The Use of Recycled Building Rubble in the Reconstruction of Demolished Buildings

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Abstract
Natural disasters and wars destroy millions of buildings and infrastructure components and result in huge amounts of rubble and debris. They also have a significant effect on the worldwide economy. The reconstruction of these buildings will require substantial amounts of materials and funds. The resulted rubble includes various materials that can be recycled and reused in the reconstruction of buildings. This research studies the possibility of recycling building rubble and using it in the reconstruction of destroyed buildings. The study includes recycling demolished concrete, concrete bricks and tiles, terrazzo tiles, stones and other materials. It was found that it possible to obtain concrete of acceptable properties by the use of recycled concrete coarse aggregate. Also, it is possible to recycle concrete bricks and tiles as fine aggregate and reuse them in the production of mortars and reconstruction of walls.

Keywords: Building rubble, recycling, recycled concrete aggregate, recycled bricks, recycled terrazzo tiles, workability, strength.

1. Introduction:
Natural disasters, such as earthquakes, floods, landslides, …etc result in destroying many buildings. In addition human made disasters such as wars would result in a substantial amount of building rubble and debris. Infrastructure components and would also be destroyed and aggravate the problem. Also, demolition of buildings due to any reason would also end with similar effects. The reconstruction of these buildings is costly and would have an adverse effect on the environment. Fig. 1 shows some building rubble produced due to demolition of a building.

The average world production of concrete in our rapid developing industrialized world is about 6 billion tons per year (Marinkovic et al, 2010) which has an adverse impact on the environment. Since earth is the source of the aggregates (either natural or crushed), then obtaining these amounts would have an adverse effect on the environment. Furthermore, demolishing concrete structures and dumping the concrete rubble would aggravate the problem. Furthermore, disasters, such as wars, earthquakes, hurricanes…..etc, destroy millions of buildings and infrastructure components while inflicting significant economic loss. These disasters can create substantial amounts of rubble and concrete debris.

Therefore, recycling construction material plays an important role to preserve the natural resources and
helps to promote sustainable development in the protection of natural resources; thus reduces the
disposal of demolition waste from demolished buildings (Yong, 2009). Hence, recycling concrete
wastes becomes important in getting rid of the demolished concrete, which accumulates with time. For
example, the amounts of demolished buildings in Europe amount to around 180 million tons per year
(Limbachiya et al, 2004).

Concrete, masonry, tiles and bricks obtained from demolished buildings can be recycled and reused as
course or fine aggregate in new concrete. Since 1982 the ASTM definition of coarse aggregate has
included crushed hydraulic cement concrete, and the definition of manufactured sand includes crushed
concrete fines (ECCO, 1999). Similarly, the U.S. Army Corps of Engineers and the Federal Highway
Administration encourage the use of recycled concrete as aggregate in their specifications and guides
survey and research results in the field of the use of recycled aggregate, concrete and masonry and their
effect on maintaining the environment. Based on these references, the advantages of using recycled
building rubble can be summarized as follows:

A. Solving the problem of accumulation of rubble:
Demolished buildings end with tons of materials that need to be transferred and dumped. This of course
has an adverse effect on the environment and requires high amounts of money for transport and
dumping in special locations. Therefore, recycling these materials will be useful in maintaining the
environment in addition to economic considerations. This can be summarized as follows:

A.1. Environmental considerations.
Recycled rubble it is a resource efficient-minimizing depletion of natural resources. Rubble can be
recycled and used as aggregate in new concrete or as fill and pavement base material. Parekh et al,
2011 considered the use of RCA in concrete as an appropriate and “green” solution to the anticipated
increased world–wide construction activity.

A.2. Economic factors
Recycling rubble is an attractive option for governmental agencies and contractors alike because most
municipalities impose tight environmental controls over opening of new aggregate sources or new
dumping areas. By time, the increase of the cost of starting new quarries is increased and will be farther
away. Hence, the cost and transport distances of conventional aggregates could continue to increase as
sources becomes scarcer. Since landfill space is limited and can be far away, especially in urban areas,
the disposal of demolished rubble becomes costly and dumping fees will most likely rise as
construction debris increases and the number of accessible landfills decreases. Such situation was faced
in Hong Kong and recycling aggregate was an attractive solution (Fong et al, 2004).

A.3. Solving the problem of lack of materials
According to Kawakami et al, 2007, utilization of concrete that uses recycled aggregates as a
construction material is expected to contribute to solving the issue of lack of raw materials, and thus
would allow the construction of infrastructures using a circulatory system for resources. Such situation
was faced in Hong Kong and recycling aggregate was an attractive solution (Fong et al, 2004).

B. Other uses
While recycled demolished rubble is useful to be applied as many types of general bulk fill, bank
protection, sub-basement, road construction and embankments, processed recycled aggregate can be
applied to new concrete including lean and structural grade concrete, soil-cement pavement bases and
bituminous concrete (PCA, 2008). Moreover, it has been used to produce high strength concrete

Special studies on the use of recycled concrete aggregate in Jordan have been performed and proved
that it is possible to produce concrete of acceptable quality (Qasrawi et al, 2012 and 2013).

The use of RCA for the production of concrete involves breaking special types of demolished rubble
into materials with specified size and quality. These materials can then be combined to produce
aggregate of a pre-determined grading and hence can be used in concrete.

In this research the author investigates the use of some special recycled materials in normal concrete
mixes and studies the possible effects on the basic properties of concrete.

2. Recycled Materials

2.1. Recycled concrete aggregate (RCA)

Coarse RCA was obtained by crushing the previously tested samples in the lab into manageable lumps and then crushing these lumps in a Los Angeles abrasion machine. These particles were then washed, dried and sieved using the standard sieves for course aggregates. Any material passing sieve 5 mm (ASTM #4) was discarded. Later, the sieved particles were combined in order to obtain a gradation similar to that of the natural aggregates. By this, the possible effect of the change of gradation on the properties of concrete is minimized. The gradation of both natural and RCA aggregates are within ASTM C33 and BS 882 for grading requirements for coarse aggregate of nominal maximum size 20 mm to 5 mm. The sand used in all mixes was natural sand graded according to ASTM C33 standards. Both NA and RCA were tested for physical properties. The results are shown in Table 1.

Table 1–Physical properties of NA and RCA

<table>
<thead>
<tr>
<th>Property</th>
<th>Coarse Aggregate</th>
<th>Fine Aggregate</th>
<th>RCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity (SSD)</td>
<td>2.51</td>
<td>2.63</td>
<td>2.22</td>
</tr>
<tr>
<td>Water absorption</td>
<td>2.60</td>
<td>2.91</td>
<td>6.83</td>
</tr>
<tr>
<td>Rodded bulk density</td>
<td>1403 kg/m³</td>
<td>-</td>
<td>1290 kg/m³</td>
</tr>
<tr>
<td>LA abrasion (%)</td>
<td>26.7</td>
<td>-</td>
<td>32.7</td>
</tr>
<tr>
<td>ACV (%)</td>
<td>22.1</td>
<td>-</td>
<td>29.6</td>
</tr>
</tbody>
</table>

Special concrete mixes were prepared in the lab and tested for workability and strength. All mixes have w/c ratio of 0.50 and cement content of 400kg/m³. The results are shown in Figures 1 and 2.

Fig. 2 shows the relationship between the slump and the replacement ratio. It is clear that the use of RCA resulted in reduction in the workability of concrete. The higher the replacement ratio, the lower the workability is. However, the workability can be enhanced by the use of plasticizers. Medium workability concrete (80-120mm) can be attained by using RCA to NA replacement ratio not exceeding 40%. However, when superplasticizers were used, these values could be obtained for RCA/NA of up to 75%.

Fig. 3 shows the relationship between the strength of concrete cubes and the replacement ratio. It is clear that the use of RCA resulted in reduction in the strength of concrete. The higher the replacement ratio, the lower the strength is.
ratio, the lower the strength is. However, the strength can be enhanced by the use of plasticizers. The reduction of strength for mixes containing 25% RCA resulted in less than 10% reduction in strength. Full replacement of NA by RCA can result in reduction of strength of about 35%.

![Graph showing the relationship between RCA replacement ratio and strength](image)

Fig. 3: Relationship between RCA replacement ratio and strength

2.2. Recycled hollow concrete bricks and tiles
Hollow concrete bricks and tiles obtained from wall and slabs can be recycled and reused in the construction of buildings as recycled fine material (RFM). In this research, the bricks were crushed to fine material in order to obtain fine aggregate which can replace natural sand (as shown in Fig.4).

![Image of concrete bricks crushed to form RFA](image)

Fig. 4: Concrete bricks crushed to form RFA

The material was crushed and then sieved on sieve #8 (2.4mm) in order to simulate the natural sand available in the lab. The fine material was first sieved using standard sieves. Later the sieved material was mixed in predetermined proportions to obtain a grading similar to the natural sand. Compared to natural sand, RFA has higher specific gravity (2.88 c.f. 2.63) and much higher absorption (12.1% c.f. 2.91). Special mortar mixes were prepared using a w/c ratio of 0.60. The sand in the mixes was partly replaced by RFA. The consistency of the mixes was measured using Vicat apparatus according to ASTM C. 50-mm cubes were prepared and tested for strength using ASTM C. The results show that replacement ratio exceeding 25% was impractical. It has zero consistency and was difficult to work
The use of superplasticizers enhanced the consistency but it was still difficult to attain practical consistency for replacement ratios exceeding 50%. This was attributed to high absorption of RCA.

Regarding strength, the 50mm-cubes made with RFA showed that the strength can be attained. Increase of up to 15% in compressive strength was recorded at the age of 28 days. Fig. 5 shows a mortar cube made using RFA. The cube is split into two halves to investigate internal weakness. No abnormality was observed.

![Fig. 5: A mortar cube made from RFA](image)

### 2.3. Recycled stones
Stones can be recycled and reused in two ways:

A. Unbroken stones can be taken from demolished walls by sawing between connecting mortar joints. The back of the stone can be cleaned using special equipment. Once ready, the stones can be used in the reconstruction of non-bearing walls.

B. Broken stones can be crushed using a crusher to obtain RCA. In this case, the RCA will have properties close to the natural aggregate obtained from the rook. The presence of some concrete in contact with some particles is not a problem. They are similar to RCA.

### 2.4. Recycled marble
Marble can be broken into crumbs and then can be recycled in the production of terrazzo tiles.

### 2.5. Recycled terrazzo tiles
Terrazzo tiles can be recycled and reused in nonstructural concrete. Tiles with mortar adhering to them can be crushed to small sizes and the reused as concrete aggregate (recycled terrazzo tiles aggregate-RTTA). In trying to recycle terrazzo tiles in the lab, tiles were broken into small pieces using LA machine. They were crushed to simulate coarse aggregate. The particles had sharp edges. Concrete mixes made with natural aggregate and some crushed terrazzo tiles were made in the lab. 15% and 30% of NA was replaced by RTTA. There was a great loss in the workability. NA mixes showed a slump of 80mm. The slump was 12mm for the 15% replacement and zero for the 30% replacement. Introducing plasticizers was not effective or economical in solving the problem. However, the use of superplasticizers increased the workability of concrete to an acceptable limit. However, the presence of RTTA in concrete ended with concrete of high air content (7 to 9% c.f 2% for NC). Hence a high loss of strength is expected. When tested in V.B. consistometer, the V.B. time exceeded 15 seconds indicating high difficulty in compaction. Therefore, it was concluded that to be safe under site conditions, RTTA is recommended for nonstructural concrete.

### 2.6. Recycling steel reinforcement
Steel reinforcement is taken off from concrete before crushing to the required sizes. This steel can be sent for recycling in the steel industry.

### 2.7. Recycling other materials
Other rubble can be recycled into useful material. Glass can be recycled and can be also used in terrazzo tiles. Aluminum can directly be transferred to special factories and recycled. Wood can also be
recycled and reused in the reconstruction or in the manufacture of furniture. Any material that cannot be recycled and reused in the construction, can be used in the reconstruction of roads and yards.

3. Conclusions and recommendations

Based on the research and the results obtained from this study, the following can be concluded:

1. Various types of rubble can be recycled and hence can be reused successfully in the reconstruction of demolished buildings.
2. Structural and nonstructural concrete can be constructed using RCA. RCA can provide the following benefits:
   a. They preserve the environment.
   b. They reduce the cost of both transferring rubble to dumping areas and also the costs of bringing new materials.
3. The use of RCA reduces the workability of concrete. Therefore, it is recommended to use admixtures in the concrete mixes.
4. The use of RCA reduces the strength of concrete especially for high amounts of replacements. Therefore, it is recommended that the design engineer takes this issue into consideration when preparing his designs.
5. For best results of structural concrete, it is recommended to combine RCA with NA in a predetermined ratio. However, any ratio can be used for nonstructural concrete.
6. The use of RFA from bricks and tiles is beneficial in preparing mortars that can be used for reconstruction of walls and tiles. It can also be used in plastering. Admixtures are required to preserve workability.
7. It is not advised to use RTTA in structural concrete. However, it can be used for nonstructural elements.
8. Stones can be recycled and reused as facades or as aggregate for concrete.
9. Steel bars can be recycled and reused for reinforcement of reconstructed buildings.
10. Many of the materials can be recycled at site eliminating transport costs.

References

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