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The hydration of reactive cement-in-polymer dispersions studied by nuclear magnetic resonance

A.M. Olaru [a], O. Weichold [b,1], A. Adams [a,*]

[a] Institut für Technische und Makromolekulare Chemie, RWTH Aachen University, Templergraben 55, 52056 Aachen, Germany
[b] DWI an der RWTH Aachen, e. V., Pauwelsstraße 8, 52056 Aachen, Germany

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ABSTRACT

The behaviour of two novel cement-in-polymer (c/p) dispersions, namely cement-in-poly(vinyl acetate) and cement-in-poly(vinyl alcohol) upon exposure to water at room temperature was investigated by a combination of various NMR methods. The swelling, cracking, and the water ingress were monitored non-destructively using ^{1}H single point imaging. The hydration of the cement matrix was investigated using ^{29}Si NMR whilst ^{13}C CPMAS NMR spectra allowed the quantification of the kinetics of the hydrolysis reaction of poly(vinyl acetate) into poly (vinyl alcohol). The polymer controls the rate of water ingress and swelling which in turn determines the behaviour of the c/p dispersions upon exposure to water. For the cement-in-poly(vinyl alcohol), the rates of water ingress and swelling are much faster than the hydration of the clinker whilst for the cement-in-poly(vinyl acetate) the slow rates of the two processes allow the formation of a cementious matrix which assures the stability of the sample.

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1. Introduction

Within the last decade, the research interest in textile-reinforced concrete has increased significantly [1,2]. This is mainly due to the fact that this material allows the construction of thin concrete elements, which are unavailable with conventional steel reinforcements. Thin concrete elements are the key to a novel type of architecture that combines the elegance of wood and steel constructions with the material properties of reinforced concrete [3]. More importantly, thin textile-reinforced concrete elements require less cement for their preparation and as a direct result lead to a significant reduction of the CO_2 emission.

For price and strength reasons, glass is the material of choice to prepare the textile reinforcement. Due to the brittleness of glass, the textile is made from glass rovings, i.e. a multifilament yarn consisting of approx. 1600 individual filaments of 10–30 μm in diameter [4,5]. The performance of rovings as reinforcements largely depends on how well the roving is penetrated by the concrete [4,6]. To spark the formation of a cementitious matrix inside the roving, a cement-in-polymer dispersion – abbreviated as c/p in analogy to water-in-oil emulsions – was developed that consists of non-hydrated cement (clinker) dispersed in a water or alkali-soluble polymer. This dispersion is coated onto the roving in such a way that it fills the voids between the individual filaments before it is embedded in concrete [7,8]. Rovings coated with such dispersions exhibit significantly increased pull-out loads and work. Scanning Electron Microscopy (SEM) investigations revealed the formation of crystalline material inside and around the roving. However, differences in terms of mechanical performance and microstructure were observed when comparing dispersions based on poly(vinyl acetate) with those based on poly(vinyl alcohol) [8]. SEM and mechanical analyses provide only information about the final situation of the system, i.e. after hardening and testing, so that mechanistic conclusion concerning the reactivity and behaviour of the dispersions remains to some extent hypothetical. In contrast, methods that provide detailed and real-time insight into how both components of the coating, namely polymer and clinker, interact with the incoming water should allow the elaboration of the mechanistic details. Such data is a basis for explaining the observed differences in the mechanical performance and the morphology of the interface of the two coatings and is a requirement to tune future dispersions for specific applications using other reactive inorganic additives.

Compared with SEM and mechanical testing, Nuclear Magnetic Resonance (NMR) is particularly favourable for the investigation of cement-based materials as it is fully compatible with water-wet samples and allows analysing the bulk of opaque sample in a truly non-destructive fashion [9–11]. ^{1}H relaxation, imaging, and self-diffusion NMR were successfully applied to investigate the water ingress, drying, and moisture distribution in ordinary Portland cement and to evaluate the effect of various additives [9–19]. Specifically, magnetic resonance imaging (MRI) provides a unique way to monitor non-destructively and with submillimetre resolution the ingress of

* Corresponding author. Tel.: +49 241 8026428; fax: +49 241 8022185.
E-mail address: aadams@mc.rwth-aachen.de (A. Adams).
[1] Present address: Institute of Building Materials Research, RWTH Aachen University, Schinkelstr. 3, 52062 Aachen.

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