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Effect of Temperature Loads in the Fresh State on the Flexural and Compressive Strength of Concrete

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Working Group 2: Concrete Technology

1 Introduction

The Selective Paste Intrusion (SPI) is an additive manufacturing method where concrete elements were produced by layering aggregates and bonding them with cement paste. This allows to create freeform and complex structures without formwork. The structure is cured in a particle bed and excavated after [1, 2]. However, in practice usually reinforced concrete is used that can also bear tensile loads. In order to additively produce reinforced concrete elements with complex shapes, Wire and Arc Additive Manufacturing (WAAM) can be combined with the SPI process. The WAAM-process is a welding process that uses molten steel wire to produce reinforcing bars [3]. However, the high temperatures that arise during welding may adversely affect the early cement hydration in the particle bed and thus reduce the concrete quality [3, 4].

Investigations were carried out to examine the impact of temperature loads on concrete in the fresh state, on the residual concrete compressive and flexural strength as a measure of concrete quality.

2 Methods

The aim of the investigations was to indirectly demonstrate the process-related introduction of a temperature load by WAAM into the SPI concrete and its effect on hardened concrete properties.

For this, a concrete was prepared corresponding to the concrete in the SPI process (Ordinary Portland Cement, w/c ratio of 0.35, ratio between Cement Paste and quartz sand (1.0 to 2.2 mm) of 42% to 58%). Prisms according to DIN 196-1 were produced with this concrete mixture using conventional casting methods.

After filling the concrete in the formwork, a temperature sensor was placed in the center of one of the prisms and the filled formwork was subjected to a preheated oven at 250°C. The temperature loads tested ranged from 30°C to 100°C in increments of 10°C, and also 150°C and 200°C. The temperature was monitored until the target temperature in the center of the prism was reached.

After that, the prisms cooled down in a controlled environment at 20°C and 65% RH for 24h, covered with a damp burlap cloth. The formwork was removed after 24h and the prisms were kept in the controlled environment until testing. For each temperature load, three prisms (without temperature sensor) were used.

Compressive and flexural strength tests were performed at a concrete age of 28 days. A reference specimen was also prepared, which was not exposed to any temperature load, and stored in the laboratory environment at 20°C and 65% RH.

3 Results and Discussion

The results of the compressive strength tests showed that the strength between 30°C and 80°C is increased compared to the reference. However, the overall level is comparable, with the exception of the specimens at 30°C, which showed a compressive strength of around 60 MPa. The specimens at 20°C and 40°C to 80°C fluctuated between 50 and 55 MPa. At temperatures above 80°C, the strength decreased (≈42 MPa). Above 100°C, the strength values further dropped to below 15 MPa.

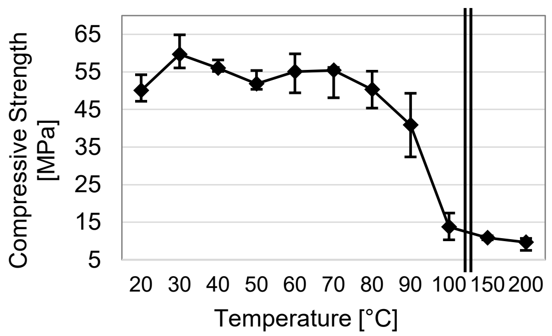

Fig. 1: Compressive Strength as a Function of External Temperature Load

An almost similar trend was observed for the flexural strength development. The flexural strengths between 30°C and 70°C (7.0 to 7.8 MPa) were slightly increased compared to the reference (6.9 MPa). Above 80°C, the strength was below the

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reference value at 20°C (5.9 MPa). This trend continued for further increasing temperature loads.

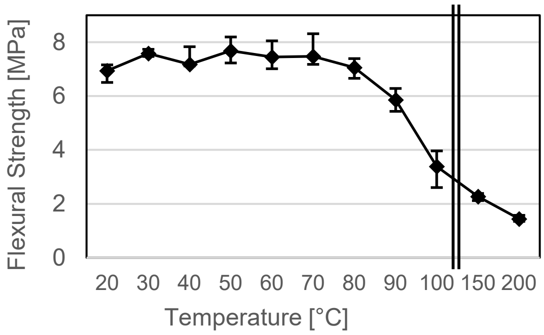

Fig. 2: Flexural Strength as a Function of External Temperature Load

It is generally assumed that strength values in fully cured concrete decrease under temperature loads [5–8]. However, large variations and increasing strengths at temperature loads between different series of tests by different authors could also be observed [5].

Temperature loads in the fresh state lead to an accelerated hydration process. This effect is used e.g. as a hardening accelerator and heat treatment, but lower final strengths were generally observed [6, 7].

According to literature, the effect of temperature not only changes the speed of hydration reactions and strength progression but also results in changes in the microstructure. With increasing temperature (up to 60°C), the C-S-H density increases while the amount of bound water decreases [6, 8]. As a result, capillary porosity increases, and thus strength and durability decrease [8].

However, the present results show an increase in 28d strength between 30°C and 70°C with increasing temperature loads.

Further investigations regarding the strength development of the concrete used for SPI have thus to be performed in order to assure our finding against those found in literature. Additionally, further testing ages (e.g. after 2 days and 7 days) should to be carried out to determine the strength development over time in a more precise manner. Furthermore, analysis on the hydration processes, the related changes in chemical composition as well as the linked development of the physical properties of the concrete as a function of time and temperature load should be performed. This enables to better categorize the divergent results between literature and our present results.

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