A study on recycling of concrete in Sweden

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ABSTRACT
Sweden’s recycled concrete waste is used up in low-utility construction such as backfilling and
dreadly as a substitute for natural aggregates in new concrete. To foster such high-utility
recycling, a literature study was conducted on the regulatory instruments, building standards,
production and properties of recycled concrete aggregates and the resulting new concrete for
Sweden and other forerunner countries.
Results urge statistics to quantify recycled concrete; regulations such as source sorting of waste
and selective demolition could potentially optimize recycled aggregate production. Also, the
adhered mortar was found to govern the properties of the recycled concrete aggregate and new
concrete.

Key words: Aggregate, Reuse and Recycling, Sustainability

1. BACKGROUND ON CONCRETE RECYCLING
The Swedish Environmental Protection Agency estimated that Sweden utilized 670,000 tons of
concrete waste arising from the construction and demolition operations for constructing landfill
covers and road backfilling in 2014. Additionally about 510,000 tons of this waste was
estimated landfilled.
Contrary to this, Germany in 2003 used Recycled Concrete Aggregates (RCA) to produce Recycled Aggregate Concrete (RAC) which contributed to about 4% of the total precast and ready mixed concrete produced in Germany that year [1]. This comparison emphasizes the scarcity of high-utility concrete recycling in Sweden and its exclusion from national statistical estimations.

2. CONCRETE WASTE TO RCA

The regulation on landfill ban has played an important role in diverting concrete waste to produce RCA in Germany and Netherlands [2]. However the landfill taxation in Sweden amounting to 435 SEK/ton is not seemingly effective for the continuous production of RCA for use in RAC.

Regulations like the source-sorting of concrete waste can create cost savings at the separation stages in the RCA production process as has happened in Portugal; where source sorting is obligatory [3]. Other regulations include selective demolition such as in Denmark that render the concrete waste free of environmentally hazardous contaminants and impurities like harmful expansion causing gypsum in RAC. Source-sorting as a sole concrete fraction in Sweden is non-existent and selective demolition is not largely implemented. Fig.1 presents the RCA production process that could be optimized by aforementioned regulations.

![Figure 1 – A Generic representation of RCA production and the reach of Swedish statistics](image)

To enable a quality control over the RCA, Building standards and technical guidelines such as RILEM and GEAR (from Spain) have classified RCA based on its constituents such as mortar, stone, cement, masonry or bricks. A unified European classification has been adopted by the Swedish standard SS-EN 12620+A1:2008 where coarse recycled aggregates are classified into Type A and B.

The amounts of type A and B recycled aggregates that could replace natural aggregates in concrete are regulated by the Swedish standard SS-137003:2015 based on RAC exposure classes. The standard prescribes the highest replacement percentage of 50% for recycled aggregates for un-reinforced concrete members indoors.

3. PHYSICAL PROPERTIES OF RCA - WATER ABSORPTION AND DENSITY

RCA comprises partly of crushed aggregate, original aggregate and adhered cement mortar. The adhered mortar causes the water absorption of RCA to be higher and the density of the RCA to be lower than that of the natural aggregate [4]. As a consequence, the mechanical and durability properties of RAC are influenced as well [5]. Thus the building standards such as aggregates for concrete SS-EN 12620+A1:2008 limits the RCA density to 2100 kg/m$^3$ and 1700 kg/m$^3$ for Type A and B respectively.

Further investigations on the adhered mortar revealed a relation between the compressive strength of the parent concrete and the porosity of the RCA, see Table 1. Concluding that the parent concrete of higher strength yield more porous RCA than parent concrete of normal strength as the bond between the mortar and the aggregate is stronger and harder to separate [6]. The results for particle density for the Swedish study [7] were difficult to relate to the parent concrete because of the inconsistent results for particle density at different RCA sizes. The
particle density of the RCA sourced from hollow-core exceeded the RCA sourced from railway sleepers for 8-16 mm but for 4-8 mm RCA fraction it was vice-versa.

Table 1 – Water absorption and density values for RCA from different parent concrete [6]

<table>
<thead>
<tr>
<th>Compressive strength (MPa)</th>
<th>37</th>
<th>50</th>
<th>58</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water absorption [% weight for 24 h]</td>
<td>3.65</td>
<td>4.1</td>
<td>4.86</td>
</tr>
<tr>
<td>Particle density [kg/m³]</td>
<td>2520</td>
<td>2510</td>
<td>2480</td>
</tr>
</tbody>
</table>

3 MECHANICAL PROPERTIES OF RAC - COMpressive strength, ElastIC MODulus, DRYING SHRINKAGE

Besides the water/cement ratio of the parent concrete and the RAC, the RCA replacement percentage additionally affects the compressive strength.

Fig. 2 shows the results for Li’s investigation of RAC’s compressive strength with varied water/cement ratios and coarse RCA replacement percentages [1]. RAC like conventional concrete shows decreased compressive strength with increasing water/cement ratio but this claim is not supported by the 50% replacement. Further investigations are required to adequately determine this relationship.

![Figure 2 – Left: Compressive strength of RAC. Right: Relative Elastic modulus of RAC.](image)

The elastic modulus of RAC is always lower than that of conventional concrete because of the adhered mortar of low elastic modulus attached around the RCA [8]. This would imply that as the RCA content increases the RAC elastic modulus must decrease. This was investigated by Xiao [1] and represented as relative elastic modulus; defined by the ratio of the elastic modulus of RAC to the elastic modulus of the reference concrete. As seen in Fig. 2, the elastic modulus decreases to 60% of that of reference concrete when RCA replaces 30% of the aggregate mass; it is then nearly constant for higher replacement percentages.

Researchers investigated that the drying shrinkage increased between 6-7% at increased coarse RCA replacements (30%, 50%, and 100%) in high-strength concrete samples compared to their control concrete. They attributed this increased shrinkage to the increased cementitious content in the RAC owing to the richness of the mix and the old cement adhered to RCA [5].
4 DURABILITY OF RAC- RESISTANCE TO FREEZE AND THAW

RAC has been speculated for being non-resistant to freeze and thaw due to its high porosity, where an increase in RCA content could increase the porosity resulting in non-durable RAC. However, with varying replacement percentages of coarse RCA and 5.5% entrained air, researchers found that RAC showed highest durability factors at 100% RCA replacement [5].

Similarly, the Swedish researchers designed RAC with varied RCA replacement percentages: with a water/cement ratio of 0.4 and 4.5% air-entrainment [7]. The scaling test results were well within the threshold value of 0.1 kg/m²; proving that the designed RAC was freeze-thaw resistant. They concluded that RCA sourced from pre-cast and pre-fabricated concrete could produce freeze-thaw resistant RAC when designed at low water/cement ratios.

5 CONCLUSIONS

- Swedish statistics include estimations on quantities of mineral waste fraction including concrete and subsequently the percentage recycled. However, a more conclusive reporting could develop the market potential by ensuring the steady supply of RCA to RAC manufacturers.
- Introducing regulatory instruments such as selective demolition and source-sorting provides concrete waste with consistent quality suitable for RAC production. Cost optimizations are additionally achieved in the RCA production process.
- Literature points out that the adhered mortar content makes the RCA porous which influences eventually the mechanical properties and durability of the RAC. More research could be conducted towards finding the relationship between adhered mortar and RAC properties to enable a forecasting of the latter.

REFERENCES