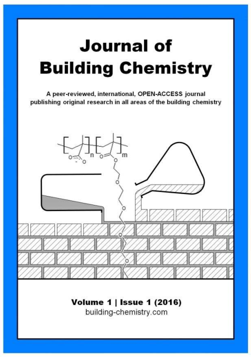

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Influence of temperature on efficiency of superplasticizing admixtures for concrete

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Abstract

Temperature is one of the most important factors affecting the efficiency of polymer admixtures to concrete, yet this relation is still not fully explained. The direction of changes depends on the type (chemical nature) of the admixture, and often also on its concentration and composition of the concrete mix. Taking into consideration the big diversity of the used polymer admixtures, it is very hard to predict their temperature characteristics; this requires detailed testing. It is possible to find out, on the base of the collected data, that in the case of the new generation of the superplasticizers an increase of temperature usually leads to diminishing of the admixture efficiency. This means the necessity of increasing dosage of the superplasticizers of new generation at higher temperature.

Keywords: Admixture; concrete; efficiency; superplasticizer; temperature

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1. Superplasticizing admixtures in concrete production

Growing requirements from the users cause the necessity of continuous improving of the concrete performance. One of the elements of this development is wide use of admixtures, which are rational and effective mean for modification of the concrete properties. According to the European Standard EN 934-2 “Admixtures for concrete, mortar and grout – Part 2: Concrete admixtures – Definitions, requirements, conformity, marking and labelling”, the admixture for concrete is *a material added during the mixing process of concrete in a quantity not more than 5% by mass of the cement content of the concrete, to modify the properties of the mix in the fresh and/or hardened state*. The larger amounts of modifiers are called additions.

The largest group of concrete admixtures create plasticizers and superplasticizers. The aim of their use is increasing fluidity of the concrete mix, while keeping constant value of the water/cement ratio, or, alternatively, maintaining the consistence and simultaneously decresing amount of the mixing water (decreasing w/c ratio). The superplasticizers – high range water reducing admixtures – allow for lowering of the content of the concrete mix by at least 12% (the superplasticizers of the new generation even by more than 30%).

The contemporary superplasticizers are polymers. The conventional admixtures of this type are sulfonated resins: naphtalene-formaldehyde, melamine-formaldehyde and melamine ones. The superplasticizers of new generation contain polycarboxylates, acrylic co-polymers and cross-linked acrylic resins.

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The efficiency of the concrete admixtures depends on many factors, like chemical composition of the modifier and the cement binder, composition of the concrete mix, including the presence of the other admixtures and additions, amount of the mixing water and, as one of the particularly important factors, temperature (ACI 2010; Łukowski 2016).

2. Effect of temperature on the properties of the concrete mix

Temperature of the concrete mix depends on the ambient and concrete components temperature. The temperature of the aggregate and water corresponds, basically, to the temperature of their storing and using. The cement, however, contains also the accumulated heat delivered during the grinding of the portland clinker. Release of this heat by the cement stored in the silos is a slow process, particularly at the high ambient temperature. The temperature of the cement delivered to the concrete production facility is often still high. Due to increased demand for the cement at the summer season, the cement with the temperature reaching even 80°C is sometimes used for the concrete manufacturing (Jackiewicz-Rek and Łukowski 2011).

Change of cement temperature by 5°C causes the change of concrete mix temperature by about 0.5°C (Kosmatka et al. 2003), but even slight increase of temperature of the can affect the properties of the concrete mix and the hardened concrete. The fluidity of the mortar mix is lower by 50% when the cement temperature rises from 25 to 90°C manufacturing (Jackiewicz-Rek and Łukowski 2011), and the loss of consistence is quicker at the higher temperature (Fig. 1).

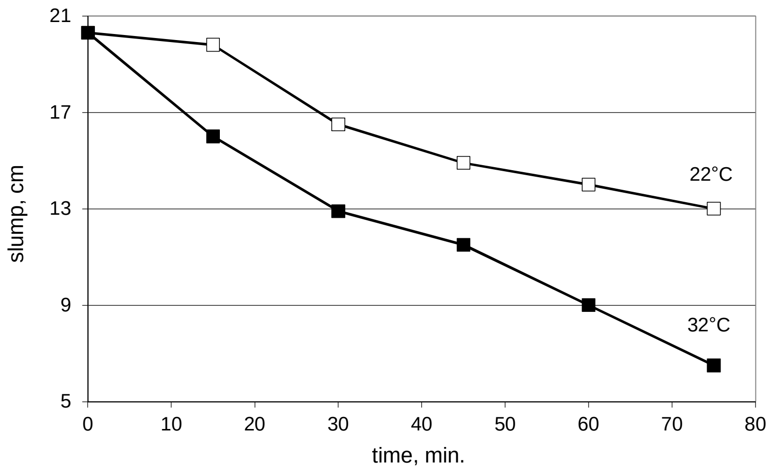

Fig. 1. Change of consistence of the concrete mixes with the same initial slump at different temperature acc. to Hampton (1981).

Rise of temperature causes also the significant rise of the water demand by the concrete mix (Fig. 2). Therefore, the technological performance of the mixes at the higher temperature is worsened.

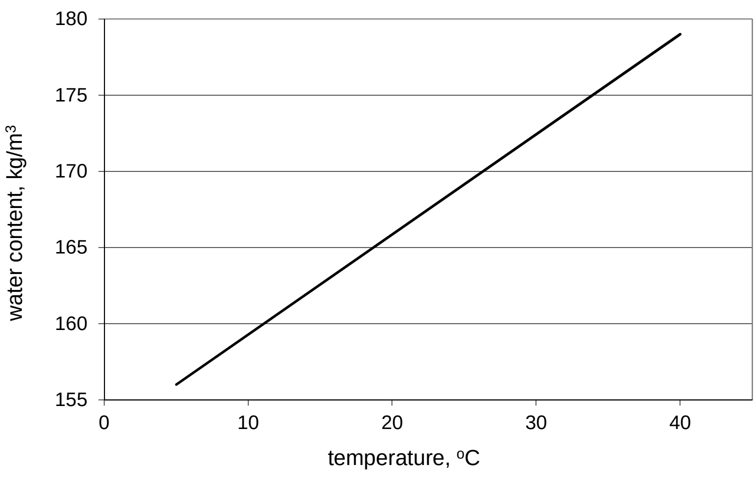

Fig. 2. Effect of temperature on the amount of mixing water necessary for achieving slump 75 mm (the typical composition of the concrete mix) acc. to US Bureau of Reclamation (1981).

3. Temperature and efficiency of superplasticizers

The contemporary high range water reducing admixtures are the polymers; the mechanisms of their action cover the complicated chemical and physico-chemical proceses (Czarnecki 1996; Łukowski 2003). These processes are obviously affected by temperature.

The dependence of the rheological properties of the superplasticized concrete mix on temperature was demonstrated by Gołaszewski and Szwabowski (2004) and Gołaszewski (2006). The rise of temperature usually causes the downfall of the plastic viscosity (Fig. 3, b), while the yield stress is increasing in this situation (Fig. 3, a). The increase of the yield stress with increasing temperature is confirmed by many researchers, e.g. (Nehdi and Al Martini 2009; Petit et al. 2010). The course of changes is depending on the composition of the mix, particularly on water/cement ratio as well as the type and content of the superplasticizer. There is, therefore, a relationship between temperature and action of the admixtures.

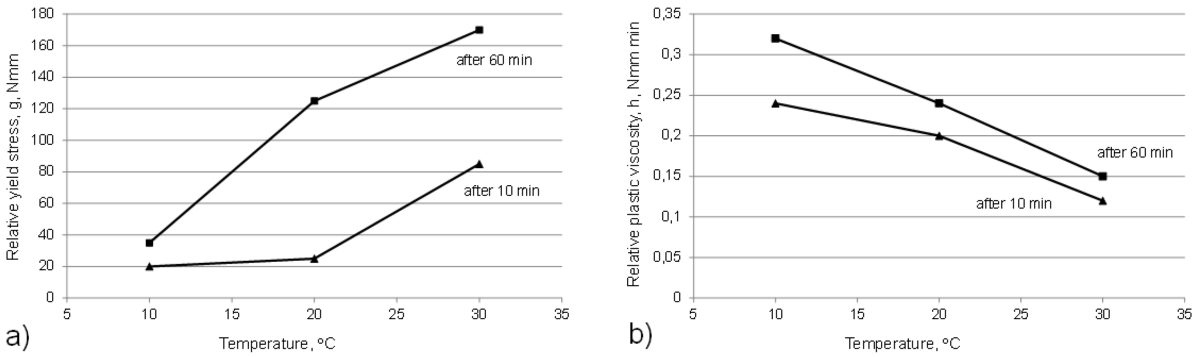

Fig. 3. An example of dependence of the rheological parameters of the concrete mix on temperature while using polyether admixture acc. to Gołaszewski and Szwabowski (2004).

According to Schmidt et al. (2014), another important factor affecting the influence of temperature on the superplasticizer action is the content of the fine (powder) fraction in the concrete mix. Temperatures affect mixes with high water to powder ratios in different way than mixes with low water to powder ratios. At low temperature a powder rich mixes show good performance, while at high temperature the powder-rich concrete is prone to quickly lose flow properties. The situation is exactly inverted for mixtes containing low amounts of powder. They perform significantly more robust at high temperatures.

According to Kaleta and Grzeszczyk (2015), a temperature increase causes also a drop of thixotropy in cement pastes containing superplasticizer.

Petit et al. (2006) have formulated, for the concrete mix containing the superplasticizer, the model relationships between yield stress and time at various temperature (Fig. 4), concluding that the higher is temperature, the quicker is growth of this property.

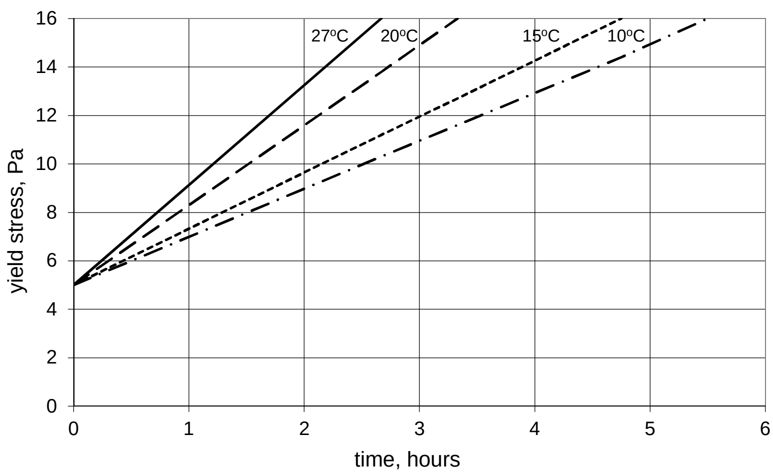

Fig. 4. Model relationships between yield stress and time at various temperature (superplasticizer – sulfonated naphtalene resin) acc. to Petit et al. (2006).

However, some authors, e.g. (Jolicoeur et al. 1997; Nawa et al. 2000) have demonstrated that worsening of the fluidity and quicker loss of consistence at higher temperature is not an absolute rule, when the superplasticizer is present in the concrete mix. They argue that the rise of temperature accelerates not only hydration of cement, but also the adsorption of polymers on the cement grains, which leads to the instant growth of the mix fluidity. In his PhD thesis Schmidt (2014) concludes that two opposing effects act in parallel in concrete mix, which are determined by the temperature. Increasing temperature negatively affects the workability by accelerating the hydration of cement. This effect is dominant in the case of concrete without or with small amounts of superplasticizer. However, the accelerated growth of ettringite quickly provides a number of adsorption sites for admixture molecules, which again positively affects the flowability. Therefore, for concrete containing high amounts of admixture, the effect of temperature may be alternate and is difficult to predict.

On the other hand, Flatt (1997) has found that the last relationships is not unequivocal; in some cases even the retarding of adsorption can be observed. According to Kurdowski (2014), in the case of some admixtures (e.g. the sodium salts of some polyacrylic acids) the concrete mix maintains the constant consistence at growing temperature. When modifying such superplasticizers, even the improving of consistence with rising temperature is possible.

The influence of temperature on the efficiency of high range water reducing admixtures is then ambiguous. This is confirmed by investigation of Tsukada et al. (2003). They search for the content of various superplasticizers, necessary for their efficient acting in the concrete mix at various temperature (Fig. 5). In the case of the new generation admixtures, the polycarboxylates (PC), demand for the admixture increases with growing temperature, while the required content of the “traditional” superplasticizers, like sulfonated melamine resins (SM) or sulfonated napftalene resins (SN), decreses at higher temperature.

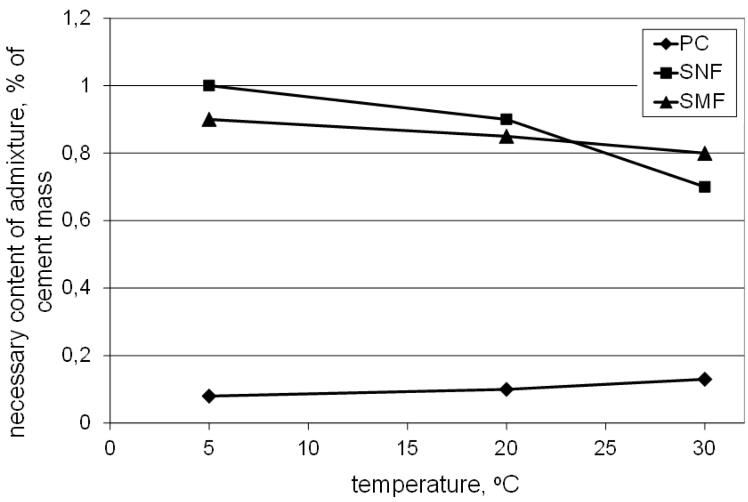

Fig. 5. Content of various admixtures in the mortar mix, necessary for slump 250 mm acc. to Tsukada et al. (2003).

This phenomenon can be explained by the investigation of Grzeszczyk and Sudoł (2003). They have found out that the range and efficiency of the steric hindrance, provided by the polycarboxylate superplasticizers, depends on the degree of hydration of the side (polyether) chains of the superplasticizer molecules adsorbed on the surface of the cement grains. The growing temperature breaks off the hydrogen bonds between the polymer chains and the water. This leads to the re-whirling of the polyether chains and, as a consequence, diminishing of the range and efficiency of the steric hindrance. At sufficiently high temperature the hindrance becomes insufficient for defloculation of the cement grains and the flowability of the concrete mix is lost.

In another attempt to explain the mechanism of temperature influence on the superplasticizers efficiency, Ridi et al. (2013) have found out that the high curing temperature shortens the duration of the induction period in the superplasticized cement paste, but only when the high range water-reducing admixture is accompanied by viscosity modifying admixture.

The influence of temperature on the efficiency of superplasticizers depends also on the compatibility between the modifier and the cement. The same admixtures can act in different, and sometimes even opposite, way, when used with various cements. From this point of view, particularly important is content of tricalcium aluminate

(C_3A) and alkalis (Na_2O_e) in the cement composition. Considering the huge diversity of the used cements, the prediction of those interactions is extremely difficult. Griesser (2002) has conducted the wide investigation, finding that for almost every combination cement – superplasticizer, the dependence of the rheological parameters on the temperature is different (Fig. 6).

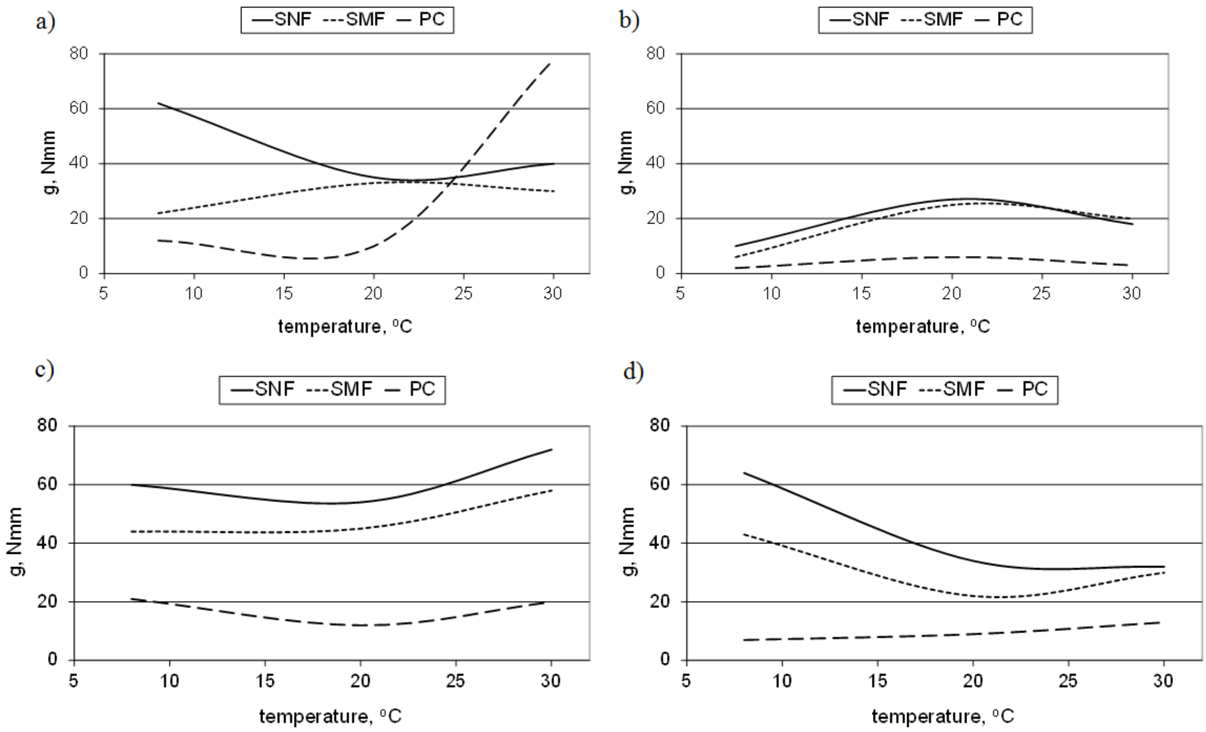

Fig. 6. Yield stress (*g* parameter) of the concrete mix vs. temperature for various cements (a-d) and superplasticizers: SNF (sulfonated naphtalene-formaldehyde resin); SMF (sulfonated melamine-formaldehyde resin); PC (polycarboxylate) acc. to Griesser (2002).

4. Sum up

Wide use of polymer admixtures is an element of the development of contemporary concrete technology. One of the important factor of the polymer admixtures efficiency is temperature. The direction of changes depends on the type (chemical nature) of the modifier as well as its content and the composition of the concrete mix. Considering the diversity of the polymer admixtures, the prediction of the temperature characteristics is difficult and requires detailed investigations. On the basis of the gathered information, one can conclude that in the case of the new generation suerplasticizers, the growth of temperature usually leads to worsening of effectiveness, and in consequence to the increasing dosage of admixtures.

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