural aggregates. Abrasion resistance is higher in recycled aggregate, which is considered as an advantage. However, the water absorption is almost doubled in recycled aggregate, which should be substituted for in the mix design. In present study, a natural aggregate concrete (NAC) and recycled aggregate concrete (RAC) design mix were prepared on the basis of the absolute volume method. The design compressive strength was decided to be 30 MPa. Moreover, only coarse aggregates were replaced by demolished ones with full volumetric replacement sizes being respectively 9.5 mm, 12.5 mm and 19 mm (ratio 1:2:3). As mentioned in Table 1, water absorption is about 5 % higher in recycled aggregate. For maintaining the same slump, about 5 % extra water was used in the concrete made with recycled aggregate. This increase in water content has an effect on the strength. Table 2 below gives the mix proportion for design mix of the present study.

**Table 1. Physical properties of used aggregates**

Properties	Natural aggregates	Recycled aggregates	Difference (%)
fineness modulus (FM)	7.68	7.88	2.6
maximum aggregate size (MAS) (mm)	19	37.5	N/A
maximum aggregate size (MAS) used in the mix (mm)	19	19	-
nominal maximum aggregate size (NMAAS) (mm)	19	19	-
Specific gravity	2.806	2.695	-3.96
Water absorption (%)	0.958%	1.955 %	104.07
Bulk Density (Mg/m <sup>3</sup> )	2.833	2.748	-3.00
Crushing Value	8	9	12.50
Abrasion Resistance	17.10	22.20	29.82

**Table 2. Mixture proportions of concretes made of 100% of natural and recycled aggregates**

Ingredients	Weight (kg/m <sup>3</sup> )
Water/cement	0.445
Water, kg	219
Cement, kg	460
Fine aggregate , kg	762
Coarse recycled aggregate, kg	1056
Superplasticizer, % by weight of cement	0.4 litter / 100 kg of cement

The preliminary strength of the original concrete (used to obtain the recycled aggregates) was measured by six cored samples. The samples were cured in water at 23 degree Celsius for 48 hours, and then capped by sulphur mortar (Sulphur Capping) before testing. The core tests results usually depend on many factors, like the designed compressive strength of the concrete, ambient temperature and moisture, admixtures, compaction of concrete, and the strength developing process. Practically, it is usually assumed that core strengths are generally 85% of the standard-cured cylinder strengths. However, the acceptance criteria for core strength are to be set by the tester. ACI 318 provides core strength acceptance criteria for new construction. The tests were conducted according to (ASTM C 42/C 42M-04) [23]. The average compressive strength was found to be 25.73 MPa, and with standard deviation of 3.4 MPa Figure 3, shows the general procedure for sampling and testing the cored samples. The details of cored samples and results are shown in Table 3.



Figure 3. Cored test preparation for the demolished material

Table 3. Results of cored samples

Sample No	Length before capping (mm)	Length after capping (mm)	Average diameter (mm)	Aspect ratio	Correction factor	Cross Sectional Area (mm <sup>2</sup> )	Load (kN)	Stress (MPa)	Average Stress (MPa)	Standard Deviation
1	89	92.2	69.00	0.74	0.944	3739	124.2	31.40	25.73	3.4
2	97	100	69.00	0.69	0.956	3739	87.82	23.48		
3	95	98	69.00	0.7	0.953	3739	86.70	23.20		
4	96	99	69.00	0.69	0.955	3739	96.15	24.60		
5	93	97	69.00	0.71	0.952	3739	91.51	23.30		
6	90	93	69.00	0.74	0.945	3739	112.2	28.40		

### 3.2. Cement

In this work, ordinary Portland cement type 1 brand obtained from a single batch was used. The chemical and physical properties of the cement are listed in Table 4 and Table 5, respectively. The cement satisfies the requirement of the gulf standard specification (GSO: 1914-2009) [24], commonly used in the Arabian Gulf area.

**Table 4. Chemical properties of ordinary Portland cement type 1**

Component	Content (%)	Requirements of GSO 1914/2009
SiO <sub>2</sub>	20.13	Limit Not Specified
Al <sub>2</sub> O <sub>3</sub>	5.21	Limit Not Specified
Fe <sub>2</sub> O <sub>3</sub>	3.74	Limit Not Specified
CaO	62.16	Limit Not Specified
MgO	2.75	Maximum 5.0 %
SO <sub>3</sub>	2.55	Maximum 3.5 %
Loss on Ignition LOI	1.70	Maximum 3.0%
Insoluble Residue IR	1.40	Maximum 1.5%
Lime Saturation Factor LSF	0.93	0.66-1.02
Tricalcium Aluminate C <sub>3</sub> A	7.47	Limit Not Specified

**Table 5. Physical properties of ordinary Portland cement type 1**

Properties	Value	Requirements of GSO 1914/2009
Fineness (cm <sup>2</sup> /g)	3207	Minimum 2800
Initial setting time	128	Minimum 45
Final setting time	258	Maximum 737
Soundness		
Le Chatelier	1.00	Maximum 10
Autoclave	0.08	Maximum 0.8
3 d compressive strength	24	Minimum 12
7 d compressive strength	30	Minimum 19
28 d compressive strength	37	Minimum 28

## 4. Experimental Results

### 4.1. Results for Compressive Strength

For this study, standard cubes of 100×100×100 mm. were casted with natural aggregates and recycled aggregates. A 24 cubes specimens were tested in order to evaluate the strength of concrete with natural and recycled aggregate at 3 days, 7 days, 14 days, and 28 days after casting. The concrete mix design is done in accordance with ASTM C39/C39M standard. [25]. The results of the tests are shown in Table 6 and Figure 4. It can be seen that natural aggregate concrete gained strength at a higher pace compared with recycled aggregate concrete, especially at the early ages, where it was more that 8% higher in strength. However, at late stage, the difference between the two concretes reduces to about 3%, where natural aggregate concrete is still higher in strength. The average compressive strength for the core tests was found to be 26.7 MPa. It can be considered acceptable compared to a strength of 33.5 MPa for natural aggregate concrete and 32.6 MPa for recycled aggregate concrete standard cylinder specimens as shown in Figure 6.

**Table 6. Concrete average compressive strength with natural and recycled aggregate**

Test age	Natural aggregates concrete strength (MPa)	Standard deviation	Recycled aggregates concrete strength (MPa)	Standard deviation	Percent difference (%)
3 days	12.6	2.05	11.5	1.09	8.73
7 days	23.8	2.02	21.8	2.35	8.40
14 days	25.2	1.75	24.4	1.65	3.17
28 days	33.5	1.45	32.6	1.48	2.69

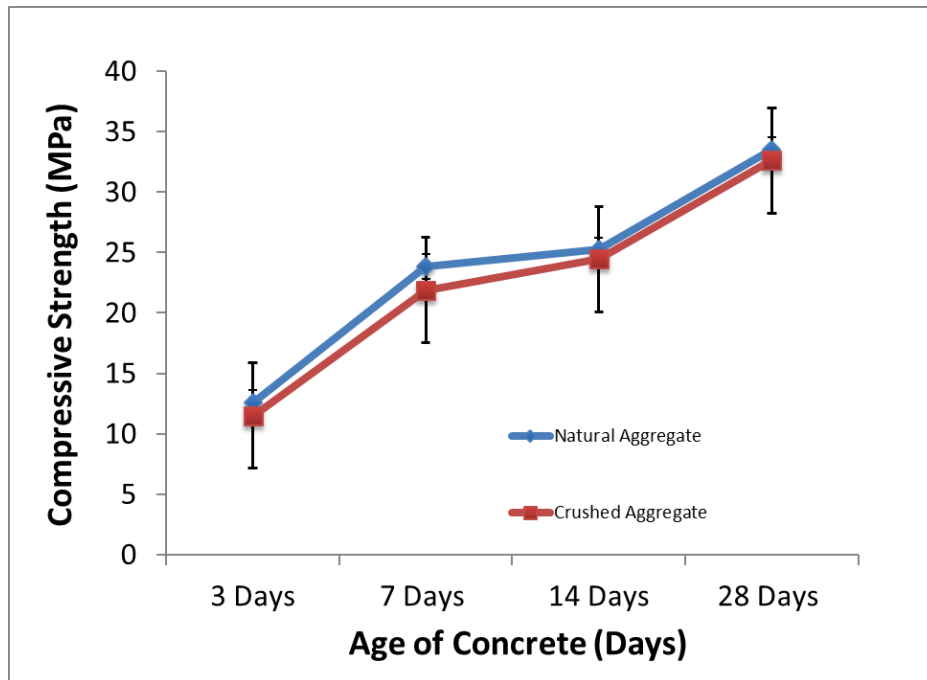


Figure 4. Compressive strength in function of curing days

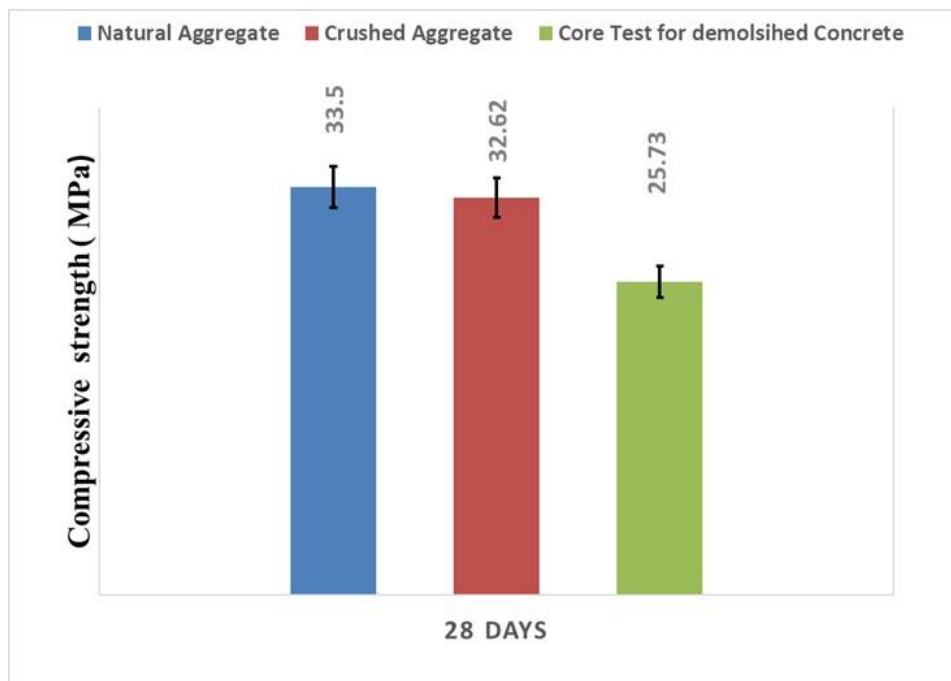
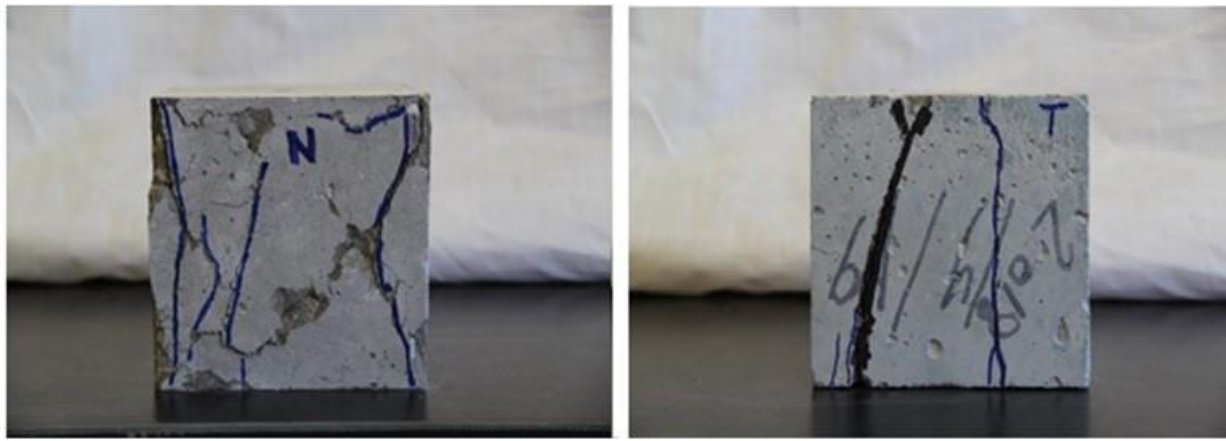


Figure 5. Comparison of compressive strength of: natural aggregate concrete, recycled aggregate concrete, and core test

**4.1.1. Crack Patterns**

The failure of the cubes depends up on the various aspect even the way it has been tested is also important. The sampling for the cube is also very important. In addition the failure of cube pattern must be decided in consideration of all parameters before reaching any final decision. Pre-cracking in a concrete cube under compression test is usually caused by local failure between the coarse aggregate surface and the cement paste. The average compressive stress where the first cracks initiate is governed by the properties of the aggregates. It can be seen in the Figure 6, the failure mode at the age of 28 days of NAC and RAC Cube is columnar type. In NAC cubes cone & shear failures were also observed in some samples but in RAC almost all samples have been failed in columnar mode only.



(a) Natural Aggregate Failure

(b) Recycle Aggregate Failure

Figure 6. The failure modes of natural aggregate concrete (NAC), and recycled aggregate concrete (RAC)

**4.2. Stress-Strain Curve**

In addition, measurements of axial force versus elongation for uniaxial compressive tests were taken in accordance to (ASTM C469 / C469M – 14) [26], to obtain the full stress-strain curve for the two types of concrete considered here at 28 days age. Standard three cylindrical specimens of 75 mm in diameter and 150 mm in length were cast and cured for 3, 7 and 28 days, for both natural aggregate and recycled aggregate concrete see Figure 7 and transverse stress strain diagrams are drawn in Figures 8, 9 and 10 respectively.

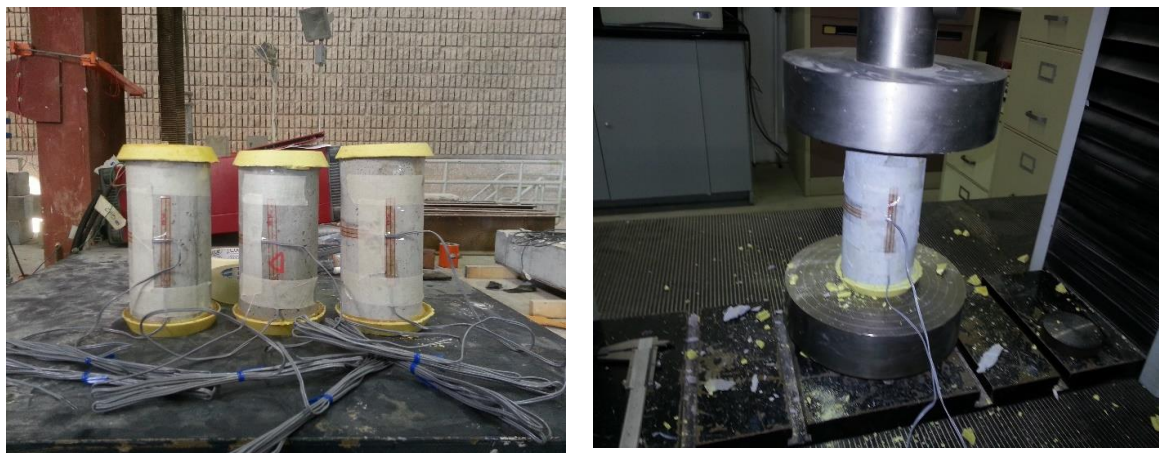


Figure 7. Compressive strength test for stress-strain curve

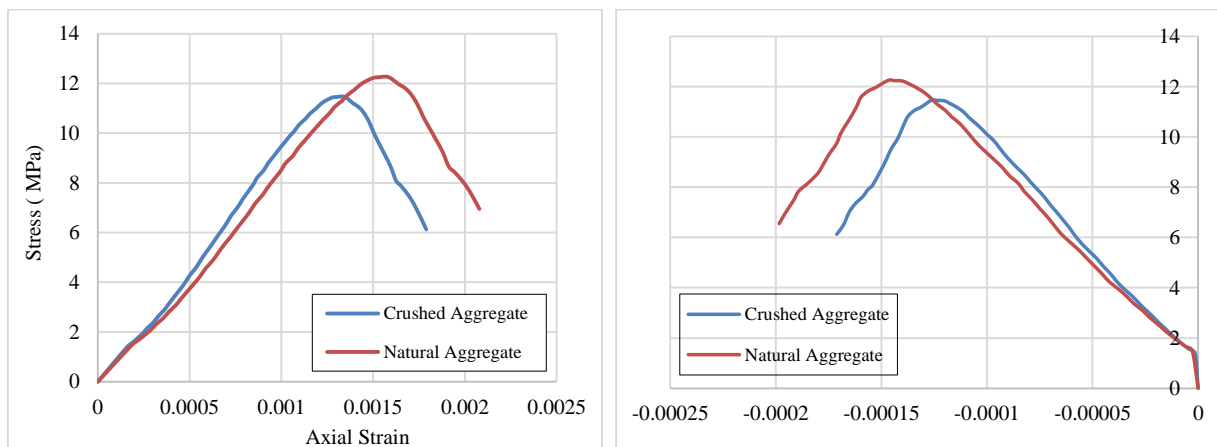


Figure 8. Axial and transverse stress-strain curves for of natural and recycled aggregate at 3-days



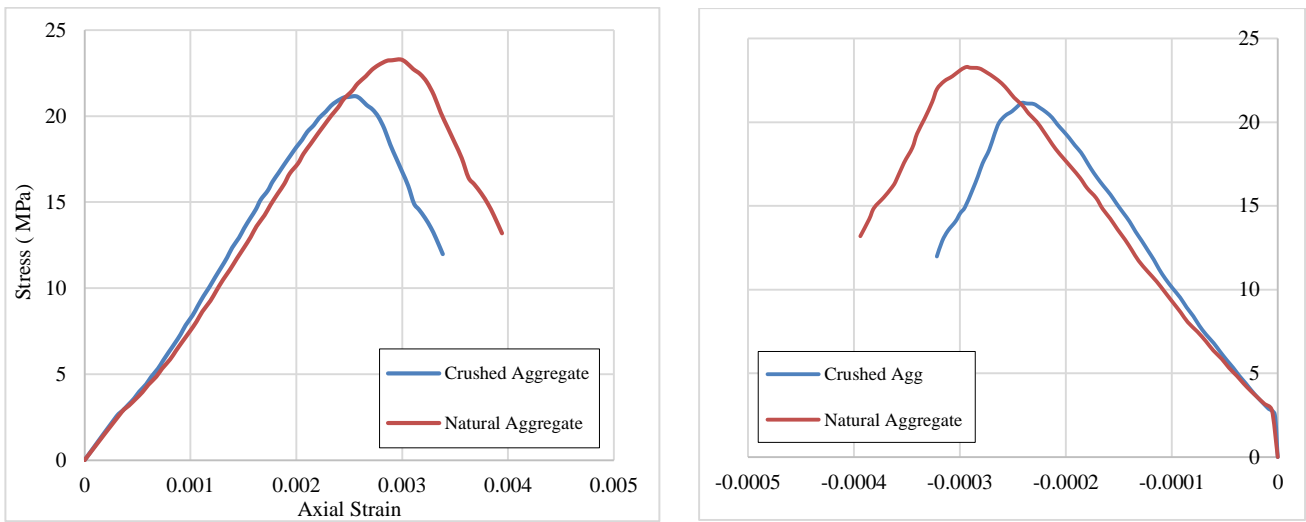


Figure 9. Axial and transverse stress-strain curve for natural and recycled concrete at 7-days

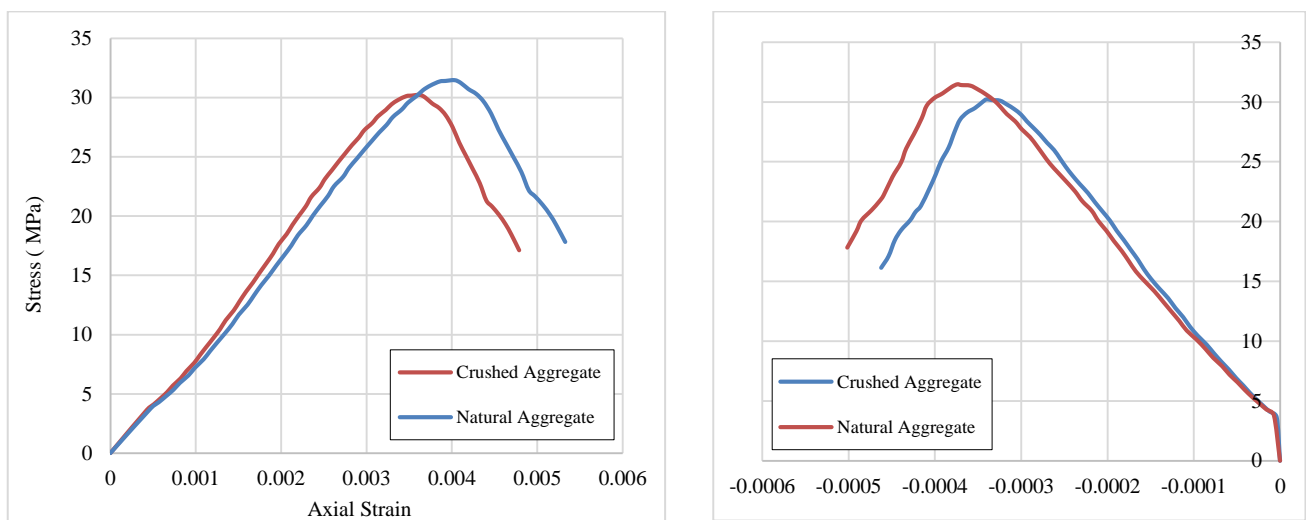


Figure 10. Axial and transverse stress-strain curve for natural and recycled concrete at 28-days

### 4.3. Modulus of Elasticity and Poisson’s Ratio

Static modulus of elasticity, and Poisson's ratio were determined from compression stress-strain diagram on cylindrical specimens (150 mm high with a diameter of 75 mm) according to ASTM C469 / C469M – 14, [26]. The mean values obtained after 28 days are reported in Table 6, it can be noticed that natural aggregate and recycled aggregate concretes achieved almost the same ultimate compressive stress (31.5 and 30.2 MPa, respectively). However, recycled aggregate concrete showed slightly lower failure strain and stress, which can be attributed to the higher bond surface between cement and concrete in recycled mix, which is where failure cracks usually initiate. Similar behavior can be seen in transverse strain as shown in Figure 10. Poisson’s ratio is found from axial and transverse stress strain diagrams to be around 2.9 and 3 for natural aggregate concrete and recycled aggregate concrete, respectively. Modulus of elasticity is found to be around 23.9 GPa for recycled aggregate concrete, which is lower than the corresponding one of natural aggregate concrete (around 26.5 GPa). This suggests that the American Concrete Institute (ACI) formula for calculating concrete modulus of elasticity in Equation 1 should be adjusted when recycled aggregate is used. According to the current research, a modified formula in Equation 2 can be suggested for recycled aggregate concrete. Table 7 shows the modulus of elasticity and Poisson’s ratio of recycled coarse aggregate concrete and natural coarse aggregate concrete. Concrete with recycled aggregate has lower modulus of elasticity by about 10%, while the Poisson’s ratio is almost the same.

Many researchers have suggested relationships between the elastic modulus (MPa) and the cube specimen compressive strength ( $f_{cu}$ , MPa) of recycled-aggregate concrete, and some of them are given in Equations 3 to 6. The result of these equation are shown in Table 8. The modulus of elasticity obtained in this research of  $f_{cu} = 32.6$  MPa is  $E=23.9$  GPa, which is close to those obtained by other researchers.

$$E = 4700\sqrt{f'_c} \quad (1)$$

$$E = 4200\sqrt{f'_c} \quad (2)$$

Dillmann [27]:

$$E_c = 634.43.f_{cu} + 3057.6 \quad (3)$$

Ravindrarajah and Tam [28]:

$$E_c = 7770.f_{cu}^{0.33} \quad (4)$$

Mellmann [29]:

$$E_c = 378.f_{cu} + 8242 \quad (5)$$

Dhir et al. [30]:

$$E_c = 370.f_{cu} + 13100 \quad (6)$$

Where;

E is the modulus of elasticity in MPa

$f'_c$  is the compressive strength of concrete in MPa

$f_{cu}$  is the cube compressive strength in MPa

**Table 7. Mechanical properties of concrete with different aggregate types at 28- days**

Concrete specimen	Compressive strength (MPa) Mean Value	Standard deviations	Static modulus of elasticity (GPa) Mean Value	Modulus of elasticity (GPa)( ACI) $4700\sqrt{f'_c}$	Strain at peak stress (mm/mm)	Poisson's ratio
Concrete of Natural Aggregate	31.5	1.34	26.5	26.36	0.004	0.29
Concrete of Crushed Aggregate	30.2	1.32	23.9	25.8	0.0035	0.3

**Table 8. Modulus of elasticity from literature**

Researcher	Modulus of elasticity (MPa)
Dillmann [27]	23740
Ravindrarajah and Tam [28]	24534
Mellmann [29]	20564.8
Dhir et al. [30]:	25162

#### 4.4. Splitting Tensile Strength

The splitting tensile strength test for cylinder of 150 mm in diameter and 300 mm high at age of 28 days was carried out. The average splitting tensile strength of three natural aggregate concrete samples was found to be 2.96 MPa, and with standard deviation of 1.26 MPa while it was found to be 2.85 MPa for recycled aggregate concrete, and with standard deviation of 1.06 MPa. This difference, which is about 4%, can be due to higher porosity and degraded quality of crushed recycled aggregate.

#### 5. Conclusion

In this research, old concrete was crushed and used as recycled aggregates to obtain new concrete. Different mechanical tests were carried out to measure and characterize the new recycled aggregate concrete. All mechanical tests showed that recycled aggregate concrete has slightly lower values of ultimate compressive strength, initial elastic modulus, and splitting tensile strength, compared to natural aggregate concrete. However, the differences can be considered negligible, where it did not exceed 5%, except for the initial tangent elastic modulus, where the difference was about 10%. A modification to the ACI formula to calculate elastic modulus for recycled aggregate concrete is suggested. On the other hand, recycled aggregate concrete showed higher failure strain than natural aggregate concrete,

which could be attributed to the higher cement content in its sample that come from recycled aggregate. Overall, it is believed that crushed old concrete can be a good alternative, to be used as a new aggregate in new concrete. It is believed that further future tests under different loading and environmental conditions can enhance and support these results and conclusions.

## 6. Acknowledgement

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## 7. Conflicts of Interest

The authors declare no conflict of interest.

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