Construction and Demolition Waste used as Recycled Aggregates in Concrete: Solutions for Increasing the Marketability of Recycled Aggregate Concrete

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Abstract

The use of crushed construction and demolition waste as a recycled aggregate in the production of new concrete has been successfully demonstrated by researchers as well as by practitioners in the field. Despite presenting suitable performance, the acceptance and utilization of recycled aggregate concrete (RAC) has not become widespread. In expanding urban areas, the intensive construction of new infrastructure, as well as rehabilitation and retrofitting of existing infrastructure, opens many potential markets for RAC produced in various grades, including non-structural hardscaping, pavements and even structural applications.

The goal of this study was to show that use of recycled aggregates in concrete is both economically viable and technically feasible. In order to elucidate the inhibiting factors, the supply and demand for recycled aggregates were studied in a growing southeastern metropolitan area. The additional effort required for source separation and other quality assurance practices was analyzed to understand the costs associated with producing concrete-grade recycled aggregates. Recycled aggregates obtained during a case study in Charlotte, North Carolina were characterized in the laboratory and successfully used in several types of concrete.

A series of applications for RAC were identified and local concrete suppliers were surveyed regarding their comfort levels with these uses. Incentives encouraging the production of RAC were considered from the perspective of demolition contractors, concrete suppliers and developers. The results of the case study and survey were used to determine the feasibility of developing a more diverse market for recycled aggregates by suggesting an appropriate palette of RAC products.
Introduction

The potential for demolition wastes to be used in the production of new concrete products has been thoroughly studied in academic settings and successfully demonstrated in the field via test cases. In rapidly growing metropolitan areas that host a robust combination of demolition activities and new construction projects, symbiotic relationships can exist between wrecking companies and materials producers with proper coordination and infrastructure. Products ranging from pavements to structural beams have been made with concrete containing recycled aggregates (RA). In addition to economic benefits, the use of RA in all capacities lightens the burden of demolition waste handling on municipalities that operate landfills.

Despite research that indicates promising economic, waste management, and engineering potential, actual use of RA in concrete applications in Mecklenburg County, NC is relatively nonexistent. Some reasons for the minimal usage of RA in concrete applications may be related to physical performance issues. Others are linked to regulatory or industry hurdles that could be cleared by decision-makers. The objective of UNC Charlotte researchers investigating the use of recycled aggregates in Mecklenburg County was to identify the feasibility of developing a substantial supply of concrete-grade RA as well as identifying a range of potential concrete products that could potentially incorporate the RA. This investigation, sponsored by the United States Department of Energy, was accomplished in several steps, including:

1. Literature review – Background information about the use of RA in Portland cement concrete was gleaned from journals, manuals and specifications
2. Case study – A demolition project was observed in Mecklenburg County and demolished building material was collected for further study
3. Aggregate characterization – The case study aggregates, created by separately crushing concrete slab and brick masonry rubble were characterized in the UNC Charlotte laboratories
4. Concrete preparation – Specimens of concrete were prepared using recycled brick aggregate and recycled concrete aggregate
5. Industry interviews – Industry representatives from demolition contractors, aggregate producers, and concrete producers were interviewed regarding their policies, experience and attitudes towards recycled aggregate production and use

Background

Recycled aggregates are composed of the rubble from the demolition of buildings roads, and other sources such as returned concrete. Although unlicensed landfills are known to be one destination for the demolition waste, the remainder arrives at either municipal or private facilities that have the capacity to crush the material into either graded or ungraded material (Elias-Ozkun 2001). In some locales, such as parts of Europe, the scarcity of both landfill space and quarry space create an impetus for the rubble to be reused for various construction purposes (Oikonomou 2005). Builders
purchase the bulk of the rubble for low-grade uses such as fill and surfacing material for temporary roads. However, there is some precedent for use as aggregates in Portland cement concrete (PCC) that could provide economic benefits to material producers (Tam 2008). In addition to demolition waste sources, RA can also be composed of excess concrete materials returned to the plant. This material is often referred to specifically as returned concrete aggregate (RCA).

The suitability of RA for concrete applications has been investigated by many. In general, concrete containing some proportion of RA has been found to have slightly diminished mechanical properties in comparison to material incorporating purely virgin aggregates. Tupcu and Sengel (2004) created concrete specimens with target strengths of 16 MPa and 20 MPa and then replaced virgin aggregates with recycled aggregates at the rate of 30, 50, 70 and 100%. It was found that the compressive strength decreased at a rate proportional to the addition of recycled aggregates. Tu et al. (2006) explored the use of recycled aggregates in high performance concrete (HPC). The research group tested concretes in strength ranges suitable for structural applications (20–40 MPa) that had been created with either recycled coarse or recycled coarse and fine aggregates. It was determined that a strength reduction of 20-30% could be expected due to aggregate replacement. Overall, the consequence of replacing virgin aggregates with RA has resulted in 10-30% reductions in compressive strength, with the least impact being found in mixes that only include recycled coarse aggregates (Ajdukiewicz and Kliszczewicz 2002; Chen et al. 2003; Topçu and Günçan 1995; Topçu and Sengel 2004; Tu et al. 2006; Xiao et al. 2005).

Work completed by Xaio and Zhang (2005) determined that RA concrete elastic properties are significantly impacted by the proportion of recycled material included in the mix. As RA was added in increments from 0% to 100% of the coarse aggregate, the elastic modulus decreased by 40% at the upper replacement levels. At the same replacement increments, the peak strain increased by 20% during uniaxial compression testing of concrete cylinders.

Using recycled fine aggregates has been shown to have additional implications pertaining to the proportioning and control of concrete mixes. Evangelista and de Brito (2007) added crushed fine aggregate to concrete mixtures and found declining performance in terms of elastic modulus, tensile strength and abrasion resistance. Compressive strength was not significantly impacted and the authors speculated that the fines contribute both hydrated and unhydrated cement to the mix and thereby improved compressive strength. A study performed by the Texas Transportation Institute (Lim et al. 2001) confirmed the negative impact of recycled concrete fines on the workability and water demand of concrete mixes containing them. However, the same report identified applications for the recycled fines that take advantage of their residual cementitious action to enhance the performance of virgin aggregate materials. Such applications included subbase and bondbreaking courses.

Research on scaled structural elements prepared with RA has confirmed the suitability of the recycled material to function in load-bearing applications. Etxeberria et al. (2007) manufactured reinforced concrete beams with varying percentages of RA. The researchers found negligible impacts on beam performance when up to 25% of the virgin aggregates were replaced. In beam designs with less-than-required transverse reinforcement, the shear capacity of concrete made with 50% and 100% recycled
aggregates was significantly reduced compared to similarly reinforced beams having only virgin aggregates. However, when the quantity of steel required by EuroCode was included, the beams with all quantities of RA achieved their code-predicted ultimate shear strength.

**Guidance Regarding the Use of Recycled Aggregates in Concrete**

The challenges to maintaining stringent mechanical performance standards while using RA in concrete mixes have been overcome by adapting either the batching process or reducing the proportion of recycled material. Tam et al. (2005) have adapted the mixing process into two stages— the first to coat the aggregate in a rich cement slurry, and the second to complete the addition of mixing water. The authors found that this technique filled microcracks along the interfacial transition zone and also allowed fresh paste to reach the surface of the mineral aggregate. The American Concrete Pavement Association reports that the problem of high water absorption capacity in RA has been addressed by simple techniques such as presoaking aggregates prior to batching (American Concrete Pavement Association 2009).

State departments of transportation as well as national level agencies, such as the National Cooperative Highway Research Program (NCHRP), National Ready Mix Concrete Association (NRMCA), the American Concrete Pavement Association (ACPA) and the Federal Highway Administration (FHWA) have produced guidance on the implementation of projects that permit or encourage recycled concrete aggregates in new PCC applications.

Control of concrete quality when RA is used is achieved via several strategies that are given in state department of transportation materials specifications or in the guidance published by the previously listed agencies. These strategies include the following major themes:

1) Limitation of the quantity of RA in the concrete
2) Preparation and handling guidelines
3) Limits to the source of acceptable materials
4) Restrictions on the type of elements permitted to contain RA
5) Characterization requirements

Table 1 provides a sampling of the specifications and recommendations given by various groups. Perhaps the most conservative risk reduction technique for specifying RA concrete products is to limit the type or allowable proportion of recycled material in the mix design. For instance, TXDOT permits a maximum of 20% recycled fine aggregate in certain non-structural concrete elements (Texas Department of Transportation 2004). A strategy introduced in Europe encourages the segregation of incoming material by source or quality so as to maintain stockpiles of rubble having known origins and quality. The MDOT specification only permits RA that was collected from MDOT demolition projects. In this way, the source material is known to have met Michigan quality standards when it was originally created (Michigan Department of Transportation 2003). The NRMCA has proposed similar recommendations for returned concrete aggregates— suggesting that they be divided by the original grade of concrete in the returning truck (Obla et al. 2007).
<table>
<thead>
<tr>
<th>Topic</th>
<th>MDOT</th>
<th>TXDOT</th>
<th>FHWA</th>
<th>NRMCA</th>
<th>ACPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limitation of the quantity of RA in the concrete</td>
<td>None given</td>
<td>Recycled fine aggregate limited to 20%</td>
<td>Recycled fine aggregate limited to 10-20%</td>
<td>10% for general source RA, 30% for returned material &gt; than 21 MPa</td>
<td>10%-20% limit on recycled fine aggregate</td>
</tr>
<tr>
<td>Preparation and handling guidelines</td>
<td>Must maintain separate stockpiles to avoid non MDOT source material</td>
<td>None given</td>
<td>Sprinkle stockpiles to keep aggregates saturated; store separately from other materials</td>
<td>Separate incoming material according to quality; maintain SSD conditions with sprinklers</td>
<td>None given</td>
</tr>
<tr>
<td>Limitation to the source of acceptable materials</td>
<td>MDOT concrete</td>
<td>None given</td>
<td>None proposed</td>
<td>Higher-quality returned material</td>
<td>None given</td>
</tr>
<tr>
<td>Restrictions on the type of elements permitted to contain RA</td>
<td>Curb and gutter, valley gutter, sidewalks, barriers, driveways, temporary pavements, ramps with commercial ADT 250, shoulders</td>
<td>Inlets, manholes, gutters, curbs, retards, sidewalks, driveways, backup walls, anchors, riprap, small signs, pavements (all of these applications require &lt;21 MPa concrete)</td>
<td>Recommendations only relate to pavements</td>
<td>Structural elements should contain less than 10%, non-structural applications up to 30%</td>
<td>Recommendations only relate to pavements</td>
</tr>
<tr>
<td>Characterization requirements</td>
<td>Project by project freeze-thaw characterization</td>
<td>None given</td>
<td>Check for deleterious materials such as chloride, sulfate</td>
<td>Weekly verification of absorption and specific gravity</td>
<td>Perform freeze-thaw evaluation on materials exhibiting D-cracking or containing fly ash</td>
</tr>
</tbody>
</table>

(American Concrete Pavement Association 2009; Federal Highway Administration 2008; Michigan Department of Transportation 2003; Obla et al. 2007; Texas Department of Transportation 2004)
Prior to the economic down turn, concrete and other hardscape rubble comprised 8% of the construction and demolition waste produced in Mecklenburg County, North Carolina. In 2005, this equaled more than 28,000 tonnes (Mecklenburg County Land Use and Environmental Services Agency 2006). Interviews with local municipal solid waste personnel have indicated that the down-turn in demolition projects within the county have reduced the intake of rubble materials at the landfill to levels that are not sufficient to meet onsite demand. Operational needs for these materials include low-grade uses such as temporary roads for earthmoving equipment and trucks that require access to unpaved areas of the landfill.

An effort to study the collection and use of RA in Mecklenburg County, NC for concrete applications included three components 1) a case study of a demolition project in which source separation and analysis of rubble for use as aggregate was performed, 2) an interview with a demolition company that operates an aggregate production yard, and 3) interviews with concrete producers regarding the potential to include greater quantities of RA, including RA produced from construction and demolition waste, in existing concrete products.

Case Study – Idlewild Elementary School, Charlotte, North Carolina

UNC Charlotte researchers observed the demolition of an elementary school facility in order to study the physical processes included in the tear-down as well as the decision making process for the disposal or the recycling methods applied to the demolished materials. The construction of the school was typical for a wide range of commercial and institutional buildings at the time. Therefore, the information presented here regarding the demolition process should be relevant to many of the buildings in the local inventory. Walls were reinforced and unreinforced masonry, the roof was a combination of prestressed concrete double-tees and steel framing, and the floor system was a concrete slab-on-grade. The demolition process was found to be very orderly and included many techniques that simplified the separation of materials such that contamination of the rubble destined for the crusher was minimized. General steps followed in the demolition (in sequential order) were:

1) Removal of hazardous materials such as asbestos
2) Removal of valuable metals such as copper and non-critical steel structures (such as awnings)
3) Demolition of non-masonry partition walls, drop ceilings, and fenestration
4) Collection and disposal of materials listed in #3
5) Demolition and removal of roof framing, decking and covering
6) Demolition and removal of masonry partition walls
7) Demolition and removal of the concrete slab

The demolition strategy used in the case of the elementary school is referred to as “top-down.” The non-rubble generating materials such as gypsum wall board, wood finishings, fixtures, and the like are removed first. Secondly, the masonry materials that
constitute the walls are crushed and removed separately. Third, the concrete floor slab is crushed and hauled off-site. While the top-down process may not be used for smaller projects in which separation of wastes is not economical, it is a practical technique for mid to large scale demolition work and also lends itself to source separation. The concrete slab was used as a sorting pad for demolished materials before they were hauled to the crusher, landfill, steel recycling facility or other location. In addition to providing a surface for the loading equipment drive on, the concrete slab could be cleared between phases to prevent the introduction of foreign materials such as cellulose, plastics and metals into the rubble for RA. UNC Charlotte researchers found that segregating the rubble materials before they were crushed helped improve the quality and predictability of the RA.

Prior to the commencement of demolition, 6.4 cm diameter core specimens were removed from the section of slab that would be crushed to produce aggregate. A portable coring drill was used to obtain the samples. A total of seven core samples were removed from three locations in the slab. Of these, due to the relatively shallow thickness of the slab-on-grade, five core samples were found to be suitable for compression testing. The ends of the cylinders were trimmed with a wet diamond saw and the specimens were tested to failure in a universal testing machine. The results of these compression tests are given in Table 2. Due to the location of the reinforcing mesh and the slab thickness, the length to diameter ratios of the trimmed cylinders were typically less than two. The compressive strength was discounted as recommended by ASTM C42 (ASTM 2004). The average adjusted compressive strength was found to be 47 MPa. This indicates that the aggregates should be suitable for concrete products in the range of 34-48 MPa.

### Table 2. Compressive strength of cores removed from the slab

<table>
<thead>
<tr>
<th>Specimen</th>
<th>L/D</th>
<th>Reduction Factor</th>
<th>$f'_c$ [MPa]</th>
<th>Adjusted $f'_c$ [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1</td>
<td>0.90</td>
<td>51.1</td>
<td>46.0</td>
</tr>
<tr>
<td>2</td>
<td>1.3</td>
<td>0.94</td>
<td>44.1</td>
<td>41.6</td>
</tr>
<tr>
<td>3</td>
<td>1.2</td>
<td>0.92</td>
<td>58.8</td>
<td>53.9</td>
</tr>
<tr>
<td>4</td>
<td>1.2</td>
<td>0.93</td>
<td>54.7</td>
<td>50.8</td>
</tr>
<tr>
<td>5</td>
<td>2.0</td>
<td>1.00</td>
<td>44.6</td>
<td>44.5</td>
</tr>
</tbody>
</table>

In addition to collecting compressive strength information from core specimens, Schmidt Hammer readings were taken from the slab in proximity to the location of the core specimens. The procedure is outlined in ASTM C805 (ASTM 2008). No clear correlation was found between the rebound hardness measured in situ and the compressive strength of the core specimens determined in the lab.

Whole clay brick and clay tile were also obtained from the demolition rubble in order to determine properties in accordance with ASTM C67 (ASTM 2009). Tests to determine the compressive strength, modulus of rupture, absorption, and initial suction of the materials were performed. Additional testing that is planned but not completed to date is freeze-thaw durability testing on the whole clay brick and clay tile specimens.
The average compressive strength of the clay brick was found to be 67.2 MPa, and the average compressive strength of the clay tile was found to be 81.4 MPa.

Concrete slab-on-grade and brick masonry rubble materials from the demolition case study were separated on-site, transported, and then crushed at the demolition contractor’s aggregate production facility. Two types of recycled aggregates were produced from the material generated at the case study site: recycled concrete aggregate and recycled brick masonry aggregate. Once crushed, these aggregates were taken to UNC Charlotte for study. The crushed aggregate was characterized in terms of gradation, bulk density and absorption capacity. Sieve analyses of the two types of recycled aggregates is presented in Table 3. Table 4 summarizes other characteristics of the recycled aggregates.

Table 3. Gradation of RA and Recycled Brick Masonry Aggregates Produced from Idlewild Elementary School Demolition Rubble

<table>
<thead>
<tr>
<th>% Finer</th>
<th>Recycled Concrete Aggregate</th>
<th>Recycled Brick Masonry Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve Opening [mm]</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>Recycled Concrete Aggregate</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Recycled Brick Masonry Aggregate</td>
<td>100</td>
<td>99.8</td>
</tr>
</tbody>
</table>

Table 4: Characteristics of RA and Recycled Brick Masonry Aggregates Produced from Idlewild Elementary School Demolition Rubble

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Recycled Concrete Aggregate</th>
<th>Recycled Brick Masonry Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Density (kg/m³)</td>
<td>1,281</td>
<td>975.5 (ASTM C29 shoveling procedure)</td>
</tr>
<tr>
<td>Absorption (%)</td>
<td>7.6</td>
<td>12.2</td>
</tr>
<tr>
<td>Abrasion Resistance (% lost)</td>
<td>TBD</td>
<td>43.1</td>
</tr>
</tbody>
</table>

The bulk density of the recycled concrete aggregates was found to be 1281 kg/m³, which is lower than typical granite aggregates used in the region. The bulk density of the recycled brick masonry aggregate was found to be 975.5 kg/m³, which is slightly higher than regionally available manufactured lightweight aggregates. Absorption of both the RA and recycled brick masonry aggregate are considerably higher than locally available granite aggregate.
The recycled brick masonry aggregate contained clay brick, clay tile, and masonry mortar. The proportion of the material, by weight and volume, is shown in Table 5. A small (but potentially significant) amount of other material was present in the aggregate. Future studies regarding the use of demolished brick masonry as recycled aggregate will need to address the influence of mortar and undesirable material contained in the aggregate.

Table 5: Composition of Recycled Brick Masonry Aggregate

<table>
<thead>
<tr>
<th>Material</th>
<th>% by weight</th>
<th>% by volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay brick</td>
<td>64.5</td>
<td>63.9</td>
</tr>
<tr>
<td>Clay tile</td>
<td>2.1</td>
<td>1.9</td>
</tr>
<tr>
<td>Mortar</td>
<td>30.1</td>
<td>31.6</td>
</tr>
<tr>
<td>Other (rock, porcelain,</td>
<td>3.3</td>
<td>2.6</td>
</tr>
<tr>
<td>lightweight debris)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To date testing has primarily been performed to obtain mechanical properties. Concrete mixes were created that incorporated the RA and recycled brick masonry aggregate as coarse aggregate. Preliminary results from these mixes have indicated that structural compressive strength can be developed in concretes incorporating up to 100% RA using standard mixing practices and economical mix designs. Careful source separation of reasonable quality materials and proper grading of the aggregates simplified the mix design process by maintaining the consistency of the input materials. Future testing includes durability testing for a number of the concrete mixtures developed. Test results and other findings for both the recycled aggregate characteristics and concrete incorporating these aggregates will be published in the project report and potentially in other papers.

Interviews With Industry Representatives from Demolition Contractors, Aggregate Producers, and Concrete Producers

UNC Charlotte researchers conducted interviews with plant managers and executives of companies involved in production and use of recycled aggregates in the Charlotte area. Specifically, the aggregate and concrete producers were asked to identify the impediments to use of recycled aggregates in concrete, as well as incentives that might help increase their use in the Mecklenburg County, North Carolina area.

Particularly insightful information was obtained from the North Carolina-based DH Griffin Companies, including DH Griffin Wrecking Company, which was responsible for demolition at the case-study site. The company is unique because it operates its own aggregate crushing and grading unit, DH Griffin Grading & Crushing. This provides a direct diversion of rubble materials from the landfill, as well as a secondary income stream from the sale of the recycled aggregates. The recycled aggregate production operation was recently inspected and certified as an aggregate source for North Carolina Department of Transportation (NCDOT) work. Despite the
success in setting up this aggregate production operation, there are not provisions for recycled aggregates in PCC pavements or structural elements in the NCDOT materials specifications. Additionally, there are several impediments to market entry as indicated by company executives. A summary of insight and opinions from this demolition contractor as well as other industry representatives interviewed as part of this study is summarized below.

**Impediments to Use of RA and Other Types of Recycled Aggregates**

* Aggregate Producers

- Existance of on-site and low-grade uses for RA
  In urban demolition projects that include reconstruction on the same site, the aggregates can often be more efficiently used as fill material. The cost benefit to keeping the aggregate on the site includes avoidance of tipping fees, hauling costs and the cost of imported fill when required.

- Potential for unsteady supply of source material
  The supply of recycled aggregate is dependent on the volume of activity in the construction and demolition sector. Currently, demolition activities in the Mecklenburg County, North Carolina area are reduced. Therefore, it has been difficult for recycled aggregate manufacturers to ensure supply for larger jobs.

- No examples of large scale use
  Owners and contractors who might be interested in using concrete that incorporates recycled aggregates do not have examples of the material in service that demonstrate the acceptability of its appearance and durability.

- Conflict with other cost centers within a company
  In recent years, companies involved in the concrete industry (including aggregate producers, cement manufacturers, and ready-mix and precast concrete suppliers) have tended to consolidate into larger business entities. Use of recycled aggregate material in the concrete production operations may not be seen as an option, simply due to potential in-house conflicts of interest with the virgin aggregate production operations.

- Equipment costs
  The cost to start a properly equipped crushing operation is around $850,000 for the loading, grading, washing and test equipment. This large initial cost is a barrier to market entry for many companies that could potentially form and create a better distributed network of recycled aggregate producers.

- Awareness of crushing as a disposal option
  Smaller hauling companies are not aware of the location of aggregate producers that will accept demolition rubble. They are likely to use
regulated or unregulated dumping areas in order to dispose of their demolition waste rather than hauling it to a recycling facility.

- Availability of illicit dump sites
  Although recycled aggregate producers offer haulers a low-cost or no-cost destination for demolition rubble, there are a sufficient number of unpermitted and unregulated sites available for dumping waste. These sites are especially desirable if the haul distance from the demolition site is shorter than the distance to the recycling facility.

- Quarries have a political advantage in large projects
  Owners of quarries that produce virgin aggregates have political sway and can influence the material standards for state projects.

### Concrete Producers

- Ready Supply of Virgin Aggregates
  Aggregate recycling is more common in some coastal and alluvial areas where there may be a shortage of virgin aggregates. Mecklenburg County, North Carolina is underlain by several rock formations, and there is no shortage of source materials for aggregate production.

- Preference for returned material
  Concrete producers that intend to include recycled materials prefer to use returned concrete with a known composition rather than that of unknown demolition rubble.

- Storage space and handling requirements
  Recycled aggregate materials must be separately stockpiled in most cases, and many producers do not have space in their facilities to store adequate quantities. Significant cost may be incurred to upfit an existing concrete production facilities with storage silos, appurtenances such as sprinkling systems, and conveying systems.

- Lack of experience with recycled aggregates
  According to NRMCA personnel, there is currently only one ready-mix supplier in North Carolina utilizing returned concrete RA on a regular basis. Broader use may require training and guidance from NRMCA and other trade organizations.

### Incentives and Tactics to Promote the Use of Recycled Aggregates

#### Aggregate Producers
• Waive tipping fees for higher quality rubble at crushing operations
  Reduced or waived tipping fees will offset the expense of hauling. The resulting increase in rubble delivered to the crushing operations could alleviate the problems of steady material supply at the crusher.

• Provide income tax credits
  Tax credits for the purchase of crushing equipment that will be used to produce recycled aggregates was identified by those interviewed as potentially the biggest incentive to aggregate producers interested in manufacturing recycled aggregate.

• Create demand from project owners
  Tax credits or other incentives for the use of recycled aggregates would encourage project owners to select recycled aggregates over virgin materials at their project site.

• Create more stationary/permanent crushers
  While many companies have invested in mobile crushers, the stationary units can be better tuned to produce consistently graded material that would be preferable for production of concrete.

Concrete Producers

• Explore potential products
  Concrete producers may feel most comfortable with routine use of recycled aggregates if mixtures were designed for specific lower strength uses such as footings. Producers interviewed expressed comfort with mixes containing up to 50% replacement of virgin aggregates with RA as long as material finer than 9.5 mm is removed.

• Consolidate operations
  Due to greater industry consolidation, some aggregate producers also operate concrete batching plants. If a single facility could receive and crush demolition waste, quarry virgin aggregates, and batch concrete, it would be possible to tailor mix materials that contain appropriate quantities of recycled aggregates.

• Engineers submit their own quality control plan
  In order for recycled aggregates to be used in concrete on niche projects, it may be necessary for engineers to provide more specific specifications regarding source material and handling, prequalification tests for mixes, and additional testing requirements.
Conclusions

General apprehension to the use of demolition waste sourced aggregates from a technical perspective has often focused on the potential for contamination and inconsistent physical properties. As part of this case study, existing source-separation techniques routinely utilized by local demolition contractors have been shown to provide relatively “clean” and uniform sources of recycled aggregates with satisfactory characteristics for PCC applications. However, a shortage of field experience with, specifications for, and demonstration of recycled aggregate concrete in North Carolina has delayed acceptance and interest in the material by engineers, contractors and suppliers. Since much of the research and guidance has been centered on RA originating from returned concrete, further research should be conducted to verify the similar performance of demolition waste sourced aggregates.

Although recycled aggregates produced from construction and demolition rubble can successfully be used in concrete mixtures that exhibit acceptable laboratory performance, impediments to widespread usage are still readily apparent from a market perspective. Due to the ample supply of virgin aggregates in North Carolina, the stream of available recycled aggregates is overwhelmingly directed to lower grade, non-concrete applications. Concrete that includes recycled aggregates has been shown to provide cost savings to producers. If the supply and consistency of demolition rubble increases, there should be improved market interest in RA. The remaining impediments will include equipment and operational cost barriers to market entry, and other economic issues such as tipping fees, hauling costs, and increased product development expenses.

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Sources


Texas Department of Transportation. (2004). "Texas Department of Transportation Materials Requirements."

