USE OF ASR DAMAGED CONCRETE PAVEMENTS AS RECYCLED AGGREGATES IN ROAD CONSTRUCTION

VERWENDUNG VON AKR-GESCHÄDIGTEN BETONFAHRBAHN-DECKEN ALS RECYCLIERTE GESTEINSKÖRNUNG IM STRAßENBAU

Oliver Mielich

Materials Testing Institute (MPA), University of Stuttgart, Otto-Graf-Institute

SUMMARY

This report presents results of the recently closed research project No. 06.0111/2015/FRB "Diagnosis, break-up, processing and utilization of ASR damaged concrete pavement" carried out at the request of the Federal Ministry of Transport and Digital Infrastructure, represented by the Federal Highway Research Institute [1]. Results gained from lab tests, existing surfaces and scientifically monitored new construction work reveal that use in unbound base layer (acronym in German: ToB) has no negative impact if subsequent ASR can be excluded. In contrast to that, use of RC-ASR material (resultant recycling material from ASR-damaged concrete pavement) for hydraulically bound base layers (acronym in German: HGT) cannot be recommended.

ZUSAMMENFASSUNG

Der vorliegende Bericht stellt Ergebnisse des kürzlich abgeschlossenen Forschungsvorhabens Nr. 06.0111/2015/FRB "Diagnose, Aufbruch, Aufbereitung und Verwertung von AKR-geschädigten Betonfahrbandecken" vor, das im Auftrag des Bundesministeriums für Verkehr und digitale Infrastruktur, vertreten durch die Bundesanstalt für Straßenwesen, durchgeführt wurde [1]. Ergebnisse, gewonnen aus Laborversuchen, Bestandsflächen und an einer wissenschaftlich begleiteten Neubaumaßnahme zeigen, dass der Einsatz in einer ungebundenen Tragschicht keine negativen Auswirkungen hat, wenn eine spätere AKR ausgeschlossen werden kann. Im Gegensatz dazu kann eine Verwertung von RC-AKR-Material in hydraulisch gebundene Tragschichten nicht empfohlen werden.

1. INTRODUCTION

The road is regarded as Germany's main mode of transport and ensures mobility of people and goods. Approximately 28% of the 13,009 km network of German federal highways is constructed in concrete. Concrete construction promises high load-bearing capacity and deformation stability, even at very high temperatures. In addition, concrete pavement is also judged to have a long service life - a service life of 30 years is usually assumed.

However, a problem has currently arisen regarding this network of German federal highways. The planned 30-year service life of concrete pavements constructed before 2005/2006 will not be achieved. Aggregates with an ASR sensitivity were used in part for these concrete road pavements. This has resulted in quite pronounced ASR damage today. Obvious signs of damage, usually beginning with discoloration in the transverse and longitudinal joints, corner fractures or longitudinal cracks in the slab, occur after 7 to 15 years [2, 3].

Fig. 1: Pavement surface of a highway associated with ASR (discoloration in the transverse and longitudinal joints, asphalt plombs in the edges)

When disassembling ASR damaged concrete, one negative impact is that resultant recycling material (RC-ASR material) is unsuitable for construction of new concrete pavements. Therefore, it must be clarified whether and under what conditions the demolished material obtained during the removal process can be used as secondary raw material in base layers without binding agents (acronym in German: ToB) or hydraulically bound base layers (acronym in German: HGT).

2. METHODICAL APPROACH

When utilizing ASR-damaged concrete pavements, a holistic assessment is required. The times before (diagnosis and breaking-up), during (processing) and after the breaking up the concrete pavement (utilization) have to be considered. Prior to breaking-up, concrete pavement is to be examined and assessed with regard to

- visual damage [3],
- concrete properties (compressive strength, elastic modulus, tensile strength) [4]
- and ASR-related residual damage potential [5, 6].

RC-ASR material resulting from breaking-up and processing has a special feature with regard to utilization planned compared to concrete recycling without damage (RC material). Even after breaking-up and processing, conditions still exist which may lead to a subsequent alkali-silica reaction. The following conditions exist which need to be considered in examinations:

- Existence of an aggregate classified as alkali-sensitive
- Existence of new reactive fractured surfaces of the broken aggregate
- Alkalis in the hydrated cement paste (from the binding agent)
- Alkali stored in the hydrated cement paste (from input of de-icing salt during use)
- Moisture (stored via input when watering for compression of a ToB and drainage when using as ToB)
- De-icing salt input (via joints) when using as ToB or HGT.

In addition to requirements included in rules and state-specific requirements for recycling material, the following should at least be identified after processing for RC-ASR material:

- particle size distribution,
- determination of resistance to fragmentation,
- the CBR (California-Bearing-Ratio) value
- and fatigue bending tensile strength for HGT application.

The time after processing is defined by requirements for bound (HGT) and unbound base layers (ToB). Requirements of a ToB include bearing capacity, water permeability and capillary-breaking effect. A hydraulically bound base layer (HGT) should be sufficiently bearing and frost-resistant.

3. TESTING PROGRAM

3.1 LABORATORY TESTS WITH RC-ASR MATERIAL FOR TOB

When assessing an ASR-damaged concrete pavement and considering the respective construction, it can be assumed that the old concrete does not necessarily originate from the same old material. Different stiffnesses (E-modules) of the old concrete have to be assumed for ASR-damaged road surfaces which may deviate considerably within one concrete slab. Deviations of up to 50% have been recorded for the elastic modulus [4]. Asphalt plombs (see Fig. 1) and partially large asphalt surfaces from previous maintenance work must also be considered.

Examinations of the break-up material prepared with an impact crusher with downstream screening system to the RC-ASR material showed that requirements resulting from technical rules and state-specific regulations could be observed. The scope of testing after processing includes definition of particle size distribution, material composition (e.g. share of asphalt granulate), fines, particle shape, purity, resistance to frost-de-icing change, volume stability, proctor density and ideal water content, environment-related properties as well as water permeability.

In addition to the scope of testing specified, two other tests have to be considered, which are of special significance in the context of damaging ASR. The damaging ASR reduces stiffness via dissolution processes and cracking in the alkali-sensitive aggregate [7]. Two criteria which accurately record such impact after processing in an impact crusher are determination of resistance to fragmentation as well as the California-Bearing-Ratio test (CBR test), which describes the bearing capacity of base layers as a lab test.

In accordance with TL Gestein-StB 04/07 [8], Annex E, determination of resistance to fragmentation is to be defined in the scope of application for layers without binding agents. In laboratory tests, determination of resistance to fragmentation occurred in accordance with EN 1097-2 [9]. All impact test values identified in the lab for RC-ASR material, $SZ_{8/12.5}$, observe the requirements in accordance with TL Gestein-StB 04/07 [8] as well as requirements of state-specific rules. This shows that ASR-caused cracking in the aggregate is negligible for the subsequent impact test by means of high-energy processing in the impact crusher.

In accordance with TL SoB-StB 04/07 [10], the CBR test, in accordance with EN 13286-47 [11], is to be determined for construction material mixes 0/32 for crushed-stone base layers beneath concrete pavement after separation of a share of > 22mm at construction material mix 0/22 after 4h water immersion. However, as already explained, since damaging ASR reduces stiffness as a result of dissolving processes and cracking in the aggregate, the CBR test should also be executed in RC-ASR material if this has been included in an anti-frost layer. The limit of above 80% was reached for all samples examined in delivery status (after processing) and after 24h water immersion so that using the material as a base layer without binding agent is possible due to the respective bearing capacity. In comparison, higher CBR values were reached with natural aggregate than with RC-ASR material. Finally, it can be also concluded for the CBR test that high bearing capacity characteristics can be achieved via high-energy processing despite ASR-caused loss of stiffness in the aggregate.

Both tests are therefore decisive for the assessment of RC-ASR material and must always be applied for the application of ToB (anti-frost layers and crushed-rock layers).

3.2 LABORATORY TESTS WITH RC-ASR MATERIAL FOR HGT

On account of its aggregate properties, RC-ASR material in principle has potential for use in a hydraulically bound base layers (HGT). Appropriate classification to observe or set characteristic values in accordance with standard is quite possible [12].

As already established in examinations executed by Hünger and Börner [12], compressive strengths are achieved in HGTs with RC-ASR material which make the recycling material appear interesting for HGT application. A change in ambient conditions (increased temperatures up to 40°C, high humidity up to 100%) does not affect the respective strengths. In fact, an increase in strength is recorded resulting from favourable temperature and humidity conditions via subsequent hydration. A similar behaviour was identified for the elastic modulus.

In contrast to examinations executed by Hünger and Börner [12], no restrictions result from length changes of HGT samples produced with RC-ASR material. The level of strain of ASR applied subsequently at temperatures up to 40°C and humidity of up to 100% can be classified as low for hydraulically bound bases made with RC-ASR material using Portland cement with $Na_2O_{eq.} \leq 0.76$ M.-%.

According to [13], it is necessary to define the decisive strength property when executing fundamental examinations for the re-use of RC material, i.e. bending tensile strength. Since traffic loads occur as repeated loads, it is therefore necessary to define the fatigue bending tensile strength (more than 2 million load changes are endured without fracture).

Bending beams with the dimensions 15 x 15 x 70 cm^3 are suitable specimens to define the fatigue bending tensile strength. Dynamic fatigue tests were carried out on these bending beams at an age of 60 days and storage in the 40°C fog chamber (to exclude differing subsequent hardening). Load was applied via two linear loads of equal size in the third points at a span of 600 mm. The bending beams were protected from drying during the test by means of foil wrapping. Minimum stress was selected at σ_u = 0.10 N/mm² and test frequency at 3.33 Hz. Maximum tension σ_o was defined respectively at 50% of the static bending tensile strength (σ_{BZvor}) at an age of 60 days. Fatigue tests were also carried out, with the same limiting conditions, on bending beams stored in the 40° C fog chamber for a period of 270 days.

Fatigue tests carried out in the lab showed that a large share of variants examined did not endure two million load changes without fracture. One possible cause could be that adhesive strength of the RC-ASR material (for new fractured surfaces) to the hydrated cement paste structure is reduced via ASR with subsequent effect. This hypothesis is supported in that gel-like products were found on the bending beams of 15 x 15 x 70 cm^3. Due to the resultant point-by-point bonding, local stress concentrations are generated which lead to failure of the overall cross-section in case of a bending load.

It is also important whether a concrete road surface contains alkali-sensitive aggregate across the entire surface thickness or if this only exists in the top concrete layer or the bottom concrete layer. In cases where alkali-sensitive aggregate is to be found across the entire surface thickness, reduced adhesive strength of RC-ASR material with the hydrated cement past can be assumed. If alkali-sensitive aggregate is only to be found in the top concrete layer (approx. 1/3 of the surface thickness), better adhesive strength can be assumed. Examinations into cases in which alkali-sensitive aggregate only exists in the bottom concrete layer (approx. 2/3 of the surface thickness) have not yet been executed.

3.3 CASE STUDY WITH RC-ASR MATERIAL

Visual inspection of the surface of base layers applied without binding agents indicate that separation of the RC material cannot be permanently avoided. However, separation was also identified for new construction work in which natural aggregates were applied. Results of bearing capacity measurements with static and dynamic plate load testers on top of crushed-rock layers as well as bearing capacity measurements with the Falling Weight Deflectometer on top of crushed-rock layers (see Fig. 2) and on top of new concrete indicate that consistent bearing capacities in bases without binding agents can also be achieved using RC-ASR material.

The E_{V2} value of 150 MN/m² required by ZTV SoB-StB 04/07 [14] can be achieved with standard compacting machines. The limit for the ratio value $Ev_2/E_{v1} \leq 2.2$ or for $E_{v1} \geq 0.6\% \cdot E_{v2,target}$ (when $E_{v2}/E_{v1} \geq 2.2$) can also be observed. However, problems may arise in fulfilling such requirements if the layers beneath the ToB do not record sufficient bearing capacity values or if the base layer itself is not sufficiently compacted. However, such problems arise irrespective of whether mixes originate from natural aggregate, recycling material of crushed concrete or from ASR-damaged concrete pavements.

Fig. 2: Determination of the bearing capacity with the Falling Weight Deflectometer (FWD) on the top of an unbound base layer with RC-ASR material

Fig. 3: Plate load test for determination of the E_{V2} and E_{v1} on a surface of an unbound base layer with RC-ASR material

Deformations which are unavoidable due to construction traffic prior to the placing of concrete should be levelled out or rolled. However, deformations occur irrespective of whether mixes originate from natural aggregate, recycling material of crushed concrete or from ASR-damaged concrete pavements. Prior to placement of concrete it must be ensured that the ToB is not dry. Otherwise there is a risk that water will be removed from the lower section of the concrete placed.

3.4 ASSESSMENT OF EXISTING ROADS WITH RC-ASR MATERIAL

In the new federal states, a base layer without binding agents made of recycling material from ASR-damaged road paving concrete was constructed for the first time on a motorway section of the BAB A24 in 1995/96. FWD measurements carried out in 2017 on this section revealed that the good bearing capacity of ToB when constructed led to an increase in bearing capacity after decades of service life. This can be explained by the subsequent hardening potential of RC material. Comparative field tests have shown that RC material had bearing capacity compared to natural aggregates. However, when RC material is used in base layers without binding agents, it can have a negative impact on water permeability. Damage resulting from a change in bearing conditions in the absence of erosion-resistant and frost-proof support, compacting defects or from insufficient drainage in the base were not identified on the motorway section on the A24 with crushed-stone base layers of RC-ASR material or on other motorway sections with RC material.

4. SUMMARY

Application of recycling material from ASR-damaged concrete pavement in base layers without binding agents (acronym in German: ToB) and hydraulically bound base layers (acronym in German: HGT) in road construction can provide a considerable contribution to conservation of resources of natural aggregates. Therefore, an integral assessment is also required. This includes diagnosis, breaking-up, processing and utilization itself [1].

In addition to the impact from temperature and humidity, ASR-caused damaging processes can also have a negative effect on the longitudinal expansion development of concrete roads. This is the case when the damaging process takes effect across the entire concrete thickness or only in the bottom concrete layer. Damaging processes in the bottom concrete layer are not typified by colour changes in the joint areas as an indication of the onset of ASR, but by longitudinal cracks in roadway slabs and diamond-shaped cracking in joint areas which indicate potential collapse [2, 3]. Longitudinal expansion development also results in an overall stress condition in the concrete roads which has to be reduced by means of appropriate break-up technology [15].

An impact crusher with downstream screening system is best suited for high-energy and targeted processing without subsequent treatment with properties which comply with requirements for recycling material.

The following results for the utilization of recycling material from ASR-damaged concrete pavement in base layers without binding agents (ToB) were derived in the laboratory, from tests on existing roads and from scientifically monitored new construction work:

- If subsequent ASR development in an unbound base layer can be excluded, utilization in a ToB has no negative impact on bearing capacity.
- In addition to the high bearing capacity resulting from the application of RC material of ASR-damaged concrete pavement, an increase in bearing capacity during service life can also be expected.
- Potential negative effects on water permeability or capillary-breaking effect on base layers without binding agents have to be considered.

- If, after breaking-up and processing, state-specific requirements and requirements resulting from technical use for the recycling material are observed, use of recycling material of ASR-damaged concrete pavement is possible.

In each case and independent of the use in an unbound base layer (anti-frost layers or in crushed-rock layers), the following additional laboratory tests must be carried out on RC-ASR materials:

- Determination of resistance to fragmentation according to EN 1097-2 [9]
- Determination of California bearing ratio according EN 13286-47 [11] in connection with TL SoB-StB 04/07 [10].

Use of recycling material of ASR-damaged concrete pavement is possible, if the following limit values are observed:

- $SZ_{8/12.5} \leq 32$ M.-%
- CBR value ≥ 80 %

It should be mentioned that the above findings could not be applied to airfields operating areas. The reasons are the use of alkali de-icing agents based on alkali acetate and alkali formiate. These de-icing agents lead to other ASR-damaging processes in concrete as de-icing agents on basis of NaCl.

The following can be derived from lab tests on the use of recycling material of ASR-damaged road surface concrete in hydraulically bound base layers (HGT):

- Gel-like reaction products were identified on some cylinders and bending beams produced.
- An impact on compressive strength and elastic modulus when storing at temperatures of 40 °C and humidity of 100% could not be identified.
- The level of strain of subsequent onset of ASR can be classified as low for hydraulically bound base layers examined with RC-ASR material using Portland cement $Na_2O_{eq.} \leq 0.76$ M.-%
- However, if adhesive strength of the RC-ASR material to the hydrated cement paste is damaged by way of subsequent onset of ASR, the resultant increase of point-by-point bonding and local stress concentrations may cause failure to the entire cross-section in case of bending stress.
- Failure in a dynamic fatigue test was identified in samples with RC-ASR material from concrete pavement, for which the top layer of concrete as well as the bottom layer of concrete were classified as alkali-sensitive.

Results recorded up to now indicate that use of RC-ASR material for hydraulically bound base layers cannot be recommended.

NOTE

This report is based on parts of the research project carried out at the request of the Federal Ministry of Transport and Digital Infrastructure, represented by the Federal Highway Research Institute, under research project No. 06.0111/2015/FRB. The author is solely responsible for the content.

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