EFFECTS OF THE CONCRETING SEQUENCE ON THE STATIC COMPRESSIVE STRENGTH AND THE POSSIBLE INFLUENCE ON THE FATIGUE RESISTANCE OF HIGH-PERFORMANCE CONCRETE

AUSWIRKUNGEN DER BETONAGEREIHENFOLGE AUF DIE STATISCHE DRUCKFESTIGKEIT UND DEN MÖGLICHEN EINFLUSS AUF DEN ERMÜDUNGSWIEDERSTAND VON HOCHFESTEM BETON

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SUMMARY

The compressive strength of concrete is a key indicator of the structural performance and durability of concrete components. To investigate the influence of the concreting or pouring sequence on the static compressive strength, a high-performance concrete (HPC) with a water-to-cement ratio of 0.35 was used. Cube-shaped specimens with an edge length of 100 mm were cast at eight-minute intervals and compacted for 60 seconds under identical conditions. The results revealed that the mass of the specimens remained constant regardless of the concreting sequence, indicating a homogeneous material composition. At the same time, a decrease in compressive strength with increasing pouring time was observed, which can be attributed to the progressive stiffening of the concrete and the resulting reduction in compaction efficiency. This illustrates how important it is to select the right test specimens for determining the static reference compressive strength, as this has a major influence on fatigue resistance. The investigation demonstrates that the compaction energy or duration should be adjusted to the respective pouring time in order to ensure consistent strength development.

ZUSAMMENFASSUNG

Die Druckfestigkeit von Beton ist ein maßgeblicher Indikator für die strukturelle Leistungsfähigkeit und Dauerhaftigkeit von Betonbauteilen. Zur Untersuchung des Einflusses der Betonier- bzw. Befüllreihenfolge auf die statische Druckfestigkeit wurde ein Hochleistungsbeton (HPC) mit einem Wasserzementwert von 0,35 verwendet. Hierfür wurden würfelförmige Probekörper mit einer Kantenlänge von 100 mm in Abständen von acht Minuten hergestellt und jeweils 60 Sekunden unter identischen Bedingungen verdichtet. Die Ergebnisse zeigen, dass die Masse der Probekörper unabhängig von der Betonierreihenfolge konstant blieb, was auf eine homogene Materialzusammensetzung hinweist. Gleichzeitig wurde ein Rückgang der Druckfestigkeit mit zunehmender Befüllzeit festgestellt, der auf das fortschreitende Ansteifen des Betons und die daraus resultierende Abnahme der Verdichtungswirksamkeit zurückzuführen ist. Dadurch wird deutlich, wie wichtig es ist welche Probekörper zur Ermittlung der statischen Referenzdruckfestigkeit ausgewählt werden und es dadurch einen großen Einflussparameter auf den Ermüdungswiderstand gibt. Die Untersuchung verdeutlicht, dass die Verdichtungsenergie bzw. -dauer an den jeweiligen Befüllzeitpunkt angepasst werden sollte, um eine gleichbleibende Festigkeitsentwicklung sicherzustellen.

1. INTRODUCTION

To determine the fatigue resistance of concrete, fatigue tests must be carried out in the laboratory. For this purpose, a reference compressive strength is determined from at least three samples using the available samples. Based on this reference compressive strength, fatigue tests are carried out at different relative upper and lower stress levels with at least three tests per stress level. The achieved number of cycles to failure are plotted logarithmically. By using three samples to determine the static compressive strength and fatigue resistance, an average can be calculated that counteracts various influences. It would be better to examine more samples, but this would require additional tests. The results can scatter widely, as can be seen in the literature [1]-[3]. The large scatter can be attributed to many causes, as concrete is a non-homogeneous material. In addition to the non-homogeneity of the material, the age of the sample and the moisture content of the concrete also have an influence on the fatigue resistance [1] & [4]. In order to minimise batch influence, as many samples as possible are produced in a single mixing process. However, as this process is carried out manually, it takes time. This means that not all samples can be concreted at the same time, instead they are filled and compacted one after the other. Cylinders with a d/h ratio of 1/3 are used to determine the fatigue resistance of concrete. Due to the height of the cylinder, the concrete must be poured in at least two layers. In order to produce the concreting process under comparable conditions, the same compaction time and frequency are often used for each stage of concreting. However, during the concreting process, the concrete begins to harden, which is why the first samples have a different consistency than the samples at the end of concreting. Therefore, it was investigated whether the time of concreting has an influence on the static compressive strength when the compaction energy is the same. This would be another influencing factor that increases the high dispersion in fatigue tests.

2. COMPOSITION AND MATERIAL

2.1 Material and Geometry

The high-performance concrete (HPC) [5] developed within the German Research Foundation's priority program 2020 (SPP2020) was utilized. An overview of its composition is provided in Table 1.

Table 1: Composition of the HPC with w/c = 0.35

Component [-]	**Density [kg/dm³]**	**Amount [kg/m³]**
CEM I 52,5 R – SR3 (na)	3.094	500
Quartz Sand H33 (0/0.5 mm)	2.70	75
Sand 0/2	2.64	850
Basalt 2/5	3.06	350
Basalt 5/8	3.06	570
BASF MasterGlenium ACE 460	1.05	5.00
BASF MasterMatrix SDC 100 (ST)	1.10	2.85
Water	1.00	176

Based on the cement content (500 kg/m³) and the water content (176 kg/m³), the water-to-cement ratio (w/c) was determined as 0.35. For the static tests, cube-shaped specimens with an edge length of 100 mm were prepared. All samples were stored at 20 °C and 65% relative humidity until testing, after being kept in the formwork for one day and subsequently cured under water for seven days.

2.2 Pouring

In order to assess the impact of the pouring order on the compressive strength, three cube-shaped specimens were poured every eight minutes. Each cube was filled uniformly and compacted for exactly 60 seconds. Compaction was performed using a vibrating table. Maintaining a constant compaction energy and duration excluded any potential influence of the pouring order.

3. TEST SETUP AND RESULTS

3.1 Test Setup

The static compressive strength tests were carried out using a compression testing machine (Toni Technik Baustoffprüfsysteme GmbH) with a maximum load capacity of 5000 kN. The specimens were loaded at a rate of 0.6 MPa/s. The results of the static compressive strength tests are shown in Table 2 and Fig. 2 in Chapter 3.2.

3.2 Results

The results of the static tests are summarized in Table 2. The table presents the pouring -start time, the mass, and the breaking load of the test specimens. For each pouring section, three specimens were produced. The corresponding mean values are also reported in Table 2. The results of the static compressive strength tests are illustrated in Fig. 2.

Table 2: Static compressive strength

Specimen	Pouring-start [min]	Mass [g]	Breaking load [kN]	Mean values [kN]
1.1	0	2544	1228.5	1242.2
1.2	0	2508	1266.8	
1.3	0	2586	1231.2	
2.1	8	2578	1246.3	1188.1
2.2	8	2470	1201.9	
2.3	8	2505	1116.2	
3.1	16	2526	1134.9	1189.1
3.2	16	2566	1239.1	
3.3	16	2503	1193.2	
4.1	24	2512	1065.5	1119.4
4.2	24	2553	1255.8	
4.3	24	2504	1036.8	
5.1	32	2494	1055.7	1038.1
5.2	32	2506	966.1	
5.3	32	2529	1092.5	
6.1	40	2520	1021.6	1103.6
6.2	40	2533	1065.5	
6.3	40	2548	1223.7	
7.1	48	2591	1046.5	1114.8
7.2	48	2563	1261.4	
7.3	48	2550	1036.4	
8.1	56	2533	1051.8	1036.2
8.2	56	2535	984.8	
8.3	56	2514	1072.1	

Fig. 1 presents a comparison between the specimen mass in g and the pouring time in min.

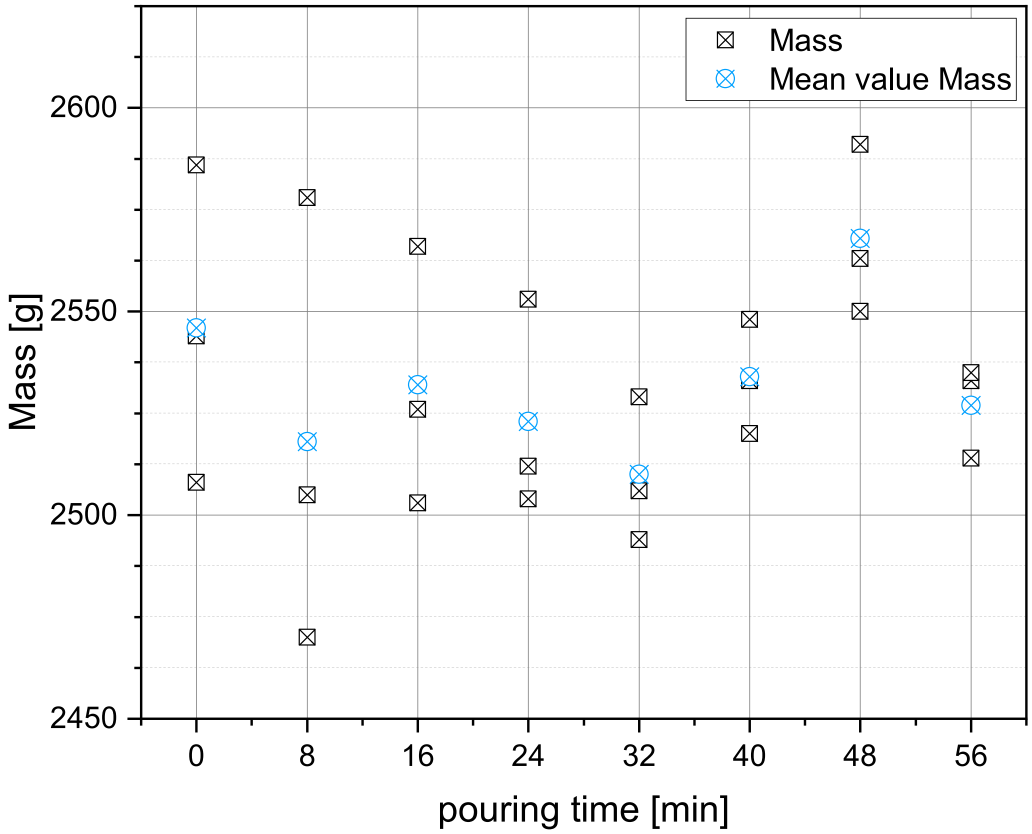

Fig. 1: Mass of the specimens compared to the pouring time

It can be seen that the mass does not correlate with the pouring time. This suggests that the concrete does not segregate during pouring and that each test specimen has the same composition, regardless of the pouring time.

Fig. 2 shows the breaking load in kN in relation to the pouring time in minutes. Three test specimens were produced and tested for each pouring section, which lasted 8 minutes. The values are illustrated as black squares and the mean values are shown in blue circles.

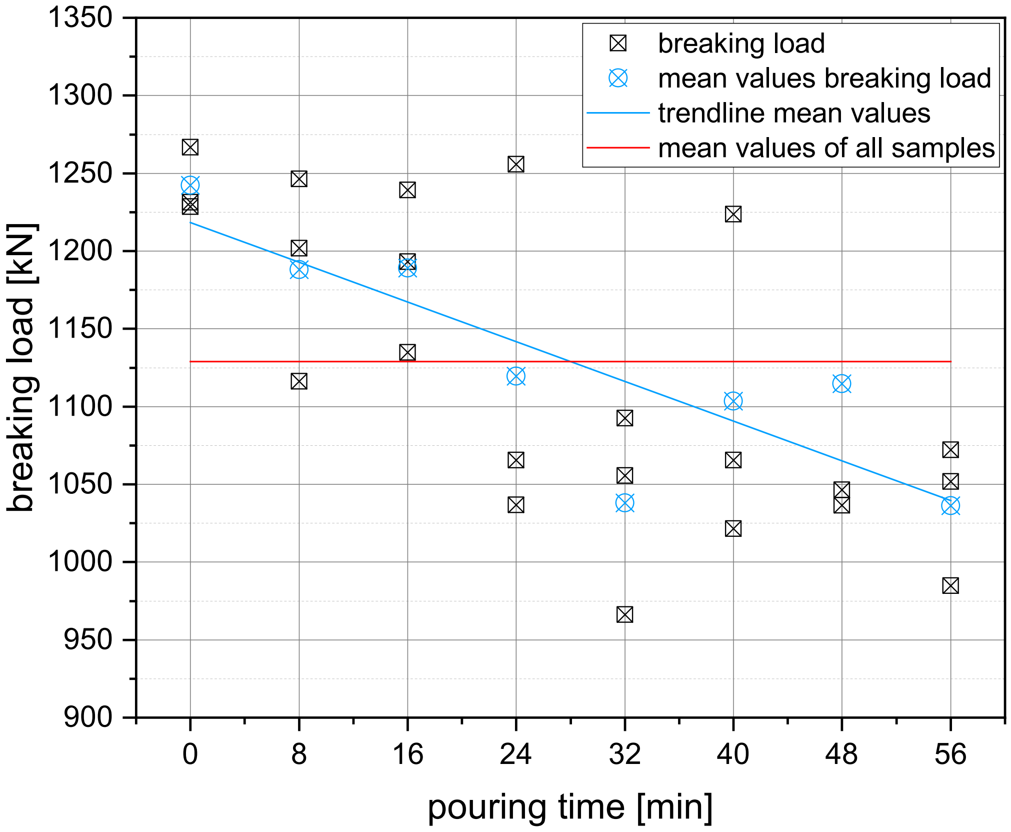

Fig. 2: Breaking load of the specimens compared to the pouring time

It can be observed that with increasing pouring time - and thus increasing stiffness of the concrete - the breaking load decreases. A possible explanation for this trend is the insufficient compaction of the specimens filled at later stages. Since all specimens were compacted for the same duration, those produced at a later stage may have required greater compaction energy due to the higher stiffness of the concrete.

Considering the percentage deviation of the respective breaking load from the mean value breaking load of all 24 samples (1128.9 kN) in Table 3 and Fig. 3, the first three concreting periods (1.1-3.3) have a higher compressive strength than the average value (10.0%; 5.2% and 5.3%). The later periods mainly have reduced compressive strengths, with the exception of a few outliers. This makes it clear that the reference compressive strength is highly dependent on the samples used. If the reference compressive strength is determined from the first three samples (1.1-1.3), for example, the compressive strength is 10% above the average compressive strength of all values. If the average is determined from samples 1.1, 4.1 and 8.1, the deviation is only be -1.2%. Overestimating or underestimating the reference compressive strength has a direct influence on fatigue resistance. For example, if the average value of all 24 samples is 100 MPa and the reference

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compressive strength is 90 MPa, the number of cycles to failure will increase. Conversely, if the reference compressive strength is overestimated, the number of cycles to failure decreases.

Table 3: Percentage deviation from the mean value

Specimen	Pouring-start [min]	Breaking load [kN]	Deviation [%]	Mean values [kN]	Average Deviation [%]
1.1-8.3		1128.9		1128.9	0.0
1.1	0	1228.5	8.8	1242.2	10.0
1.2	0	1266.8	12.2		
1.3	0	1231.2	9.1		
2.1	8	1246.3	10.4	1188.1	5.2
2.2	8	1201.9	6.5		
2.3	8	1116.2	-1.1		
3.1	16	1134.9	0.5	1189.1	5.3
3.2	16	1239.1	9.8		
3.3	16	1193.2	5.7		
4.1	24	1065.5	-5.6	1119.4	-0.8
4.2	24	1255.8	11.2		
4.3	24	1036.8	-8.2		
5.1	32	1055.7	-6.5	1038.1	-8.0
5.2	32	966.1	-14.4		
5.3	32	1092.5	-3.2		
6.1	40	1021.6	-9.5	1103.6	-2.2
6.2	40	1065.5	-5.6		
6.3	40	1223.7	8.4		
7.1	48	1046.5	-7.3	1114.8	-1.3
7.2	48	1261.4	11.7		
7.3	48	1036.4	-8.2		
8.1	56	1051.8	-6.8	1036.2	-8.2
8.2	56	984.8	-12.8		
8.3	56	1072.1	-5.0		

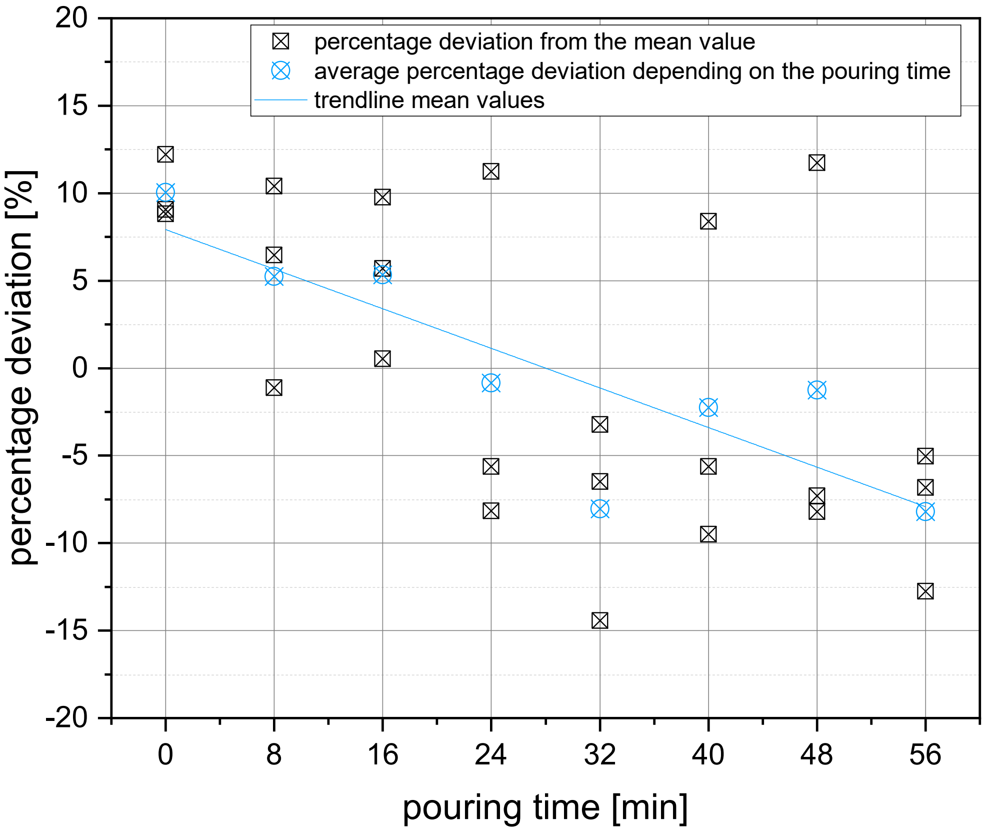

Fig. 3: Percentage deviation from the mean value

5. CONCLUSION AND OUTLOOK

During the tests, three specimens were cast every 8 minutes. All specimens were compacted for 30 seconds using the same compaction energy. After demolding and storage, the specimens were subjected to a static compressive strength test. The investigation showed that static compressive strength depends on the pouring time. This is evident from the higher static compressive strengths of the samples filled at the beginning of the concreting process than those filled towards the end. When the mass of the test specimens was considered at the same time, no correlation was found between the mass and the pouring time of the specimens. This in turn indicates that the pouring time has an influence on the static compressive strength and that the compaction time or compaction energy must be adjusted to the pouring time of the specimens. This means that test specimens that are concreted at a later stage must be compacted for longer due to the increasing stiffening of the concrete. Furthermore, it has been shown that the samples used for the reference compressive strength have a very significant influence. It is important that the samples are labelled according to their production time and tested evenly distributed. In this way, the influence of the dispersion from the static compressive strength could also be taken into account in fatigue resistance tests. To confirm this thesis, repeated tests must be carried out in which the compaction energy is adjusted. In addition, the effect of the pouring time would also have to be considered in further investigations such as fatigue or freeze-thaw stress tests.

REFERENCES

[1] MARKERT, M., KATZMANN, J., BIRTEL, V., GARRECHT, H., STEEB, H.: *Investigation on the Influence of Moisture Content on Fatigue Behaviour of HPC by Using DMA and XRCT*, Materials 15(1):91 (2021) https://doi.org/10.3390/ma15010091

[2] SCHMIDT, B., MARX, S., SCHNEIDER, S., BETZ, T.: *Einfluss der Druckfestigkeitsstreuung auf den Ermüdungswiderstand von druckschwellbeanspruchtem Beton,* https://doi.org/10.1002/best.202100025, 2021

[3] LOHAUS, L., ONESCHKOW, N., BASALDELLA, M.: *Influence of the specimen production and preparation on the compressive strength and the fatigue resistance of HPC and UHPC*, 2021, Doi: 10.1617/s11527-021-01696-9

[4] VOß, S., SCHMIDT, B., OETTEL, V.: *Fatigue resistance of concrete: influence of time-dependent scattering of compressive strength*, Materials and Structures 58 (3) (2025), https://doi.org/10.1617/s11527-024-02517-5

[5] BASALDELLA, M., JENTSCH, M., ONESCHKOW, N., MARKERT, M., LOHAUS, L.: *Compressive Fatigue Investigation on High-Strength and Ultra-High-Strength Concrete within the SPP 2020*, Materials 15 (11) (2022) https://doi.org/10.3390/ma15113793