A Sustainable Method for Consuming Waste Concrete and Limestone

Khalid M. Shaheen, Ehab E. Aziz

Abstract: This research focuses on recycling of waste concrete and limestone resulting from processing raw limestone to render it suitable for use as building envelopes and decorative purposes. The recycled concrete and limestone were used as coarse aggregate in concrete mixes. Tests applied on the resulting fresh and hardened concrete were slump, compressive strength, flexural strength, splitting strength and modulus of elasticity tests. The data obtained were compared to those of conventional concrete made with natural aggregate using the same mix proportions. The workability of the recycled concrete was considerably less than that of natural aggregate concrete (NAC). Crushed limestone aggregate (CLA) and crushed concrete aggregate (CCA) has absorption ratio of about 14 and 8 times than that of natural aggregate, respectively. Concrete made with recycled CLA has a density of 8% less than the reference concrete or natural aggregate concrete (NAC) and absorption at about 74% greater than NAC. Concrete made with recycled CCA has density 97% than that of NAC and absorption at about 54% greater than NAC.

Index Terms — D&C waste, Recycling, concrete waste, limestone waste.

I. INTRODUCTION

Recycling is the act of processing the used material for use in creating new product. The usage of natural aggregate is getting more and more intense with the advanced development of the infrastructures. In order to reduce the usage of natural aggregate, recycled aggregate can be adopted as the replacement materials. Recycled aggregate are comprised of crushed, graded inorganic particles processed from the materials that have been used in the constructions and demolition debris. These materials are generally from buildings, roads, bridges, and sometimes even from catastrophes, such as wars and earthquakes.

With the sharp development of construction and increase of people's awareness of environmental protection, waste control and management becomes one of the great challenges of modern society for the mission of sustainable development. Construction and demolition (C&D) waste constitutes one major portion of total solid waste produced in the world, including demolished concrete, bricks, and masonry, limestone, ceramic and other materials. The environmental protection agency EPA defines the C&D debris as "waste material that is produced in the process of construction, renovation, or demolition of structures. Structures include buildings of all types, both residential and non-residential, as well as roads and bridges. Components of C&D debris typically include concrete, asphalt, wood, metals, gypsum wallboard and roofing" [1]. The growth of population on the planet earth necessitates the construction of more and more buildings. The increasing quantity of C&D waste leads to the increase of loads on landfills. Large numbers of countries, especially developed ones, suffer from inefficient waste management. For example, in one of the big Brazilian cities only 20% of civil construction waste is collected by companies licensed by public authorities, and only 1% of the waste collected in 2004 by authorized companies went to solid waste landfill of the city [2]. Demolition works in Kuwait was reported to produce about 600×10^3 tons of C&D wastes annually at an average rate of about 1.5 tons/m^2 of building area [3].

Mosul city (Iraq) suffers from increasing quantities of D&C waste. Waste collected by Mosul municipality was estimated to be 182×10^3, 178×10^3, and 598×10^3 m^3 for the years 2009, 2010, and 2011 respectively. Mosul city doesn't have landfill facility for waste disposal but it is dumped in remote suburbs. Some of these wastes are used for swamps filling near residential areas [4].

Three approaches can be employed for project waste reduction. The first is to look for ways waste can be prevented by identifying potential waste early in the design process. The second is to identify waste that can be salvaged for reuse, and the third approach is to figure out which waste materials can be recycled [5]. The developed world has recognized the importance of such strategies and developed ways to consume the waste. The European Demolition Association estimates that out of the 200 million tons of waste produced annually in Europe, about 30% of this quantity is currently being recycled [6]. Japan is a leading country in recycling concrete waste, with 100% recycling of the wastes that are used for new structural applications. The recycling rates of various types of C&D waste there for the years 1995, 2000, and 2003 were 65%, 96%, and 98%, respectively [7].

The nature of building in Mosul city is distinguished with using concrete as main construction material. Concrete blocks are widespread in construction as bearing wall or even partitions. The availability and cheapness of concrete constituents made it the most famous material compared to other construction materials. This means that most of D&C wastes in Mosul city are composed of concrete. Recycling process is the most important method for consuming the waste and protects the environment. There are different methods to recycle waste such as using it as sub-base in roads, in filtrations layers, in asphalt pavement or in concrete. Tests showed the ability of using recycled coarse aggregate at self consolidating concrete with optimum content up to 50% of NA [8].
Limestone is a familiar construction material in the city of Mosul since the Assyrian civilization. Nowadays, limestone is mainly used as decorative material for different types of buildings, mainly residential ones. The sources of limestone waste are the construction waste, demolition waste, and raw limestone processing. Most of the limestone waste is generated during cutting large stone to smaller desired shapes. As much as one-half of quarried stone may become waste during fabrication [9]. About 80 Limestone processing mills are spread at the left side suburbs of Mosul city [10]. Limestone dust can be used as an additive in concrete mixes to improve the strength of concrete at late ages [11]. Limestone can be used in concrete as coarse aggregate in places exposed to chemical attack or without [12].

This paper investigates recycling of waste concrete and limestone as coarse aggregate at certain percentages in concrete instead of natural aggregate. Studying the properties of recycled aggregate and the concrete produced is the other goal of the present study.

II. METHODOLOGY

A. Materials:

1. Crushed concrete aggregate (CCA):
Concrete is a widespread building material in Mosul city. It is used in slabs, columns, building blocks, pavements and other applications. Waste concrete used in this study was a mix of beam, column, slab and pavement concrete. The samples collected was crushed, sieved, and then washed. The size of aggregate ranged between 5 – 20 mm. Fig. 1 shows a sample of the waste concrete before crushing. Fig. 2 depicts the construction and demolition wastes near a swamp.

Fig. 1: A Sample of Waste Concrete

Fig. 2: Dumps of Demolition and Construction Waste

2. Crushed limestone aggregate (CLA):
The industrial district in the city of Mosul contains huge dumps of waste limestone which appear as a by-product from processing of raw limestone, Fig. 3. Processed Limestone is usually used in the finishing works of building envelopes as decorative materials.

Fig. 3: A waste Limestone dump

Samples of waste limestone were collected and crushed to convert it to coarse aggregate with maximum size of 20mm and minimum size of 5mm. Fig. 4 shows the crushed limestone aggregate used in this study.

Fig. 4: Crushed limestone aggregate

3. Natural coarse aggregate (NA):
The natural coarse aggregate used was river bed gravel obtained from River Dijla (Mosul/Iraq). This gravel was prepared to have the same size range as CCA and CLA.

4. Fine aggregate (sand):
Sand used in this study was natural sand supplied from Kanhash region (Mosul). This type of sand is known for its good grading according to the BS 882 limits. Fig. 5 shows the sieve analysis of this sand.

Fig. 5: Grading Curve of the Sand
5. Cement:
The binding material used was ordinary Portland cement produced by Sinjar Factory (Mosul). Table 1 shows the Chemical composition of the cement used [13].

<table>
<thead>
<tr>
<th>Main Oxides</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>64.06</td>
</tr>
<tr>
<td>SiO₂</td>
<td>19.99</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>6.32</td>
</tr>
<tr>
<td>MgO</td>
<td>2.75</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2.8</td>
</tr>
<tr>
<td>SO₃</td>
<td>2.06</td>
</tr>
</tbody>
</table>

6. Water:
Tap water was used for concrete mixtures as a medium for cement hydration. The water was free from impurities that could adversely affect the properties of the resulting concrete.

B. Methods:

1. Mix Proportion, Casting and Curing:
A predetermined compressive strength of 34 MPa was decided for the resulting concrete at age of 28 days. Accordingly, the mix proportions obtained through ACI mix design method were (1: 1.8: 2.4) with water cement ratio W/C ratio of 40%. The cement content of the mix was 417 kg/m³. Fresh concrete has casted in cast iron molds immediately after mixing in a batch mixer for 3 minutes followed by 3 minutes rest, then another 2 minutes mixing. Samples were then cured with water at temperature of 23 ± 2 according to ASTM (C 511).

2. Aggregate tests:
Several testes were applied to the aggregate according to ASTM such as specific gravity and absorption (C 128) for fine aggregate, and (C 127) for coarse aggregate. Voids ratio and bulk density(C 29), and clay content (C 117).

3. Concrete Tests:
A concrete mix of 100% NA was used as the reference concrete (NAC). Other five mixes were made with replacement percentage of 25%, 50%, 75%, and 100% between crushed concrete and limestone, Table 2 shows list the type of mixes. All mixes were prepared with the same mix proportions of (1: 1.8: 2.4). The volume of CCA and CLA was equal to that of NA.

<table>
<thead>
<tr>
<th>Tests</th>
<th>N A</th>
<th>CCA</th>
<th>CLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity (SSD)(kg/m³)</td>
<td>26</td>
<td>2439</td>
<td>2172</td>
</tr>
<tr>
<td>Bulk dry density (kg/m³)</td>
<td>59</td>
<td>1349</td>
<td>1174</td>
</tr>
<tr>
<td>Absorption (%)</td>
<td>0.6</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Voids (%)</td>
<td>37.</td>
<td>41.5</td>
<td>40.4</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>0.2</td>
<td>5</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Comparing CCA to NA it can be found that the CCA has less specific gravity, less bulk density, and more water absorption. The same findings of the comparison were reached by Radonjanin et al (2010) [14], Abed (2009) [15], and Obla et al (2007) [16]. The results of the specific gravity at SSD condition show that the NA has a specific gravity greater than that of CLA, and CCA by about 24% and 10%, respectively. A bulk dry density of

The fresh concrete was tested for slump value. Compressive strength, flexural strength, splitting strength, modulus of elasticity, density, and absorption tests were applied on hardened concrete. The tests were conducted according to ASTM and BS.

3.1. Slump test:
Slump test was conducted to determine the workability of fresh concrete. The test was according to the ASTM (C143).

3.2. Compressive strength test:
British standard BS 1881: Parts 116 was used as a guide for testing the compressive strength of the hardened concrete. The concrete cubes were tested at ages of 7, 14, 28, and 56 days for each of NAC and RAC. Cube dimensions were 100mm x 100mm x 100mm.

3.3. Flexural strength test:
Flexural strength was determined according to ASTM (C 78) using simple beam with third point loading. Test beam dimensions were 100mmX 100mm X 400 mm.

3.4. Splitting strength test:
Splitting strength was tested according to ASTM (C 469). Cylindrical sample with dimensions of 100mmX 200mm were used. Samples were tested at age of 28 days.

3.5. Modulus of elasticity:
A Cylindrical samples with dimensions of 150mm × 300mm were used for modulus of elasticity determination for both NAC and RAC at age of 28 days as for ASTM (C 469).

III. RESULT AND DISCUSSIONS

A. Aggregate tests:
Table 3 presents the results of tests applied on the aggregate used in the mixes. All tests were performed in accordance with ASTM specification.

<table>
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<td>1174</td>
</tr>
<tr>
<td>Absorption (%)</td>
<td>0.6</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Voids (%)</td>
<td>8</td>
<td>41.5</td>
<td>40.4</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>5</td>
<td>26.</td>
<td>0.8</td>
</tr>
</tbody>
</table>
CLA represents about 71% of that of NA, and about 81% of that of CCA. The absorption values of CLA and CCA are estimated to be about 14 times and 8 times than that of NA, respectively. The voids ratio in the NA was slightly less than that found in both CCA and CLA.

B. Slump values:
The slump value for the NAC was higher than that of RAC. Fig. 6 shows the slump test performed.

Increasing the W/C ratio may have bad effects on the properties of the resulting concrete.

C. Compressive strength values:
It is observed that there is no much difference between reference mix A and mix B. The difference at age of 28 days was 6.8%, then it got decrease at subsequent ages. This means that the CCA results in good compressive strength properties. The compressive strength of mix A was found to be 25.4% - 36.2 % greater than that of mix F. This suggests that CLA reduces the strength of concrete, as shown in Table 4. The greatest difference was noticed at early ages. The difference in strength has then become lower until it was 25.4% at the age of 56 days. Figure 8 shows the strength development of various mixes through ages progress.

<table>
<thead>
<tr>
<th>Age (days)</th>
<th>Compressive strength of mixes (MPa)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>7</td>
<td>48.6</td>
</tr>
<tr>
<td>14</td>
<td>51.3</td>
</tr>
<tr>
<td>28</td>
<td>54.4</td>
</tr>
<tr>
<td>56</td>
<td>56.6</td>
</tr>
</tbody>
</table>

There was no significant variation in strength of concrete made from NA and CCA. Similar results were obtained by limbachiya (2004) [20]. Some studies found that of CCA tend to reduce the compressive strength of the resulting concrete [16].The compressive strength obtained from the test was clearly more than that already been determined through mix design. This could be attributed to the use of 100mm×100mm×100mm cubes instead of cylindrical molds. Small cubes result in a compressive strength higher than that obtained from cylinders [19].The strength obtained for RAC is suitable.
for structural application. Figure 9 depicts a cube during and after the test.

D. Flexural strength:
The flexural strength obtained for RAC is less than that of NAC. The difference in strength with mix B do not exceed 2%, but the mix F a flexural strength of about 24% less than that of NAC. Figure 10 shows the variation between the mixes in this respect.

E. Splitting strength:
The results reveal that the splitting strength of NAC is more than that of RAC with reduction percentage about 5% and 40% for CCA and CLA, respectively. Fig. 12 shows the values of splitting strength for the six mixes.
Fig. 12: Splitting strength tests at 28 days
Fig. 13 shows halves of cylindrical samples A, B, C, D, E, and F after failure by splitting test.

Fig. 13: Halves of Cylindrical samples of NAC and RAC after Splitting Test

F. Density:
The hardened concrete shows that the density of CCA in mix B was less than that of NAC, and CLA in mix F was lighter than all samples shown in Fig. 13. The density of RAC is less than that of NAC, and the density reduces by increasing the limestone percentage. It can be observed that the density of RAC in mix F is about 92% of the NAC density. This is because the CLA is lighter than NA of about 29% by weight, and the CCA is lighter than that of NA of about 13%. CCA is decreasing the density [14, 15]. Fig. 14 illustrates the densities of six concrete mixes.

Fig. 14: Densities of the Six Mixes Involved in the Study
The density of lightweight concrete not exceed 1840 kg/m$^3$ [19], therefore, the (RAC) used could not be consider as lightweight concrete.

G. Absorption of hardened concrete:
The absorption of RAC is higher than that of NAC as shown at Fig. 15. This is because the absorption of CLA and CCA is greater than that of NA, review Table 2.

Fig. 15: Absorption of The Six Mixes Involving in The Study
Recycled aggregate was increasing the absorption of concrete more than that of NAC. Absorbed water was proportionally increased with increasing recycled CLA content, but such variation was reduced in mixes (D, E, and F). The CCA is increasing the absorption of concrete [14, 15]. Absorption ratios of RAC for the mixes B to F samples is ranged between (6.64% - 7.5%) compared to mix A. Mix A has an absorption ratio of 4.3%.

H. Modulus of elasticity:
The modulus of elasticity test indicates a decrease in modulus of elasticity when recycled aggregate was used. It was observed that CCA reduces the modulus of elasticity, and the trend of modulus of elasticity value inversely proportional to the replacement percentage of limestone. The modulus of elasticity of concrete also decreases with increasing CCA. Similar results were obtained by Rdonjanin (2011) [14], and Nelson et al (2004) [17]. Fig. 16 shows stress-strain curve for NAC and RAC.

Fig. 16: Modulus of Elasticity Test (Stress-Strain Curve)
Figure 17 shows the apparatus used for the determination of modulus of elasticity before and during the test.

**IV. CONCLUSION**

The following conclusions could be reached through the results of the experimental works carried out in this research:

1. Recycled aggregate concrete has good strength about 53.4 MPa for mix with 100% crushed concrete aggregate and 38.7 MPa at mix with 100% crushed limestone aggregate at 28 days.

2. The crushed concrete aggregate is lighter than that of natural aggregate, but crushed Limestone aggregate was the lightest of them. This property may result in less dead load in building.

3. The strength of concrete with 100% limestone aggregate lower than that of natural aggregate concrete for the same mix proportion. Variation in strength ranged between 25.4% - 36.2% through the ages 7 - 56 days.

4. Slump of recycled aggregate concrete is less than that of natural aggregate concrete. The slump is inversely proportional with the limestone aggregate which shown very poor slump.

5. The absorption in mixe with 100% crushed concrete aggregate and other mix with 100% crushed limestone aggregate greater than that of reference mix with 100% natural aggregate concrete at about 54% and 74%, respectively.

6. Recycled aggregate concrete reduces the modulus of elasticity. The crushed limestone aggregate reduces the modulus of elasticity according to its percentages when used in concrete.

**REFERENCES**


