RECYCLED CONCRETE AGGREGATE -
- DURABILITY ASPECTS

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Key words: concrete, recycling, durability, frost, deterioration
Abstract: *Since the mid-90s the recycling, reuse and reduction of construction and demolition waste (C&D-waste) have received increasing attention in Norway. The main focus of the Norwegian recycling effort has been on the concrete and masonry ruble and recycled aggregate (RCA), as it makes up the largest segment of all the C&D-waste generated.*

This paper presents a summary of the most important results related to RCA durability characteristics from two major R&D programs carried out in Norway: RESIBA (1999 - 2002), and Norwegian Roads Recycled Materials R&D Program (2002 – 2005).

The main focus has been documentation of freeze-thaw durability and degradation from water drainage. The results of extensive testing of RCA with different exposure conditions confirm that freeze-thaw resistance is sufficient for the most common exposure conditions. However, for extreme exposure conditions such as when aggregate is submerged in water in combination with deicing salts the freeze-thaw resistance is not acceptable. The results have been implemented in a revised test method based on EN 1367-1.

Degradation from water drainage is an important aspect of durability for RCA in unbound applications such as trenches and road base. The paper presents a laboratory set-up aimed at investigating the impact of steady water drainage at two different pH-levels on the basic material properties such as mechanical strength, density and water absorption.

1. INTRODUCTION

Since the mid-90s the recycling, reuse and reduction of construction and demolition waste (C&D-waste) have received increasing attention in Norway. The main focus of the Norwegian recycling effort has been on the concrete and masonry ruble and the production of recycled concrete aggregate (RCA), since concrete and masonry ruble makes up the largest segment. As experience has shown in other countries, unbound application in road and highway construction, backfill in trenches etc. is expected to be the most common and most profitable area of use.

This paper presents a summary of the most important results related to durability characteristics of recycled concrete from two major R&D programs carried out in Norway:
- RESIBA (1999-2002), which focused on RCA with documentation of material properties, development of a quality declaration system and documentation from demonstration projects[1,2];
- Norwegian Roads Recycled Materials R&D Program (2002 – 2005)[3], which focuses on alternative materials in road construction, including in addition to RCA also asphalt and shredded tires and cellular glass utilized as lightweight fill materials.

2. RECYCLED CONCRETE AGGREGATE

2.1 Waste volumes and recycling

Approximately 1,5 mill tons of C&D waste is generated every year in Norway, of which an estimated 1,1 mill tons is concrete and masonry rubble[4]. This roughly corresponds to 2 % of the total annual aggregate production. Recycled concrete aggregate (RCA) is produced by crushing C&D waste, removing the reinforcement by magnetic belts and finally crushing and sieving to a given particle size distribution. The result is a granular material consisting mainly of concrete, rock, and sometimes masonry and asphalt particles. Although it resembles and is mostly used as a substitute for natural aggregate, the composition of recycled concrete aggregate gives the material some special characteristics such as for example lower particle density and higher water absorption

Ambitious environmental policies and a general change of attitude towards the use of primary raw materials have proven to be important motivations for the recycling of C&D waste. Since the mid 90s several R&D projects has been carried out. This work has included documentation of technical and environmental properties of RCA[5,6], documentation of demonstration projects[7,8,9], and development of both guidelines for use[10,11] and a quality certification system[12,13]. In 2004 recycled concrete aggregate was included in the new edition of Norwegian guidelines for road construction[14] as a construction material for road sub-base, base and trenches. As a part of this R&D effort, durability concerns such as freeze-thaw durability, chemical degradation, chloride and sulphur content, shrinkage etc. has received considerable attention.

2.2 Properties and classification

The Norwegian quality certification scheme for RCA[13], includes requirements for documentation of the basic material properties for both bound and unbound applications. Material composition is the basis for classification of recycled concrete aggregate in two main types: Type 1 (crushed concrete) and Type 2 ("mixed materials"). Each of these types is divided in a class for bound (A) and a class for unbound (B) use. A list of required material properties to be documented according to the Norwegian quality certification scheme and typical properties for Norwegian recycled concrete aggregate Type 2 (mixed materials) are listed in Table 1.

Req. material properties to be documented	**Test method**	**Approx. values Type 2**
Particle size distribution	EN 933-1	
Fines content < 0,075 mm of mat. < 19 mm	EN 933-1	1,5-8 %
Content mat. < 0,020 mm of mat. < 19 mm	EN 933-1	1-3,5 %
Material composition	EN 933-11	
Organic materials	EN 1744-1	2-10 %
Shape – Flakiness index (of mat. > 8 mm)	EN 933-3	10-15
Mechanical properties (Los Angles)	EN 1097-2	27-40
Particle density (SSD)	EN 1097-6	2-2,5 kg/dm^3
Water absorption	EN 1097-6	5-10 %
Chloride content	EN 1744-1	0,003-0,013 (mass %)
Sulphur-containing compounds	EN 1744-1	0,04-0,25 (mass %)
Chemical analyses (leaching test)	EN 1744-3 or alt.	

Table 1: Properties of RCA included in the quality certification scheme and typical values, where relevant, for Type 2 (mixed materials)[15]

In addition, more application-specific testing is also required. Documentation of long term durability properties such as freeze-thaw and chemical resistance is crucial for the status of RCA as a reliable building material for both unbound and bound applications.

3. FREEZE-THAW DURABILITY

3.1 Background – standard tests for frost durability

The European standard EN 13242[16] provides specifications for documentation of natural, crushed and recycled aggregate for bound and unbound applications, including freeze-thaw durability requirements for unbound applications. For aggregate with water absorption of 2 % (percent by mass) or less, section 7.3 of EN 13242 allows for a simplified classification of freeze-thaw durability. However, due to the composition of RCA, the porosity and therefore water absorption levels will be much higher than in natural aggregate (Table 1). A closer testing of the frost properties will therefore almost always be necessary in cases when frost durability is a relevant property for the chosen application. The standard method for testing frost durability of aggregate is freeze-thaw test according to NS-EN 1367-1[17]. The testing consists of exposing aggregate to freeze-thaw cycles in de-ionized water, or 1% NaCl solution, as suggested in Appendix B.

EN 13242 divides aggregate in categories according to freeze-thaw durability measured as mass loss. The freeze-thaw category (F) for a given application will depend on both the local environmental exposure conditions and the regional climate in which the aggregate will be used. The regional climate in Norway will vary between Continental and Atlantic. In addition, aggregate used for unbound applications such as road base or backfill in utility trenches is assumed to be fully saturated during freeze-thaw cycles. Thus the corresponding freeze-thaw category for these applications will be F_1 to F_2.

3.2 Modifications of standard test procedures

NORDTEST (Nordic cooperative research project between Norway, Iceland and Sweden) project 1440-99 was dedicated to frost durability of porous aggregate, including recycled concrete aggregate[18]. The aim was to suggest modifications of standard freeze-thaw test designed for natural aggregate. The results of the project showed that:
- pre-drying of specimens (at 105 ˚C to determine dry weight) has a detrimental effect on the results of testing. This part of the specimen preparation is unnecessarily severe for RCA and leads to conclusions about poor frost properties.
- submerging specimens in salt solution instead of de-ionized water had negative effect of the result. Salt is, however, a necessary part of the test for Nordic conditions.

A student project supervised by Norwegian Building Research Institute[19] lead to similar conclusions: pre-drying, salt content and submerged conditions were the main factors reducing the tested frost durability of RCA.

Applications in road structures require frost durability, and an alternative test procedure was required for the NPRA manual for laboratory testing[20]. The original test method according to EN 1367-1 was modified by different combinations of preparation and exposure variables, as shown in Table 2.

Procedure	Specimens			
1*	P-Na-Sub	Pre-drying	1% NaCl solution	Submerged
2	P-Na-Sat	Pre-drying	1% NaCl solution	Water saturated
3	NP-Na-Sub	-	1% NaCl solution	Submerged
4	NP-Na-Sat	-	1% NaCl solution	Water saturated
5	NP-D-Sub	-	De-ionized water	Submerged
6	NP-D-Sat	-	De-ionized water	Water saturated

Table 2: Variables in the test preparation procedure (*procedure 1 is a reference procedure according to NS-EN 1367-1)

Results of five test series are shown in Figure 1. The mass loss was highest for the specimens that were submerged in 1% NaCl solution. The results also reveal variations in material between batches.

The relationship between concrete content and loss of mass after freeze-thaw testing was investigated, and is shown in Figure 2 for specimens submerged in a salt solution (Na-Sub). Although the results appear to correlate relatively well, it is important to be aware that the number of observations is limited. In addition, relationship between loss of mass from freeze-thaw testing and aggregate material properties such as particle density and water absorption has been investigated, also yielding promising results.

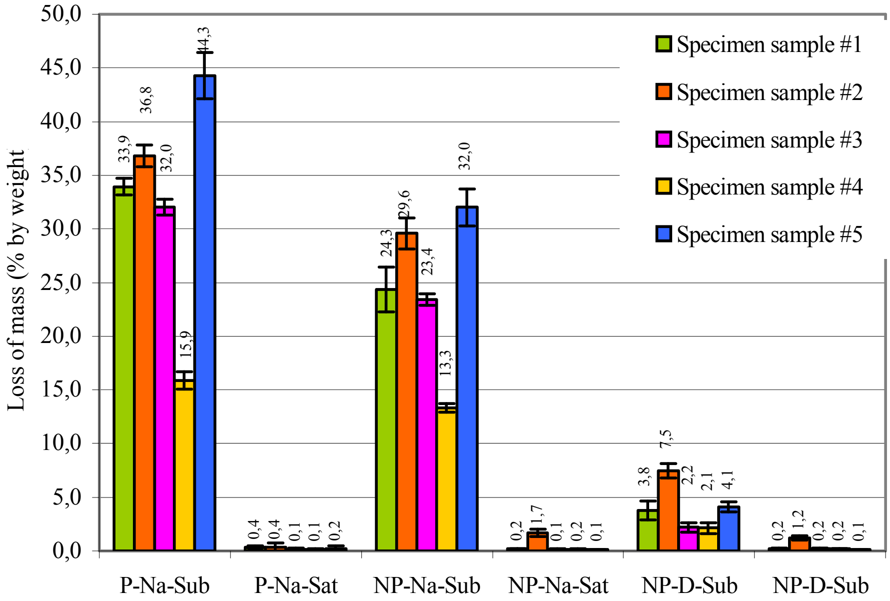

Figure 1: Average loss of mass after freeze-thaw testing for RCA specimens with different preparation and exposure conditions.

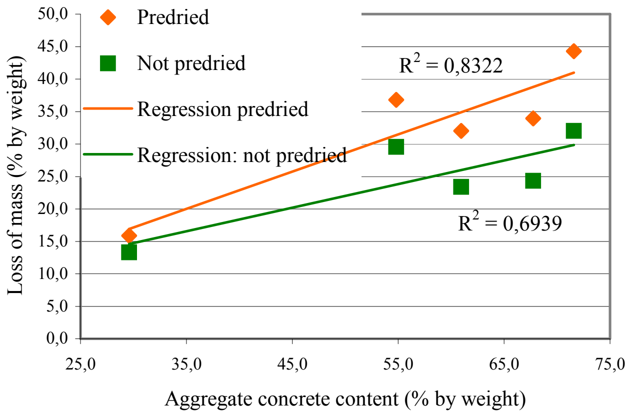

Figure 2: Relationship between loss of mass from freeze-thaw testing and concrete content for mixed mass recycled aggregate specimens, submerged in a salt solution.

3.3 New standard procedure

On the basis of this investigation, the following modifications of the standard freeze-thaw test NS-EN 1367-1 have been suggested:

- Pre-drying is not included in the preparation procedure. Drying to determine dry weight is performed after freeze-thaw testing and requires an adjustment of the calculation of mass loss.
- Exposure to de-icing salts (1% NaCl solution) is made a regular part of the testing procedure.
- Water-saturated conditions have replaced submerged conditions. Submerging has a detrimental effect on the performance of RCA, while it is not a realistic exposure condition for RCA.

The modified test method is now being implemented in NPRA's manual for laboratory testing[20]. Norwegian guidelines for road construction[14] do not recommend use of recycled concrete aggregate in applications where freezing could occur in submerged conditions.

4. CHEMICAL DETERIORATION

4.1 Background

Degradation from water is an important aspect of durability for RCA in unbound applications such as trenches and road base. Most research work concerning water flow through recycled materials is focused on controlling pollution from the recycled material to the environment. In the case of RCA it is also important to look into the changes of material properties, i.e. water deterioration.

4.2 Preliminary tests

To simulate water deterioration of recycled concrete aggregate, a laboratory rig for an accelerated experiment was decided built at the Norwegian Building Research Institute. Recycled concrete aggregate was to be placed in columns and exposed to constantly flowing water. The effect of the water flow was to be determined on changes in chosen material properties. Performing such a test required a careful choice of variables, both material and exposure parameters[21]. Preliminary tests consisted of the following:

- Literature review of water deterioration, where the following parameters were identified as crucial: grain size, water quality (defined by pH and CO_2 content), flow rate and temperature[22],
- Evaluation of the effect of acceleration parameters on deterioration: water quality, water flow rate and temperature,
- Documentation of material properties, based on the quality declaration scheme, see Table 1,
- Design and construction of the testing rig,
- Design of the test program, i.e. variation of test parameters.

In order to simplify the investigation, the effect of dry periods was excluded and deterioration of the natural aggregate in the RCA neglected. In addition, only one particle size was included, 10 – 20 mm, which is the most relevant for trenches where water deterioration may be an issue. Fines < 2 mm were removed from the samples before the start of the test, since they would have been washed away within the first days of the test.

The major part of the preliminary investigations was dedicated to adjusting the pH-level of water. Two levels were chosen: 7 (corresponding to tap water) and 4 (an extreme but natural low level). It was necessary to test how frequently the water in columns has to be replaced in order to compensate for the reduction in pH induced by the material. In addition, the content of acid necessary for achieving and maintaining pH-level of 4 had to be determined. This is shown in Figure 3.

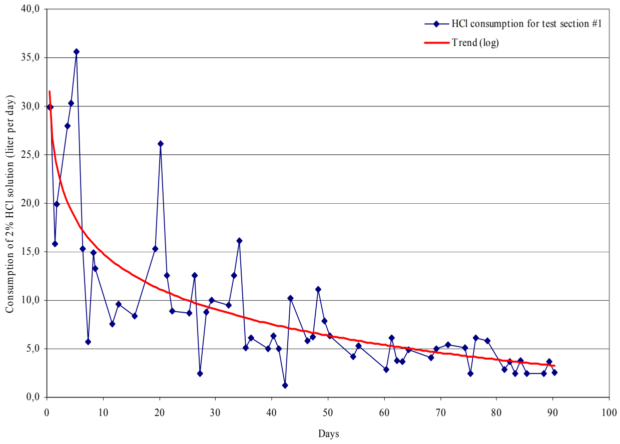

Figure 3: HCl consumption (liter pr. day) for test section with pH = 4

4.3 Laboratory set-up for accelerated water deterioration

Based on the preliminary investigations a test set-up was constructed consisting of 2 series of 4 columns and activated early spring 2004, see Figure 4.

Figure 4: Test set-up for chemical deterioration of recycled aggregate

The test set up is designed to last for two years. A rough approximation of the acceleration level is that each year corresponds to 730 years middle zone and 24 years for the bottom zone of a trench. The process is accelerated due to the fact that the water flow is constant (with no dry periods) and that the flow rate is unrealistically high (316 l/column pr hour). Parameters that were chosen within realistic ranges and have therefore no accelerating effect are: temperature (although laboratory temperature is somewhat accelerating), and particle size distribution 10 – 20 mm (higher exposure surface would have been an accelerating factor). Variation of the CO_2 content had to be excluded from the test due to practical reasons. The importance of this factor should however, not be overseen.

The test rig is built as two series of four columns (normal and low pH-level). The rate flow was set at 316 liter pr hour pr column. The testing program is summarized in Table 3.

Testing of water	Continuous measurements	pH Conductivity Temperature Added HCl content	pH 4 og pH 7 100-200 µS/cm 15˚C ml (registration)	Every 10 minutes.
	Regular (frequent) measurements	Water samples	Analysis of content of K, Ca, Na, Mg, Al og Si.	1pr hour the first day, 2 pr day and finally once a week. No parallel samples.
Testing of the material	Periodical measurements	LA-test Density and water absorption Cement paste content	3 x 6 kg 3 x 5 kg 2 x 2 kg	Every 6 months. 3 parallel samples for LA-test, density and water absorption. 2 parallel samples for cement paste content.

* LA-test are performed on the original grain size distribution, relevant as a comparison only

Table 3: Test program for accelerated water deterioration

4.4 Preliminary results

This test started in early spring of 2004, and no measurements on water or material samples have been carried out yet. Only reference properties of the material, before placement in the laboratory rig, have been determined.

One can expect that porosity of the material increases, resulting in higher water absorption and lower density. Consequently, the mechanical properties (as measured by the comparative LA-test) can be expected to be poorer. An interesting observation that can be done is that the material in the columns with acid content has already sunk by approximately 10 %, probably due to the deterioration of the mortar phase in concrete particles.

5. CONCLUSIONS AND FUTURE WORK

Recycled concrete aggregate seems to have satisfying durability properties for the most common exposure conditions. The composition of the material requires, however, tailored test methods.
Tests of freeze-thaw durability need to include de-icing salts for Nordic climate conditions. Drying the specimens for the calculation of dry mass is suggested performed after the freeze-thaw test, since pre-drying damages the material. In addition, submerged conditions are suggested replaced by water saturated conditions. Applications where the material can be exposed to frost in submerged conditions are suggested avoided.
Acid containing water seems to affect recycled concrete aggregate substantially, probably due to the deterioration of the concrete phase. A laboratory test rig for accelerated testing of water deterioration is expected to give basis for the documentation of changes in material properties such as mechanical strength, density and water absorption.

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