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Influence of type of superplasticizer and cement composition on the adhesive bonding between aged and fresh concrete

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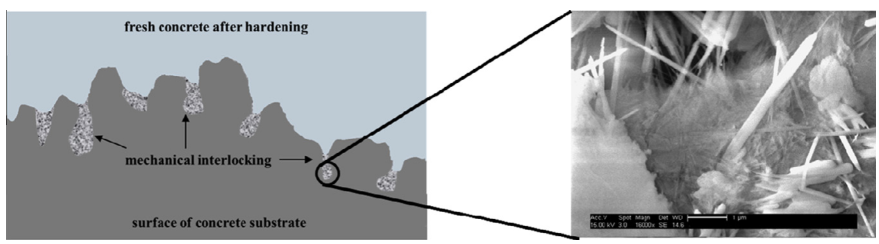
HIGHLIGHTS

- Adhesive bonding between old and freshly supplemented concrete was studied.
- Mechanism for successful interlocking was uncovered.
- Successful interlocking depends on proper combination of specific kind of cement and superplasticizer.
- Interlocking effect is based on mineralization in the transition zone cement/aggregate of the old concrete.

GRAPHICAL ABSTRACT



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ABSTRACT

The influence of polycondensate and polycarboxylate superplasticizers on the adhesion strength between aged and fresh concrete was investigated by measuring the imbibition of pore solution released from fresh concrete into aged concrete bars and SEM imaging of minerals formed in the transition zone cement/aggregate. Apparently, effective interlocking occurs when much pore solution is soaked up and cement hydrates crystallize abundantly within the transition zone. For the polycondensate, adhesive strength was independent of cement composition while the polycarboxylate only worked with cement possessing high C_3A content. The difference is owed to reduced capillary suction behavior of pore solution holding polycarboxylate superplasticizer.

1. Introduction

The demolition and rebuilding of existing concrete structures e.g. of bridges and buildings is quite undesirable from the viewpoint of ecology and economy. Particularly, the ever-expanding traffic causes concrete structures which were built decades ago to reach their limits. They often require an upgrade to meet the current demand, preferably by applying an inexpensive and fast method. Ideally, a nearly monolithic composite between the aged and fresh concrete should be targeted [1,2]. However, it is well established that concretes of different ages do not interlock well. Therefore, applying fresh concrete onto an existing structure often does not provide the desired increase in load capacity. This effect is owed to several factors including early age (plastic) shrinkage or thermal stresses resulting from early cement hydration [3]. They prevent intimate interlocking between the two concretes. In a recent study it was surprisingly found that when the fresh concrete (C35/40, w/c = 0.6) contained a β-naphthalene sulfonate formaldehyde (BNS) superplasticizer, the adhesive bonding was increased by up to 30% [4]. There, at a w/c ratio of 0.6, the splitting tensile strength was 3.9 N/mm^2

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for the fresh concrete holding BNS. The reason behind this positive effect remained unclear.

When upgrading e.g. bridges, a commonly applied method includes roughening of the surface of the existing concrete and subsequent addition of a reinforced concrete slab. However, this method normally does not produce satisfactory adhesion bond. Therefore, latex polymer coatings are sometimes applied onto the surface of the aged concrete. The disadvantage of this procedure is that such coatings can also work as release agents and thus may influence the adhesive bonding negatively [5]. Moreover, their application presents an additional step. Consequently, addition of a non-reinforced supplementary concrete would be the most cost-effective method for rehabilitation as long as a high quality adhesive bond is achieved.

The adhesion strength between aged and fresh concrete derives from specific as well as mechanical adhesion [6]. The specific adhesion is based on chemical and physical interactions occurring in the transition zone between aged and fresh concrete while mechanical interlocking is owed to capillary suction whereby the fresh concrete infiltrates the pores of the aged concrete substrate and thus anchors after hardening (Fig. 1).

According to a previous work, the parameters as follow affect the adhesion strength [4]:

- Surface roughness and condition of the concrete substrate.
- Phase composition of the cement contained in the freshly applied concrete.
- Properties of the superplasticizer admixed to the freshly applied concrete.

The authors suggest that the surface of the aged concrete be rough, because this increases the effective contact area and improves the interlocking between the two surfaces. In the fresh concrete, superplasticizers are used to further increase the effective contact area, because they fluidify the fresh concrete and allow a higher strength at the same time. Such improved dispersion of the binder particles enhances the penetration of the surface of aged concrete with fresh concrete.

Large scale experiments by the same group had revealed that after roughening the surface of the aged concrete, the splitting tensile strength of the composite corresponds to that of a monolith [4]. Furthermore, it was observed that when the fresh concrete contained high sulfate resistant (HSR) cement and β-naphthalene sulfonate formaldehyde superplasticizer, then a much superior adhesive strength compared to that of the same cement holding a polycarboxylate (PCE) type admixture was achieved [4]. This result suggested that the chemical nature of the superplasticizer as well as the composition of the cement may strongly impact the adhesion between fresh and aged concrete, yet the detailed mechanism was not understood. It was therefore the goal of this study to investigate the interactions occurring between aged and fresh concrete, and to propose a mechanistic explanation for the effects observed.

2. Materials and methods

2.1. Superplasticizers

Two different commercial superplasticizer samples were used. The first, Melcret® 500F, presents a linear β-naphthalene sulfonate formaldehyde polycondensate (BNS) while the second (Woerment® FM 794) constitutes a comb-shaped polycarboxylate (PCE). Both products were obtained from BASF Construction Polymers GmbH, Trostberg/Germany. The chemical structures of both polymers are presented in Fig. 2.

The polymers were characterized via size exclusion chromatography (Waters Alliance 2695 instrument from Waters, Eschborn/Germany equipped with RI detector 2414, also from Waters, Eschborn/Germany) and a 3 angle dynamic light scattering detector (mini Dawn from Wyatt Technologies, Santa Barbara, CA/USA). Prior to application on the columns, the polymer solutions were filtered through a 0.2 μm syringe filter. The PCE polymer was separated on an Ultrahydrogel™ precolumn and three Ultrahydrogel™ columns (120, 250 and 500; Waters, Eschborn/Germany). Molecular weights (M_w and M_n) and hydrodynamic radius ($R_{h(z)}$) of the polymers were determined in a 0.1 M aqueous $NaNO_3$ solution (adjusted to pH 12.0 with NaOH) as an eluant at a flow rate of 1.0 mL/min. To calculate M_w and M_n for the PCE, a value of 0.135 mL/g (value for polyethylene oxide) [7] was used for dn/dc. BNS could not be applied on the columns because of its brownish color which interferes with the light scattering detector. Therefore, its molecular weights were captured via batch measurement using a dn/dc of 0.195 mL/g (value for polystyrene sulfonate) [8].

2.2. Cement samples

Two commercially available Portland cements were used. An ordinary Portland cement CEM I 42.5 R (Märker Zement GmbH, Harburg/Germany) and a high sulfate resistant Portland cement CEM I 42.5 R-HS (Schwenk Zement KG, Ulm/Germany). The phase compositions as determined by XRD using *Rietveld* refinement and thermogravimetry and the physical properties of the samples are provided in Table 1.

2.3. Concrete compositions

For the fresh and aged concrete, simplified model systems were used. Table 2 presents the composition of the aged concrete (aging time: 1 month) which was used in the SEM investigations.

For the imbibition tests, as substrate representing the aged concrete at first plates (15 × 15 cm) without aggregates were prepared from cement pastes according to the recipe above. Into the fresh paste, individual aggregate particles with a diameter of approx. 2 cm were embedded. After the specimens were cured for 1 month at a relative humidity of 60% and 23 °C, using a diamond saw the plates were cut in such way as to produce defined cross-sections of the embedded aggregates.

As model for the fresh concrete, the same cement pastes without aggregates were used to match the composition of the aged concrete substrate. To the fresh concrete and independent of the type of cement, superplasticizer dosages of 0.23% by weight of cement (bwoc) for BNS and of 0.11% bwoc of PCE were admixed.

The composites prepared from the substrate representing the aged concrete and a layer of 1 cm of fresh paste deposited on this surface and aged for one day were used in the SEM investigations.

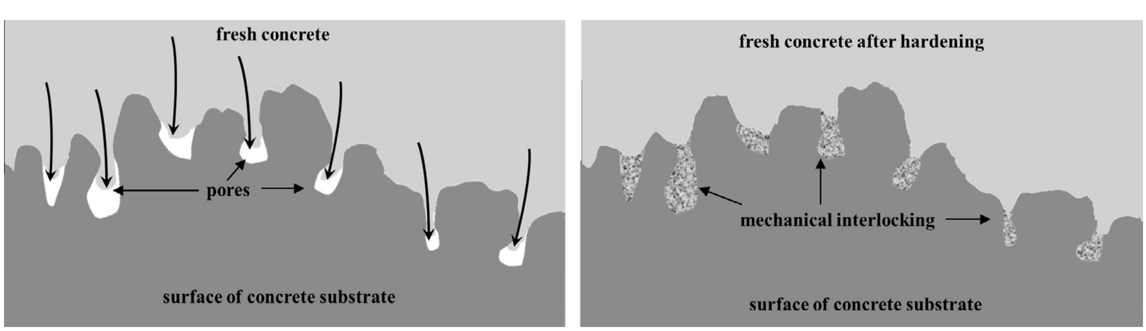

Fig. 1. Schematic illustration of the mechanical interlocking process between an aged concrete substrate and freshly applied concrete.