Method Statement

Strength Measurement of Shotcrete

(Instruction for use)

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Introduction

The compressive strength of the initial strength development of fresh shotcrete up to 1.5 MPa has to be measured by needle penetration methods. Beyond this strength studs are used which are driven into the specimen surface. The recently released EN 14488-2 “Testing sprayed concrete - Part 2: Compressive strength of young sprayed concrete” describes this procedure. For internal use, Sika has improved and simplified the sprayed concrete strength development measurement, i.e. only readings for the penetration depth of the studs are collected whereas the readings from the corresponding pull out test are neglected.

Chemical Processes in Shotcrete

Essentially, the strength development of shotcrete can be described as an effect of two major chemical processes which start subsequently after the mixing of the fresh concrete with the shotcrete accelerator at the nozzle.

These processes are illustrated in Figure 2. The strength development of a non accelerated concrete would basically follow the dashed blue curve which is characterised by an initial dormant period followed by a strong increase of the compressive strength due to the cement hydration reaction. Far different, as a result of overlapping effects of two chemical reactions the accelerated shotcrete would follow the straight red curve. There is the initial strength development (ca. 0 - 60 min) due to the chemical reaction of the accelerator with the cement solution (dotted green curve) followed by the strength development due to the cement hydration reaction (from 3 - 4 h).
Measurement methods

Initial and early compressive strength development of shotcrete, i.e. up to 24h, is measured using indirect methods, namely penetrometer and Hilti stud. Both methods correlate the impact of the compressive strength on the penetration of a needle. Apart from any recommendation as they are given by this method statement or local regulations (Hilti brochure, EN 14488-2, etc.) one has to keep in mind that any general correlation function describing these impacts would be just an approximation. Thus, results from these methods depend on the mix design, i.e. on the used aggregates (0 - 8 mm), and would not necessarily result in absolute values of the compressive strength.

The entire compressive strength measurement of sprayed concrete requires three methods:

Table 1: Measurement methods for strength development of sprayed concrete

<table>
<thead>
<tr>
<th>Development of</th>
<th>Method</th>
<th>Instrument</th>
<th>Strength</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial strength</td>
<td>needle penetration</td>
<td>Penetrometer</td>
<td>up to 1.5 MPa</td>
<td>0 to 3 h</td>
</tr>
<tr>
<td>Early strength</td>
<td>stud driving</td>
<td>Hilti DX 450-SCT</td>
<td>3 to 20 MPa</td>
<td>3 to 24 h</td>
</tr>
<tr>
<td>Final strength</td>
<td>coring</td>
<td>Compression testing machine</td>
<td>5 to 100 MPa</td>
<td>1 to 28 d</td>
</tr>
</tbody>
</table>

Needle penetration method

Results from this method are calculated from the force which is required to penetrate 15 mm of the specimen's surface using a 3 mm needle. The tip of the needle has an angle of 60°. Using this method one can manually determine the strength up to approx. 1.5 MPa.

At Sika usually digital penetrometer are used, e.g. Mecmesin AFG 1000. The instrument is used in the N-mode (Newton). From ten readings the compressive strength in MPa is according the formula: \( y = \frac{(x + 35)}{690} \) as illustrated in figure 5.

Alternatively, one can use a mechanical penetrometer for a measurement range from 0.16 MPa to 1.0 MPa (Figure 6 and Figure 8).
Figure 4: Penetration of freshly sprayed concrete using a digital penetrometer (Mecmesin AFG 1000)

Figure 5: Correlation between compressive strength and penetrometer readings e.g. 323 N (Figure 4) yields 0.52 MPa (Figure 5)

\[ y_i = \frac{y_i + 35}{690} \]
Figure 6: Mechanical penetration needle

Figure 7: Reading of measurement: 27 Kiloponds [kp]
Figure 8: Determination of the strength using a mechanical penetration needle (official Meyco curve 0-8mm) \[ 27 \text{ kp} = 0.42 \text{ MPa} \]

**Stud driving method (HILTI)**

Compressive strengths between 3 and 20 MPa are determined by threaded studs, which are driven into the shotcrete surface (Figures 9 - 12). The depth of penetration \( h_{nom} \) results in the compressive strength according to the Sika calibration curve (Figure 10). Five readings per measurement are necessary.

The measurement tool for this method is the Hilti DX 450-SCT (former: Hilti DX 450 L) with green cartridges. Initially longer studs are used (X-M6-8-95 D12) until the penetration depth is below 20 mm and, subsequently, shorter studs are used (X-M6-8-52 D12). The driving force of the Hilti gun has to be adjusted to 1 (Figure 9).

**Differences of the Sika method compared to EN 14488-2**

- Modified stud curve: \[ y = 59.727e^{-0.036x} \] (Sika) substitutes \( y = 7.69x^{-2.7} \) (EN 14488-2, Annex B (informative))
- Only five studs are used per measurement instead of ten.
- No pullout tests using the studs.
Figure 9: The setting of the power regulation must be adjusted to level 1.
Figure 10: Penetration of young sprayed concrete with studs using a Hilti DX 450-SCT (left) and measurement of the stud standoff for the determination of the penetration

Figure 11: The penetration depth $h_{nom}$ is used for the determination of the compressive strength
Figure 12: Correlation between compressive strength and stud penetration depth (Sika method).
Drill core method
The Final compressive strength is determined using concrete drill cores according EN 12504-1 “Testing concrete in structures”.

Figure 13: Core drilling from sprayed concrete sample (left) and compressive strength measurement of a drill core (right)
Test set-up and equipment

Below, there is a check list with materials, parameters and workflow, which are necessary and important for the execution of shotcrete trials.

**Material**
- Admixtures
- Concrete
- Stopwatches, writing materials
- Penetrometer Mecmesin
- Hilti DX 450-SCT, green cartridges, studs (95 & 52 mm), folding rule
- Colour spray, spray boxes
- Covering material (protection & insulation)
- Drill core equipment

**Environment**
- Concrete factory
- Concrete truck mixer
- Spray equipment
- Nozzle man
- Application place

**Workflow**
- Targets of trial, Mix Design calculation
- Installation at the workspace
- Definition of application parameters (distance nozzle to specimen, spraying angle, concrete output, air pressure nozzle, time of spraying)
- Check of spraying equipment (air pressure, hydraulic pressure, concrete- and accelerator flow, pulsation at nozzle, order of nozzle and Injector, fill factor, Mix Design input: accelerator dosage and density, cement content)
- Monitoring of concrete production (cleaning water has to be got off from the truck mixer drum, no using of oil (release agent), no water addition on site)
- Measuring of fresh concrete parameters (flow spread, temperature, air void and water content, density)
- Spraying, covering and evacuation of the samples
- Measuring of the sprayed concrete strength development

**Recommended Parameters**
- 1.5 m distance from nozzle to wall (optimal compaction)
- Rotating nozzle (optimal compaction)
- Spray angle nozzle to wall: 90° (optimal compaction)
- 4.5 bar air pressure (optimal compaction)
- 1st mix should be used as dummy. All kind of contaminations (lubrication agents, cleaning water in the truck and release agent) decrease the strength development
- Initially to the production of the specimen the spraying should last minimum one minute, i.e. the entire system has to achieve equilibrium condition (optimal homogenisation of concrete and accelerator)
- Using of boxes are recommended (safety, handling)
- shape of boxes should avoid rebound inclusions (cone shaped, downside open)
- As a compromise regarding portability (to high weight) and prevention of cooling (low volume/surface ratio) the filled boxes should have a weight of 60-80 kg.
The concrete output should be < 12 m$^3$/h in order to avoid strong pulsation at the nozzle, thus, achieving a better mixing of accelerator and concrete as well as ensuring a reasonable dosage control.

**Frequency of measurement**
- **Initial strength development:** 6', 20', 40', 60' and 120' Minutes or up to 1.5 MPa with penetrometer. 10 readings per measurement. Target: Recording of the accelerating curve
- **Early strength development:** Two times by Hilti DX 450-SCT between 3 to 8 hours. 5 readings per measurement. Target: Recording of onset and initial slope of the hydration increase.
- **Final strength development:** 12 and 24 hours; up to 20 MPa (Hilti). 5 readings per measurement. Target: Project related.
- **Final strength (28 days):** if necessary by drill cores > 20 MPa. 5 readings per measurement. Target: Project related.

**Storage of freshly sprayed samples**
Any movement and vibration of the samples should be avoided as good as possible during the first 12 hours. Therefore, the specimens have to be handled carefully. Due to the rather high volume to surface ratio of this type of specimens there is a far higher loss of temperature over time compared to a real bulk shotcrete. Any decrease of temperature yields in a retardation of the chemical processes during the first 12 hours, i.e. compared to “real shotcrete conditions” the hydration start and development is negatively influenced. Therefore, the specimens have to be accordingly insulated immediately after spraying.

**Additional testing**
- Fresh concrete control: shotcrete performance is not interpretable and must not be interpreted without these values.
- Mix design analysis (sieve curve, cement, water content, …)
- Quality of application (substrate preparation, impaction, pulsation, …)
- Cast cubes of concrete (28d-difference between unaccelerated to accelerated concrete)

**Analysis**
- Strength classes according EN 14487-1
- Comparison with project requirements
- Calculation of effective accelerator consumption per cubic meter of sprayed concrete.
Figure 14: Shotcrete early strength classes according EN 14487-1

Class J1 sprayed concrete is appropriate for application in thin layers on a dry substrate. No structural requirements are to be expected in this type of sprayed concrete during the first hours after application.

Class J2 sprayed concrete is used in applications where thicker layers have to be achieved within short time. This type of sprayed concrete can be applied over head and is suitable even at difficult circumstances, e.g. in case of slight water afflux and immediate subsequent work steps like drilling and blasting.

Class J3 sprayed concrete is used in case of highly fragile rock or strong water afflux. Due it’s rapid setting, more dust and rebound occurs during the application and, therefore, class J3 sprayed concrete is only used in special cases.

Table 2: Example of a filled field test sheet with readings from 6min to 24 hrs
**Strength development of sprayed concrete**

<table>
<thead>
<tr>
<th>Jobsite</th>
<th>Tunnel Azoos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box</td>
<td>2.1</td>
</tr>
<tr>
<td>Concrete temperature</td>
<td>17.0 °C</td>
</tr>
<tr>
<td>Air temperature</td>
<td>15.0 °C</td>
</tr>
<tr>
<td>SF 0'/60'120'</td>
<td>620/550/510 mm</td>
</tr>
<tr>
<td>Water content</td>
<td>190 kg</td>
</tr>
<tr>
<td>Spraying time</td>
<td>09:35 h</td>
</tr>
</tbody>
</table>

Concrete production 06.06.09 09:01 h

Concrete mix Number 2 Beton Sargans 2 m3

Concrete producer Cement producer Holcim CEM II A-LL/42.5 (Fluvio 4) 400 kg/m3

Cement type Limestone 20 kg/m3

Additive Cement type Sika/ViscoCreteSC-305 1.0 %

Admixture Cement type Sigunit-L83 AF 6.0%

Additive Cement type Cement type Water content 190 kg

Spraying time 09:35 h

Drill core strength 28d

**Figure 15:** Field test result showed in excel-graph

**Addresses**

**HILTI:**

- Hilti DX 450-SCT
- Green cartridges
- Threaded studs (length: 52 & 95)


The following **Mecmesin**-Instruments are possible:

- BFG 500
- BFG 1000
- AFG 500
- AFG 1000

The adapter and the needle for the Mecmesin have to be prepared locally.

Figure 17: Adapter and needle for the digital penetrometer (Mecmesin)

Attachement

- Sika Concrete News, Dr. Gusti Bracher
- Manual HILTI