Evaluation of unbound crushed concrete as road building material – Mechanical properties vs field performance

Corresponding author: Joralf Aurstad
Norwegian Public Roads Administration, Trondheim, Norway

Co-authors: Geir Berntsen, Gordana Petkovic
Norwegian Public Roads Administration, Oslo, Norway

ABSTRACT:

Recycled concrete aggregate has recently been introduced in design codes for road construction in Norway, including material specifications. A number of field projects have proven good functional properties and suitability as road construction materials. However, the mechanical properties of the materials are often not in compliance with current specifications. Traditional empirical test methods tend to disqualify secondary, non-homogeneous materials. A proper evaluation should therefore be based on performance-related (functional) tests. The freeze-thaw resistance and the frost susceptibility should also be evaluated in the same respect.

This paper discusses questions concerning performance of recycled concrete aggregate as road building material and focuses on the following aspects:

- Suitability of tests for mechanical properties
- The influence of fines in bearing capacity
- Frost susceptibility of recycled concrete aggregate

This is done with reference to a field trial at highway E6 south of the city of Trondheim, Norway. In this road, constructed 2003-2004, crushed concrete was used as sub-base layer in a pavement designed for rather heavy traffic (ADT > 10000).

Several field and laboratory tests were conducted before, during and after construction of the trial sections. The field tests have been compared with both empirical (old) and functional (new) laboratory tests, including large-scale cyclic tri-axial tests. The effects of the crushed concrete fines have also been studied by frost susceptibility tests in the laboratory.

The road will be followed up by frequent field measurements (bearing capacity, rutting, evenness etc). These data, both from field and laboratory investigations, will give valuable inputs to new Norwegian pavement design standards, in which it is important that both the potentials and the possible limitations are taken into account. When knowing how to utilise the materials in best way, further use of recycled/secondary materials is encouraged.

This work is conducted as a part of the 4-year “Norwegian Roads Recycling R&D Program” of the Norwegian Public Roads Administration, currently being finalized. The main objective of this program is to facilitate more frequent and environmentally safe applications of recycled materials in road construction.

KEY WORDS: Crushed concrete, functional behaviour, test methods

1 RECYCLED CONCRETE AGGREGATE IN NORWAY

Approximately 1,5 mill tons of construction and demolition waste (C&D) is generated every year in Norway, of which an estimated 1,1 mill tons is concrete and masonry rubble. This corresponds to 2 % of the total annual aggregate production. The main focus of the Norwegian recycling effort has been on the concrete and masonry rubble and the production of recycled concrete aggregate (RCA). Although it resembles and is mostly used as a substitute for natural aggregate, the composition of RCA gives this material some special characteristics (low particle density, high water absorption etc). As experience has shown in other countries, unbound application in road and highway construction is expected to be the most common and most profitable area of use.

In 2004 recycled concrete aggregate was included in the new edition of Norwegian guidelines for road construction as a construction material for road sub-base, base and trenches. As a part of this R&D effort, different engineering concerns such as mechanical properties, freeze-thaw durability, chemical degradation etc. has received considerable attention.

This paper presents a summary of the most important results related to strength and durability characteristics of RCA from recent laboratory and field investigations.
The major work has been conducted by the 4-year “Norwegian Roads Recycling R&D Program” of the Norwegian Public Roads Administration (NPRA), currently being finalized. The main objective of this program has been to facilitate more frequent and environmentally safe applications of recycled materials in road construction [1].

2 LABORATORY VS FIELD PERFORMANCE

In Norway, recycled concrete aggregate has recently been introduced in design codes for road construction, including material specifications. The RCA is classified in two main types based on composition: Type 1 (crushed concrete) and Type 2 (“mixed materials”). Each of these types is divided in a class for bound use and a class for unbound use.

A number of field projects have revealed good functional properties (proven suitability), despite the fact that the mechanical properties of the materials in many cases do not comply with specifications concerning mechanical strength. Many traditional test methods for mechanical properties are clearly not suitable for this kind of materials. A proper evaluation should therefore be based on performance-related (functional) tests, testing the layer properties, not only aggregate strength. This also includes long term durability properties such as freeze-thaw and chemical resistance.

3 INVESTIGATION OF MECHANICAL PROPERTIES FOR UNBOUND USE OF RCA AT MELHUS TEST ROAD

Mechanical properties for unbound use of RCA have been particularly investigated at the Melhus test road, constructed 2003-2004 about 20 km south of Trondheim, Norway. Here different unbound RCA materials have been tried out as sub-base layers in a pavement designed for rather heavy traffic (ADT > 10000). Materials with and without fines have been compared (dense-graded 0-100 mm and open-graded 20-100 mm, respectively). A number of field measurements have been conducted, parallel to an extensive laboratory program carried out on the same materials.
More detailed descriptions and results can be found in [1] and [2]. The main conclusions are as follows:

Laboratory results

Water absorption: Tests reveal considerable porosity in the aggregates that should be compensated by abundant water addition to improve workability and compactability and also reduce crushing and disintegration during construction.

CBR: CBR-tests reveal good bearing capacity/shear strength, CBR = 120-130.

Triaxial tests: Elastic stiffness and deformation resistance have been investigated by use of a large-scale dynamic triaxial test apparatus. The results reveal high elastic stiffness values compared to ordinary gravel or crushed rock materials; E = 350-650 MPa (with highest values for the open-graded material). Regarding deformation properties, these results were also higher/better than for natural/ordinary materials (here also the open-graded specimens got the highest values). This implies high stability and good permanent deformation resistance for the RCA sub-base.

Tests conducted on samples stored 100 days after compaction revealed a substantial increase in both stiffness and permanent deformation resistance. This was most evident on the dense-graded 0-100 mm material (with fines).

Field behaviour

Bearing capacity: Falling weight deflectometer (FWD) measurements on the road 1½ year after construction have shown substantial increase in stiffness on the crushed concrete sections. This is most evident on the section with 0-100 mm material, where back-calculations give crushed concrete E-moduli in the order of 800-900 MPa. This complies with the laboratory findings.

Evenness: Laser measurements on the road 1½ year after construction reveal very satisfying surface conditions; IRI (International Roughness Index) = 0,5-1,0.

Conclusion: According to the results from the test road, recycled crushed concrete should perform excellent as unbound sub-base layers, even on rather high volume roads.

4 FROST SUSCEPTIBILITY

4.1 Frost heave properties

Water absorption and frost heave may cause severe damages on highway construction elements, and bearing capacity reductions and accelerated pavement distresses can be a big problem. Thus, controlling the frost susceptibility of the road building materials is a crucial matter in the Nordic countries.

To what extent crushed concrete materials may be frost susceptive has been a matter of discussion, so far there have been limited experiences with these materials in road construction in Norway.

As part of the NPRA Recycling R&D Program, some dense-graded crushed concrete materials, included the materials used at Melhus test road, were tested with respect on frost heave properties. In this particular study, the development of ice lenses during a 96 hours laboratory freezing test was used as a measure of the materials frost susceptibility.

The results have been compared to different frost heave criteria based on grain size distribution of the same materials. An evaluation of the frost heave tests together with the grading criteria is shown in table 1.

Table 1: Frost heave classification of crushed concrete materials

Material	Frost heave classification [1]					
	Grading criteria				Frost heave tests	
	Casagrande	Beskow	Nordal	USCS [2]	New samples	Cured samples [3]
Melhus 0-20 mm	T1/T2	T1	T1/T2	T1/T2	T3/T4	-
Melhus 0-10 mm	T1/T2	T1	T2	T1/T2	T3	T3/T4
BA Gjenv 0-11 mm	T1	T1	T1	T1	T2/T3	T2/T3
Silt Klæbu (ref)	T4	T4	T4	T4	T2/T3	T3/T4
Sand Ramlo (ref)	T1	T1	T1	T1	T1	-

[1] *T1 = Frost proof, T2 = slightly susceptible, T3 = medium susceptible, T4 = frost susceptible*
[2] *Unified Soil Classification System*
[3] *Cured for 100 days after compaction, 5 °C, ca 100 % relative humidity*

The results show some variations, but the recycled concrete materials tend to appear more frost susceptible than what could be expected when just looking at the grading curves.
The consequences of possible frost heaves should therefore be taken into concern when these materials are used.

4.2 Frost durability

Due to the composition and the porosity, the water absorption levels will be much higher in RCA than in natural aggregates. A closer testing of the frost properties will therefore be necessary in cases when frost susceptibility is a relevant property for the chosen application.
The standard method for testing frost durability of aggregates (disintegration) is freeze-thaw test according to NS-EN 1367-1. The testing consists of exposing aggregate to freeze-thaw cycles in de-ionized water or in 1 % NaCl solution.

Nordic cooperating projects (NORDTEST) have recently been carried out to evaluate and modify these procedures for Nordic conditions. On the basis of the findings from these investigations, the following modifications of the standard freeze-thaw test NS-EN 1367-1 have been suggested for porous aggregates, including RCA:

- 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 seems unnecessarily severe for RCA and leads to conclusions about poor frost properties.
  Therefore, 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.
- Use of salts is an important road maintenance effort for Nordic conditions. Thus, 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. (Norwegian guidelines for road construction do not recommend use of recycled concrete aggregate in applications where freezing could occur in submerged conditions.)

The modified test method is now being implemented in NPRA's manual for laboratory testing.

5 CONCLUSIONS

Unbound crushed concrete aggregates seem to perform very well as base and sub-base materials, even on rather high volume roads. Both elastic stiffness and stability are high compared to traditional gravel and crushed rock materials tested in the laboratory. This implies high bearing capacity and good permanent deformation resistance.

The laboratory results have been confirmed by field measurements, showing very high bearing capacities and layer stiffnesses for the RCA materials.

The consequences of possible frost heaves should be taken into concern when these materials are used. Norwegian guidelines for road construction do not recommend use of recycled concrete aggregate in applications where freezing could occur in submerged conditions.

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.

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