Influence of environmental conditions for the rheological properties of SCC

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Abstract. The aim of a research project at the University of Luxembourg is on one side to develop a formula for Self-Compacting Concrete (SCC) without any admixtures, and on the other side to reduce high compression strengths. Thus, it was decided to develop Self-Compacting Concretes of the "Combination-Type" with smaller content of fines but a higher amount of cement than from the "Powder-Type" and with the use of stabilizer. As binder was used blast furnace cement. In this paper are results from one part of this research project presented.
An essential problem of SCC is the significant influence on the workability of the fresh concrete as a result of fluctuations of environmental conditions. Therefore, the properties of workability during production and processing of SCC, when different temperatures and levels of humidity applied, were investigated.
With these investigations, as estimated, an augmentation of the slump-flow with rising temperatures appeared. At lower temperatures the effect of the superplasticizer was strongly retarded. The lower the ambient temperatures were the lower became also the early strengths. In order to be able to ensure a continuous consistency at the different climatic points, the amount of superplasticizer had to rise with falling ambient temperatures. At the climatic point K_{20} (20°C/60%) an optimal setting behavior with a minimal workability loss could be observed.

1 Experimental program

To guarantee that the temperature and level of humidity at the respective climatic point is constant, the production as well as the testing and processing were realized inside a climatic test chamber. The investigations are separated in two test series. For the 1st series of tests the content of the superplasticizer and the stabilizer were constant. On the one hand the change of the workability of the fresh concrete after the end of the mixing and on the other hand the developments of the compression strength from the hardened concrete in dependence of the environmental conditions were tested. In the 2nd series of tests the needed superplasticizer amount, in order to maintain the initial consistencies at different climatic conditions, will be determined. In addition, the workability losses of the new designed Self-Compacting Concretes at each “climatic point” were estimated.

2 Materials and Proportion

Realized as Combination-Type, the amount of fines of the Self-Compacting Concrete should be covered exclusively by the cement content. Another basic condition was to restrict the final strengths. With these objectives new formulations were developed. Blast furnace cement (CEM III/A 52.5 L) was used as binder. The w/c-ratio was kept constant with a value of 0.45. Beside a superplasticizer on the basis of polycarboxylate ethers (PCE) a stabilizer on the basis of synthetic copolymers was added. In table 1 the formulation of the tested concrete is presented.

Table I. Formulation of the tested SCC

Material	Proportion / m³		
	Density [g/cm³]	Volume [dm³]	Mass [kg]
Cement (CEM III/A 52,5L)	3.01	139	417
Sand 0/1 mm	2.65	36	95
Sand 0/2 mm	2.65	267	708
Gravel 4/8 mm	2.65	240	636
Gravel 8/16 mm	2.65	110	292
Water (incl. SP + ST)	1.0	188	188
w/c-ratio	0.45		
m_{cement} / m_{sand}	0.52		

3 Test methods

As well the preconditioning of the raw materials as the production of the mixtures and the tests of the fresh concrete characteristics were realized at different climatic points.

In order to determinate the relevant climatic couple of temperature and humidity the weather data of Luxembourg [1] with the minimal and maximal monthly temperatures and the associate humidity during the last 10 years were analyzed.

With the climatic points defined in table 2, the local climate conditions can be satisfyingly represented. Since under a concrete temperature of 5°C no more concrete should be accomplished, the definition of the climatic points ends at this temperature.

Table II. Climatic points for measurements

Climatic point	K_5	K_{10}	K_{15}	K_{20}	K_{25}	K_{30}
Temperature [°C]	5	10	15	20	25	30
Humidity [%]	90	90	75	60	45	30

At all these climatic points the slump-flow and the funnel-time were measured according to the German Guideline for Self-Compacting Concrete [2]. The relative viscosity and the relative yield stress were also measured with the Rheometer BT2 from the company Schleibinger Geräte Teubert & Greim GmbH. The basic experimental setup and the implementation of the test with the BT2 you can find in [3]. To estimate the workability loss of the SCC, all these rheological parameters were measured every 30 min up to an age of 2 hours.

Figure 1. Experimental setup - climatic test chamber outside (a) and inside (b), BT2-Rheometer (c), funnel-time (d) and slump-flow (e)

Furthermore, the developments of the compression strengths were determined in according to DIN EN 12390-3 [4]. The preconditioning of the raw materials, the production of the mixtures and the tests at the fresh concrete were realized in a climatic test chamber (fig. 1).

4 Test results

4.1 Constant mixture composition [series of tests 1]

Fresh Concrete: At the beginning the formulation of the SCC were modified and optimized in order to obtain a slump flow of 70 cm at the climatic point K_{20}. Without any changes to this formulation at all other climatic points, the measurements of the slump-flow as well as of the funnel-time were realized. Generally, it is assumed that rheological parameters from measurements with rheometers describe the workability of SCC more precise than the slump-flow and the funnel-time, as the rheological parameters, rel. yield stress and viscosity are numerically described. So, the rheological characteristics were determined by the Rheometer BT2, too. Fig. 2 shows the slump-flow in comparison to the relative yield stress measured with the BT2 at the individual climatic points. As desired the slump-flow increase if the relative yield stress decrease. Only at the climatic point K_{15} the relative yield stress is lower than expected.

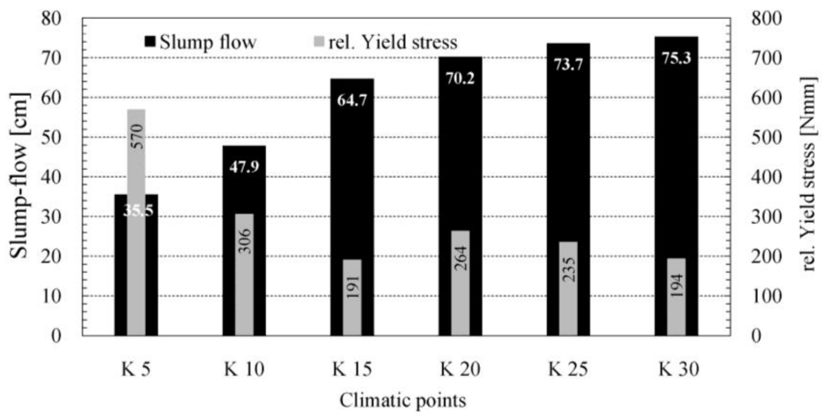

Figure 2. Slump-flow vs. relative yield stress at the different climatic points

It can be stated that with rising temperatures the slump-flow rises likewise. This becomes more obvious for lower temperatures (5°C…15°C) than for the higher temperatures (20°C…30°C). The superplasticizer (SP) acts more intensively at higher temperatures. At lower temperatures the effect of the SP is strongly

retarded. While casting the test specimens (about 15 min after tests) the liquefaction was clearly stronger than at the moment of the measurements.
In Fig. 3 the funnel-time and the relative viscosities are compared. At the climatic point K_{20} the lowest funnel-time was measured with 10.5 seconds. As well at higher as at lower temperatures the funnel-time increases.

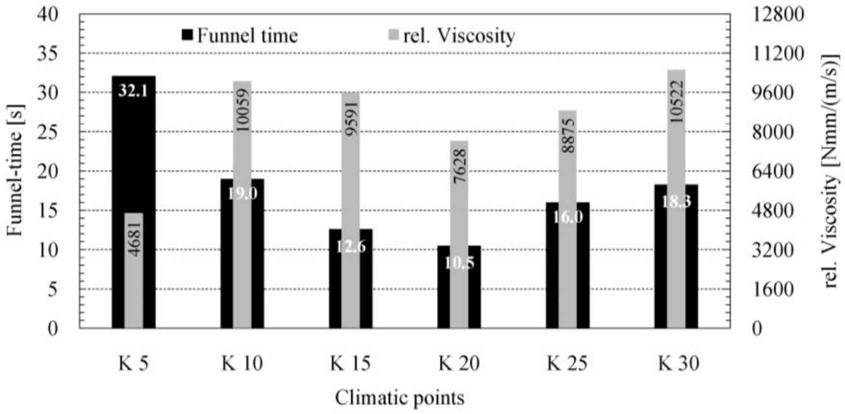

Figure 3. Funnel-time vs. relative viscosity at the different climatic points

If the temperatures rise, then the reactivity of the cement increases. Accordingly, the funnel-time rise at higher temperatures. At lower temperatures the effectiveness of the superplasticizer is again substantially retarded. One reason for this retarding could be the different adsorption rates of the superplasticizer at different temperatures. So, the slump-flow decreases. Thus, the viscosity and as a consequence the funnel-time will be influenced too and their values increase. The relative viscosities show a similar tendency as the funnel-time. An exception appears at the climatic point K_5. Here, the retarded liquefaction at low temperatures can be observed, since this measurement took place at about 4 minutes later than the measurement of the funnel-time. This short time was long enough to see this pronounced effect appear.

Hardened Concrete: In order to evaluate the development of the compression strength, nine 150 mm cubes were manufactured. The plastic formworks were pre-conditioned at the respective climate point, too. The specimens were stored until the measurement of the 16 h-strength in the current climates. Up to the respective dates of measurement (7d and 28d) the remaining probes were after the stripping storage under water at 20°C. In Fig. 4 the developments of the compression strength of the concrete, produced at different climatic points, are represented.

The early resistance lies in range between 0.7 N/mm² and 21.3 N/mm². The lower the ambient temperatures were, the lower the early compression strength also is. Thereby only a retard of strength development seems to be at the origin of this phenomenon, since already at an age of 7days hardly any deviations of the resistance between the different climatic points can be recognized. The hardened concrete densities remain nearly identical (2.33 g/cm³…2.36 g/cm³).

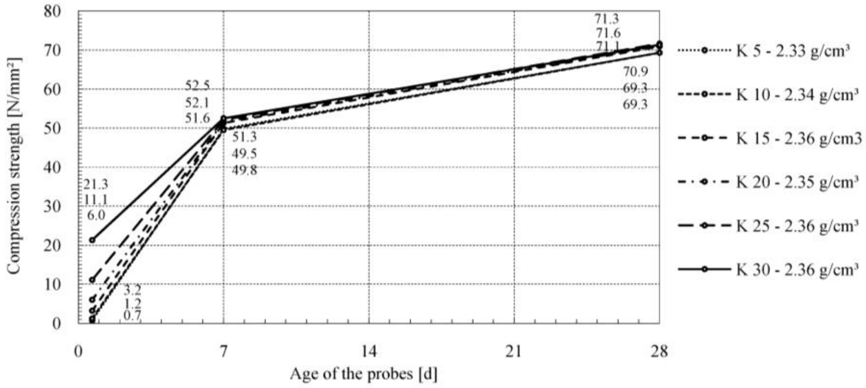

Figure 4. Development of the compression strength at different climatic points

It can be observed a high increase of the early strengths with rising temperatures. As rule of thumb, it can be stated that an increase of the concrete temperature of 5°C causes a doubling of the early strengths.

4.2 Constant initial consistence [series of tests 2]

Fresh Concrete: The formulations were optimized by variation of the super-plasticizer amount in such a way that at all climatic points the initial consistence after mixing with a slump-flow of 70 cm was guaranteed. Fig. 5 shows the necessary superplasticizer dosage in mass-% of the cement content at all climatic points. In order to be able to ensure a continuous initial consistency, the super-plasticizer content must rise with falling concrete temperature. Here, it must be remarked that the slump-flow at the climatic points K_5 and K_{15} respectively K_{20} and K_{30} the needed superplasticizer amount decreases almost evenly. However, between the climatic points K_{15} and K_{20} a larger step can be recognized. At the climatic points K_5 and K_{10} the measurements had to be repeated after 30 minutes because of the high retarding of the superplasticizer at low temperatures. These values are indicated in brackets.

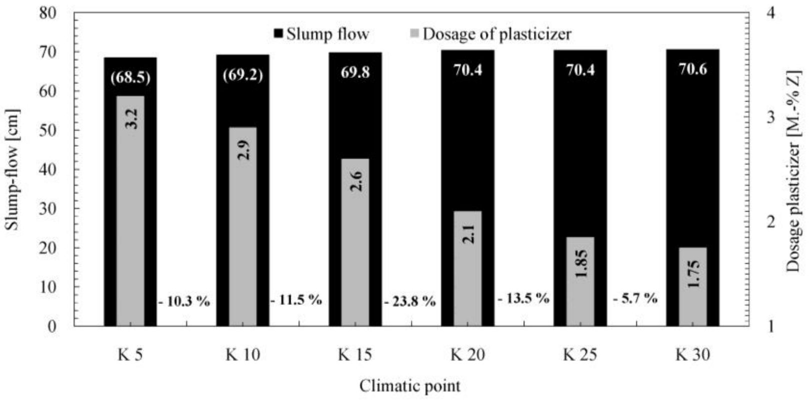

Figure 5. Variation of the superplasticizer dosage at different climatic points

Workability loss: At these new optimized formulations the workability loss was examined. Therefore, the mixes were repeated and the slump-flow and the funnel-time were determined at different times (after end of mixing, 30, 60, 90 and 120 min after beginning of mixing). The concrete was stored during the test breaks in a slowly rotation free-fall mixer with cover (fig. 6). In figure 7 the slump-flows and the associate funnel-times are plotted.

Figure 6. Covered free-fall mixer

The initial consistency of the concretes measured with the slump-flow, which were tested at the climatic points $K_{15}…K_{30}$ lay between 69.8 cm and 71.6 cm and so in the fixed range of 70 cm. At the climatic points K_5 and K_{10} a strong liquefaction can be observed due to a retarding effect generated by low temperatures. Thirty minutes after the mixing start, the slump-flow of these two concretes lay likewise in the desired range.

The slump-flow of the concretes of the climatic points K_{25} and K_{30} decrease substantially faster than those of the concretes of the other climatic points. Although, for the slump-flow of the concretes of the climatic points $K_5…K_{20}$ an influence of the temperature can be recognized, the effects of the temperature differences are not any longer as important as for those of the climatic points K_{25} and K_{30}. Though, therefore with decreasing temperatures, the slump-flow decreases more slowly.

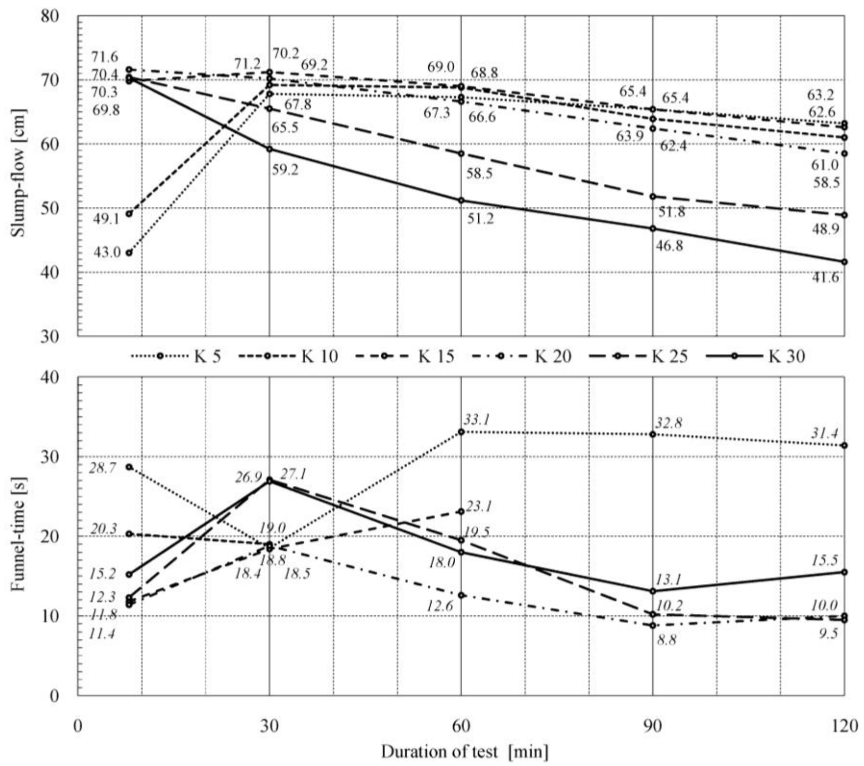

Figure 7. Workability loss (slump-flow and funnel-time) of the concrete at different climatic points

The funnel-time rises at the climatic points K_{20} to K_{30} to an age of 30 min, in order to decrease afterwards up to an age of 90 min again within an acceptable range. After 90 min they remain constant respectively increase again slightly. The funnel-time of the concretes at the climatic points K5 and K10 fall up to an age of 30 min and increase again up to an unacceptable value. An exception is given by the concrete at the climatic point K_{15}. Here the funnel-time constantly rises and is already not measurable any longer after 90 min. A possible reason for these decreasing and increasing funnel-times is that the content of the water is to low. It is remarkable that the concretes of the climatic points K_5 to K_{20} present almost identical funnel-times of approx. 19 seconds after 30 min.

The results (slump-flow and funnel-time) show that the best behavior is attained at the climatic point K_{20}. Since the funnel-time with 10 s lies after 120 min in a good range, the slump-flow with scarcely 60 cm is acceptable.

5 Conclusions

With increasing temperatures in the climate test chamber the slump-flow rises, too. However, at lower temperatures the effect of the superplasticizer is strongly retarded. At the climatic point K_{20} the lowest funnel-time is given with 10.5 s. Both at higher and even at lower temperatures the funnel-times increase. At higher temperatures the increased reactivity of the cement affects the rheology of the concrete.

The lower the ambient temperatures are, the lower also the early resistances are. By curing the elements after stripping in a 20°C water bath, this retard in strength development could be regained after casting already at 7 days.

In order to be able to ensure a continuous workability at different climatic points, the superplasticizer content must be increased with falling ambient temperatures. The investigations of the workability loss showed that the slump-flow of the climatic points K_{25} and K_{30} diminished more rapidly than those of the other climatic points. At the climatic point K_{20} the most favorable setting behavior for practical applications could be observed.

At the end of the tests it was possible to develop a model for concrete formulations taking into account varying environmental conditions.

References

[1] Administration de la Navigation Aèrienne: „weather data of the Luxemburgish meteorological service“, in: www.aeroport.public.lu/de/meteo/ index.html, February 2009.
[2] Deutscher Ausschuss für Stahlbeton (DAfStb) - Guideline: „Self-Compacting Concrete“, Beuth-Verlag, November 2003.
[3] Schleibinger testing systems: „BT-SCC Rheometer for fresh concrete“, in: www.schleibinger. com/cmsimple/en/?Rheometers%A0:BT_SCC_Rheometer_for_Fresh_Concrete.
[4] Deutsches Institut für Normung (DIN) e.V.: „Testing hardened concrete - Part 3: Compressive strength of test specimens“, Beuth-Verlag, April 2002.