Cement & Concrete Composites 52 (2014) 1–8

Contents lists available at ScienceDirect

Cement & Concrete Composites

journal homepage: www.elsevier.com/locate/cemconcomp

# The use of superabsorbent polymers to reduce cracking of bonded mortar overlays

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ARTICLE INFO

*Article history:*
Received 19 April 2013
Received in revised form 10 March 2014
Accepted 28 March 2014
Available online 4 April 2014

*Keywords:*
Blended cement mortars
Superabsorbent polymers
Restrained shrinkage
Cracking
Tensile relaxation
Elastic modulus
Concrete repair

ABSTRACT

The use of superabsorbent polymers (SAP) was found to significantly improve cracking characteristics of normal strength bonded mortar overlays containing silica fume. Mortars were designed with two water/binder ratios and three different SAP contents and tested for relevant material properties such as tensile strength, tensile relaxation, elastic modulus and drying shrinkage. With respect to overlay cracking, SAP addition generally resulted in an improvement in all tested properties, especially with respect to increasing relaxation and reduced elastic modulus. To observe cracking in real bonded overlays, mortars were cast on a rigid substrate and their cracking behavior observed for a period of approximately 7 weeks. The results indicate that SAP additions of 0.4% and 0.6% are very effective in reducing cracking in bonded mortar overlays with water/binder ratios of 0.45 and 0.55, respectively.


## 1. Introduction

Bonded mortar overlays are common in concrete repair projects and for the lining and leveling of concrete members. The performance requirements for bonded overlays include crack resistance and sufficient bond strength to the concrete substrate. Further, for repair patches, sufficient resistance against penetration of aggressive agents such as carbon dioxide and chlorides is usually required. A common shortfall of bonded overlays is cracking due to restrained shrinkage, which is unsightly, can initiate debonding, and locally increases penetrability (see, for example [1,2]). With respect to cracking, the most important material parameters for mortar overlays are tensile strength, elastic modulus, relaxation, and shrinkage [3,4]. When subjected to restrained shrinkage, bonded mortars can be expected to remain crack-free if the following (simplified) condition is fulfilled:

$$\frac{\alpha_{\gamma} \cdot \varepsilon \cdot E_t \cdot \psi_t}{f_t} \leqslant 1 \quad (1)$$

where $\alpha_r$ is the factor describing the degree of restraint [3]; $\varepsilon$ the free shrinkage strain; $E_t$ the elastic modulus in tension; $\psi_t$ the factor accounting for tensile relaxation and $f_t$ is the tensile strength.

In terms of overlay material properties, increasing tensile strength results in increased crack resistance. However, the common method to increase strength is to decrease the w/b ratio, which also results in a higher elastic modulus and reduced creep and relaxation, and therefore in higher stresses. Consequently, the overall effect of changing the mix design to increase strength may actually result in increased cracking. What is therefore needed from a material technology perspective is a method to effectively change some of the above material properties without negatively affecting the others. The aim of the research discussed in this paper was to use superabsorbent polymers (SAP) to alter mortar material properties to obtain an overall positive effect on cracking.

For a number of years, SAP has been used to improve the performance of high strength concrete and reduce cracking due to autogeneous shrinkage [5,6]. The principle of internal curing with SAP relates to the provision of water-filled cavities in the hardened cement paste, which gradually release the water during cement hydration and thus facilitate the development of a denser microstructure [7]. The addition of SAP can result in a higher number of voids in the concrete and thus in reduced elastic modulus and increased creep [8]. These effects are undesirable for most structural applications but very helpful reducing stresses due to restrained deformation (compare Eq. (1)). The addition of SAP was therefore expected to have a positive effect on material properties and crack development of bonded mortar overlays. This hypothesis was tested by investigating the influence of SAP

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http://dx.doi.org/10.1016/j.cemconcomp.2014.03.009
0958-9465/

addition on all material properties included in Eq. (1), and by observing the cracking behavior of bonded mortars containing SAP.

Application of Eq. (1) for the analytical modeling of stress development in concrete subjected to restrained shrinkage would require knowledge on the time-dependent development of all material properties included in the equation. However, in the scope of this research, some of these properties were measured at individual test ages only, which does not permit time-development stress modeling. Eq. (1) is therefore simply shown to summarize how various material properties affect cracking performance of bonded overlays. In the experimental work, cracking was analyzed based on the cracking performance of real bonded overlays under restrained deformation.

In a preliminary experimental study, the effect of SAP addition on durability-related mortar properties was investigated, which generally yielded very positive results, especially for mortars containing silica fume. For the investigation of crack development, mortars containing silica fume and various amounts of SAP were therefore selected.

## 2. Experimental details and test results

### 2.1. Mix design and concrete manufacture

The aim of this research was to identify if the addition of SAP to bonded mortar overlays results in decreased overlay cracking and to explain the observed cracking behavior with the measurement of relevant mortar material properties. Various contents of SAP were used in the mix design to identify if an optimum content of SAP exists at which cracking can be minimized.

Mortars were produced with 2 different w/b ratios of 0.45 and 0.55. A total of 8 mixes were designed, as presented in Table 1. The oxide composition of the binders used is presented in Table 2. The water content was kept constant at 250 $l/m^3$ and superplasticizer (SP) was added when necessary. The SP consisted of a sodium salt of polymerized naphthalene sulfonic acid, supplied in dry powder form by BASF. The sand used was silicious pit sand with a fineness modulus of 2.7 and relative density of 2.65. The target slump was set at 50 ± 20 mm. SP was added to the mix after an initial slump test had been performed, the amount being adjusted to achieve the desired slump value. The SAP content was set at 0% (reference mortar), 0.2%, 0.4% and 0.6%, in order to identify if an optimum replacement level can be found for the cracking performance of repair mortars.

In order to compare the direct influence of SAP addition on mortar properties it was deemed practical to use the same water content in all mortars, such that the same basic mix was used. Since the water demand was not adjusted to the SAP content, the higher absorption of water in mortars with higher SAP contents can be expected to have had an influence on the microstructure of the cement paste. This in turn will have an effect on the mechanical material properties that were measured in this research. It was therefore assumed that the effects of changes in microstructure due to SAP addition were sufficiently identified in the experimental program. Also from a practical point of view, it was considered relevant to assess how the addition of SAP to a given mortar mix of constant composition would affect its cracking performance.

**Table 2**
% Oxide composition of binders.

| Oxide | CEM I42.5N | SF |
|---|---|---|
| CaO | 64.12 | 0.0 |
| $SiO_2$ | 20.75 | 91.9 |
| $Al_2O_3$ | 4.17 | 0.7 |
| $Fe_2O_3$ | 3.21 | 0.8 |
| $SO_3$ | 2.30 | 0.46 |
| MgO | 0.74 | 0.26 |
| $K_2O$ | 0.73 | 1.33 |
| $TiO_2$ | 0.28 | 0.11 |
| $Mn_2O_3$ | 0.05 | 0.09 |
| $Na_2O$ | 0.04 | 0.42 |
| $P_2O_5$ | 0.08 | Not available |

SAP was added as a dry powder the mix prior to water addition. The workability of the mortars was assessed using a common slump test. As expected from literature (e.g. [6]), a decrease in workability with increasing SAP content was observed, resulting from the water uptake of the polymer particles. Similarly, increasing SAP contents resulted in more efforts for casting, compaction and finishing operations, as well as reduced bleed water accumulation on the concrete surface.

The SAP material used in this research consisted of covalently cross-linked acrylamide/acrylic acid copolymers. The suspension polymerized spherical particles had an average particle size of approximately 200 μm. The properties of the SAP material, including absorption characteristics, were previously published by Jensen and Hansen [7].

All samples were kept in their moulds under plastic sheeting for 1 day and then demoulded and cured for a further 2 days under plastic sheeting to prevent moisture loss and replicate common site curing conditions for repair work. Subsequently, samples were exposed to various environmental conditions, depending on the test parameter, as discussed in the following sections.

A shortcoming of the data analysis in the following sections is that the measured individual material properties were not statistically evaluated, partly due to insufficient numbers of test specimens. Consequently, a statistically significant comparison of mortars with various SAP contents could not be performed. However, such a comparison was not the focus of this research, which aimed at identifying the influence of SAP on actual overlay cracking performance. The individual material properties were obtained to only provide an indicative explanation for the effect that increasing SAP addition has on mortar cracking performance. A detailed investigation into time-dependent mortar properties was therefore not considered relevant, but should be considered in future work.

**Table 1**
Mix design and workability (slump).

| Mix [a] | w/b | Total binder (kg) | CEM I42.5 (kg) | FA (kg) | GGBS (kg) | SF (kg) | Water (kg) | Sand 002 (kg) | SAP (kg) | Slump (mm) | SP (kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 0.45 | 556 | 500 | 0 | 0 | 56 | 250 | 1490 | 1.11 | 40 | 1.00 |
| 8 | 0.45 | 556 | 500 | 0 | 0 | 56 | 250 | 1490 | 2.22 | 50 | 1.76 |
| 9 | 0.45 | 556 | 500 | 0 | 0 | 56 | 250 | 1490 | 3.33 | 40 | 2.94 |
| 16 | 0.55 | 455 | 409 | 0 | 0 | 45 | 250 | 1530 | 0.91 | 70 | 0.25 |
| 17 | 0.55 | 455 | 409 | 0 | 0 | 45 | 250 | 1530 | 1.82 | 50 | 0.59 |
| 18 | 0.55 | 455 | 409 | 0 | 0 | 45 | 250 | 1530 | 2.73 | 50 | 2.35 |
| *Controls* | | | | | | | | | | | |
| 21 | 0.45 | 556 | 500 | 0 | 0 | 56 | 250 | 1490 | 0 | 80 | 2.35 |
| 24 | 0.55 | 455 | 409 | 0 | 0 | 45 | 250 | 1530 | 0 | 50 | 0.59 |

[a] The mix number was contained from the complete research project, which included testing of other mixes for durability characteristics.