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Influences of superplasticizer modification and mixture composition on the performance of self-compacting concrete at varied ambient temperatures

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ABSTRACT

The fresh behaviour of self-compacting concrete (SCC) at varying temperatures differs from that of normal vibrated concrete. This is because the rheology of SCC depends not only on degree of cement hydration, but also on the adsorption of superplasticizers – mostly polycarboxylate based polymers (PCE) -, which is affected by the time and hydration progress. Due to the variety of PCEs and mixture compositions for SCC a prediction of the rheology at varying temperatures is complicated. The charge densities of PCEs as well as the water to solid ratio in the paste are identified to be the main decisive parameters for robust fresh concrete properties.

Rheometric concrete investigations with different SCC mixture compositions and varied anionic charge densities of the PCE were conducted. SCC which is rich in powder components showed robust performance at low temperatures while SCC with low powder content was favourable at high temperatures. High charge density PCE pointed out to be very robust at low temperatures but at high temperatures it significantly reduced the flow retention. Low charge density PCE could not generate self-compacting properties at low temperatures but retained the flow performance over sufficiently long time. Based on considerations about particle interactions and adsorption mechanisms of PCEs, the relevant processes are explained and options for the development of robust mixture compositions for individual temperature ranges are itemised.

1. Introduction

In addition to cost, one major obstacle to the extensive usage of self-consolidating concrete (SCC) within the ready-mix industry is the high complexity of its constituents working together. The high complexity and the sometime unpredictable performance upon changes of ambient or processing parameters can make SCC less robust than vibrated concrete. For successful applications of SCC at the construction site, it should be robust with respect to variations in processing parameters and the environmental boundary conditions.

Robustness is typically understood as stability against variations in quality and quantity of the constituents or as the capability to absorb human or process-technological uncertainties [1–5]. Most influences can be overcome by a good quality control system, improved logistics and process technologies. These can be directly controlled by the staff. However, the environmental conditions during the whole concreting process can only be predicted by weather forecast, but moderate to rapid temperature changes at the construction site can cause trouble during SCC casting. The robustness of ready-mix concrete with respect to such environmental temperatures can thus be considered as a major key to improving the acceptance of SCC technology for ready-mix applications.

1.1. Importance of consideration of the ambient temperature

As reported by Brameshuber and Übachs [6] already slight changes of the temperature might already cause serious problems for the workability or the durability of SCC. From that point of view temperature dependent performance changes are generally critical for pre-cast and ready-mix or construction site concreting. However, the range of temperatures that are likely to occur during casting is much wider in the field of the ready-mix concrete.

The annual temperature differences are of importance in case of casting the same concrete mixture composition at different periods of the year. However, temperatures can also strongly vary throughout a single day, which is even more critically for concreting. For example, the “Digitaler Umweltatlas Berlin, 2001” [7] provides

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data from July 8, 1991 where daily temperatures measured at a height of 2 m varied within 24 h depending upon the location between 10.2 and 17.5 °C. Khayat et al. report about SCC that was cast in Montreal during at a day when ambient temperatures varied between 10 °C in the night and 30 °C during the day [8].

The annual as well as the daily temperature changes are a serious threat to SCC, since the handling of performance loss is much more delicate than it is for normal concrete. While for vibrated concrete stiff consistencies can be partly compensated by higher or longer vibration, vibrating SCC can cause segregation which would likely deteriorate the structure even more than inadequate filling.

In order to safely cast SCC on the construction site the specific effects of the environmental temperature on the flow properties of SCC need to be taken into account, and mixture compositions need to be developed that are robust against varying temperatures.

1.2. Influence of temperature on the workability of normal concrete

Upon addition of water to a cementitious system metal ions, calcium ions (Ca^{2+}), sulphate ions (SO_4^{2-}) hydroxide ions (OH^-), and smaller amounts of aluminates and silicate are interacting in the solution [9–13]. Within short time a gel like layer, which is rich of alumina and silica, forms around the surfaces of the cement grain and within approximately 10 min ettringite forms stubby rods on the surfaces of the grain and in the solution. The latter are generated from sulphate and calcium aluminate reaction. Depending upon the sulphate and aluminate contents, alumina, ferric oxide mono-sulphate phase (AFt), ferric oxide tri-sulphate phase (AFm) or gypsum can occur. The most significant AFt and AFm phases at this point in time are ettringite and monosulphate, respectively. After this initial reaction, a dormant period occurs for several hours at which no significant amounts of new reaction products are building. Despite the use of the word dormant period reactions yielding morphological changes on the surfaces take place. According to Locher [10] ettringite undergoes re-crystallisation during the dormant period although no new reaction products are built or chemical reactions take place. This is brought in context with loss of workability. According to Yamada et al. [14] the specific surface of cement paste increases steadily throughout the first 120 min after water addition. The latter changes take place quicker at high temperature and slower at low temperature. Hence, temperature acts as accelerator or retarder of reactions, typically generating a quick loss of workability at high temperature and extended workability time at lower temperatures.

1.3. Influence of temperature on the workability of SCC

The formerly mentioned effects of temperature on the workability basically taking place in the binder paste are generally valid for SCC and normal concrete likewise. The major difference between SCC and normal concrete is the high amount of superplasticizer (SP) that is required for SCC to provide a sufficiently low yield stress for self-compacting properties. For SCC typically SPs with polycarboxylic backbone (PCE) are typically used. SPs adsorb on the surfaces of cement and mineral particles [15–20]. As all common types of SPs provide a negatively charged backbone as adsorbing unit they are typically attracted by positively charged surfaces or upon flow by areas providing a positively charged zeta potential (ζ). According to Yoshioka et al. [21] adsorption of SPs predominantly takes place on the surfaces of C_3A and C_4AF initially [21] as well as on monosulphate and ettringite, of which ettringite provides the highest ζ [22]. If in case of SCC high amounts of SP are added to the mixture significant amounts of PCE do not adsorb immediately but with time shift upon formation of ettringite. This means that ettringite, which reduces the workability of a cementitious system without SP, virtually provides flowability in a system incorporating high amounts of SP.

Finally two opposing effects act in parallel in SCC, which are determined by the temperature. While increasing temperature

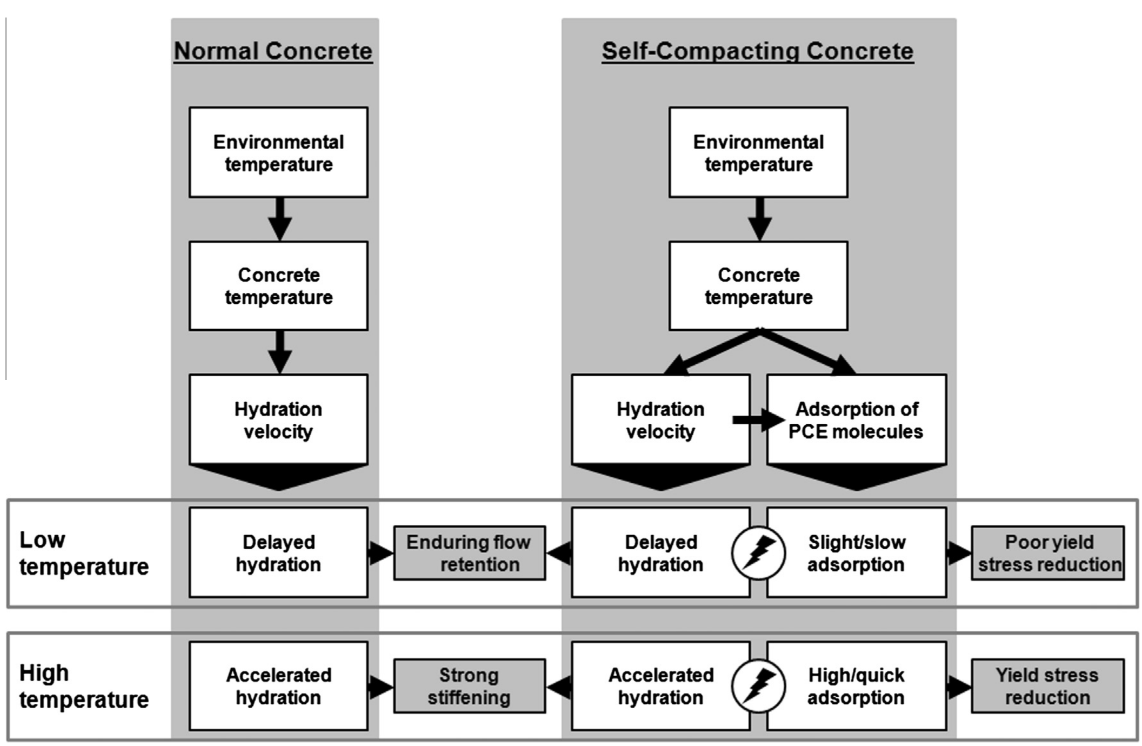

Fig. 1. Difference between normal concrete and SCC at exposure to varying temperatures.