Feasibility of waste concrete as recycled aggregates in construction

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Abstract

Recycled concrete has been gaining an increasing interest worldwide due to a multitude of environmental, economic and energy considerations. Among the key environmental concerns are depletion of natural sources of good quality aggregate materials, limited availability of landfills for the dumping of demolished construction waste and possible contamination of groundwater that results from washing out fresh concrete returned from job sites. When properly implemented, concrete incorporating recycled constituents can carry economic advantages and may result in considerable energy savings. Previous work has shown that recycled concrete can yield technical properties, which are comparable to concrete made with conventional materials. In fact, the authors – among other investigators- have strong indications that recycled concrete can yield superior quality in some aspects such as flexural strength, concrete durability and fire resistance. Yet, questions are still raised by contractors and applicators with respect to the acceptance and implementation of this composite as well as its overall feasibility in construction projects. This paper presents and overview of recycled concrete properties with alternatives for its preparation and handling. The data herein is acquired from selected international sources together with sample results from an ongoing experimental program jointly performed in the USA and Egypt. Parameters that govern the feasibility of using recycled concrete are highlighted and discussed. Obstacles encountered that can hinder its use are also stated with some suggested actions to be taken.
1 Introduction

Portland cement concrete is a composite material that is made of four prime ingredients: Portland cement, water, fine aggregates and coarse aggregates. Over more than a century, sand, gravel, crushed rocks have been quarried as the most commonly incorporated concrete aggregates. Due to depletion of good quality virgin aggregates together with the increasing awareness and consideration of environmental impact and empowered legislation, the use of recycling aggregate concrete has been promoted in various parts of the world. In general, recycled concrete is prepared by one of two approaches. In the first, conventional coarse aggregates are replaced by recycled concrete aggregates resulting from the crushing of “old concrete” while in the second both coarse and fine aggregates are replaced by recycled concrete aggregates.

Considering the massive volume of concrete works worldwide which is simply reflected by approximately six billion concrete cubic meters produced in the year 2000, concerns are always raised with respect to concrete properties, its life cycle and disposal. Among these concerns is the fact that quarries of good quality aggregates are depleting in various regions worldwide. Due to urbanization, quarries often lie further away from job sites within the center of business districts thus adding transportation costs to project matrix. Moreover, demolished concrete structures represent a burden to both the contractor and community since disposal requires large areas that shortens the life of landfills. When fresh concrete is rejected in a job site for one reason or another, washing out often takes place to separate aggregate from cement slurry to prevent the concrete hardening. When discharged, the cement slurry contributes to sewage problems and may result in significant contamination of groundwater [1, 2].

Environmental legislations worldwide, particularly in the western hemisphere, are becoming steadily stringent so as not to eliminate disposal abuse and promote healthier treatment of solid waste. For instance, countries like the Netherlands place a considerable tax on both the use of landfills and mining in one hand and introduce incentives for adequate use of recycled materials on the other. In its definition of concrete aggregates, the American Society for Testing and Materials ASTM C 33 “Standard Specifications for Coarse Aggregates” included crushed hydraulic cement concrete among the types of concrete aggregates used, thus opening the door for its use in construction applications [3]. In terms of implementation, the State Highway Agencies in Connecticut, Kansas, Minnesota, Wisconsin and Wyoming have successfully constructed rigid pavements containing recycled concrete aggregate. As of today, major sectors of the Interstate Highway I-70 have been constructed using recycled materials [4]. Also, countries like Japan and Scandinavian nations have all sound provisions in their codes of practice to regulate the use of recycled aggregates in concrete works.

Recycled aggregates can be obtained from two major sources: demolished structures and pavements as well as concrete returned from job sites to the originating mixing plant. Nevertheless, impurities and foreign inclusions are usually present within concrete in the form of steel, tiles, wood, bricks, etc.
Removal of these inclusions helps in achieving better quality of produced concrete and more consistent performance. For example, magnets are used for separating steel pieces from concrete debris, which in themselves can represent some value for contractors as scrap iron. A number of processes are possible for crushing and sieving of recycled aggregates including manual tools, mobile diesel hammers, wrecking tools and hydraulic shears together with stationary plants. Recently, resonant breakers and advanced mobile hammers have been introduced [5].

2 Technical characteristics

Due to concrete complexity, qualitative and quantitative aspects of recycled ingredients and the presence of wide arrays of parameters, it is not easy to state a set of properties and characteristics that applies to all types of recycled concrete. However, the following is an overview of the recycled concrete technical characteristics in its fresh, hardened and long-term state [5, 6].

2.1 Fresh concrete

Fresh recycled concrete is characterized by the following key aspects:

- The unit weight of recycled concrete is slightly less (about 5 to 10%) than conventional concrete. As such, its units weight usually falls in the range between 2100 and 2250 kg/m³.
- It is perhaps more difficult to control air content in recycled concrete, however, such concrete often yields about 1% higher air content than conventional concrete.
- Due to a sharp irregular shape and rough surface of recycled aggregates, recycled concrete yields inferior workability and a higher water requirement when a specific workability/consistency is targeted.
- Work supervised by the authors reveals that recycled concrete exhibits less workability and consistency retention than conventional concrete which needs to be considered when transporting concrete for relatively long durations. Figure 1 reflects an increased drop in both slump and slump retention as the recycled aggregates content increases. This is particularly the case for concrete incorporating fine and coarse recycled aggregates.

2.2 Hardened concrete

The hardened recycled concrete is characterized by the following properties [5, 6, 7]:

- Absorption of recycled concrete is 1 to 2% higher than conjugate concrete made with virgin aggregates.
- When properly prepared and proportioned, recycled concrete can yield compressive strength that is comparable with conventional concrete. Figure 2 shows sample results of concrete made with conventional and recycled
materials in which recycled concrete exhibited comparable results. In fact, Figure 2 shows that the strength gap between the two types narrows as concrete matures in age beyond 7 days.

- The tensile strength of recycled concrete is similar to that of conventional concrete. Since the compressive strength of recycled concrete is somewhat less than that of conventional concrete, the tensile-to-compressive strength ratio is relatively higher for recycled concrete.
- Young's Modulus of recycled concrete is less than that of conventional concrete. The estimated drop was reported not to exceed 40% [6].
- Work performed by the authors in the University of Kansas indicates that the bond between reinforcing steel and concrete can be even superior to what is encountered in case of conventional concrete.
- Flexural fatigue of recycled concrete was reported to be superior than conventional concrete and that was mainly attributed to a stronger bond between cement paste and recycled aggregates.

2.3 Long-term properties

Similar to other innovative materials and trends having a relatively short history of application, long term properties and durability represent major concerns. In this regard, the following long-term trends can be stated:

- As a result of the absence of strong virgin aggregates, abrasion resistance of recycled concrete is inferior to that of conventional concrete, which limits its use in applications involving wear and heavy frictional loads.
- In the presence of aggressive chemicals, work conducted by the authors reveals that such concrete can truly exhibit superior performance in the presence of wide spectrum of chemicals. In fact, some preliminary results suggest enhanced resistance for recycled concrete when subjected to sulfuric acid, which is often present in sewage applications.
- In terms of performance in freezing and thawing conditions, highway segments -among other examples- have shown satisfactory performance for concrete after more than 10-15 years of service [8].
- Little data is available for creep of recycled concrete. However, it was reported that due to the larger content of mortar, creep of recycled concrete could be up to 50% higher than that of conventional concrete.
- Due to higher internal voids and enhanced bond, recycled concrete was reported to have a somewhat enhanced performance in fire and elevated temperatures [6].
Figure 1: Slump and Slump retention of conventional and recycled concrete.

Figure 2: Compressive strength of conventional and recycled concrete.
3 Economic feasibility parameters

The feasibility of recycled concrete is directly related to its technical properties and long term performance. Its economic feasibility is determined in the light of a complexity of parameters, which are summarized in this section.

3.1 Availability

The annual amount of recycled aggregates from demolished structures is estimated as 2% of total volume of existing concrete. Needless to say, regions of natural disasters or conflict can have higher percentage of recycled concrete utilization than this. In addition, the estimated amount of rejected fresh concrete produced can be as high as 3%. The latter is advantageous since it includes minimal amount of contaminants and debris. Table 1 provides an estimate for the amount of building and road demolition waste in various countries with a mention of its use as recycled material [9, 10].

Table 1. Estimated building and road demolition waste and its use.

<table>
<thead>
<tr>
<th>Country</th>
<th>Estimated annual quantity ($10^6$ tons)</th>
<th>Percent recycled</th>
<th>Major applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>1.2</td>
<td>81%</td>
<td>Concrete &amp; paving, subbase</td>
</tr>
<tr>
<td>Egypt</td>
<td>4.0-6.0</td>
<td>10-15%</td>
<td>Mainly fill materials</td>
</tr>
<tr>
<td>France</td>
<td>5.0</td>
<td>N/A</td>
<td>Wearing &amp; base courses</td>
</tr>
<tr>
<td>Germany</td>
<td>30-42</td>
<td>40-50%</td>
<td>Bases, barriers, backfilling</td>
</tr>
<tr>
<td>Netherlands</td>
<td>9.2</td>
<td>85%</td>
<td>Base course &amp; concrete</td>
</tr>
<tr>
<td>Sweden</td>
<td>1.5-2.0</td>
<td>small percent</td>
<td>Fill material &amp; subbase</td>
</tr>
<tr>
<td>USA</td>
<td>70-90</td>
<td>N/A</td>
<td>Lean concrete, fill, pavement</td>
</tr>
</tbody>
</table>

It is often the case that the recycled materials are available at no cost on its initial demolition location for example. In fact, it is customary that its removal from site is against payment.

3.2 Crushing and impurities

The type, efficiency and capacity of crushers have a direct influence on the overall feasibility. Crushers can vary from stationary crushers of large capacity to mobile crushers that produce quantities as little as few tons per hour. The latter clearly suits small jobs and jobs characterized by high mobility.

The overall efficiency of the crushing process is to be coupled with proper separation and handling of impurities present in demolished concrete. This matter can become a cumbersome one particularly for residential building
demolition containing various types of rubble unless some system is established for separation and sorting. However, four factors need to be well considered in this regard:

- Skilled labor is indispensable in the handling and sorting of waste materials
- Steel can be separated from the gross demolition through magnets.
- Concrete returned from jobs has almost no impurities since it had not yet been placed with other ingredients.
- It may be feasible to use demolition waste with a high degree of impurities in lean concrete or as a fill material.

3.3 Transportation

The feasibility of the recycled concrete is highly influenced by transportation costs. Transportation costs herein is threefold. First, the cost of transporting demolished concrete to job site. Secondly, the transportation cost of virgin raw alternative aggregates. Thirdly, the cost of transporting demolished concrete to landfill dumping site (if applicable to contractor). In road construction, transportation cost can be the decisive factor. This is also the case for projects within centers of urban zones where transportation and access to sites is not easy and thus site-available demolished aggregates is highly considered.

3.4 Incentive and disincentive policy intervention

It is the practice in many countries that incentive/disincentive policy is implemented, which ultimately leads to encouraging the use of waste materials in various applications. The practices followed in this regard can be summarized as follows [9]:

A. Placing a tax for the use of raw materials. For example, in Denmark, a tax of about $0.70 is imposed on each 1 cubic meter of mining.

B. Enforcing a tax on the use of landfills for dumping wastes. This tax is within the range of $9 and $36 per ton in Germany and Denmark, respectively. Higher taxes are imposed for hazardous waste.

C. Subsidizing and facilitating the establishment of recycling plants in appropriate locations; particularly in urban regions for preparing aggregates.

D. Encouraging unions, federations and private sector to promote recycling as concept. A good example is the German Industry Association for Recycling established in 1983. This association works with end users to improve recycling aspects and minimize environmental hazardous effects.

3.5 Codes of practice

Codes of practice are integral part of the construction industry without which a widespread use of recycled materials. Codes for the use of recycled aggregates have been developed in Japan, Scandinavian countries, Germany and The Netherlands, to name only some. On the other hand, many developed as well as developing nations such as the US and Egypt have not yet developed
comprehensive codes for recycled concrete. Such codes can be more effective when accompanied with adequate testing methods and quality control schemes. This is imperative since traditional test methods may not fulfill quality control expectations as in the case for conventional concrete. Some investigators go as far as developing new testing methods for recycled concrete [6, 9].

3.6 Cost of alternative aggregates

As expected, feasibility is influenced in the first place by costs of adequate alternatives. For that reason, contractors in many countries are not encouraged to use recycled materials when virgin aggregate is available at low cost particularly in the absence of taxes on mining or on landfill use. It should be noted that regions having aggregates possessing detrimental properties such as those exhibiting alkali-aggregate reactions are strongly encouraged to consider recycled materials as good alternative to poor quality virgin aggregates.

3.7 Know-how and skilled labor

Proportioning of recycled concrete constituents in mixtures is not the same as in conventional concrete since it often subjected to qualitative and quantitative adjustment in the light of recycled materials used. For instance, cement content and water-to-cement ratios have different implications in recycled concrete. Perhaps more importantly, due to its harsh consistency, skilled labor is even needed for mixing, transporting and placement of recycled concrete and to carry out a meaningful quality control program. The authors have experienced variations of up to 45% in compressive strength of recycled concrete cubes due primarily to human factor only.

4 Challenges

The use of recycled concrete and its widespread faces several challenges, which exist at various degrees in the different parts of the world. Major challenges can be summarized as follows:
A. Although good practices exist for recycled concrete applications, yet, efforts appear more as good initiatives, which requires further harmonization and coordination. The development of common recycling strategy is needed at least on a regional level.
B. As codes of practices are available in many countries, testing methods and implementation practices and awareness guides need to be developed in parallel and made available to end-users.
C. It is the authors' observation that, on the whole, most of recycled concrete users are contractors handling large jobs while small and medium size contractors shy away from tackling it. Hence, consultants, federations and vocational chambers need to better target that cluster of applicators towards better utilizing the material in day-to-day jobs.
D. There still a strong need for research works in this regard particularly those investigating long term properties and performance criteria.

E. The use of recycled concrete in sophisticated structures and high performance concrete has not been extensively explored. Therefore, it is wiser to initiate its use in the first place in landfills, lean concrete and non-load bearing elements.

F. Economic indicators have to be developed on a regional basis to provide some assessment towards feasibility. Policy intervention in terms of taxation and fees for landfills can be considered when needed.

5 Concluding remarks

In the light of the parameters associated with recycled concrete, the following concluding remarks can be stated:

- Recycled concrete can be successfully produced either by replacing conventional coarse aggregates or the entire aggregates by demolished concrete. Concrete for recycling is either available from demolished structures or from concrete rejected from job sites.

- From a technical point of view, recycled concrete yields comparable properties to that of conventional concrete. In fact, recycled concrete can exhibit superior properties to those of conventional concrete, such as its resistance to some chemicals. Good records of recycled concrete projects reflect adequate performance over more than 10 years time span.

- Several nations have developed codes of practice and promoted recycled waste use through incentive and disincentive interventions. Financial support and cost sharing of crushing and recycling plants has been considered by governments.

- Economic feasibility is influenced by multiple parameters that includes availability, transportation, crushing and handling criteria as well as positive government intervention.

- The feasibility of recycled materials is strengthened for projects located in central urban zones and in areas where remote or inadequate aggregates are prevailing.

- The need arises for the development of well-defined strategy of recycled concrete and integrate its codes with adequate test methods and sound quality control measures.

- Recycled concrete research works should be further encouraged, particularly those targeting long term properties and performance criteria.

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References


