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#### SUMMARY

A European comparison shows that recycled water is used to differing extents in ready-mixed concrete plants. Some basic questions about the use of recycled water in readymixed concrete plants in different countries were therefore examined again in a European research project. Recycled water was sampled in various ready-mixed concrete plants and then concentrated in the laboratory up to and beyond the limits given in EN 1008 for the density and solids content. The fresh and hardened concrete properties of concretes produced with and without recycled water were compared. Rising density of the recycled water used leads, among other things, to a higher water and admixture demand, increased early strength and increased scaling in the freeze-thaw test for concretes without artificial air voids. No significant changes were found with respect to the 2-day to 28-day strengths of air-entrained concrete or high-strength concretes or to the freeze-thaw resistance of concretes containing artificial air voids. Within the limits set by EN 1008, recycled water could therefore also be used in high-strength concretes and concretes containing artificial air voids.

#### ZUSAMMENFASSUNG

Die Nutzung von Restwasser in Transportbetonwerken findet im europäischen Vergleich in unterschiedlichem Umfang statt. In einem europäischen Forschungsprojekt wurden daher einige grundlegende Fragen der Restwassernutzung in Transportbetonwerken noch einmal grenzübergreifend untersucht. Hierzu wurde Restwasser in verschiedenen Transportbetonwerken beprobt und im Labor auf den in EN 1008 genannten Grenzwert der Dichte bzw. des Feststoffgehaltes sowie darüber hinaus konzentriert. Die Frisch- und Festbetoneigenschaften von Betonen mit und ohne Restwasser wurden verglichen. Die Verwendung von Restwasser führt mit steigender Dichte des eingesetzten Restwassers u.a. zu einem höheren Wasser- bzw. Zusatzmittelanspruch, zu einer erhöhten Frühfestigkeit sowie zu einer erhöhten Abwitterung im Frostversuch bei Betonen ohne künstliche Luftporen. Keine signifikanten Änderungen konnten festgestellt werden bezüglich der 2d- bis 28d-Festigkeiten von Luftporenbeton oder hochfesten Betonen sowie des Frostwiderstandes von Betonen mit künstlichen Luftporen. Der Einsatz von Restwasser in den von der EN 1008 festgelegten Grenzen wäre daher auch in hochfesten Betonen und Betonen mit künstlichen Luftporen möglich. 4

Figure 1: Setting times

# **Re-use of recycled water in the production of air-entrained and high strength concretes**

Wiederverwendung von Restwasser in der Herstellung von Luftporen- und hochfesten Betonen

#### **1** Introduction

The research project investigated whether the restrictions applying in all three countries involved to the use of recycled water for air-entrained and high-strength concretes at ready-mixed concrete plants are justified or could be lifted. In addition, a stipulation in Belgium states that recycled water can only be used for the production of concrete if it does not contain any solids. The CRIC is therefore also interested in finding out whether non-filtered recycled water containing solids can be used for the production of all concretes and how high the admissible maximum solids content of the recycled water may be. The third aspect examined was the influence of any admixtures, and particularly retarders, present in the recycled water on the suitability of recycled water for the production of concrete.

#### **2 Experiments**

#### 2.1 General

Experiments were conducted both with artificial recycled water in accordance with CUR 28 to investigate the influence of retarders and also with real recycled water from ready-mixed concrete plants.

#### 2.2 Artificial recycled water

Six samples of artificial recycled water conforming to CUR 28 were produced with various retarders. The following constituents were mixed and stored for 16 hours at  $(20 \pm 2)$  °C:

- One part CEM I 52,5 N in accordance with EN 480-1 (1.35 kg),
- Two parts CEN standard sand in accordance with EN 196-1 (2.70 kg corresponds to two bags of standard sand),
- Three parts tap water (4.05 kg),
- Retarder in the maximum concentration specified in the applicable data sheet.

Following storage, the mixtures were manually shaken for

30 seconds and subsequently sieved through a 2 mm screen.

The (artificial) recycled water was then filtered.  $(24 \pm 2)$  hours

after filtration, the artificial recycled water samples were used to produce cement pastes in accordance with EN 196-3 and mortars in accordance with EN 196-1. Use was made of CEM I 52,5 N cement in accordance with EN 480-1. Tap water was used to produce a reference mixture. The setting times were determined on the basis of EN 196-3. The results are shown in **)** Fig. 1. The compressive strength of the mortars was determined after 2, 7 and 28 days in accordance with EN 196-1. **)** Fig. 2 shows the results.

The use of artificial recycled water in accordance with CUR 28 had no significant influence on water demand, setting times or strength development. All subsequent experiments were therefore conducted with real recycled water.

#### 2.3 Real recycled water - sampling and analysis

Samples of recycled water were taken at three ready-mixed concrete plants. Sampling at the plants was performed once in winter (W) and once in summer (S), so that a total of six recycled water samples were analysed for testing with mortar. Instead of summer sampling at one ready-mixed concrete plant, a recycled water sample was taken from the concrete laboratory sedimentation tank at VDZ. In addition to the recycled water samples for the mortar tests, a sample of recycled water for the concrete tests ("B") was also taken from one of the same ready-mixed concrete plants. Following collection, the recycled water samples were stored in 120 I vessels at  $(20 \pm 2)$  °C. A paddle mixer was used to keep the samples constantly in motion at a speed of around 1000 rpm to largely prevent sedimentation.

The recycled water was analysed in accordance with EN 1008. The results are shown in **)** Table 1. The comparatively high concentrations of chlorides and alkalis in the recycled water from VDZ can be attributed to the fact that sampling was performed in the sedimentation basin prior to chemical neutralisation. This basin is also used for the disposal of fluids employed in freeze-thaw tests with de-icing agent (alkalis, chlorides) and chloride migration and diffusion tests (chlorides), as well as in ASR tests (alkalis).





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#### Table 1:Analysis of the recycled water

Measured value	Unit	1(W)	2(W)	3(W)	1(S)	3(S)	VDZ	В
Oils and fats	-	Traces	Not present					
Detergents	-		Not present Present Not present				Not present	
Colour	-	Pale yellow	Colourless	Pale yellow	Colourless			
Odour	-		Like cement					
Acids (pH)	-	12.6	12.6	12.5	12.6	12.6	12.3	12.6
Humic matter	-	Not present						
Chlorides	mg/l	12	18	14	16	27	4620	30
Sulfates	mg/l	2	2	4	3	2	41	3
Na <sub>2</sub> 0-equivalent	mg/l	522	444	946	347	361	3 5 9 4	533
Sugar	mg/l	Not present						
Phosphate	mg/l	< 1	< 1	< 1	< 1	< 1	< 1	4.4
Nitrate	mg/l	1	1	3	5	4	8	1
Lead	µg/l	3	1	4	1	1	0	0
Zinc	µg/l	393	528	175	201	146	199	244
Density of the residual water	g/cm³	1.08	1.07	1.14	1.06	1.04	1.08	Not determined
Density of the solids	g/cm <sup>3</sup>	2.56	2.56	2.51	2.32	2.16	2.23	2.14

## 2.4 Real recycled water – testing with cement paste and mortar

Use was made of CEM I 52,5 N cement in accordance with EN 480-1. Tap water was used to produce reference mixtures. In the test mixtures, use was made of recycled water specimens with defined densities set by way of sedimentation or dilution. As a departure from EN 196-3/EN 196-1, the quantity of superplasticiser (SP) required to attain a constant flow value of (140  $\pm$  10) mm in accordance with EN 1015-3 was added to each of these.

The water demand was determined according to EN 196-3. **)** Fig. 3 shows the results. The water demand increases as the density of the recycled water increases. This can be partially offset by the use of superplasticisers.

The compressive strength of the mortars was determined after 2, 7 and 28 days in accordance with EN 196-1. Fig. 4 shows the results. The use of recycled water had no significant influence on strength development. An exception to this was the "VDZ" recycled water. According to EN 1008, this recycled water would however not be approved for the production of concrete.

#### 2.5 Real recycled water – compressive strength and durability of concrete

#### 2.5.1 General

For the concrete experiments, a further recycled water sample "B" was taken from a ready-mixed concrete plant. This recycled water was set to two different densities:

- Density corresponding in accordance with EN 1008 to around 1 mass % of the aggregate in the concrete (around 1.06 g/cm<sup>3</sup>) and
- ) 1.15 g/cm<sup>3</sup>.

Three concretes and one mortar () Table 2) were each produced with tap water and with recycled water in the two

given concentrations. The grading curve for the concretes B1 to B3 was set in accordance with EN 480-1 and DIN 1045-2 (A16/B16). Use was made of a PCE-based superplasticiser.

#### 2.5.2 Fresh concrete properties

The fresh concrete properties of the concretes B1 to B3 are shown in ) Figs. 5 to 9. To determine the influence of time, temperature and recycled water density on consistency development for the concrete formulation B2, 3 batches of around 10 litres of concrete each were transferred to sealable PE buckets immediately following production at  $(20 \pm 2)$  °C. One bucket was stored at  $(10 \pm 2)$  °C, one at  $(20 \pm 2)$  °C and one at  $(30 \pm 2)$  °C. The flow value was checked in accordance with DIN EN 12350-5 after 10, 30, 60, 90 and 120 min.

The amount of admixture required to set a constant flow value or air content increases with increasing recycled water density (see Figs. 5 and 6). In addition, a loss of consistency can be seen to start earlier as the recycled water density increases (see Figs. 7 to 9). No significant relationship with temperature could be observed.

#### 2.5.3 Concrete compressive strength

The 1, 2, 7 and 28-day concrete compressive strength was determined in each case using three cubes with an edge length of 150 mm in accordance with DIN EN 12390-3. **)** Figs. 10 and 11 show the results. The use of recycled water leads to an increase of around 15 % to around 50 % in the 1-day strength of all three concretes. With concrete B1, an increase of around 20 % can be observed for the other test ages as well. The 2 d to 28 d strengths of the concretes B2 and B3 with recycled water are in a range  $\pm$  10 % of the corresponding concrete strength without recycled water.

#### 2.5.4 Carbonation

The carbonation resistance was determined in accordance with DIN EN 13295 with a  $CO_2$  concentration of 1 % for concrete B1. For this purpose, three bars measuring





SP = Superplasticizer

SP = Superplasticizer





Table 2: Concrete/mortar mix formulations

	Unit	B1 Reference concrete	B2 Concrete with artificial air voids	B3 High strength concrete	MS Mortar for testing the sulfate resistance
Cement	kg/m <sup>3</sup>	300	340	430	450 <sup>*)</sup>
Silica fume	kg/m <sup>3</sup>	-	-	30	-
w/c	-	0.60	0.45	0.31	0.50
Target air content	Vol. %	-	5.0 ± 0.5	-	-
Target consistency class	-	F3/F4	F3/F4	F4	-
Aggregate	_	Sand, Rhine gravel	Sand, Rhine gravel	Sand, Rhine gravel	Standard sand

\*<sup>)</sup> g/mortar mix

100 mm x 100 mm x 500 mm were produced and put into preliminary storage in accordance with DIN EN 13295, Annex A 1.2. The carbonation depth was tested after 14, 28 and 56 days storage at a temperature of  $(20 \pm 2)$  °C, with  $(65 \pm 5)$  % relative humidity and 1 % CO<sub>2</sub> concentration. **)** Figs. 12 and 13 show the results.

Fig. 12 shows a decreasing rate of carbonation between 28 d and 56 d for the concretes with recycled water. This profile indicates errors in the testing procedure. The  $CO_2$  concentration in the climatic chamber could have dropped without being noticed, for example. The rate of carbonation was therefore obtained for the 56<sup>th</sup> day by way of interpolation

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Figure 5: Flow value of the concretes, determined after 10 minutes, and quantities of admixtures required

based on the curves for all three concretes up to the 28<sup>th</sup> day. For the reference concrete this then yields a negligible difference from the actual measured value. The carbonation depths were calculated from the carbonation rates of the concretes with recycled water (Fig. 13). This result indicates that the use of recycled water leads to a greater carbonation depth (16 % and 44 %). As, in contrast to concrete with recycled water of density 1.15 g/cm<sup>3</sup>, concrete with recycled water of density 1.06 g/cm<sup>3</sup> is permissible in Germany, only the 16 % increase in carbonation depth is to be evaluated. Within the scope of accuracy of the testing procedure, this can be classified as being minimal.

#### 2.5.5 Freeze-thaw resistance with de-icing salt

The 28-day freeze-thaw resistance with de-icing salt of the concretes B2 and B3 was tested in accordance with CEN/TS 12390-9 employing the slab test method. Use was made of a 3 % NaCl solution as test fluid. **)** Fig. 14 shows the results. For concretes with artificial air voids (B2), no significant dependence of the freeze-thaw resistance with de-icing salt on the density of the recycled water used can be seen. In the freeze-thaw experiment without artificial air voids (B3), the concretes with recycled water exhibit far greater scaling than the reference concrete. The scaling is however below the limit value of 1 kg/m<sup>2</sup>.

#### 2.5.6 Chloride diffusion

The chloride diffusion resistance was tested in accordance with prEN 12390-11:2014 on concretes B2 and B3. In accordance with DIN EN 12390-2, the test specimens (TS) were put into preliminary storage in water at  $(20 \pm 1)$  °C for 28 days. Main storage in a 3 % NaCl solution took place up to an age of 118 days. J Figs. 15 and 16 show the chloride diffusion profiles. J Fig. 17 shows the calculated diffusion coefficients. As expected, the diffusion coefficients of the high-strength concretes with artificial air voids (B2). In the case of air-entrained concretes, the use of recycled water does not produce any change or leads to slightly higher diffusion coefficients. The use of recycled water lowers the diffusion coefficient of high-strength concretes. The reduction was between around 20 % and 55 %.

#### 2.5.7 Sulphate resistance

The sulphate resistance was tested in accordance with CUR 48. Prisms measuring 20 mm x 20 mm x 160 mm were made from standard mortar (MS, Table 2) with tap water or



Figure 6: Air content of the fresh concretes, determined after 10 min, and quantities of admixtures required



Figure 7: Development of the relative flow value of concrete B2 at 10 °C relative to the 20 °C value 10 min after end of mixing



Figure 8: Development of the relative flow value of concrete B2 at 20 °C relative to the 20 °C value 10 min after end of mixing



Figure 9: Development of the relative flow value of concrete B2 at 30 °C relative to the 20 °C value 10 min after end of mixing





Figure 10: Concrete compressive strength

Figure 11: Relative concrete compressive strength

Figure 13: Depth of carbonation of concrete B1







Figure 14: Scaling in the freeze-thaw test with de-icing salt

recycled water with densities of 1.06 g/cm<sup>3</sup> and 1.15 g/cm<sup>3</sup>. Six prisms of each mix formulation were initially stored in water at (20  $\pm$  2) °C. After 28 days, three prisms each were transferred to a solution with (16  $\pm$  0.5) g SO<sub>4</sub><sup>2-</sup>/l. The other three prisms were left in the water.

) Fig. 18 shows the expansion of the test specimens which were stored in the sulphate solution. The use of recycled water with a high density led to greater expansion, whereas the use of recycled water with a density in the range of the limit value set down by EN 1008 did not produce any significant changes in the expansion profile.

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#### Figure 15: Chloride profiles of the B2 concretes





Figure 17: Chloride diffusion coefficients



Figure 18: Expansion behaviour, sulfate storage

#### **3** Summary

### 3.1 Composition of recycled water from ready-mixed concrete plants

The density of the solids suspended in the recycled water lay between about 2.15 g/cm<sup>3</sup> and 2.55 g/cm<sup>3</sup>. The densities of the samples taken in winter tended to be higher than the densities of the samples taken in summer.

No significant fluctuations in chemical composition due the time of year or the plant were detected. However, the alkali content appeared to be somewhat higher in winter – possibly due to the introduction of de-icing agents.

# 3.2 Effect of recycled water on the properties of fresh mortar and concrete

Increasing density of the recycled water used leads to

- ) higher water demand,
- earlier stiffening,
- ) increased admixture requirement.

These effects have to be taken into account when ensuring robust fresh concrete properties that are suitable for construction site conditions and, if necessary, have to be determined during (extended) preliminary tests by the readymixed concrete producer.

#### Figure 16: Chloride profiles of the B3 concretes

### 3.3 Effect of recycled water on the properties of hardened mortar and concrete

Increasing density of the recycled water used leads to

- ) increased early strength,
- higher 28-day strengths for concretes with lower target strengths (in this case B1),
- a slightly lower carbonation resistance when using recycled water in the range stipulated in the standard,
- a significantly lower carbonation resistance when using recycled water beyond the range stipulated in the standard,
- increased scaling in the freeze-thaw test for concretes without synthetic air voids,
- I reduced sulfate resistance when using recycled water with densities that go beyond DIN EN 1008.

No significant changes were detected with respect to

- the 2-day to 28-day strengths of air-entrained concrete or high-strength concretes,
- the freeze-thaw resistance of concretes containing synthetic air voids,
- > the resistance to chloride diffusion.

This means that the results of the research project confirm some of the experience already described in [1]. It therefore also appears that, within the limits laid down in DIN EN 1008, recycled water can basically also be used in high strength concretes and concretes containing synthetic air voids. The influencing factors that have been determined have to be taken into account when ensuring robust fresh concrete properties that are suitable for construction site conditions and, if necessary, have to be determined during (extended) preliminary tests by the ready-mixed concrete producer.

#### 4 Further results

Other results obtained by the VDZ and by CRIC and Smart Minerals, the partners involved in the research project, can be made available on request.

#### **5** Acknowledgements

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#### LITERATURE

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