WRF를 이용한 모르터의 응결 및 경화 예측

Setting and Hardening of Portland Cement Mortar Investigated with Wave Reflection Factor

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ABSTRACT

Previous research has been conducted on an ultrasonic wave reflection method that utilizes a steel plate embedded in the concrete to measure the reflection loss of shear waves at the steel-concrete interface. The reflection loss has been shown to have a linear relationship to compressive strength at early ages. The presented investigations continue this research by examining the fundamental relationship between the reflection loss, measured with shear waves, and the hydration kinetics of Portland cement mortar, represented by dynamic elastic moduli, compressive strength and degree of hydration. Dynamic elastic moduli are measured by fundamental resonant frequency and degree of hydration is determined by thermogravimetric analysis. The water/cement ratio was varied for the tested mixture compositions. The results presented herein show that compressive strength, dynamic shear modulus and degree of hydration have a linear relationship to the reflection loss for the tested mortars at early ages.

1. Wave Reflection Method

The wave reflection method monitors the reflection loss of ultrasonic shear waves at an interface between a steel plate and a cementitious material over time. The amount of the lost wave energy depends on the reflection coefficient, which in turn is a function of the acoustical properties of the materials that form the interface.

A schematic of the experimental technique is shown in Fig 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 shear wave pulse into the steel. The pulse undergoes a multiple reflection process, which is shown in Fig 1.

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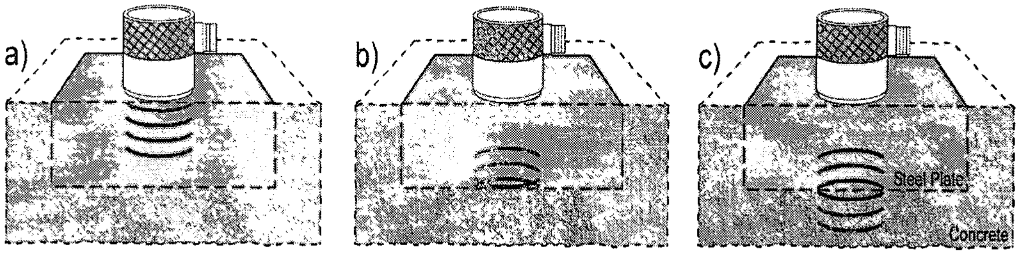

Fig. 1. Schematic of multiple reflection process

The transducer transmits a pulse into the steel plate (Fig 1a). When the concrete is in liquid state the pulse is entirely reflected at the steel-concrete interface, since shear waves do not propagate in liquid materials (Fig 1b). With progressing hydration, the microstructure built up by the hydration products allows the shear waves to propagate into the concrete: the pulse is partially reflected and transmitted at the steel-concrete interface (Fig 1c). The reflections are received by the transducer and used for the calculation of the reflection loss. The pulse transmitted into the concrete attenuates and is not further evaluated. The described reflection process repeats several times until the transducer transmits a new pulse.

After transforming the received signals from time domain into frequency domain, the reflection loss can be calculated from the difference between the amplitudes of the first and second reflections. In this paper the reflection loss will be expressed in decibel and describes the reduction in amplitude of the traveling shear wave due to transmission losses at the steel-concrete interface. The complete numerical procedure for calculation of the reflection loss can be found in 2).

2. Experimental Program

The experimental study was conducted on cement mortars containing Portland cement type I (after ASTM C-150) and silica sand as fine aggregates. The cement mortar was tested in three different water-cement ratios : 0.35, 0.5, 0.6. The mixture composition of the mortars is given in Table 1.

To determine the hydration behaviour of the mortar mixtures the reflection loss and three alternate material parameters were measured: compressive strength, dynamic shear modulus and degree of hydration. The tested materials were cured at a constant temperature of 25℃ throughout the duration of the experiments.

Table 1 Mixture proportions by weight of cement

mix	cement	water	sand
A	1	0.35	2
B	1	0.50	2
C	1	0.60	2

3. Relationship between Reflection Loss and Compressive Strength

The relationship between compressive strength and reflection loss was already established previously in 2) and 3). It was found that both parameters are linear related for mortars and concretes with varying composition and curing conditions in a time range of up to four days. The linearity of this relationship could be reproduced for the mortars tested in this study. Due to the very early start time of the compressive strength tests (around initial set) an additional feature of the strength-reflection loss relationship (S-R_L relationship) could be identified.

As shown in Fig 2, the S-R_L relationship exhibits a strong bilinear pattern, dividing the relationship into two parts. The first part at very early ages has a clearly lower slope compared to the second part of the relationship at later ages.

The slope changes at a certain time, which is 10.5 hours for the shown mortar with w/c = 0.5. It was observed, that the time of transition (t_{trans}) between the two slopes changes with the kinetics of the strength gain. It is assumed that the bilinear behaviour of the S-R_L relationship is attributed to changes in the growth characteristic of both parameters: reflection loss as well as compressive strength.

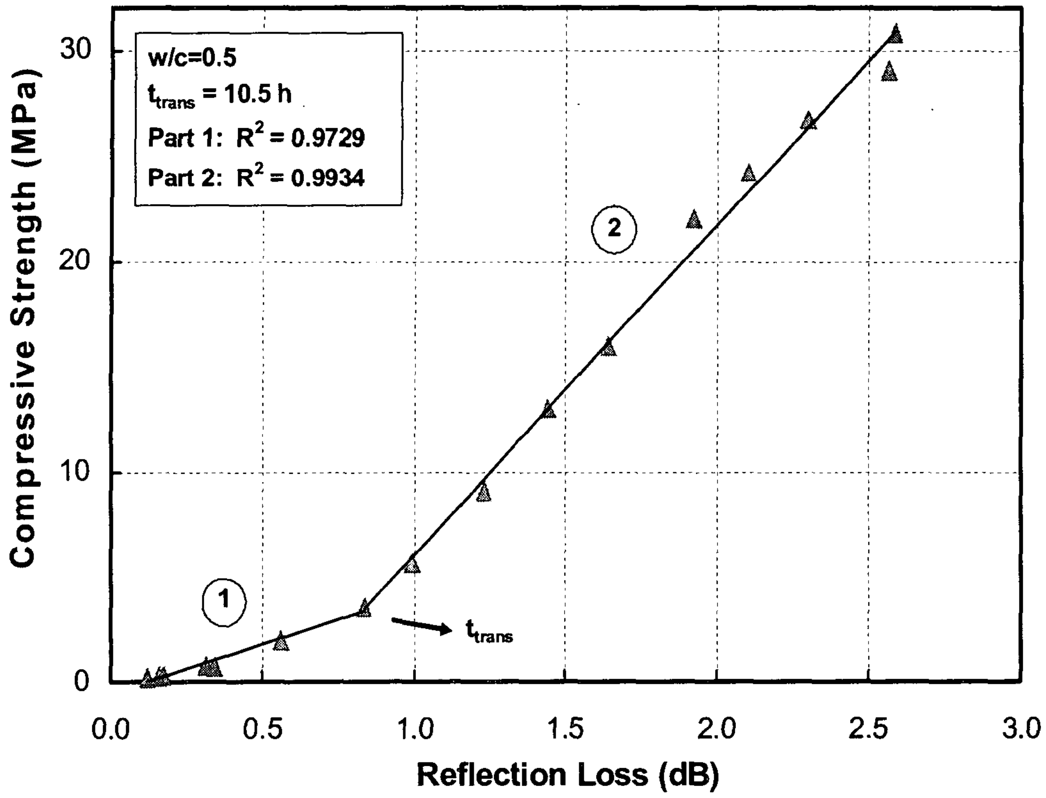

Fig. 2 Relationship between reflection loss and compressive strength for mortar with w/c=0.5

4. Relationship between Reflection Loss and Dynamic Shear Modulus

The relationship between the dynamic shear modulus and reflection loss is an essential part for understanding how the wave reflection measurements are related to fundamental material parameters. The reflection loss is an expression of the reflection coefficient at the steel-mortar interface. The reflection coefficient measured with shear waves can theoretically be related to the shear wave velocity of the tested mortar. By knowing the acoustic impedance of the used steel plate the dynamic shear modulus of the mortar can be calculated. It will be analyzed in the following how the dynamic shear modulus calculated from reflection loss G_r is related to the dynamic shear modulus measured by fundamental torsional resonant frequency G_{tors}.

The relationship between G_r and G_{tors} is given in Fig 3. The linear trend indicates that the reflection loss strongly depends on the evolution of the dynamic shear modulus. This shows that the reflection loss is governed by an important mechanical material property.

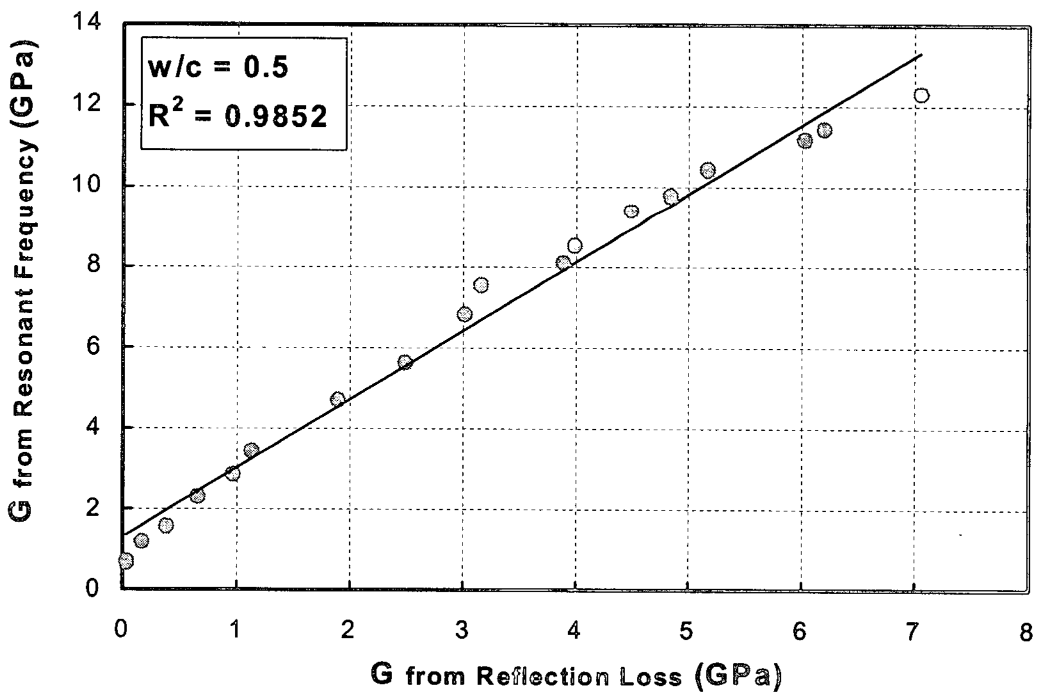

Fig. 3 Relationship between G_r and G_{tors}

5. Relationship between Reflection Loss and Degree of Hydration

The degree of hydration is one of the most fundamental material parameters of a Portland cement mortar. It describes the progress of the hydration reaction and is a governing parameter for many mechanical mortar and concrete properties.

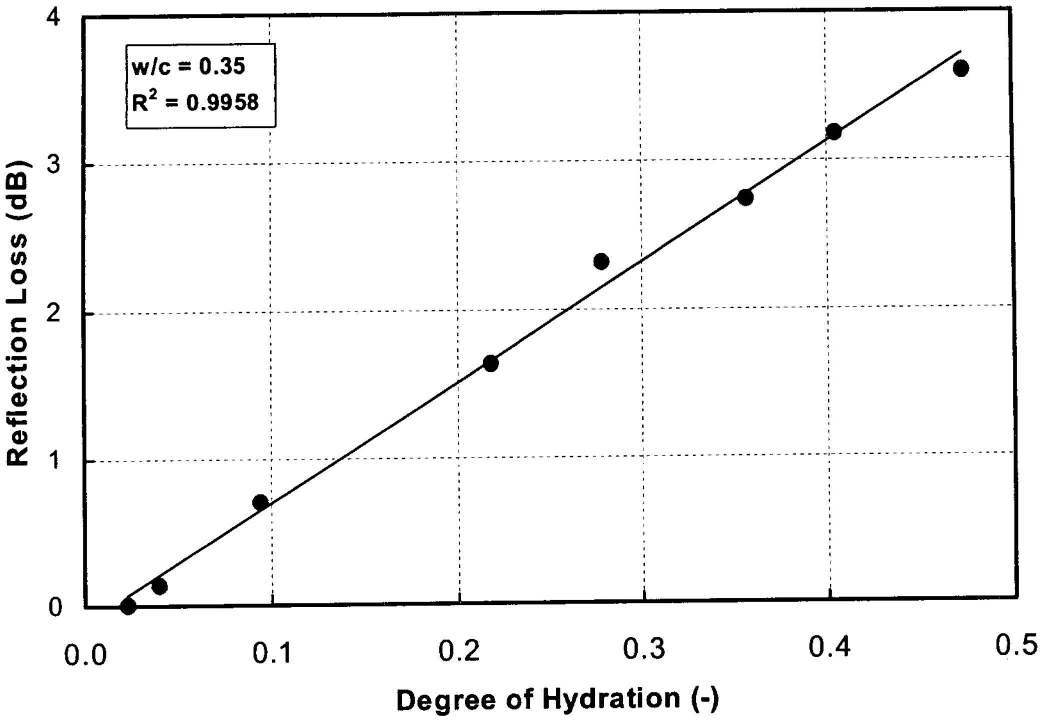

Fig. 4 Relationship between degree of hydration and reflection loss

The relationship between degree of hydration and reflection loss is given in Fig. 4. The presented data show a very strong linear trend over the entire period of time that is plotted. The same linear trend exists for the other two mortars tested in this study. It was also found that the slope of the relationship changes with w/c-ratio, where a low w/c-ratio corresponds to a high slope.

6. Conclusions

1) The relationship between reflection loss and compressive strength has a bilinear character for the tested mortar mixtures at early ages (70 to 90 hours). The time of the transition point depends on the kinetics of the strength gain.
2) Dynamic shear moduli calculated from torsional resonant frequency and reflection loss are linear related at early ages. This shows that the wave reflection method is governed by the evolution of an important mechanical parameter.
3) Degree of hydration and reflection loss are linear related at early ages. This demonstrates the high sensitivity of the presented wave reflection method to changes in the microstructure of cementitious materials due to hydration.

Reference

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