Influence of Microcracks in High Strength Concrete on Durability Properties

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Abstract
Microcracks in High Strength Concrete (HSC) are often held responsible for unexpected effects related to durability. The aim of this research was to investigate how microcracks influence some durability properties.

High Strength Concrete specimens were exposed, preloaded or non-preloaded, to either freeze-thaw-cycles, sodium chloride solution, or carbon dioxide. Each specimen was sawn in two parts before testing. The larger piece was used in the durability tests while the smaller piece was used to examine the formation of microcracks right after cutting. At the end of the exposure, the larger specimens were analyzed with regard to their durability and the results were related to the microcracks formed.

Major findings were the enhanced damage of preloaded specimens caused by freeze-thaw-exposure. Capillary suction and carbonation of concrete exhibited no correlation to the microcracks contained.

1. INTRODUCTION, RESEARCH SIGNIFICANCE

The results presented here provide an insight into influences on the formation of microcracks and their effect on mechanical properties and durability of the hardened concrete.

According to [1] microcracks in concrete increase drying diffusivity in the initial period. Bishhop and van Mier [2] observed an increased drying rate accompanied by an extreme degree of microcracks in the concrete structure. The relationship between cracking and permeability was also investigated by Aldea et al. [3], [4]. They found that an increasing crack width will result in higher permeability.

2. EXPERIMENTAL METHOD

Specimens were preloaded to create an ample set of microcracks. These microcracks may affect durability of concrete exposed to aggressive substances. Within the investigation, preloaded and their companion non-preloaded specimens of HSC were exposed to either freeze-thaw-exposure or sodium chloride solution or carbon dioxide.

2.1 Materials, mix design and storing

In this study specimens made of one type of HSC were investigated. The basic mix design used cement and 8 % silica fume as binder. Sand and gravel were calcareous moraine...
aggregate originating from local sources around Munich. The detailed mix design is given in Table 1.

Table 1: Concrete mixture for the HSC

<table>
<thead>
<tr>
<th>Material</th>
<th>Bulk density [kg/dm³]</th>
<th>Mass [kg/m³] for 1 m³ fresh concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement CEM I 42,5 R</td>
<td>3,100</td>
<td>414</td>
</tr>
<tr>
<td>Silica fume (slurry)</td>
<td>1,390</td>
<td>72</td>
</tr>
<tr>
<td>Calcareous sand (0/4)</td>
<td>2,680</td>
<td>841</td>
</tr>
<tr>
<td>Calcareous gravel (4/8)</td>
<td>2,715</td>
<td>408</td>
</tr>
<tr>
<td>Calcareous gravel (8/16)</td>
<td>2,730</td>
<td>596</td>
</tr>
<tr>
<td>Additive (Woermann FM 375)</td>
<td>1,080</td>
<td>2,5</td>
</tr>
<tr>
<td>Water (Munich tap water)</td>
<td>1,000</td>
<td>121,5</td>
</tr>
</tbody>
</table>

The HSC specimens were demoulded after one day and cured under water until the age of 7 days. Subsequently they were stored in a 20 °C / 65 % r. h. climate until they reached the age of 28 days.

2.2 Accompanying tests
Water permeability was tested on 100 mm cubes. The preparation and testing of the cubes followed the relevant protocols in DIN 1048 [5] and DIN EN 12390 [6]. Compressive strength was measured on 150 mm cubes and splitting tensile strength (Brazilian test) on 100 mm cubes. The values given in Table 2 represent the average results of three specimens after 28 days.

Table 2: Mechanical properties of the high strength concrete, age 28 days

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength [MPa]</td>
<td>88,8</td>
</tr>
<tr>
<td>Bulk density [kg/dm³]</td>
<td>2,428</td>
</tr>
<tr>
<td>Splitting tensile strength [MPa]</td>
<td>7,1</td>
</tr>
<tr>
<td>Water permeability [mm]</td>
<td>12</td>
</tr>
</tbody>
</table>

2.3 Specimen preparation
10 cm cubes were used as specimens to investigate the influence of microcracks on durability properties. At 28 days, half the specimens explored were preloaded with a load of 67 % of the maximum compressive strength (see table 2) to create sufficient microcracks. Subsequently preloaded and non-preloaded specimens were sawn in two parts of different size perpendicular to the loading direction. The larger piece comprising two thirds of the original sample was intended for the durability tests while the remaining third was used to examine microcracks originally present right after cutting. Figure 1 illustrates the procedure.
After sawing, the surfaces intended for the subsequent investigation were smoothed, ground and dried. A special casting resin of low viscosity was poured onto the ground surface, dried and later polished so that cracks and pores became visible. The surface was investigated under a microscope camera. Microcracks were measurable down to a width of 3 µm. The preparation procedure and the evaluation are documented in detail in [7] and [8]. In this research program, cracks with widths up to 25 µm were defined as microcracks. Wider cracks were referred to as macrocracks.

2.4 Exposure to different media

2.4.1 Suction of sodium chloride solution

Specimens for testing the suction of sodium chloride were sealed with paraffin wax on four sides perpendicular to the exposed surface. Thereafter specimens were stored on two small three-edge bars in a basin with 3 % sodium chloride solution. For the suction testing, the loaded surface was dipped into the solution to a depth of 10 mm. In this paper only the weight-changing results are presented.

2.4.2 Freeze-thaw-resistance

Specimens were sealed on their four sides with a weather resistant tape. Following the procedure described in 2.4.1 the concrete specimens sucked sodium chloride solution for 7 days. The freeze-thaw resistance was tested according to the CDF-procedure given in DIN EN 13290-9 [9]. The results are given as mass of scaled material over time of testing.

2.4.3 Carbonation

Part of the specimens were stored in a Kesternich-chamber containing a 0,3-% concentration of carbon dioxide. Depth of carbonation was measured upto an age of almost two years. For this purpose the specimens were split in two parts and the uneven rough surfaces were sprayed with phenolphthalein solution. The maximum depth of carbonation was measured.

3. TEST RESULTS

Measurements were carried out at different ages. The results presented here are based on measurements at 28, 63 and 75 days. The formation of microcracks was investigated directly after cutting at an age of 28 days.
The latter results are based on 6 specimens of HSC cubes. The comparison of the formation of microcracks with the durability properties is always based on two specimens originating from the same concrete cube (see Figure 1).

### 3.1 Freeze-thaw-resistance

Scaling of the HSC specimens was measured after 8, 16, 42 and 112 freeze-thaw cycles (Figure 2). The preloaded specimens always showed a little more scaling, especially those of a higher age. Two of the preloaded specimens and one non-preloaded specimen were destroyed after 42 freeze-thaw cycles. After 112 freeze-thaw cycles all specimens were seriously damaged.

![Figure 2: Scaling of high strength concrete](image)

### 3.2 Suction of sodium chloride solution

The preloaded specimens showed the highest mass increase during the testing of suction of sodium chloride. The values measured for one specimen exceed the others by far. This concrete cube exhibited a few macrocracks with crack widths up to 200 µm. Apart from this specimen, the difference between non-preloaded and preloaded concrete specimens is marginal.
Figure 3: Increase of mass of specimens sucking sodium chloride solution

3.3 Carbonation

No carbonation was detected in any of the specimens during the test. Even specimens stored for almost two years (594 days) in the 0.3-% carbon dioxide climate chamber showed no carbonation after splitting and testing with the indicator.

3.4 Microcracking

The total number of cracks, their distribution, as well as their length and width were explored by using a grid placed upon the specimens surface. Moreover, the microcracks were classified as either those present in the mortar matrix, or those visible in the contact zone around aggregates, or in microcracks present in the rim area of the sample or in its inner section. The rim area was defined as the outer 12 mm of the specimen’s surface.

In this chapter only microcracks were considered in the evaluation. The examination of the relation between the microcracks and the durability properties include all cracks present: both micro- and macrocracks. But only two samples in this study contained macrocracks with widths up to 200 µm.

The preloading to a level of 67 % of the maximum compressive strength led in most cases to a higher number (Figure 4) and a higher total area of microcracks. The inner section of the loaded specimen was more affected showing a higher increase of microcracks compared to the rim. This holds especially true for the total area of microcracks (Figure 5).

The total area of microcracks in the contact zone in the inner section of the preloaded specimens is higher, although the number of contact zone microcracks is lower. The average width of microcracks in the contact zone in the inner section is twice as high as in the rim area, the microcrack length of the contact zone in the inner section is about three times as high as in the rim area (Figure 6). The average width and length of microcracks in the mortar matrix are almost the same.
Figure 4: Number of microcracks in the mortar matrix and in the contact zone

Figure 5: Total area of microcracks in the mortar matrix and in the contact zone

Figure 6: Average length and width of microcracks in the mortar matrix and in the contact zone
3.4 Correlation between microcracks and durability properties

Scaling caused by freeze-thaw cycles shows neither a clear dependency on the microcrack width nor the length or the total area. Figure 7 shows exemplarily the correlation between the average crack width of microcracks and scaling after 8 respective 42 freeze-thaw cycles. Scaling is slightly more severe for preloaded specimens which also exhibit a higher total area of microcracks.

![Figure 7: Average crack width of microcracks in relation to the scaling material](attachment:figure.png)

Preloading does not affect mass increase during suction of sodium chloride solution nor is there a relation of the latter to microcrack width, length, number or total microcrack area. Depth of carbonation was not measurable for the HSC used, thus no influence possibly caused by microcracks could be detected.

4. DISCUSSION

4.1 Influence of preloading on durability properties

The durability properties, carbonation and suction of sodium chloride solution exhibit no clear dependency to the microcracks contained in the HSC samples. The increased suction of sodium chloride was due to macrocracks, with widths up to 200 µm, but microcracks seem to be too small to have an impact on fluid transportation. [1] also states that cracks with widths of about 100 µm influence the moisture diffusion of concrete. But very small cracks do not influence the permeability properties according to [1], [3] and [4].

No influence of microcracks was observed for CO₂ ingress. Obviously, the microcracks present in HSC are too small to be permeable to CO₂. Also [10] ascertained that microcracking has a greater influence on permeability than diffusivity.

The slightly higher damage that preloaded specimens suffered when exposed to the freeze-thaw tests could be due to crystallization pressure acting in the microcracks while freezing. Moreover the average width of microcracks increased significantly due to the preloading.
4.2 Formation of microcracks

The higher area of microcracks in the contact zone especially in the inner section of preloaded specimens is probably due to local stresses caused by the different stiffness of the aggregate and the surrounding cement paste. These local tensile stresses are superimposed by tensile stresses caused by self-desiccation due to the low water binder ratio of the HSC.

4.3 Influence of microcracks on durability properties

Microcracks present in the HSC may be too small to influence durability properties investigated here. The higher scaling of the preloaded specimens could not be related to a higher number, area, length or width of microcracks.

5. CONCLUSIONS

- Preloaded specimens showed no difference with respect to suction of sodium chloride and carbonation when compared to non-preloaded specimens. Freeze-thaw resistance is lower and damage is visible earlier than for non-preloaded specimens.
- Preloading led to a higher area of microcracks, especially in the inner section.
- Preloading led to microcracks with an enhanced average width and higher average length, which result consequently in a higher total area of microcracks, especially in the contact zone in the inner section. However, preloading did not have a similar affect on the number of microcracks formed.
- The results presented in this paper did not show a correlation between the microcracks in the high strength concrete structure and carbonation or the suction of sodium chloride solution. Freeze-thaw resistance showed slightly higher damage when higher average crack widths occurred.

REFERENCES


