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EFFICIENCY OF USING RECYCLED FINE AGGREGATE FOR A NEW CONCRETE

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Abstract

Using construction and demolition waste (C&DW) as a source for aggregates draws attention lately due to the large quantities of C&DW accumulating in the modern world. The coarse fraction of this waste was studied extensively in the past as a source for coarse aggregates in the production of new concrete. It is quite acceptable that replacing 10-20% of the virgin coarse aggregate with recycled one will have a minor effect on the properties of the new concrete. However, using the fine fraction of C&DW to replace virgin aggregate is still in question and is restricted in the standards.

In the study presented here the fine fraction of C&DW from two sorting plants was used to prepare new mortar and to replace natural sand crushed from natural stone. Two water/cement ratios were studied with three replacement ratios of 0%, 30% and 100%. The results showed that the mortars prepared with the recycled fine aggregates were inferior to the mortar prepared with virgin aggregate. The compressive strength has reduced and the permeability increased. It was found that reducing the water/cement ratio from 0.6 to 0.4 can preserve the compressive strength of the mix while replacing 100% of one of the aggregates studied. Similarly, the equivalent water/cement ratio was evaluated for the other aggregates and replacement ratios. These relationships can be used to evaluate the environmental efficiency of using recycled fine aggregates from C&DW for making new concrete.

Keywords:

Recycled fine aggregate; concrete; strength; permeability

1 INTRODUCTION

Recycled aggregate from construction and demolition waste (CDW) accumulates in large quantities worldwide. The amount of waste is estimated at 0.5-1.0 ton/capita/year depending on the degree of industrialization and whether waste from infrastructure works is included [1]. The largest portion of the waste is granular material arising from old concrete, mortar, bricks, soil, stones etc.

Thus, for example, Katz and Baum [2] found that large parts of the waste generated in the construction of the frame of a building is composed of granular material that has a potential for recycling. Indeed, most of the standards worldwide enable the use of coarse recycled aggregate but the use of the fine fraction is accompanied by caveats [3]. Recycled fine aggregated was tested in some studies [4-8] but the results were mixed though in most cases the properties of the new concrete were inferior to concrete made with natural aggregates.

In this study the properties of mortar made with recycled aggregate derived from regional recycling plants were evaluated and conclusions were derived as for its use in the production of new concrete.

2 MATERIALS AND METHODS

Recycled aggregates were collected from two recycling plants. These plants are located in different regions of the country. In both plants the waste stream is inspected and coarsely sorted first to remove organic matter and green waste and then crushed and sieved to produce coarse (>5 mm) and fine (<5 mm) aggregate. The fine

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aggregate from either plant was labelled as RA-3 and RA-4. The initial inspection in the plant producing RA-3 is more stringent than in the other plant. In addition, RA-3 is further treated by washing and precipitation to yield RA-1, a fine fraction, and RA-2, a coarse fraction. Natural crashed sand was used as a reference sand.

Two water/cement ratios were tested: 0.4 and 0.6 in 3 replacement ratios of 0%, 30%, and 100%. Mix composition was 1:0.4 (or 0.6):2 of cement:water:sand. CEM I 52.5N complying with EN 197, was used in all the mixes.

3 RESULTS

3.1 Aggregate properties

Aggregates' grading is shown in Fig. 1. It seems that the recycled aggregates as derived from the waste stream (RA-3 and RA-4) are somewhat finer than the reference natural crushed sand. RA-3 contains more fine particles in the range of 0.15 to 0.3 mm than RA-4 but the other particle distribution is quite similar. Additional treatment to RA-3 separates the fine fraction to RA-1 that contains mostly 0-0.3 mm particles and RA-2 that contains mostly particles of 1.18-9.5 mm. All the aggregates were sieved over 4.75 mm before making the mortars to produce sand that is smaller than 4.75 mm.

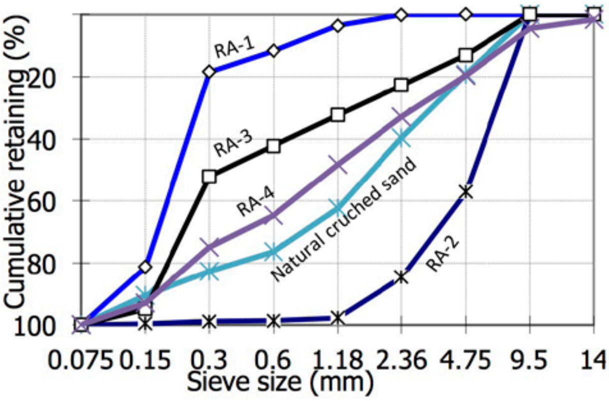

Fig. 1: Aggregates' grading.

Additional aggregate testing indicated that RA-1 is composed mostly from quartz particles with little amount of fines (particles smaller than 75μm) whereas RA-2 is made from natural aggregates glued together with hardened cement paste (both are derived from RA-3). Aggregate RA-4 is made of crushed natural limestone or dolomite with hardened cement paste. These differences stem from the different geographical regions of these two recycling plants, representing the typical construction materials in these regions.

Aggregates RA-2, RA-3 and RA-4 contained relatively large quantities of old cement past identified by relatively large water absorption values, lower density and microscope observations. RA-1 was relatively clean from old cement paste but its properties were somewhat lower than natural aggregate.

An interesting finding from other tests is the presence of green waste, as was found by thermal gravimetric analysis.

3.2 Properties of the hardened mix

The compressive strength of the hardened mixes was tested at 3, 7 and 28 days. The results of mixes prepared with w/c ratio of 0.4 and with 100% replacement ratio are presented in Fig. 2 and Fig. 3 presents the results of w/c=0.6.

The results clearly demonstrate that replacing the natural sand with sand produced in recycling plant significantly reduce the compressive strength. Aggregate RA-4, which was produced at the lowest quality, demonstrated the lowest quality with a strength reduction of ~50% compared with mixes with natural aggregate. The second source of aggregate, RA-3, demonstrated better performances, though, only slightly better. The effect of secondary treatment is clearly seen by the better performances of RA-2 and RA-1 which are made from RA-3. RA-1 presents the highest quality among the recycled aggregates but full replacement of the natural aggregate with this one led to a significant reduction of strength as can be seen Fig. 2 and Fig. 3.

The effect of aggregate replacement on the strength was different in the two water/cement ratios tested. At the low w/c (0.4) the compressive strength has reduced by 34% compared with mortar made with natural aggregate, whereas at higher w/c (0.6) the reduction was of only 19%. This phenomenon is quite known from lightweight aggregate concrete in which the strength reduction becomes larger when the difference between the aggregate quality and paste quality becomes larger.

At the early age of 3 days all the lower quality aggregates, i.e. RA-2, RA-3 and RA4, demonstrated similar strength in each of the w/c ratios, resulting probably from the lower quality together with low properties of the new cement paste.

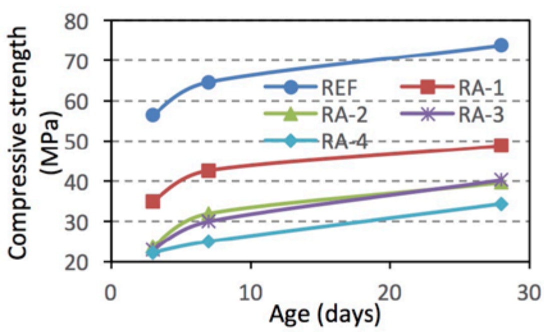

Fig. 2: Development of compressive strength of w/c=0.4 and 100% replacement ratio.

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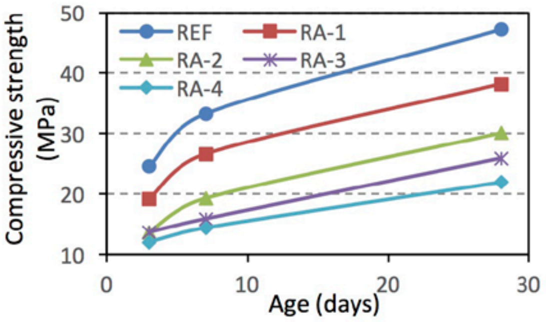

Fig. 3: Development of compressive strength of w/c=0.6 and 100% replacement ratio.

Lower replacement ratio of 30% showed that the properties of the mixes were inferior to those of the reference mixes with natural aggregate only (REF, see Fig. 4), however to less extent when comparing with strong effect at 100% replacement ratio. In-fact, the effect of using aggregate RA-1 was minor, a reduction of only 3% and 9% was identified at the lower or higher w/c ratios, respectively. RA-2 exhibited some strength reduction at the lower w/c but similar strength as RA-1 at the higher w/c. More strength reduction was seen when RA-3 and RA-4 were used (Fig. 4).

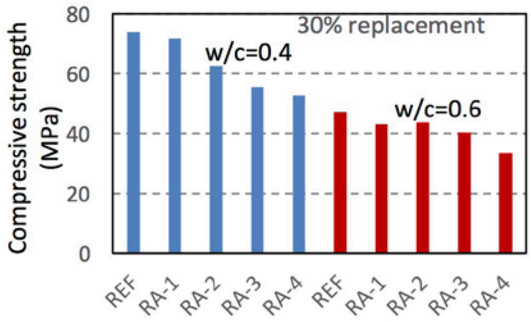

Fig. 4: Compressive strength at 28 days with replacement ratio of 30%.

Diffusion was measured by the Torrent method [9] using 50 mm thick discs with a diameter of 200 mm. The absolute results indicated poor to very poor performances (indices of 4-5) of all mixes thus the results were normalized with respect to the reference mix with natural aggregate only (REF) in each of the w/c tested. The results are presented in Fig. 5. It appears that replacing the natural aggregates with recycled ones increased the air permeability of the mortars tested. The smallest effect was identified in RA-1 with permeability increase of 75% and 20% at w/c=0.4 and 0.6, respectively. The largest influence was identified with RA-2 with 700% and 300% increase, respectively.

Two parameters seem to control the influence of aggregates replacement: the amount of old cement paste adhered to the recycled aggregate; and the difference between the properties of the new cement paste and the old paste. Air penetration is related to the total content of paste, thus increased amount of paste, from the old and new paste, is expected to increase the air permeability. However, differences between the two pastes, new and old, may also affect the permeability, leading to a more significant effect when air can penetrate easily through the particles with the old paste.

This phenomenon was more evident with aggregate RA-2 that contained significant amounts of old paste thus exhibiting the largest changes.

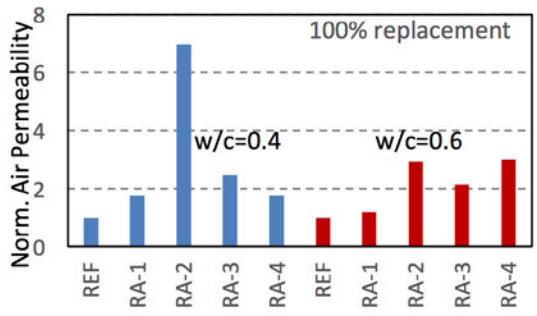

Fig. 5: Normalized air permeability results for full replacement of the aggregates.

3.3 Efficiency of mixes with recycled aggregates

The efficiency of mixes with recycled aggregates was measured by the reduction required in the water/cement ratio to maintain the same property as obtained with natural aggregates. This is demonstrated in Fig. 6 that presents the results of compressive strength vs. water/cement ratio together with a regression line connecting between these results (REF and 30% aggregate replacement). It is clear that it is possible to preserve the compressive strength obtained with natural aggregates while replacing the aggregates with recycled ones but adjustment of the water/cement ratio is needed. It can be seen that the compressive strength of 47 MPa obtained in w/c=0.6 and with 100% natural aggregate is achieved when lowering the w/c to 0.56 for aggregates RA-1 and RA-2 and to lower values of 0.50 and 0.45 for RA-3 and RA-4, respectively.

The effect of 30% aggregate replacement on air permeability is demonstrated in Fig. 7. The same level of air permeability of the reference mix prepared with w/c=0.6 is maintained if the w/c ratio is reduced to 0.57 to 0.55 for aggregates RA-1 to RA-4. Practically, about the same w/c for all the aggregates.

It appears that the effect of replacing recycled fine aggregates with natural aggregates is different when different properties are considered. When 30% replacement rate was analysed the effect on compressive strength was large and in a wide range depending on the

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properties of the individual recycled aggregate. The effect on air permeability, on the other hand, was much smaller with small differences between the aggregates.

This way, the value, both financial and environmental, of using the recycled aggregates can be calculated. Lowering the water/cement ratio requires an increase in the cement content in these mixes while preserving the same amount of water that is required to maintain workability. For example, lowering w/c from 0.6 to 0.45 as required in order to preserve the compressive strength when 30% of the aggregate is replaced with RA-4 leads to an increase of 33% in the cement content. Its environmental impact as well as its cost can be calculated and the worthiness of this act can be assessed.

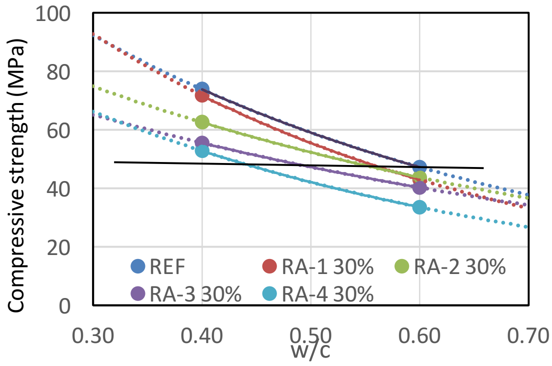

Fig. 6: Efficiency of 30% aggregate replacement - Strength.

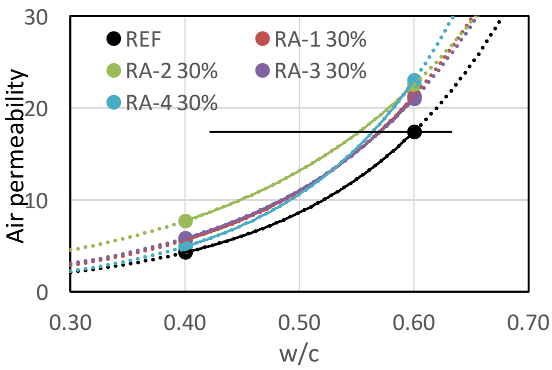

Fig. 7: Efficiency of 30% aggregate replacement – Air permeability.

4 SUMMARY AND CONCLUSIONS

The properties of recycled fine aggregate from construction and demolition waste were tested together with its impact on the properties of new concrete prepared at water/cement ratios of 0.4 and 0.6.

The aggregates derived from the recycling plants were of lower quality compared with new aggregates. It was clear that beneficiation processes can improve its properties but not back to its initial properties. The mechanical properties (compressive strength) and durability (air permeability) are inferior by up to 50% compared with mixes prepared with natural aggregates.

It is possible to compensate for the reduced properties by lowering the water/cement ratio. The reduction is different for different source of aggregate or different property. For example, w/c of 0.45 is needed to preserve the compressive strength of a mix prepared with w/c of 0.6 when RA-4 replaces 30% of the aggregates, but a reduction of w/c to 0.55 only is needed in order to maintain the air permeability. The monetary and environmental cost can be calculated this way.

5 ACKNOWLEDGMENTS

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