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ReBuilt

Activity 2.2 – Upscaling and testing of green and bio-concrete products

D.2.2.2 Report on Tested Green Concrete Solutions with 100 % Recycled Aggregate and Alternative Binders

Prof. Dr. Andrea Kustermann (PP14 HM)

Johanna Zentner (PP14 HM)

Lukas Hausner (PP6 TUW)

Elena Yaneva (HEMPSTATIC)

Sergej Gutsmandl (PP3 Nigrad)

Rok Rudolf (PP1 ZAG)

Prof. Dr. Martin Palou (PP10 URSTARH)

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1. Introduction

As part of Activity 2.2 – Upscaling and testing of green and bio-concrete products, focused on deliverable **D.2.2.2 'Report on tested green concrete solutions with 100 % recycled aggregate and alternative binders'**, the following products should be developed and tested both in the laboratory and in pilot projects:

- Recycled concrete with 100 % recycled aggregates (PP14)
- Concrete with alternative binders (PP10)
- Recycled concrete with 100 % recycled aggregates including natural fibres and alternative binders (PP14)

2. Recycled Concrete with 100 % Recycled Aggregate (PP14) [1]

Consistent with the principles of the circular economy and resource conservation, **recycled concrete with 100 % recycled aggregates** was developed in the laboratory at HM (PP14). The recycled aggregate used in the concrete came from the demolition site "Bayernkaserne München" from the company "Ettengruber" is project partner of ReBuilt. The concrete was tested in the laboratory for its properties, before being used in the "Campus Ost" pilot project in Munich in cooperation with project partner City of Munich.

2.1. Materials

2.1.1. Recycled Concrete Aggregates (RCA)

The recycled aggregates (RCA) were obtained from the demolition site "Bayernkaserne München". The partner company "Ettengruber" processed the material and crushed it to a maximum grain size of 16 mm.

At the HM laboratory (PP14), the RCA were characterised in terms of grain size distribution, density and water absorption. The aggregates show a grading curve according to AB16 (see Figure 1), a bulk density of 2.5 g/cm³, and a water absorption capacity of 6 % in accordance with DIN EN 1097-6, Appendix D.

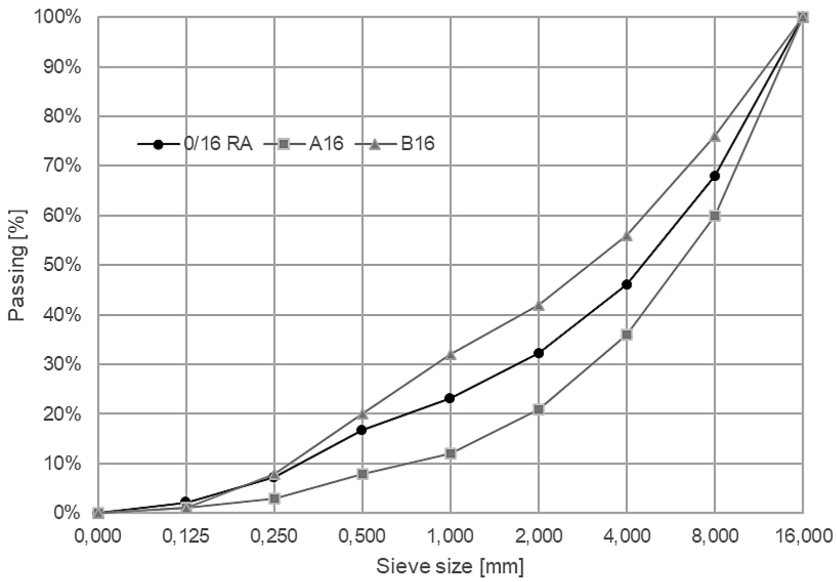

Figure 1:Grading curve of the RCA used compared with the standard curves A16, B16

2.1.2. Recycled Concrete (RC)

For the concrete mixture, exposure classes XC3 and XF1 and strength class C30/37 were targeted according to DIN EN 1992-1-1; Eurocode 2 (EC2). The concrete was produced with 100 % RCA, including the sand fraction. Several mixtures were tested for fresh concrete density and compressive strength after seven days. The mixture, see Table 1 proved to be the most suitable and was therefore selected for application in the Campus Ost pilot project.

For the concrete mixture (Table 1) we used:

- CEM II/A-S 42.5 R
- Blast Furnace Slag (BFS)
- Limestone Powder
- W/b = 0.42 (equivalent)
- Plasticiser = 1.4 wt.-%/c

Table 1: Mixture composition of 100 % recycled concrete

Type	Density [kg/m³]	Mass [kg/m³]	Volume [dm³]
CEM II/A-S 42.5 R	3.14	365	116
BFS	2.90	101	35
Limestone Powder	2.73	41	15
Water	1.00	169	169
RCA (AB16)	2.50	1587	635
Air	-	-	30
Σ	-	2263	1000

2.2. Laboratory Tests

2.2.1. Fresh Concrete Properties

1 m³ of concrete was produced in a large-scale mixer. Slump-Test were performed according to DIN EN 12350-5 at 10, 30, 60 and 90 minutes after mixing. The results are shown in Table 2. A slump reduction of approx. 14 cm was observed within the first 60 minutes.

Table 2: Results of the Slump-Test depending on the time

Time [min]	Spread [cm]	Class [-]	Consistency Range [-]
10	55	F4	Very soft
30	51	F4	Very soft
60	41	F2	Plastic
90	31	F1	Stiff

Fresh density and air content were determined according to DIN EN 12350-6 and DIN EN 12350-7. The fresh density was about 2299 kg/m³, and the air content was about 2.2 %. Both values deviated only slightly from the expected range.

Pumping tests were carried out with a 40 m truck-mounted concrete pump (hose diameter 150 mm). No negative effects on fresh concrete behaviour were observed. All hardened concrete properties were tested on specimens produced with fresh concrete after pumping 40 m.

2.2.2. Hardened Concrete Properties

Mechanical Properties:

Compressive strength was determined after 2, 14, 28 and 56 days in accordance with DIN EN 12390-3. The Young's modulus was measured after 28 and 56 days according to DIN EN 12390-13. Results are presented in Table 3.

Table 3: Results of the hardened concrete tests

Age [d]	Compressive Strength (Cube) [N/mm²]	Young's Modulus [N/mm²]
2	25.1	-
14	42.0	-
28	55.8	26300
56	60.4	27233

After 28 days, compressive strength class C35/45 (target strength C30/37) was achieved. Compared to EC2 estimations (Young's modulus ~33,000 N/mm² for C30/37), the measured modulus values were significantly lower.

Deformation:

Drying shrinkage was tested according to DIN EN 12390-16 over a period of 140 days. Figure 2 shows the measured total shrinkage of 0.65 mm/m (0.065 %). This value is about 45 % higher than the EC2 estimate for C30/37 (0.045 %).

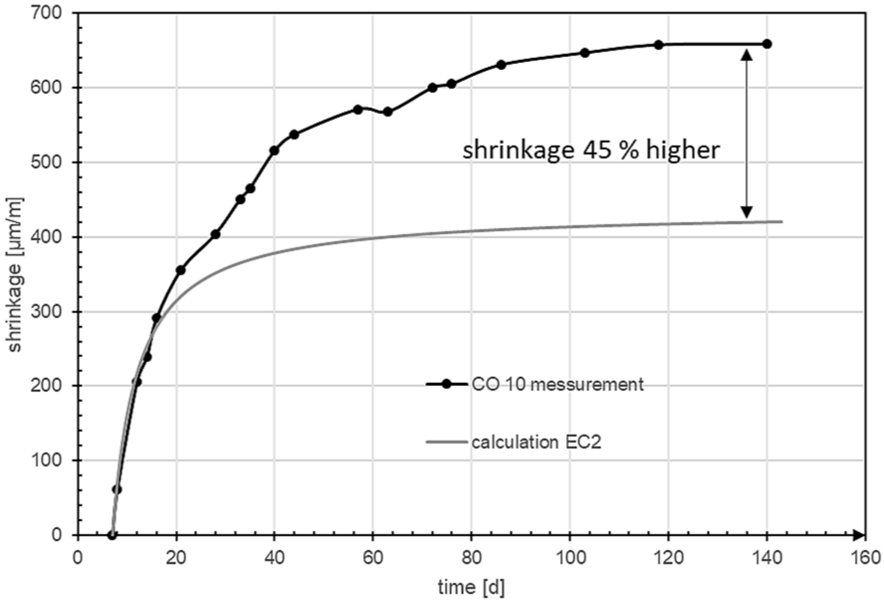

Figure 2:Drying shrinkage compared to estimated shrinkage for C30/37 according to EC2

Creep was determined according to DIN EN 12390-17, with loading applied at 28 days. After 35 days, a creep coefficient of 1.22 was measured, approx. 17 % above EC2 estimates for a concrete strength class C30/37, see Figure 3.

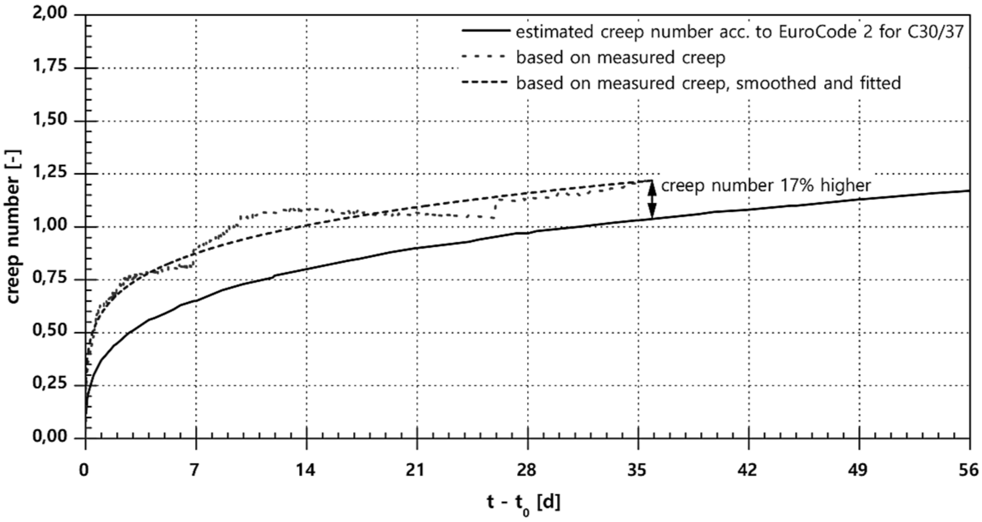

Figure 3:Creep test compared to estimated creep for C30/37 according to EC2

The deformation results for the RC are within the typical range of creep and shrinkage, see e.g. Stengel et al. [1].

2.2.3. Durability Properties

Freeze-Thaw Resistance:

The freeze-thaw resistance was evaluated in accordance with CEN TR 15177. After 32 cycles, the relative dynamic modulus dropped below 75 %. After 56 freeze-thaw cycles, weathering of 122 g/m² was measured, which is below the limit value of 1000 g/m² specified in the German guidelines [2]. The concrete therefore meets the requirements for exposure class XC3.

Carbonation Resistance:

Carbonation depth was determined according to DIN EN 12390-12 under accelerated conditions (3 Vol.-% CO_2, 65 % RH, 20°C). Figure 4 shows the measured carbonation depth as a function of time. For a minimum concrete cover of 25 mm (c_{min}) and exposure class XC4, the service life index ß drops below 1.5 after 45 years, calculated in accordance with [3].

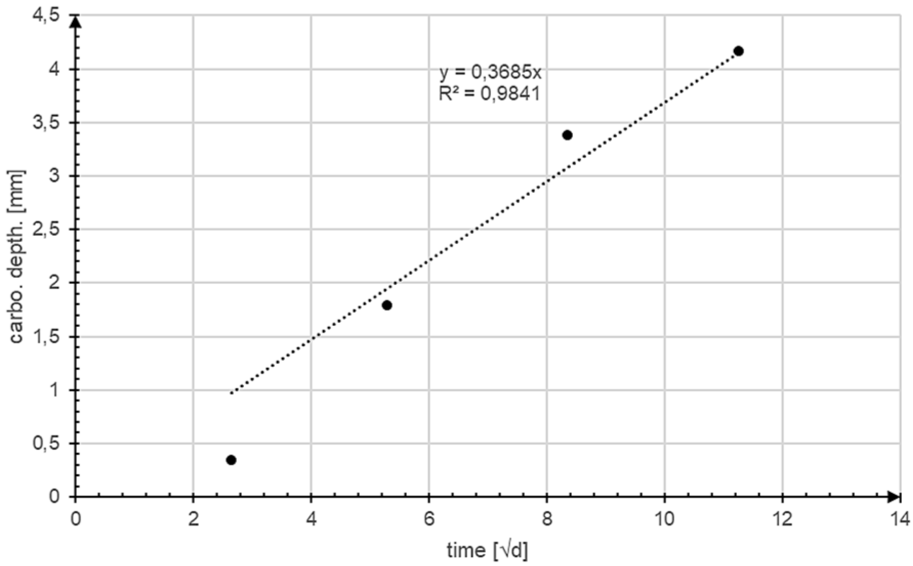

Figure 4:Carbonation depth under accelerated conditions (3 Vol.-% CO_2, 65 % RH, 20°C)

2.3. Life Cycle Assessment (LCA) [4]

2.3.1. Methodology

A life cycle assessment (LCA) was carried out to evaluate the environmental impact of the concrete developed as part of the “Campus Ost” pilot project, which contains 100 % recycled aggregate including recycled sand fraction (100RAC).

The study was conducted in accordance with EN 15804 and EN 15978. The aim was to compare a circular system (100RAC) with a linear reference system (NAC) that uses only natural aggregates, see Figure 5. The assessment was based on the global warming potential (GWP100a) according to CML-IA baseline EU25.

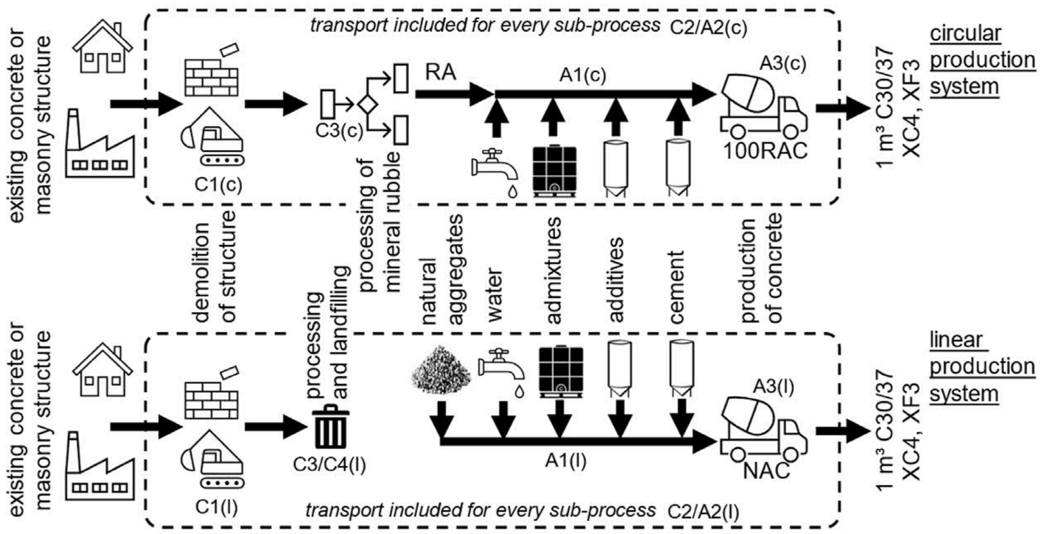

Figure 5:Outline of the circular (100RCA) and linear (NAC) production system

A binder content of 360 kg/m³ (CEM II/C-M) was assumed for the linear system (NAC). The circular system (100RAC) is based on the mixture developed in the HM laboratory (see 2.1.2) with a binder content of 507 kg/m³ (CEM II/A-S 42.5 R, granulated blast furnace slag, limestone powder, w/b = 0.42). The functional unit of the investigation is 1 m³ of concrete.

The data is based on actual demolition and processing processes from the Bayernkaserne Munich project, from which the demolition material used was obtained. This made it possible to take into account practical energy costs for demolition, processing and transport.

2.3.2. Results

The results show that the binder content has the most significant impact on global warming potential (GWP100a). Cement and granulated blast furnace slag (GBFS) together account for around 80 – 87 % of CO_2 emissions, while demolition, processing, transport and landfill together account for only 4.7 – 10.5 %.

The following values were obtained for the systems investigated (based on 1 m³ of concrete), see Table 4:

Table 4: Results of GWP100a for NAC and 100RCA

System	GWP100a [kg CO_2-eq./m³]
NAC (linear): Concrete with natural aggregates	211.5
100RAC (circular): Concrete with 100 % RCA	285.0

The higher GWP values of 100RAC are due to its increased binder content. A reduction in the binder content would directly lead to a reduction in GWP.

Figure 6 shows the relationship between the binder content of 100RAC and the transport distance to the landfill site compared to NAC. With increasing transport distance (and thus rising emissions), 100RAC can have an equivalent or lower GWP profile despite its higher cement content.

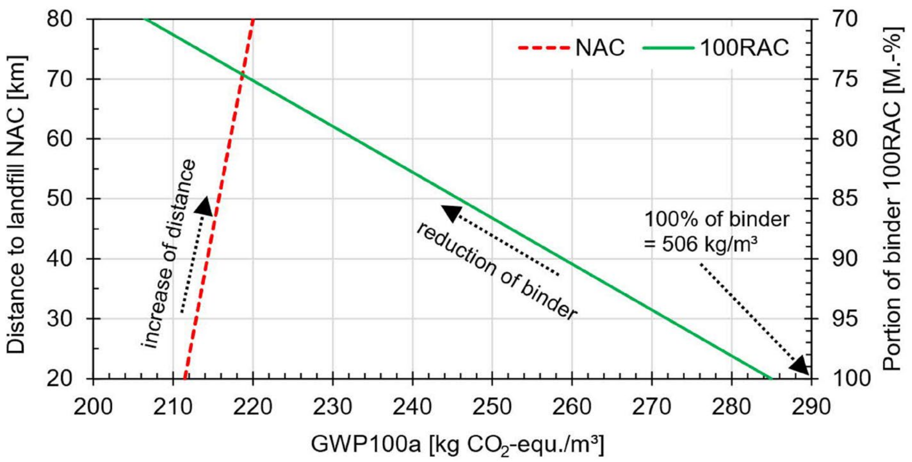

Figure 6:GWP100a for 100RCA depending on portion of binder and NAC depending on transport distance to landfill

For an equal GWP, the following limit values apply to the binder content of 100RAC:

- at a landfill distance of 20 km: ≤ 364 kg/m³
- at a landfill distance of 100 km: ≤ 386 kg/m³

This means that even with a slightly higher cement content (approx. +12 kg/m³ compared to NAC), a comparable climate impact can be achieved, provided that longer transport distances or higher landfill costs are incurred in the linear system.

2.4. Conclusion and Discussion

As part of the ReBuilt project, a concrete was developed for the "Campus Ost" pilot project HM (PP14). An optimised mixture of 100 % recycled aggregates (including the sand fraction) with a conventional cement content was used, which was evaluated in terms of workability, mechanical behaviour and durability in accordance with the requirements C30/37, XC3 and XF1 of Eurocode 2 (EC2). The concrete was also evaluated in terms of life cycle assessment (LCA).

The results show that the workability of the concrete is suitable for pumping and in-situ concrete construction. The mechanical behaviour corresponded to the requirements for normal concrete according to EC2, although the modulus of elasticity was slightly lower. The drying shrinkage was about 45 % higher and the creep values were slightly increased. Frost-thaw resistance was verified in accordance with German guidelines for a lifetime of 50 years; the requirements of exposure class XC3 regarding carbonation were also fulfilled.

The life cycle assessment (LCA) carried out shows that concrete with 100 % recycled aggregate (100RAC) is an ecologically advantageous alternative system if regional recycling cycles exist and the binder content is optimised. Taking real process data into account, the circular system investigated can achieve a comparable or better carbon footprint than conventional concrete.

The concrete was determined to be suitable for use as structural concrete in selected components (bored piles, wall and ceiling sections) at the "Campus Ost" construction site. The results of the on-site monitoring will be documented in the forthcoming report on the pilot project (A 2.5). Overall, it can be expected that concrete with 100 % RCA and a conventional clinker content represents a sustainable alternative to conventional concrete.

Recycled concrete can reduce construction waste, lower the use of primary raw materials and thus make an important contribution to CO_2 reduction, resource protection and the development of the circular economy in the construction industry.

3. Concrete with Alternative Binders (PP10)

The aim was to develop **concrete with alternative binders** in order to reduce the use of Portland cement while evaluating the mechanical properties and environmental impact. This work was carried out at ÚSTARCH (PP10).

3.1. Used Materials

3.1.1. Low-Carbon Cement (Alternative Binders)

Three different low-carbon cement (alternative binders) were developed and compared with a reference mix based on Portland cement (CEM I 42.5 R). The binder compositions included combinations of limestone (LS), metakaolin (MK), and ground granulated blast furnace slag (GBFS) as supplementary cementitious materials.

The detailed oxide composition of the binder components is presented in Table 5.

- CEM I 42.5 R – Portland Cement (OPC)
- Ground Limestone (LS)
- Metakaolin (MK)
- Ground Granulated Blast Furnace Slag (GBFS)

Table 5:Oxide composition of binder components

Binders	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3
CEM I 42.5 R	64.24	19.73	4.40	2.51	1.85	2.95
LS	54.13	0.17	0.10	-	2.30	-
MK	0.24	49.70	42.36	0.79	0.22	0.08
GBFS	36.53	35.76	9.39	0.24	14.0	0.03

3.1.2. Concrete

Concrete samples were produced using an optimised grading curve A/B16 with natural aggregates (NA). The mixtures were developed using low-carbon binders with Portland cement replacement ratios of 30 %, 40 % and 50 % and compared with a reference mixture of 100 % Portland cement (CEM I 42.5 R).

The binder composition of the various low-carbon systems is shown in Table 6.

Table 6:Proportion of binder [%] components in low-carbon systems

Binders	CEMI	Mix1	Mix2	Mix3
CEM 42.5 R	100	50	40	30
LS	-	15	20	25
MK	-	10	10	10
GBFS	-	25	30	35
Σ	100 %	100 %	100 %	100 %

The following was used for the concrete (see Table 7):

- CEM I 42.5 R
- W/b = 0.35
- Grading curve: A/B16
- Plasticiser = 0.66 wt.-%/c

Table 7:Concrete mix design for reference and low-carbon systems

Type	CEMI	Mix1	Mix2	Mix3
CEM I 42.5 R	405.46	202.74	162.18	121.64
LS	-	60.82	81.01	101.36
MK	-	40.54	40.54	40.54
GBFS	-	101.36	121.64	141.93
NA A/B16	1828.34	1828.34	1828.34	1828.34
Water	141.93	141.93	141.93	141.93
Plasticiser	2.66	2.66	2.66	2.66
Σ	2378.40	2378.40	2378.40	2378.40

3.2. Laboratory Tests

3.2.1. Hydration Reaction

Conduction Calorimetry:

To investigate the hydration behaviour of the different binder systems, a conduction calorimeter was used. Figure 7 shows the heat flow (A) and cumulative heat release (B) of the tested systems.

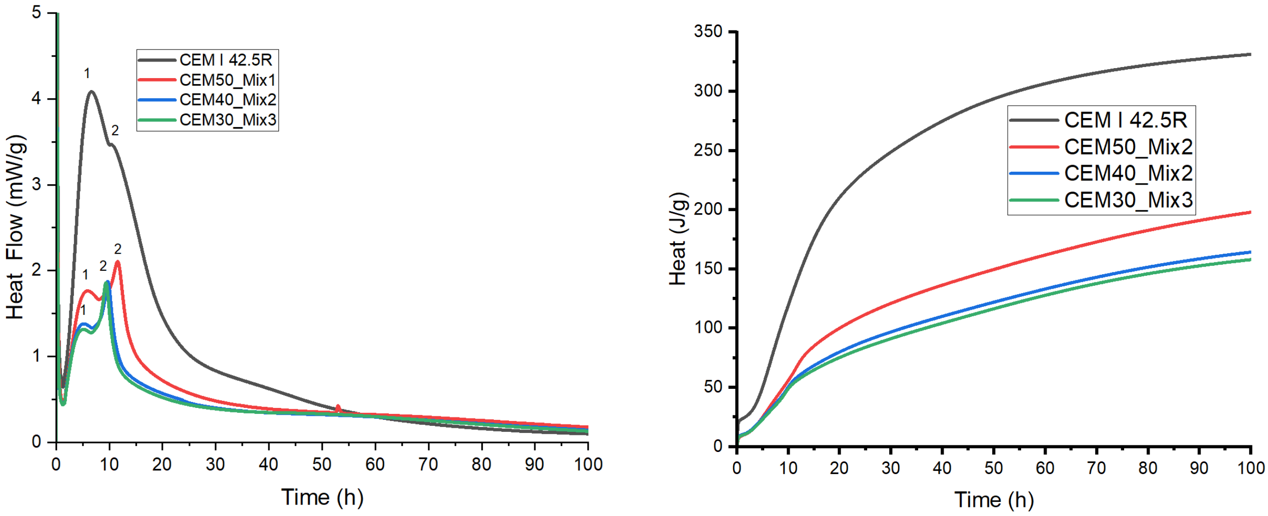

Figure 7:Heat flow (left) and overall heat (right) of different binders

The total hydration heat and flow rate are relatively low, depending on the degree of replacement and the binder composition. The reduced early heat release indicates lower early strength. Due to the limited formation of $Ca(OH)_2$ from C_3S and C_2S in alternative binders, the alkali activation reactions are less intense.

However, the addition of cementitious additives (SCMs) has a strong influence on the secondary hydration peak, which is more pronounced in low-carbon binders.

While OPC hydration develops gradually over time, additional hydration products form in low-carbon systems, improving the mechanical and physical properties and potentially increasing long-term durability compared to OPC-based concretes.

Thermal Analysis (DTG/TG):

To identify the hydration products formed during curing, Differential Thermogravimetry (DTG) and Thermogravimetry (TG) were performed after 2 and 28 days of water curing (Figure 8).

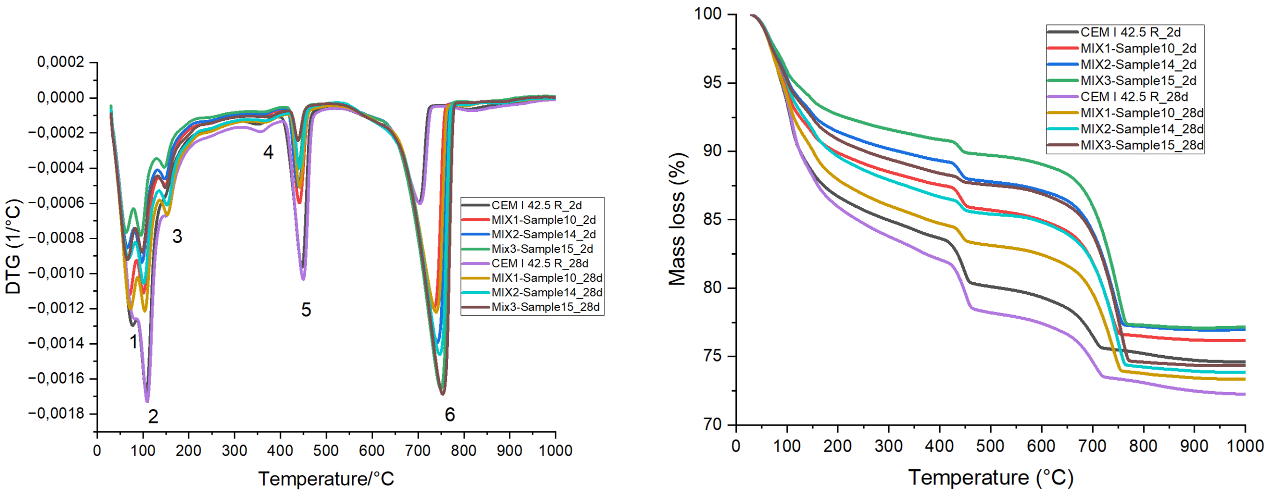

Figure 8:DTG (left) and TG (right) curves of samples cured for 2 and 28 days

DTG analysis enables the identification of specific hydration phases, while TG quantifies the amount of products formed. The hydration phases observed are similar for all mixtures, but differ in intensity and quantity depending on the curing time and binder composition.

A reduction in peak intensity between 400 and 500 °C indicates ongoing pozzolanic reactions, reflecting both the lower OPC content and $Ca(OH)_2$ consumption during alkali activation and carbonation. The carbonation process demonstrates the beneficial CO_2 sequestration effect of low-carbon systems.

Based on the results of XRD and thermal analysis (TA), the following (see Table 8) hydration products were identified. Their formation depends on the binder composition and curing time.

Table 8:Identified hydration products based on thermal analysis

Peak Number	**Temperature [°C]**	**Hydrated Products**
1	80	Ettringite - AFt (Carbonated Ettringite)
2	110	CSH - Mc (Monocarboaluminate)
3	160	CASH - Str (Strätlingite)
4	350	Hydrogarnet
5	440	Portlandite
6	700	Calcite
7	900	Well-crystallized calcite

3.2.2. Mechanical Properties

Compressive Strength:

The compressive strength of the samples was tested after 2, 7, 28 and 90 days (see Figure 9).

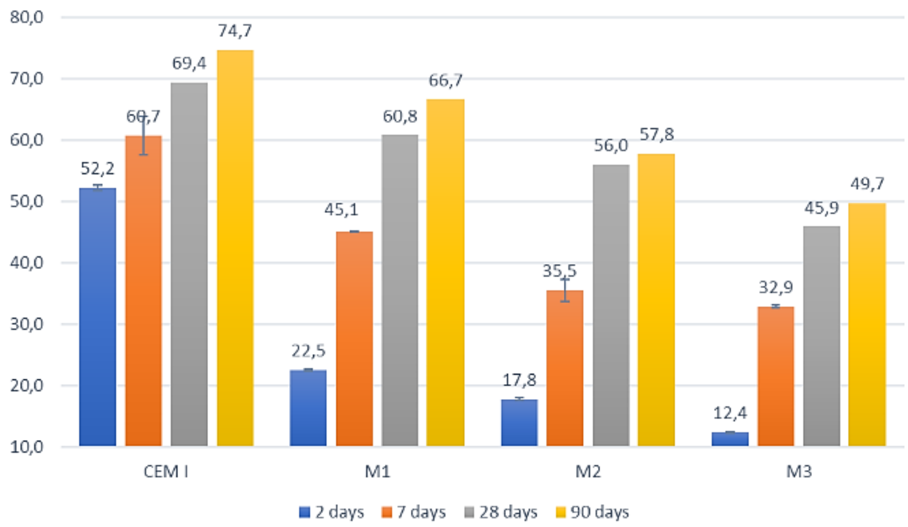

Figure 9:Development of compressive strength of reference and low-carbon mixtures

The results show that the early strength (2 days) is significantly lower for all substitution levels compared to the reference mixture. From day 7 onwards, a steady increase in strength was observed, which continued up to 90 days. All mixtures containing alternative binders show continuous strength development throughout the curing period. The relative increase in strength exceeds the respective substitution rates of 50 %, 40 % and 30 %, confirming the effective contribution of the mixed binders at a later age.

Young’s Modulus:

The results for the Young’s modulus show a similar trend to the compressive strength (see Figure 10).

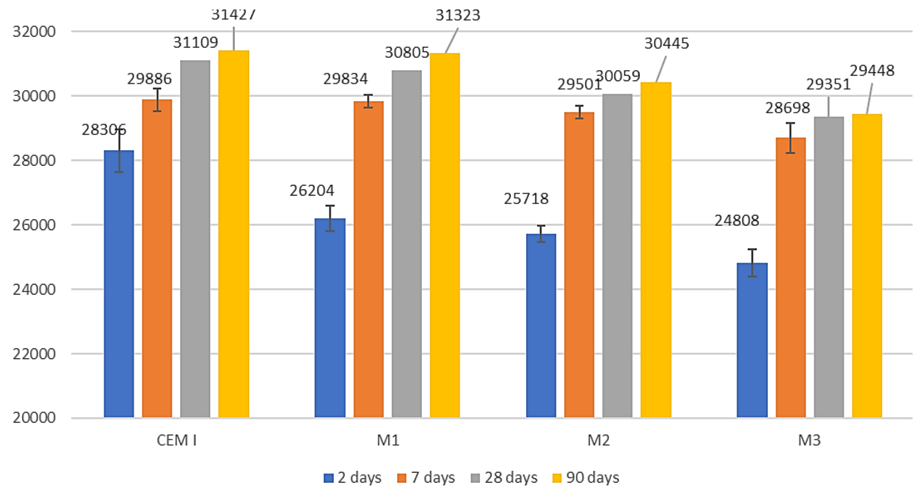

Figure 10:Development of the Young’s modulus of reference and low-carbon mixtures

All samples show a continuous increase in stiffness with increasing curing time. Although the absolute values of the low-carbon concretes remain below those of the reference mixture, their relative increase is more pronounced, suggesting that the growth rate of the DEM is stronger than that of the compressive strength.

3.3. Conclusion and Discussion

As part of PP10, a comprehensive study was conducted on the development of low-carbon binders with a Portland cement replacement content of up to 50 %, with the aim of reducing the clinker content while ensuring adequate mechanical and durability performance.

The results of the hydration studies (conduction calorimetry, DTG/TG) show that the reaction kinetics of low-carbon binders are influenced by their composition. Due to the reduced formation of $Ca(OH)_2$, the early hydration rate and early strength are lower than for the OPC reference. However, the continuous formation of secondary hydration products over time led to a steady increase in compressive strength and stiffness.

Mechanical tests confirm that all low-carbon mixtures exhibit continuous strength development, with relative strength gains exceeding the respective replacement ratios (50 %, 40 %, 30 %). Despite slightly lower early strength properties, the long-term behaviour demonstrates the efficiency of mixing systems containing limestone, metakaolin and blast furnace slag.

Overall, the results underscore the potential of low-carbon binders to reduce Portland cement content while maintaining adequate performance. Future research will focus on further optimising binder composition, improving early strength and integrating life cycle analysis (LCA) to quantify environmental benefits.

4. Recycled Concrete with 100 % Recycled Aggregate Including Natural Fibres and Alternative Binders (PP14)

HM (PP14) developed a **‘green concrete’ with 100 % recycled aggregates, natural fibres and alternative binders**, with the aim of improving mechanical properties and increasing sustainability.

4.1. Materials

4.1.1. Recycled Concrete Aggregates (RCA)

The recycled aggregates (RCA) were obtained from the „Kreppold“ recycling plant. Kreppold processed the material and crushed it to a maximum grain size of 16 mm. According to German standard DIN 4226-101, it is type I concrete demolition material with a maximum brick content of 10 %.

At the HM laboratory (PP14), the RCA were tested for its grain size distribution and bulk density. The grain size distribution corresponds to the standard sieve curve AB16. The bulk density of the 0-4 mm fraction is 2.25 g/cm³, and that of the 4–16 mm fraction is 2.45 g/cm³.

4.1.2. Hemp Fibres

Three different hemp fibres (see Figure 11) were analysed to improve the material properties:

- Short-cut fibres (K517)
- Short fibres (KF)
- Fleece-compatible fibres (VFF)

Figure 11:Hemp fibres (left: K517, center: KF, right: VFF)

In accordance with DIN EN 1097-6, Annex D, the fibres were tested for water absorption and density. The water absorption was recorded at defined intervals over a period of 24 hours. The results (see Figure 12) show that the water absorption stabilised significantly after approximately 10 minutes.

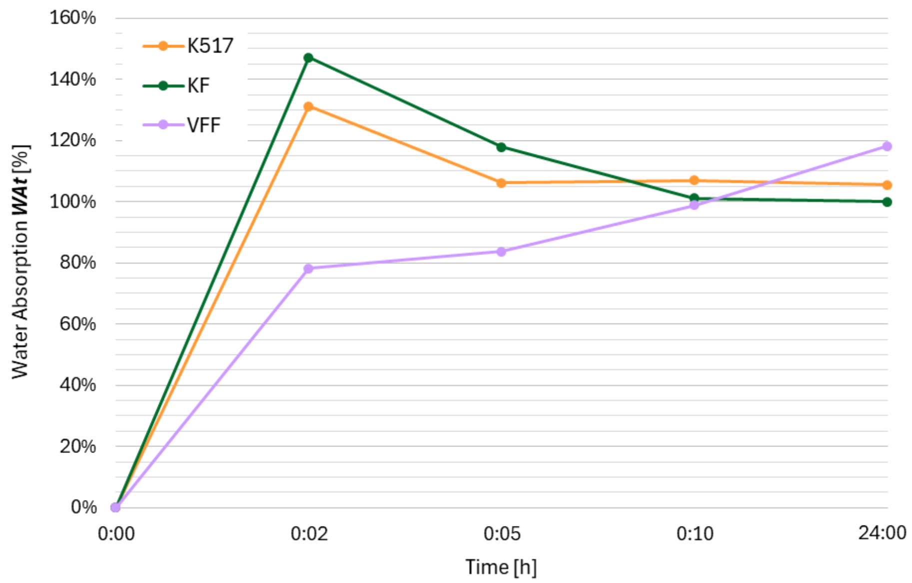

Figure 12:Water absorption of the fibres over time

The density of the fibres was also determined as a function of water absorption time using a pycnometer. A stable density was reached after approximately 5 minutes (see Figure 13).

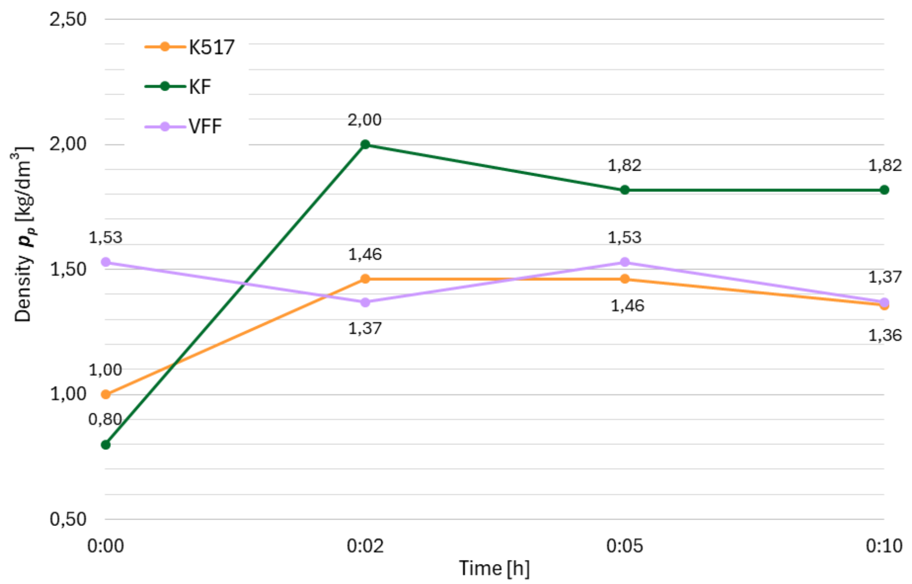

Figure 13:Density of the fibres as a function of water absorption time

4.1.3. Alternative Binder

Brick dust (KZS), a by-product of brick sawing during the production process, was used as an alternative binder. The material was characterised in terms of its particle distribution, density, and pozzolanic reactivity. The brick dust had a density of 2.83 g/cm³ and showed a reactivity of 125 J/g. According to Suraneni et al. [5], this level of reactivity is low.

4.1.4. Mortar

The hemp fibres were tested in standard mortar. The mortar samples were tested for compressive and flexural strength according to DIN EN 196-1. Based on these results (see Figure 14), the fibre with the best mechanical properties and workability was selected – the short fibre-**KF**.

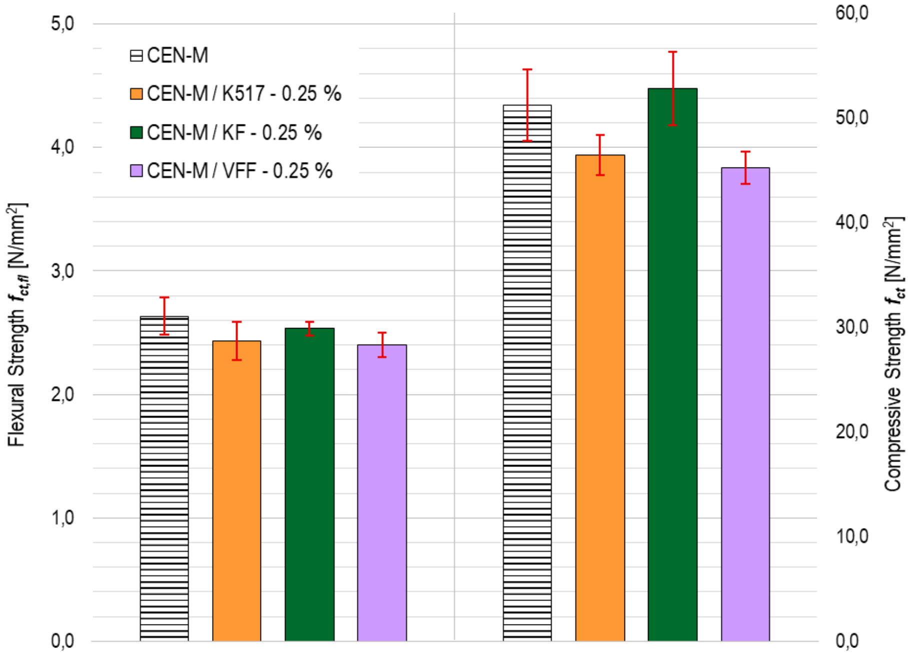

Figure 14:Flexural and compressive strengths of mortar samples with different fibres

Further mortar samples were then produced using different fibre contents and additional RCA. The aim was to determine the optimum fibre content. The test samples were again tested for flexural and compressive strength. The results (see Figure 15) led to the selection of a fibre content of **0.20 Vol.-% KF**.

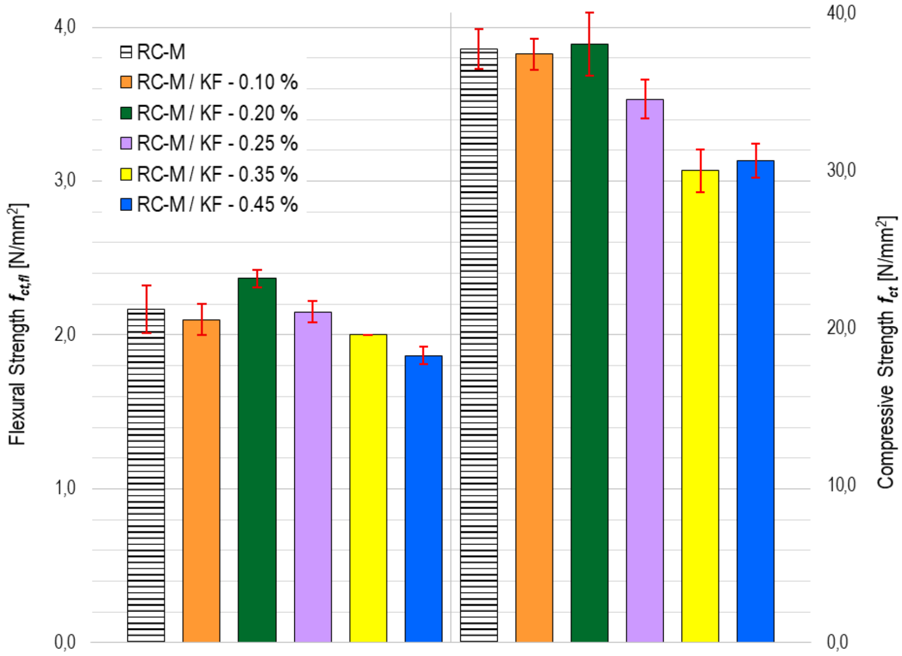

Figure 15:Flexural and compressive strength of mortar samples with different fibre contents (KF)

4.1.5. Concrete

A total of three different types of concrete were produced using 100 % RCA, including fine aggregates.

- RC: reference concrete with 100 % RCA
- RC-KZS: concrete with 100 % RCA and brick dust (KZS)
- RC-KZS-KF: concrete with 100 % RCA, brick dust, and hemp fibres

For the concrete mix design (see Table 9), we used:

- CEM II/A-LL 42.5 N
- W/b = 0.47
- Grading curve: A16
- Plasticiser = 0.67 wt.-%/c (RC, RC-KZS), or 1.0 wt.-%/c (RC-KZS-KF)

Table 9:Concrete mix design of the three concretes

Type	Density [kg/m³]	RCA [dm³/m³]	RCA-KZS [dm³/m³]	RCA-KZS-KF [dm³/m³]
CEM II/A-LL 42.5 N	3.10	350	350	350
KZS	2.83	-	55	55
KF	1.82	-	-	3.6
Water	1.00	165	190	190
RCA (0/4 mm)	2.25	216	203	202
RCA (4/16 mm)	2.45	504	473	470
Air	-	15	15	15
Σ	-	1000	1000	1000

A proportion of 13 wt.-% was selected for the alternative binder KZS. In the concrete with hemp fibres, 0.20 Vol.-% KF fibres were used. The fibres were pre-wetted before addition. Due to the fibre content, the plasticiser content was increased accordingly.

4.2. Laboratory Tests

4.2.1. Fresh Concrete Properties

The spread was determined according to DIN EN 12350-5 as a function of time. Figure 16 shows the spread for the three types of concrete. It can be seen that the consistency of the concrete RC-KZS-KF is significantly stiffer than the others due to the addition of hemp fibres.

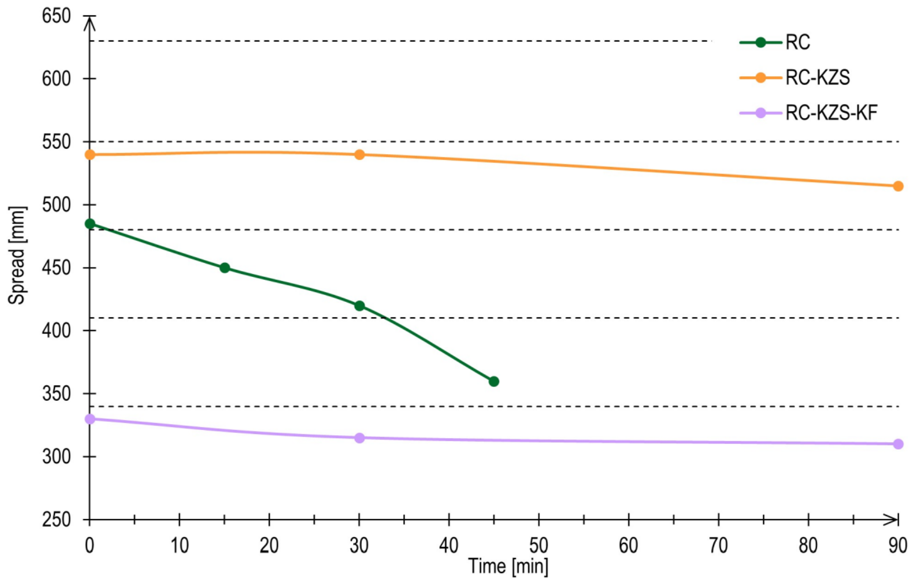

Figure 16:Spread as a function of time

4.2.2. Hardened Concrete Properties

Mechanical Properties:

The compressive strength was tested in accordance with DIN EN 12390-3 and the flexural strength in accordance with DIN EN 12390-5, both after 28 days. The results are shown in Figure 17. It can be seen that the compressive and flexural strengths of the concrete with brick dust (RC-KZS) are lower than those of the reference concrete (RC). The concrete with hemp fibres (RC-KZS-KF), on the other hand, shows higher compressive and flexural strengths than the RC.

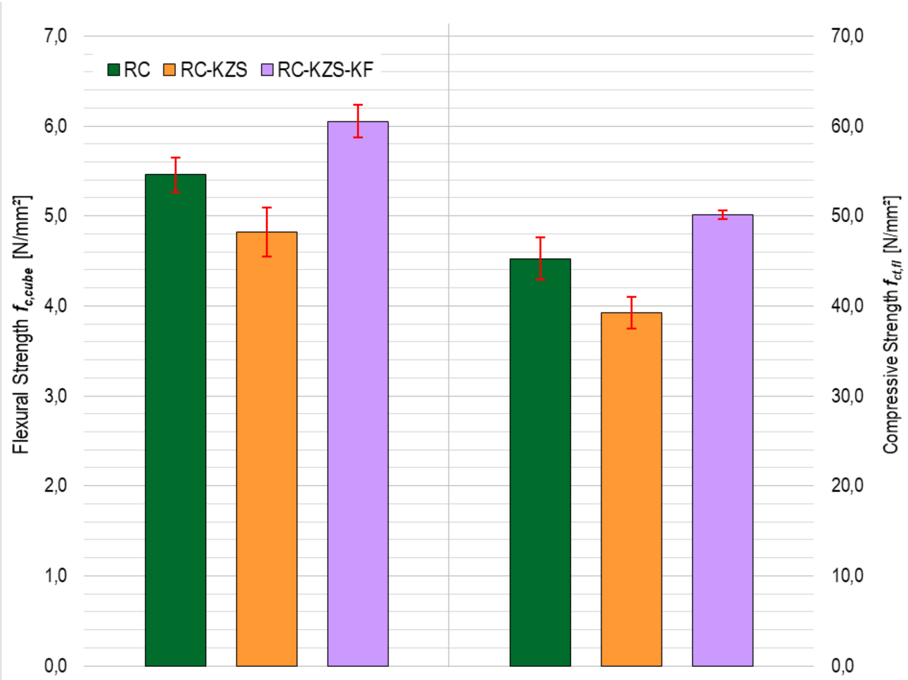

Figure 17:Flexural and compressive strength after 28 days

The Young's modulus was also determined after 28 days in accordance with DIN EN 12390-13. Table 10 shows the determined values. The reference concrete (RC) has the highest modulus of elasticity, while the other two types of concrete (RC-KZS and RC-KZS-KF) differ only slightly.

Table 10:Young's Modulus after 28 days

Concrete	Young's Modulus [N/mm²]
RC	27.686
RC-KZS	23.508
RC-KZS-KF	23.942

Shrinkage:

Drying shrinkage was measured in accordance with DIN EN 12390-16 over a period of 55 days (with ongoing measurements). Figure 18 shows the shrinkage curves for the three types of concrete tested. Outliers are shown as dots in the diagram but were not taken into account when drawing the lines. Until approx. day 35, there is almost no difference in the shrinkage values of the three types of concrete. However, contrary to initial expectations, the concrete with hemp fibres (RC-KZS-KF) shows less shrinkage than the other types of concrete over time.

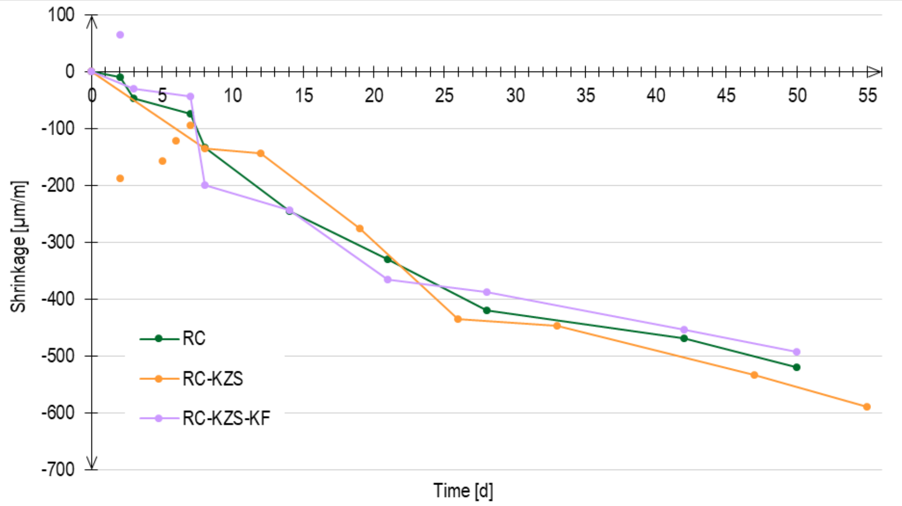

Figure 18:Drying shrinkage as a function of time

4.2.2.1. Durability Properties

Carbonation depth was determined according to DIN EN 12390-12 under accelerated conditions (3 Vol.-% CO_2, 65 % RH, 20°C). Figure 19 shows the measured carbonation depths over time. To date only an initial series of measurements is available; the dotted line shows the expected carbonation depth. It can be seen that concrete containing hemp fibres (RC-KZS-KF) is the most resistant to carbonation.

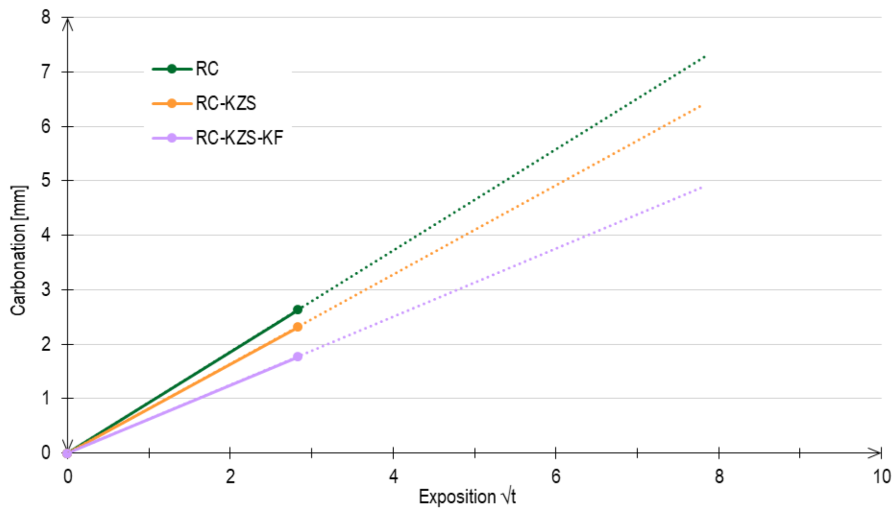

Figure 19:Carbonation depth under accelerated conditions (3 Vol.-% CO_2, 65 % RH, 20°C)

4.3. Conclusion and Discussion

As part of the ReBuilt project, “green concrete” consisting of 100 % RCA, alternative binders (brick dust) and natural fibres (hemp fibres) was developed at HM (PP14). The aim was to investigate the influence of these additives on workability, mechanical properties, and durability and to compare the results with a reference concrete (RC).

The results show that the consistency becomes significantly stiffer with the addition of hemp fibres, requiring an increase in the plasticiser content. Adding brick dust (RC-KZS) alone led to a slight reduction in compressive and flexural strength, while combining it with hemp fibres (RC-KZS-KF) increased the strengths compared to the RC. The modulus of elasticity of the modified concretes (RC-KZS and RC-KZS-KF) was slightly lower than that of the RC.

Drying shrinkage showed similar values for all concretes up to about 35 days. Thereafter, the concrete with hemp fibers (RC-KZS-KF) showed lower shrinkage. This may indicate an effect of the fibres that restricts shrinkage and improve crack behaviour. Additionally, preliminary results indicated that RC-KZS-KF concrete had a lower carbonation depth, suggesting enhanced durability.

In summary, it can be said that the combination of 100 % recycled aggregate, brick dust, and hemp fibers can be used to produce concrete with improved mechanical and durability properties. The addition of hemp fibers in particular has a positive effect on strength, shrinkage, and carbonation behaviour. Further investigations, especially regarding to long-term behaviour, are ongoing.

5. Peer-to-Peer Review (PP14)

As part of the laboratory tests and the development of bio-concrete and green concrete, the task is to conduct peer-to-peer reviews. The goal of these reviews was to discuss and evaluate the different results in order to identify optimization potentials.

The following peer-to-peer reviews took place during this activity:

During this activity following peer-to-peer reviews took place:

- ReBuilt A2.2 + A2.1 (July 2024, via Teams)
  - Participants: PP3, PP6, PP10, PP14
- Concrete Party Vol. 1 (October 2024, Munich)
  - Participants: PP3, PP6, PP10, PP14
- ReBuilt A2.2 demos with Hempstatic (June 2025, via Teams)
  - Participants: PP3, PP6
- Concrete Party Vol. 2.1 (August 2025, via Zoom)
  - Participants: PP6, PP14, Hempstatic
- Concrete Party Vol. 2.2 (August 2025, via Zoom)
  - Participants: PP3, PP10, PP14

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