

REACTIVITY IN RECYCLED CONCRETE AGGREGATE

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SUMMARY

Full scale tests with crushed concrete used in sub-bases in roads show that the material has capacity to reharden, very slowly but also after prolonged periods of time. The rehardening process in crushed concrete aggregate has been analysed with a thermogravimetric method, comparing the change in chemical composition in the aggregate when set with water, compacted and hardened. It has been shown that grinding of crushed mortar, even if reground to cement fineness, will not activate the unhydrated cores of cement observably. If the mortar is ground together with surface active additive, the material set with water gives compressive strength of 2.8 MPa in 15 days. This is likely due to increased bonding between the ground cores of sand and cement, allowing further crystallisation of ground material to occur closer and chemically better bonded to silicate surfaces.

Keywords: Recycling, concrete, aggregate, thermogravimetry

1. INTRODUCTION

1.1 Background

Annually 1.5 million tons of mineral demolition waste, mainly consisting of concrete and bricks, is produced in Sweden every year (Karlsson, 1997). The use of recycled concrete in Sweden is currently being impeded by the lack of material acceptability criteria and control procedures associated with processes and implementations as well as by rules and regulations which are unsuited for this type of material. Recycled concrete aggregate (RCA) has in field tests in road constructions shown to be well as good as conventional materials, and the material has been used as normal aggregates as 1:1 (which means complete replacement). RCA also contains recoverable binding energy. In Finland, the material have, with the right treatment, shown to give the earth constructions a bearing capacity 2-3 times higher than that of crushed rock (Kivekäs, 1997).

The objective with this paper is to investigate if there is a resource value in recycled old crushed concrete related to the cement. Results from life cycle assessment of concrete (Vold, Rønning, 1995) show that the emissions and resource depletion are mostly generated within the life cycle of cement. Concrete may contain cores of unhydrated cement and calcium hydroxide formed during the hydration. Since all concrete structures to be demolished has been degraded due to carbonation, the calcium hydroxide has been more or less reduced and formed calcium carbonate. The carbonation means that the recycled concrete aggregate in the cement phase will partly consist of limestone, one of the minerals from which cement once was produced.

1.2 About the project

The general aim of the ongoing project “recycling concrete” is to establish a sustainable waste management of concrete, in particular the utilization of concrete waste as a resource. Concrete waste may be used in road construction and in building construction.

The research is intended to have two main streams.

The **first main stream** comprises systematising, treatment and sorting at recycling of concrete with Swedish aggregates taking into account the cleanness of the aggregate, the properties of the fresh and the hardened concrete. A guide-line proposal for use of recycled concrete aggregates in new concrete has been forwarded from Building Technology, Chalmers University of Technology, to Swedish National House of Boarding and Planning (NBHP) in October 1997, and in December 1997 a proposed document is distributed for consideration by NBHP (NBHP Handbook, 1997) and will be published during summer 1998. The handbook is based very much on Danish and Dutch experiences. It is however necessary, that the handbook coefficients for calculation of deformations and for shrinkage and creep are determined for Swedish recycling materials. Further, the systems for quality assurance should be controlled and eventually be improved.

The **other main stream** comprises an analysis of rehardening reactions obtained at crushing of concrete. These are mainly to be found in the corn fraction 0-4 mm. At fabrication of self-compacting concrete, concrete filler amount of more than 500 kg/m³ are needed. Lime filler, which is used for the time being, could be replaced by cheaper ground recycling concrete together with very efficient new superplasticizers. The degradation of calcium hydrate in concrete due to carbonation will be in different stages for different types of concrete structures, depending on original concrete, climate and age of structure. It will therefore be necessary to quantify not only the strength but also the condition of demolished concrete to be able to predict characteristics of crushed concrete in different applications.

The investigations presented in this paper belong to the “other main stream” and have a preliminary character.

1.3 Reactivity in mortar phase

The fact that crushed concrete aggregate rehardens in earth constructions has been shown during the last decades. Concrete is a material with an initial high energy level and the degradation in the material is often slow. The cement in concrete hydrates until the growth becomes limited through limited water supply to the cement core. There is consequently always a buffer of unhydrated cement in concrete depending mainly on the water-cement ratio.

The reactivity in the mortar phase in RCA is investigated for two reasons.

1. It is valuable to be able to quantify the rehardening properties in RCA to use the material as efficient as possible.

2. For the time being it is difficult to use the fine fraction at mixing new concrete because of lacking knowledge about its properties. Grinding and activation of the fines will show whether these could be separated and used more efficiently as binder.

2. LABORATORY TESTS

2.1 Methodology

Laboratory samples with well-defined properties of hardened mortar are produced. The concretes were cast in 40•40•160 mm standard prisms for testing of cement, according to EN 196-1.

After one day of curing the mortar samples were remoulded and stored at room temperature (20°C) in water until day of crushing. Then the mortar was crushed, in some cases reground to cement fineness, and set with water again. The material was set with water to an earth moisture consistency and compacted by hand in the moulds with a similar performance in all cases.

The set material was then tested for compressive strength after different periods of curing at room temperature (20°C) under dense plastic membrane.

The rehardening mechanisms were analysed with a thermogravimetric method, comparing the chemical composition in the material at crushing and after different periods of rehardening.

In thermogravimetry the weight loss is registered when a specimen is heated. The weight losses recorded is due to evaporation of water or decomposition of hydration products. A program suitable for hydrated cement and cement composites has been developed at Chalmers University of Technology (Helsing-Atlassi, 1993), for a thermogravimetric analyser which could be programmed for 5 temperature steps; a LECO-Mac500. The chosen temperature intervals and the corresponding decomposition compounds are:

| | |
|-----------|--|
| 20-105 °C | physically bound water |
| 105-380°C | CSH and CAH (calcium silicate hydrates and calcium aluminate hydrates) |
| 380-450°C | Ca(OH) ₂ + some hydrates |
| 450-600°C | Some hydrates + carbonation products other than calcite |
| 600-975°C | calcite + some secondary hydration products |

2.2 Materials

The specimen preparation was performed according to Methods of testing cement, EN 196-1. The cement used was standard Portland and the sand used complies with particle size distribution and mineral composition according to CEN Standard sand, with maximum particle size of 1.6 mm. The amount of cement was 500 kg/ m³ and that of sand was 1500 kg/ m³. The water cement ratio was 0.50 and the prisms were tested for compressive strength before crushing.

2.3 Test program

Three series of investigation have been performed. Specimens in all three series were prepared from the same batch of mortar and casted at the same time.

1. After 8 days of curing the mortar was crushed with a jaw having opening corresponding to the initial aggregate maximum size, i.e. 1.5 mm. Compressive strength at crushing was 40 MPa. The crushed material set with water was tested for compressive strength after 36 days and 52 days, and was compared with the strength of the original mortar.
2. After 28 days of curing the mortar was crushed and also ground for 3 hours in a laboratory ball mill. Compressive strength at crushing was 46 MPa. The ground material, set with water, was tested for compressive strength after 31 days of curing.
3. After 44 days of curing the mortar was crushed and separated in two parts. Compressive strength at crushing was 50 MPa. One part of the material was ground as in series two, and the other part was ground together with an superplasticiser, Mighty 100, dry powder. The ground material was tested for compressive strength after 8 and 15 days.

3. RESULTS AND DISCUSSION

When the original mortar was 8 days old, prisms was taken for the **1st series of investigation**. In series 1 there is still a significant hydration increase in the original concrete, but it is obvious that the secondary mortar has not achieved any higher degree of hydration compared to original mortar. Fig.1, show the thermogravimetric weight loss for secondary mortar after 36 days of membrane curing, the original mortar when crushed (8 days) and original reference stored in water (44 days). The weight loss is obtained by weighting the mortar when weight becomes constant weight at investigated temperature (retained weight) and then relating it to weight of cement in mortar at 975 °C. The compressive strength increased from 40 MPa in original mortar after 8 days to 50 MPa after 44 days. Meanwhile the secondary mortar achieved a maximum compressive strength of 1.7 MPa.

The investigation was repeated also when secondary mortar was cured for 52 days. The thermogravimetric weight loss curves are almost identical to those given in Fig.1, for original 44 days and secondary mortar. Compressive strength of secondary mortar increased slightly to 2.0 MPa.

The crushed material is shown to be reactive and increases strength parallel with hydration growth in reference mortar. Completely hydrated cement contains about 25 % chemically bound water. At 8 days the amount of chemically bound water was 10% of ignited cement, which means that 60 % of the cement cores still were unhydrated.

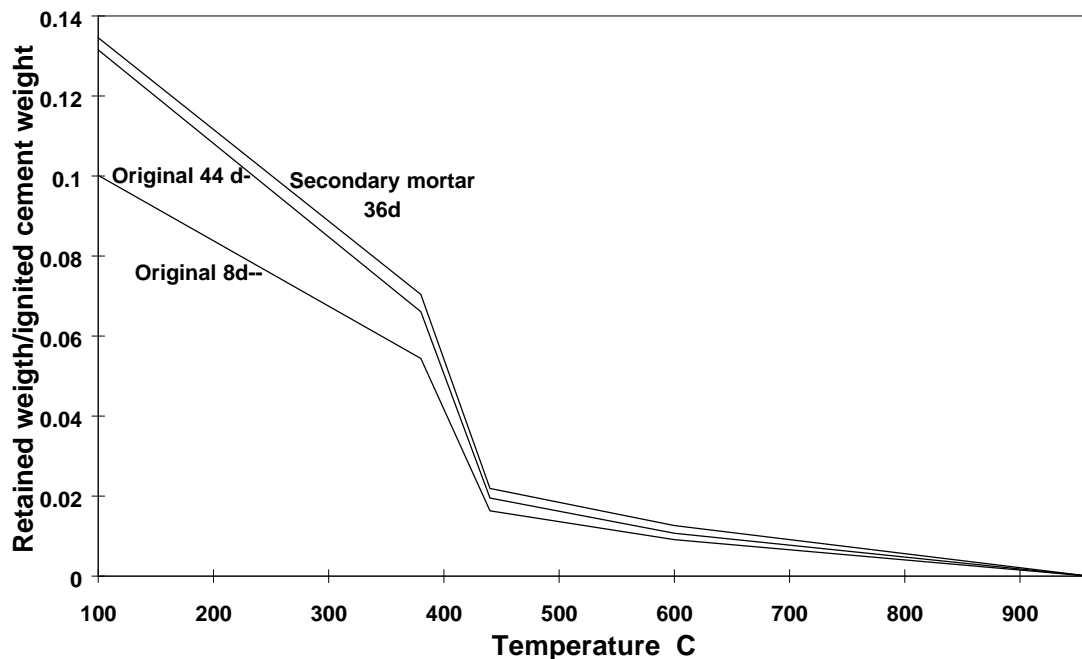


Figure 1. Thermogravimetric weight loss curves for hydrated cement systems in original mortar after 8 and 44 days and secondary mortar after 36 days.

In 2nd series of investigation prisms with the original mortar were taken after 28 days of curing. Even though approximately 40 % of the cement had not hydrated in the mortar, no increased hydration in the ground material could be observed. The secondary mortar was tested for compressive strength after 31 days of curing and reached only 0.3 MPa.

The unhydrated cores of cement in the original mortar are by this shown to be very hard, if not impossible to activate. This supports earlier findings (Hansen, Narud, 1982), showing that crusher fines from recycled aggregate do not qualify as hydraulic cements even when ground to cement fineness.

In the 3rd series of investigation prisms with the original mortar were taken after 44 days of curing. Two separate secondary mortars were made, one activated when grinding with 1 % by mass surface active additive of the crushed mortar to be grind. The additive was Mighty 100 dry powder. Compressive strength was tested after 8 days and 15 days. No difference in the thermogravimetric analysis were observed between 8 and 15 days of curing. For the secondary activated mortar compressive strength after 8 days was 1.8 MPa and after 15 days 2.8 MPa. The Secondary mortar not activated had no measurable compressive strength after 8 days and reached only 0.3 MPa after 15 days of curing.

The thermogravimetric weight loss curves shows a significant reduction between 380-450 °C, showing a weight loss of Calcium hydroxide in the activated material, see Fig. 2. The grinding damages silicate crystals and the surfaces of these becomes in some extent amorphous. The addition of surface active additives while grinding prevent the surfaces from ageing (re-crystallisation). Consequently calcium hydroxide formed during cement hydration is likely to

give crushed concrete aggregate rehardening properties if siliceous particles are dissolved from concrete aggregate and cement grains, causing a pozzolanic type reaction. However, when comparing thermogravimetric weight loss curves for the secondary activated mortars at 8 and 15 days of curing there is no visible difference. A separate investigation was performed to investigate if a chemical reaction occurs with calcium hydroxide and superplasticiser. It became obvious that that this was the case. However, this reaction seems to occur relatively fast, and will therefore not explain the strength increase in the secondary activated mortar between 8 days and 15 days. More likely the bonding between the ground cores of sand and cement has been improved by the surface active additive, allowing further crystallisation of ground material to occur, not faster but closer and becoming chemically better bonded to silicate surfaces.

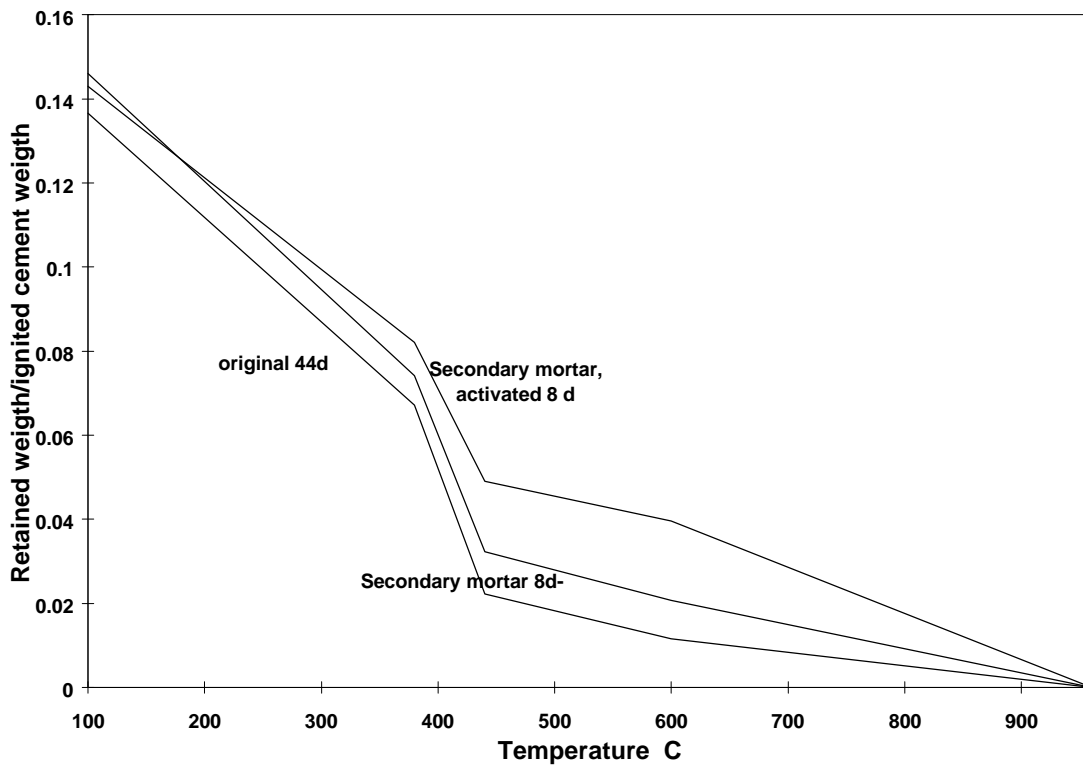


Figure 2. Thermogravimetric weight loss curves for hydrated cement systems in original mortar after 44 days and secondary mortar unactivated and activated after 8 days.

4. CONCLUSIONS

The rehardening process in crushed concrete aggregate has been analysed with a thermogravimetric method, comparing the change in chemical composition in the material. It has been shown that grinding of crushed mortar, even if reground to cement fineness and set with water, will not activate the unhydrated cores of cement observably. This indicates that the unhydrated cores of cement continues to hydrate slowly towards core centre hidden in an inert shell. The termograviometric analysis show, besides some carbonation in the ground material, no change in degree of hydration for the ground material set with water, compared to reference concrete.

Grinding increases the degree of amorphous structure of siliceous aggregates and the addition of surface active superplasticiser prevent the surfaces from ageing. The grinding destroys silica crystals and the surfaces of these becomes in some extent amorphous. Calcium hydroxide formed during cement hydration is likely to give crushed concrete aggregate rehardening properties if siliceous particles are dissolved from concrete aggregate, causing a pozzolanic type reaction. It is doubtful that this mechanism is the explanation to the short time strength increase for the mortar ground with superplasticiser, since the sand used is a commonly used aggregate of granite with highly crystalline nature and thus low silicate solubility. This is supported with the thermogravimetric analysis, showing no difference in the set material between 8 and 15 days, inspite the strength increase. More likely bonding between the ground cores of sand and cement has been improved, allowing further crystallisation of ground material to occur and form closer and chemically better bonded surfaces.

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