

TNO 2024 R12810A – 7 February 2025
**Cement recycling with help of
biobased additives**

Report D3-2. Estalishing lab scale demo products of
concrete

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Classification report	TNO Public
Title	TNO Public
Report text	TNO Public
Number of pages	12
Number of appendices	0
Programme name	Cement recycling
Project number	060.51606/01.01

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1 Introduction

1.1 Background of the research

The currently most used material worldwide is concrete. Cement, being the binder in concrete, is responsible for about 7% of total CO₂ emissions on the planet. Therefore, alternative binders with lower or even zero CO₂ emission will reduce the environmental impact of concrete considerably and contribute to the worldwide ambition to reduce global warming. At the same time, many concrete structures are reaching the end of their service life: they must be dismantled and, in most cases, demolished. Concrete Demolition Waste (CDW) must be disposed as environmentally friendly as possible. To this aim, concrete recycling encompasses retrieving as much original components as possible: gravel, sand and old cement paste and reusing them in new concrete. This is in line with the goals of the Dutch government which has as aim to reduce by 50% the CO₂ emissions of the construction industry as well as to reduce the use of raw materials by 30 % by 2030.

Using recycled old cement paste as cement replacement would contribute both to the aim of CO₂ reduction and upscaling. However, the old cement paste is cement that, upon mixed with water, has reacted to a solid and very stable stone-like material. In order to recycle the old cement paste and to use it as new binding material, this material must be finely ground and then reactivated. The current project 'Cement recycling with help of biobased additives' focuses on the reactivation of the ground reacted cement paste by using biobased additives to enhance the dissolution and precipitation of the material.

1.2 Aim of this research

The project ultimately aims at testing the developed additives and/or binder formulations with the recycled cement paste into new products for which the performance is tested at a field laboratory located at the municipality of Amsterdam. The project consortium has decided that the first product to be made will be tiles. The most important performance demand for tiles is the bending tensile strength. The aim of this part of the research is to set up a concise reference framework for the various stages of the testing for this performance. This implies calibration from factory made tiles to laboratory produced tiles, and from the concrete of the tiles to the mortar bars that are used to solely test the performance of the binder. Moreover, since it is not always possible to wait 28 days before testing, also 7 days compressive and bending (tensile) strength of the mortar bars has to be established so that also an early age calibration value for the research is obtained. This research is part of WP3 'Lab scale testing of the novel technology on recycled cement and biobased additives'.

It has been decided to find a producer of tiles that would be willing to share their tile composition with TNO (in confidence) and help with the factory produced tiles. Struyk Verwo Infra (SVI) has agreed to participate in this calibration procedure and to deliver both the tile component materials as well as tiles to the Delft Building Innovation Lab of TNO in Delft. They have sent both tiles and materials to the TNO Building Innovation Laboratory Delft for further testing.

1.3 Content of this report

Chapter 2 provides an overview of the used materials and methods. The results are presented in chapter 3 while a summary is provided in chapter 4. References can be found in chapter 5.

2 Materials and Methods

Materials for making mortar bars and 8 tiles have been received at TNO on March 13, 2024. Materials for the mortar bars comprised of binder materials, additives and aggregates < 4 mm. The exact composition of the tiles is however confidential, as requested by SVI.

According to the supplied information, the tiles were cast at SVI on February 14, 2024 and were thus 28 days at the time of delivery. They were tested at the same day, according to the standard NEN-EN 1339 (tiles). As initial load rate, a rate of 200 N/s was chosen according to the table send by SVI. Since at this load rate the tiles did not fail between 30 and 60 s as prescribed in the standard, a higher load rate of 265 N/s was used for the remaining 6 tiles.

The strength of the binder used in the tiles was subsequently tested by standard mortar bar strength tests. The mortar bars have been cast according to NEN-EN 196-1 on March 6, 2024, demoulded after 1 day and cured by wrapping them in cling foil and storing them at 20 °C until the day of testing. The bending strength and the compressive strength have been tested at 7 days on March 13, 2024 and at 28 days on April 3, 2024 in threefold. The flexural strength is tested in bending on the total bars (160 mm x 40 mm x 40 mm), while the compressive strength is tested on the remaining two halves, according to the NEN-EN 196-1.

3 Results

The results of the bending strength tests are given in Table 3.1.

Table 3.1 Results of the three-point bending strength test on tiles

Specimen Number	Width [mm]	Height [mm]	Failure load [kN]	Bending strength [MPa]	Loading rate [N/s]
MP4007-1	299.9	49.1	12.1	6.3	200
MP4007-2	299.8	49.8	11.9	6.0	200
MP4007-3	300.6	49.6	11.1	5.6	265
MP4007-4	299.9	47.7	11.0	6.1	265
MP4007-5	300.0	48.1	11.9	6.4	265
MP4007-6	299.9	48.8	10.3	5.4	265
MP4007-7	300.3	49.7	9.8	5.0	265
MP4007-8	300.1	50.8	12.0	5.8	265

According to the standard NEN-EN 1339, the strength class can be determined from its characteristic strength, that can be calculated by taking the (long term) standard deviation of the testing equipment into account. This value is not available for the testing equipment at TNO. Therefore, the characteristic value $f_{b, kar}$ is calculated as:

$$f_{b, kar} = f_{b, av} - q_n s$$

With $f_{b, av}$ the average bending strength of the 8 tested tiles and s the experimental standard deviation of these 8 experiments. Factor q_n is 1.4, based on the student t-distribution with a one tail 90 % probability and a degree of freedom $n = 7$. The characteristic value then is 5.1 MPa and each individual value is larger than a minimum value of 4.0 MPa. This means that the tiles comply to the highest strength class (class 3) according to the NEN-EN 1339.

The results of the bending strength on the mortar bars at 7 and 28 days are shown in Table 3.2 and Table 3.3. The average bending strength at 7 days is 6.3 ± 0.3 MPa, while at 28 days it is 7.6 ± 0.7 MPa.

Table 3.2 Results of the bending strength test on mortar bars (160 x 40 x 40 mm) at an age of 7 days

Specimen	Failure load [N]	Bending strength [MPa]
CEM IIIA-3	2930	6.5
CEM IIIA-4	2760	6.3
CEM IIIA-5	2760	6.0

Table 3.3 Results of the bending strength test on mortar bars (160 x 40 x 40 mm) at an age of 28 days

Specimen	Failure load [N]	Bending strength [MPa]
CEM IIIA-1	2890	6.8
CEM IIIA-2	3320	7.8
CEM IIIA-6	3440	8.1

The results of the compressive strength on the mortar bars at 7 and 28 days are given in Table 3.4 and Table 3.5. The average bending strength at 7 days is 30.2 ± 2.9 MPa, while at 28 days it is 41.5 ± 2.2 MPa.

Table 3.4 Results of the compressive strength test on mortar (load plates 40 x 40; height 40 mm) at an age of 7 days

Specimen	F_{max} [N]	F_c [MPa]
CEM IIIA-3.1	54100	33.1
CEM IIIA-3.2	55600	34.0
CEM IIIA-4.1	45000	27.8
CEM IIIA-4.2	49800	30.7
CEM IIIA-5.1	47500	28.9
CEM IIIA-5.2	43700	26.6

Table 3.5 Results of the compressive strength test on mortar (load plates 40 x 40; height 40 mm) at an age of 28 days

Specimen	F_{max} [N]	F_c [MPa]
CEM IIIA-1.1	72500	45.3
CEM IIIA-1.2	64800	40.5
CEM IIIA-2.1	68500	42.8
CEMIntern BMS - Bi- obase overleg IIIA- 2.2	64100	40.1
CEM IIIA-6.1	65500	40.9
CEM IIIA-6.2	62700	39.2

4 Summary

A summary of the results is given in Table 4.1. These strength results can be used as calibration values for the developed binder formulations at the various stages of the research.

Table 4.1 Summary of the strength test

Age	7 days		28 days	
Strength [MPa]	Average	Stdev	Average	Stdev
fc, mortar bars	30.2	2.9	41.5	2.2
fb, mortar bars	6.3	0.3	7.6	0.7
fb, concrete tiles	-	-	5.8	0.5

5 References

NEN 196-1 (2016): Methods of testing cement - Part 1: Determination of strength.

NEN-EN 1339 (Ontw 2010) Concrete paving flags - Requirements and test methods.

6 Signature

TNO › Mobility & Built Environment Mobility & Built Environment › Delft, 7 February 2025

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