Featured Research

Nondestructive Testing of Early Age Concrete

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Introduction

The nondestructive, in-situ testing of early-age concrete properties is a crucial point for the progress of many construction projects in the building sector. The application of such techniques can establish e.g. the earliest possible form removal from concrete construction elements, thereby opening highways to traffic or releasing prestress from steel reinforcement with greatest efficiency. A nondestructive, ultrasonic technique, which measures the reflection coefficient of ultrasonic transverse waves from the concrete surface, was developed at the Center for Advanced Cement-Based Materials [1]. The focus of this research project is to develop a nondestructive field sensor for in-situ monitoring of the setting, hardening, and strength gain of cementitious materials.

Experimental Technique

The wave reflection method monitors the development of the reflection coefficient at the interface between two materials over time. When a longitudinal or transverse wave is reflected at a boundary between Material 1 and Material 2 the reflection coefficient r can be calculated as

$$r = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1} \qquad (1)$$

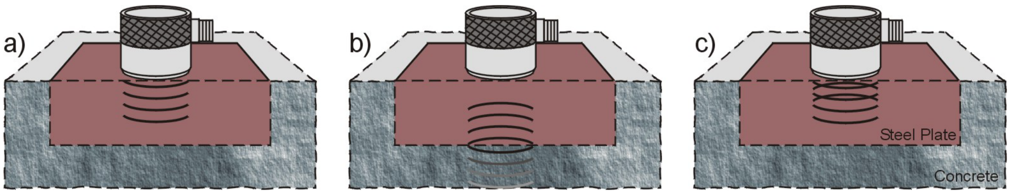
where ρ_1 and ρ_2 are the density of the Materials 1 and 2 and v_1 and v_2 the wave velocity in the Materials 1 and 2 respectively. Knowing the density ρ and the transverse wave velocity v_T of a material the shear modulus can be calculated as follows:

$$G = \rho \cdot v_T^2 . \qquad (2)$$

The interconnection of r and G expressed by Equations 1 and 2 shows that the reflection coefficient is directly related to the physical properties of the tested material.

A schematic of the experimental technique is shown in Figure 1. A steel plate is embedded in the concrete. A transducer with a center frequency of 2.25 MHz, which is attached to the steel plate transmits a T-wave pulse into the steel. The pulse undergoes a multiple reflection process, which is explained in Fig. 1. The described reflection process repeats until the pulse attenuates and the transducer transmits a new pulse.

Figure 1. Schematic of Multiple Reflection Process



a) the transducer transmits a pulse into the steel plate

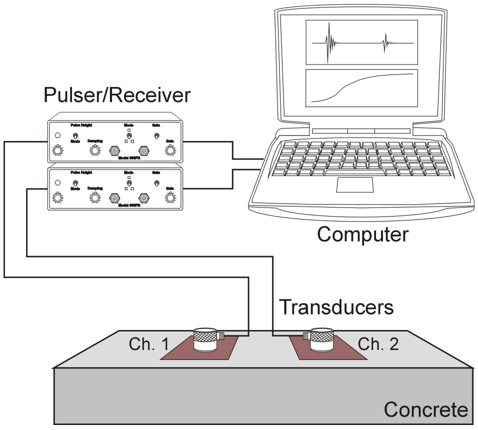
b) ***for fresh concrete:*** the pulse is entirely reflected at the steel-concrete interface (T-waves do not propagate in liquids)

for hardened concrete: the pulse is partially reflected and transmitted at the steel-concrete interface

c) the reflected pulse encounters the steel-transducer interface and is reflected again

The experimental setup, which is used for the wave reflection test is given in Fig. 2. It basically consists of a laptop computer, a pulser/receiver, a transducer and, a steel plate. The transducer, which generates the ultrasonic waves, is connected to the computer via the pulser/receiver. This unit excites the transducer and transmits the information of the received reflections from the transducer to the computer. The setup shown in Fig. 2 is capable to measure the reflection coefficient at two separate channels. Consequently, by using two transducers, which are each connected to a separate pulser/receiver the reflection coefficient can be measured at two different points at the specimen or structure.

Figure 2. Experimental Setup



Signal Analysis

The reflection coefficient is calculated from the first and second reflection received from the steel-concrete interface. The reflections are acquired in time domain (Fig. 3) and then transformed into frequency domain (Fig. 4) using a fast Fourier transform (FFT) algorithm. The reflection factor is calculated from the first and second reflections represented in frequency domain and describes the amount of the wave energy that is reflected from the steel-concrete interface.

Figure 3. Time Domain of acquired Signals

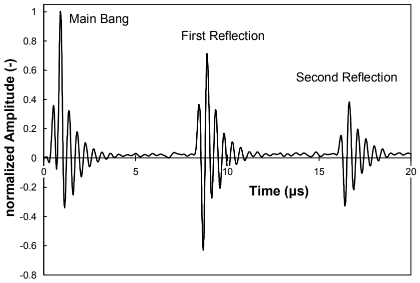
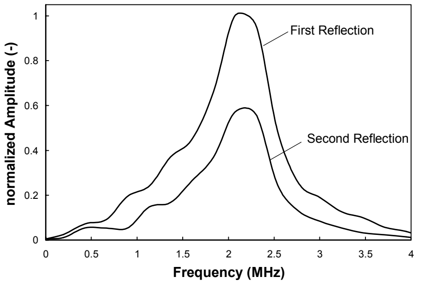


Figure 4. Frequency Domain of First and Second Reflection



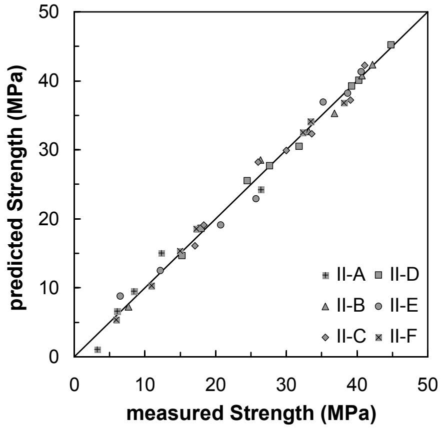
Since the amplitude of the incident wave (main bang in Fig. 3) cannot be determined reliably, the amplitude ratio of the second to the first reflection is calculated. Basically, this ratio corresponds to the reflection coefficient r (Eq. 1). However, a further calculation has to be applied to eliminate effects due to transducer-steel coupling as well as material and geometric losses in steel. The complete numerical procedure for calculating r is explained in [1].

Experimental Work

Previous experiments have shown a high sensitivity of the wave reflection method to the hydration process of cementitious materials. A direct relationship between distinctive points in the wave reflection curve and the initial setting time could be proven.

Experiments in the following stage of the research project were focused on the relationship between reflection factor and compressive strength. It could be found that both quantities are linearly related for concrete at early ages (3-4 days). Based on this relationship a prediction procedure has been developed [2]. A comparison between the compressive strength measured by common compression test and predicted by the developed procedure is given in Fig. 5.

Figure 5. Predicted and Measured Strength for Outdoor Conditions

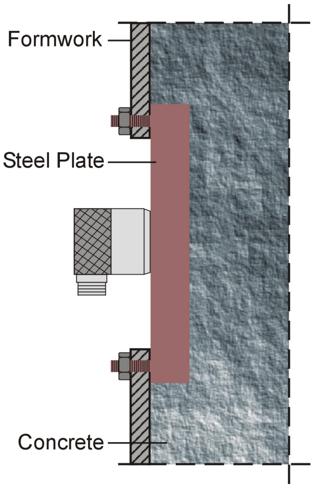


It is important to mention that the prediction procedure requires a calibration.

Field Application

The presented method is easy to apply in the field, since access to only one side of the structure is required. In Fig. 6, a steel plate fixture is shown, as it can be attached to any vertical member with non-steel formwork. When the formwork is made of steel, as it often occurs in the precast industry, the transducer can be attached directly to the formwork.

Figure 6. Application for Vertical Members with Non-Steel Formwork

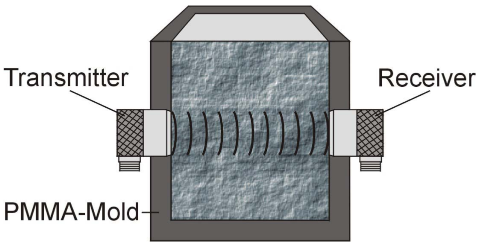


International Collaboration

The research work is conducted in close relationship with international partners. One important part of the collaboration is the active involvement in the RILEM Technical Committee of “Advanced testing of cement-based materials during setting and hardening”. The goal of the committee is to evaluate different test methods in terms of their suitability to reliably monitor the hydration process of cementitious materials. To objectively compare the methods a series of round robin tests has been established.

Within the frame of this round robin test program, tests have been conducted at Northwestern University together with researchers of Stuttgart University, Germany. In Stuttgart a technique has been developed, which evaluates the hydration of concrete with trough transmission of ultrasonic waves [3]. The method determines the pulse velocity and the energy of longitudinal waves propagating through the sample. The schematic of the test setup is shown in Fig 7.

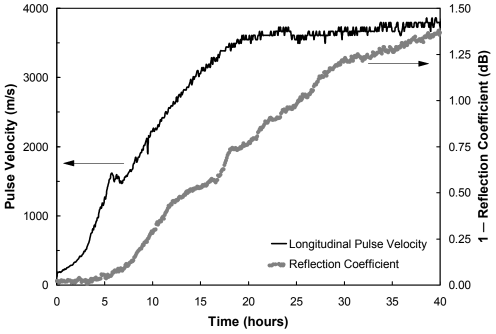
Figure 7. Schematic of Through Transmission Technique developed by Stuttgart University



During the experiments, a set of mortar and concrete mixes was tested with Stuttgart’s transmission and ACBM’s wave reflection technique. This gives a good opportunity to compare the different methods since identical materials are tested at exactly the same conditions. Fig. 8 shows the development of the longitudinal pulse velocity and the reflection coefficient as measured by the two techniques.

It can be seen clearly that the different wave types (longitudinal and transverse) characterize the hydration behavior of the test material in different ways. The reflection coefficient starts to change much later than the longitudinal wave velocity, whereas the velocity levels off at an earlier time than the reflection coefficient.

Figure 8. Longitudinal Wave Velocity and Transverse Wave Reflection Coefficient



To understand why the different modes of transmission give different dependency with rate of hydration, a collaborative research has been started with Delft Technical University (Prof. van Breugel), which will include developing a microstructure model.

Future Work

The future research will focus on the industrial application of the proposed wave reflection method. The first step will be done in cooperation with the precast industry. In precast concrete construction, certain concrete mixtures are repeatedly used under essentially the same conditions for the same application. This protocol provides relatively constant conditions concerning the tested material and the curing procedure, which is advantageous for introducing a new method of concrete testing.

References

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