Rheometer as a measuring tool for the reproducibility of concrete in the Shotcrete 3D Printing Process

Rheometer als Messmethode für die Reproduzierbarkeit von Beton im Shotcrete 3D Printing Prozess

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Abstract

Currently the concrete 3D printing technology "Shotcrete 3D Printing" (SC3DP) is under development at the TU Braunschweig. Once a suitable concrete mixture for this technology is established, a high reproducibility is crucial to achieve the same high printing quality at all times. In this paper it is investigated if the reproducibility of the mixture can be measured with a rheometer.

1. Motivation

Today research activities in the field of concrete 3D printing are constantly rising. Compared to conventional building processes this kind of manufacturing allows an increase in productivity, a reduction in costs and more complex shapes /1/.

A concrete 3D printing technology currently under development at the TU Braunschweig is the "Shotcrete 3D Printing" (SC3DP). This technology is based on the wet-spraying process of concrete and allows for the fabrication of complex elements with large dimensions. Figure 1 displays an example of a prototype with an overhang of 40 cm /2/.

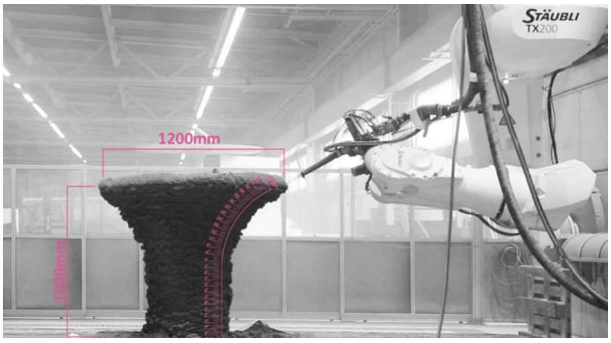

Figure 1: Fabrication of a prototype with a horizontal overhang of 40 cm /3/

Compared to other concrete 3D printing technologies like extrusion the SC3DP process has many benefits for example a better interlayer strength and a reduced risk of cold joints /2/. One key area of innovation is the concrete development.

2. Issues

Due to the shotcrete process (mixing, pumping and spraying) the concrete is exposed to different shear rates which lead to contrary rheological requirements. For example, during pumping the concrete should have a sufficiently high yield stress at low shear rates to reduce the risk of segregation and sedimentation. However, at the same time the yield stress should be sufficiently low at high shear rates to allow a good workability of the concrete /4/. Additionally, high yield stress after leaving the nozzle is required for sufficient vertical buildability.

Currently research is being done on the composition of the concrete to meet these complex rheological requirements. Once the rheological requirements are met, a high reproducibility of the concrete is crucial to allow for the same high printing quality at all times. In order to verify that always the same rheological behavior is achieved and to allow for an adjustment of the concrete if needed, quality control has to be performed. As a testing tool a rheometer could be used after the mixing step.

To investigate if the reproducibility can be measured with a rheometer, tests are carried out after mixing. In the presented tests the effect of i) viscosity modifying agent (VMA) on static yield stress and ii) the reproducibility of the rheological behavior is evaluated. The VMA is supposed to enable shear thinning behavior at high shear rates and an increased thixotropic behavior and therefore help to achieve the complex rheological requirements /5/.

3. Materials and Methods

The composition of the studied concrete is listed in table 1. Three different VMA dosages (Mix 1 - 3) are examined. To evaluate the reproducibility each mix is fabricated three times.

To achieve a homogeneous material a specific mixing procedure is carried out. First water is added to the mixer. Then cement, limestone powder and aggregate are added during the first two minutes of mixing. 15 sec after the mixing started the VMA is added followed by the PCE

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superplasticizer at 45 sec. Once all components are added, the material is mixed for additional two minutes.

Table 1: Composition of the studied concrete

Components	Amount	Unit
CEM I 52,5 R (OPC)	600	kg/m³
Ground limestone	97	kg/m³
Aggregate d= 0 – 3,15 mm	1258	kg/m³
Tap water	270	kg/m³
PCE superplasticizer	0.4	%bwoc
VMA	Mix 1: 0.0	%
	Mix 2: 0.1	%
	Mix 3: 0.2	%

The static yield stress is measured with an ICAR Plus Rheometer. The rheometer consists of a rotating vane on a static container. The vane is rotating at a low, constant speed while, monitoring the build-up torque. The maximum torque corresponds to the static yield stress.

4. Results

Overall the test with the ICAR Plus rheometer were easy and fast to perform. In figure 2 the measured torque [Nm] is displayed over the elapsed time [s] for the three tests with 0.1 % VMA (Mix 1).

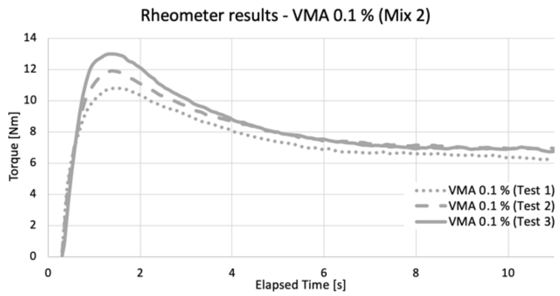

Figure 3: Rheometer results Test 1 – 3 for VMA 0.1 % (Mix 1)

All in all, the graphs overlap and show a good reproducibility since this mix has very low standard deviation, as displayed in table 2.

Table 2: Average static yield and standard deviation (n=3)

Components	Average static yield	Standard deviation	Units
Mix 1 (0.0 % VMA)	0.11	0.02	kPa
Mix 2 (0.1 % VMA)	2.78	0.21	kPa
Mix 3 (0.2 % VMA)	4.09	0.17	kPa

It can be noted that the standard deviation for every mix is low and therefore the reproducibility is good.

Figure 3 shows the result of a test of mix 1 to mix 3. The graphs from figure 3 and the data from table 2 show that an increase in VMA results in an increase in static yield stress. The increase is attributed to the formation of a three-dimensional network between the particles by the VMA, which increases the static yield stress. It was further noticed that mix 3 with 0.2% VMA was difficult to process due to its stiff consistency. Mix 2 had the best consistency, stiff enough to hinder segregation and sedimentation while still being workable. Mix 1 was very flowable and does not enable to sufficient vertical buildability.

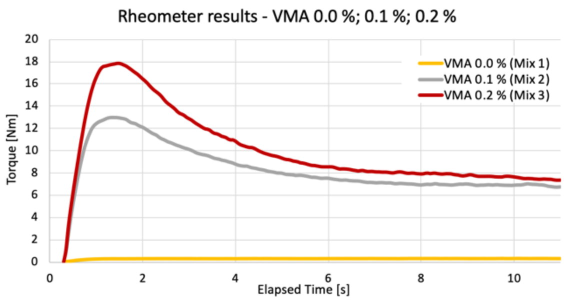

Figure 2: Rheometer results VMA 0.0 %; 0.1 %; 0.2 %

In summary it can be concluded that a rheometer is a good tool to measure the reproducibility for the SC3DP process and is herewith suitable as a quality measuring tool during the SC3DP-process. Additionally, it was discovered that a VMA can be helpful to modify the mixture's yield stress as well as increase the thixotropic behavior of the concrete and is herewith a suitable admixture for SC3DP.

5. References

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