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Ultrasound monitoring of the influence of different accelerating admixtures and cement types for shotcrete on setting and hardening behaviour

N. De Belie[a,*], C.U. Grosse[b], J. Kurz[b], H.-W. Reinhardt[b]

[a]*Magnel Laboratory for Concrete Research, Department. of Structural Engineering, Ghent University, Technologiepark Zwijnaarde 904, B-9052 Ghent, Belgium*

[b]*Department of Construction Materials, Stuttgart University, Pfaffenwaldring 4, D-70550 Stuttgart, Germany*

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Abstract

The possible use of ultrasound measurements for monitoring setting and hardening of mortar containing different accelerating admixtures for shotcrete was investigated. The sensitivity to accelerator type (alkaline aluminate or alkali-free) and dosage, and accelerator–cement compatibility were evaluated. Furthermore, a new automatic onset picking algorithm for ultrasound signals was tested. A stepwise increase of the accelerator dosage resulted in increasing values for the ultrasound pulse velocity at early ages. In the accelerated mortar no dormant period could be noticed before the pulse velocity started to increase sharply, indicating a quick change in solid phase connectivity. The alkaline accelerator had a larger effect than the alkali-free accelerator, especially at ages below 90 min. The effect of the alkali-free accelerator was at very early age more pronounced on mortar containing CEM I in comparison with CEM II, while the alkaline accelerator had a larger influence on mortar containing CEM II. The increase of ultrasound energy could be related to the setting phenomenon and the maximum energy was reached when the end of workability was approached. Only the alkaline accelerator caused a significant reduction in compressive strength and this for all the dosages tested.

Keywords: Shotcrete; Acceleration; Cement; Admixture; Workability

1. Introduction

Since its first use, the number of practical applications for shotcrete has continued to increase. Shotcrete is employed in particular for repair works, for immediate temporary support of tunnel walls following excavations in unstable ground, for stabilisation of bridges and for concreting in difficult locations, such as abutments, undersides of beams and interiors of chimneys [1,2]. It is also particularly useful for structures with a special architectural shape, such as arches and curved forms. Important basic requirements are adequate adhesion to the substrate, satisfactory shooting stiffness enabling build-up of thicker sections and preventing dangerous fallout of fresh material from walls and overheads, and high early strength. In this context, setting accelerators become especially important. Chemically, accelerating admixtures for concrete can be divided into four major groups [3]: alkaline silicates, alkaline earth metal carbonates/hydroxides, sodium and potassium aluminates, and alkali-free accelerators often based on aluminium sulfate or calcium sulfoaluminate. A side effect of the traditional alkali-rich accelerators is a significant reduction of the ultimate strength (typical values for strength reduction at 28 days range between 20% and 50%) [3]. Also important are the health hazards associated with handling alkalis. A new generation of alkali-free accelerators was therefore introduced for the improvement of the mechanical parameters, working conditions, safety, lower environmental

* Corresponding author. Tel.: +32 9 264 55 35; fax: +32 9 264 58 45.
E-mail address: nele.debelie@ugent.be (N. De Belie).

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impact, and easier maintenance of existing tunnel facilities [4]. The effect of accelerators on the early strength depends basically on their chemical base, dosage and temperature. Since they act chemically, their performance is closely related to the cement employed, its chemical composition, fineness, and the presence of other possible shotcrete additives [5]. A change in any of these parameters may jeopardize this interaction; therefore it is necessary to determine in each case the compatibility between cement and accelerator.

One of the main difficulties in the study of accelerators performance is to define a method to monitor the shotcrete initial stiffness and strength evolution. Until recently, laboratory tests on cement paste with Gillmore needles [6] or a Vicat needle were normally used to define standardized initial and final setting times [7]. However, these paste tests have been criticised for providing results distinct from those observed in the field [5,8]. Moreover, the selection of these two points in the continuous process of cement hydration is rather arbitrary. More recently, the constant depth penetrometer has been used to evaluate the compressive strength of cast-in-place concrete for strengths up to 1 MPa. The constant energy penetrometer enables assessment of compressive strengths up to 10 MPa [9]. During the last decade, other non-destructive techniques have attracted attention for the characterisation of the behaviour of concrete at early age. Among these, ultrasonic pulse velocity measurements permit to continuously monitor microstructure development in concrete and mortar at early age [10–14]. The ultrasonic pulse velocity measurements are related to the development of the modulus of elasticity and the Poisson ratio [10]. [14] showed that the reflection of ultrasound wave energy was sensitive to the presence of admixtures. [15] stated that the ultrasonic pulse velocity measurements could be used to monitor the microstructure development during setting and hardening of mortar and concrete. A correlation with more traditional methods such as pin penetration or heat evolution has been established [16].

2. Aim of the research

The aim of the current research was to investigate the possible use of ultrasound measurements for monitoring binding and hardening of shotcrete. The sensitivity to changes in accelerator type and dosage, and the effect of accelerators in combination with different cement types was evaluated.

3. Materials and methods

3.1. Wave transmission measuring device

The ultrasound device used for the current investigations was the FreshCon developed at the University of Stuttgart and described in more detail in earlier publications (among others [17,11–13]). Separate devices are available for concrete and mortar, and the latter was used here. The container consists of two polymethacrylate (PMMA) walls which are tied together with four screws with spacers (Fig. 1). The mould is a U-shaped rubber foam element with high damping properties, suppressing waves from travelling through the mould and thus around the mortar. The volume of the mould is approximately 45 cm^3. At one side of the mould a pulse is generated using a broadband frequency generator (Hameg), an amplifier (Develogic) and an ultrasound transmitter (Vallen VS 30). After travelling through the mortar sample in the mould, the signal is recorded at the other side by an ultrasound receiver (Vallen VS 30), with a sampling rate of 20 MHz. Preliminary tests showed that the change in ultrasound velocity and energy could be adequately monitored using a recording interval of 0.5 min during the first half hour and a recording interval of 2 to 5 min later on. Before the experiment, the FreshCon device was calibrated both with an empty container and the two PMMA plates coupled, and with a reference sample with known travel time of the p-wave in between. The calibration parameters obtained were a time delay of 3.18 μs and a reference energy of 968.21×10^{-6}. The time delay is the time the ultrasound wave needs to travel through the sensors and the container walls. It has to be subtracted from the measured time to calculate the ultrasound velocity in the mortar sample. Furthermore, the ultrasound energy, determined by numerical integration of the squared amplitude values following the trigger time (which correlates to the onset), is divided by the reference energy and presented as a dimensionless value. The FreshCon software shows the received ultrasound signals and their frequency spectrum (using an FFT-algorithm) online during the experiment. Also the change in ultrasound velocity and energy and the frequency content vs. concrete age are represented. An offline version of the software allows re-evaluating the data after the test, using different algorithms for picking the onset times of the signals. [11] determined that, between repetitions, measured velocities vary only by approximately 1%.

Furthermore, a new automatic onset picking algorithm was tested offline. The onset detection by hand is a very

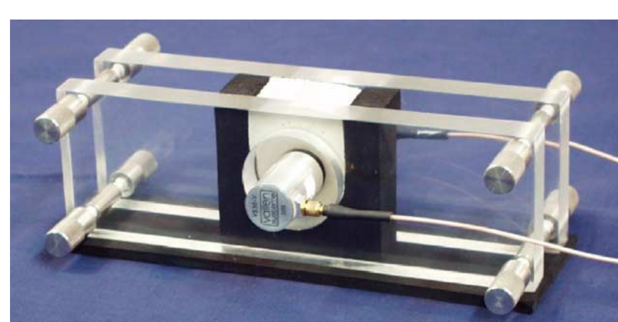

Fig. 1. View of the freshCon mortar container.