


## **Laser-Based Evaluation of Cement Hydration** Non-Contact Inspection of Curing Processes Application Note



This Application Note Shows How to Inspect Cement-Based Materials During the Curing Process Without Contacting Them. The Ultrasonic Excitation is Created by a Small Amount of Ablation Produced by a Short-Pulsed Nd:YAG-Laser, and the Detection on the Reverse Side of the Sample is Carried Out Interferometrically by a Laser Vibrometer.



By matching the appropriate pulsed laser beam parameters to the material under study, a reproducible sound excitation was achieved. This allows the interferometric measurement of the ultrasonic pulse velocity,  $v_p$ , as well as the velocity amplitudes of the compressive wave.

# Characterization of Cement-Based Materials with Laser-Ultrasonics

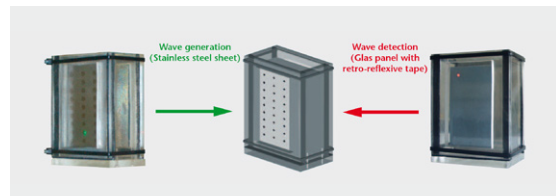
An understanding of the curing process for fresh cement-based materials is essential for material research, quality control, and the practical planning and implementation of construction projects. In order to describe the material properties, the ultrasonic pulse velocity ( $v_p$ ), the first amplitude of the longitudinal wave and the transmitted frequency content can be used. Immediately after mixing, cement-based materials show a significant damping effect on ultrasonic waves together with low pulse velocity. During the course of the curing process, the ultrasonic pulse velocities and signal amplitudes increase continuously. The ultrasonic pulse velocity depends on the used cements, admixtures and additives but also on the water/cement (w/c) ratio, grain distribution and air pore content. Since objects can be

non-destructively investigated without contact and at a standoff distance of several meters, laser-ultrasonic inspection is a preferred technique for a number of specific applications. Pulsed lasers permit a contactless excitation of longitudinal, shear and surface waves directly on the exposed surfaces. The resulting velocity amplitudes are measured without contact by means of a laser vibrometer using the Doppler effect and heterodyne detection. In the following paragraphs, the principles of laser-induced excitation and interferometric detection of ultrasonic waves are described with respect to the specific experimental setup that permits the investigation of cement pastes and mortars.



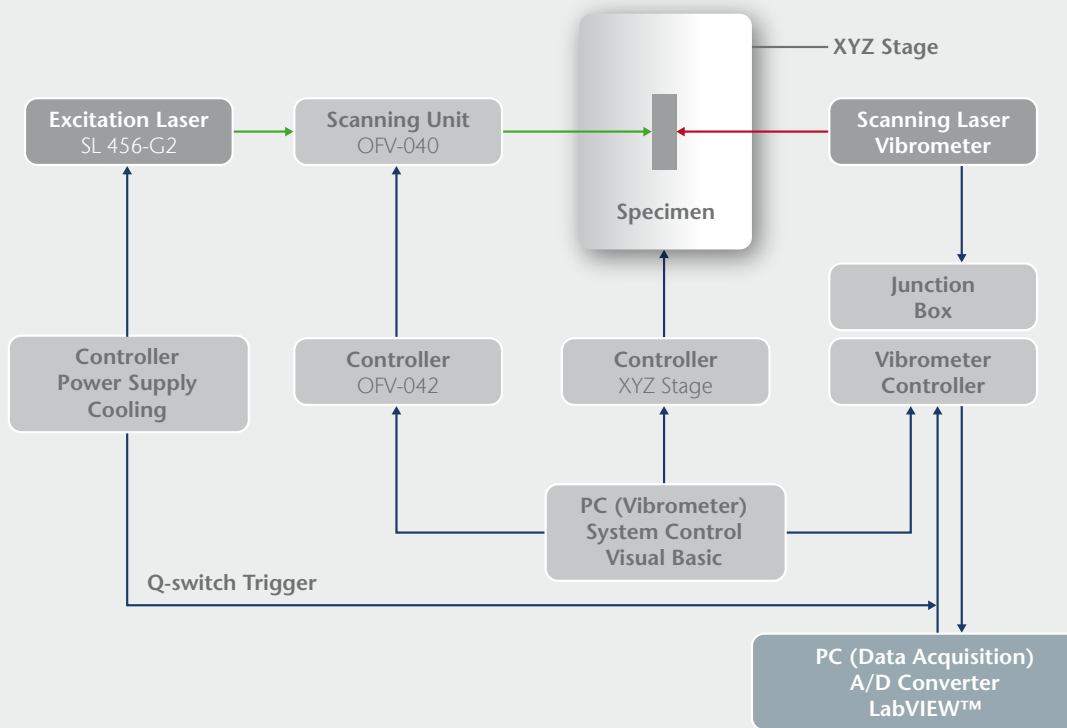
## Experimental Setup

The principle hardware configuration is shown in Fig. 1. For laser ultrasonic generation, a Q-switched, solid-state Nd:YAG-laser with a fundamental wavelength of 1064 nm is used (Fig. 2). To characterize the excited ultrasonic waves, a scanning laser vibrometer is deployed which uses a heterodyne interferometer to detect the acoustic displacements. A sample mold with transparent walls was specifically developed for this application to allow laser-induced excitation and detection of through-transmission ultrasonic waves in setting and hardening mixtures (Fig. 3). Two measuring grids consisting of 27 measuring points for excitation and detection were created and aligned opposite to each other. The data acquisition and evaluation was managed by an algorithm implemented in LabVIEW. This algorithm allows the automatic detection of the compressive wave onset and further signal parameters such as the first amplitude of the longitudinal wave and the signal-to-noise ratio.



**2** Laboratory setup: Excitation laser with scanner (right, background); positioning stage with sample (center); Scanning Laser Vibrometer (left, foreground).

**3** Testing mold for laser-based ultrasonic evaluation



**1** Laser ultrasonic inspection setup and configuration.

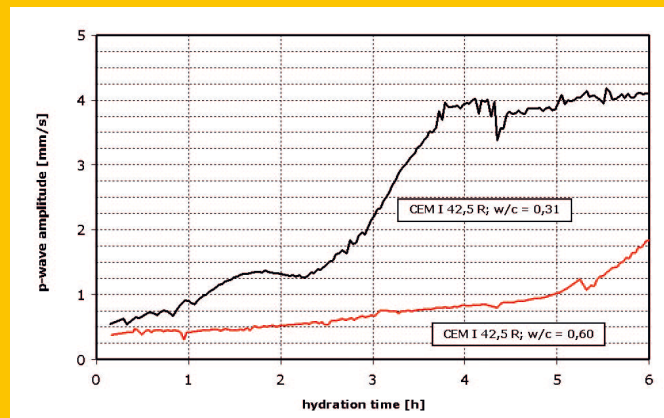
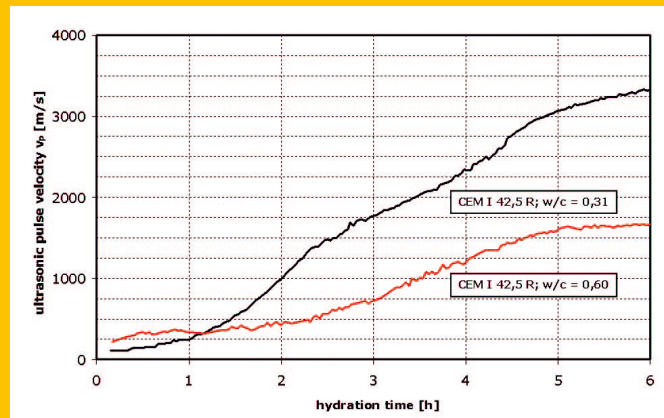
## Experimental Investigations and Results

Continuous investigations on cement-based materials during the hydration process have been carried out. Further more, the local distribution of the ultrasonic pulse velocity,  $v_p$ , have been determined at definite times after mixing. Various cement pastes and mortars were investigated. Regarding the cement pastes, two different w/c ratios were applied. The mortar samples had various grain size distributions and various PCE-based superplasticizer content.

In Fig. 4 the development of the ultrasonic pulse velocity is shown for two cement pastes under variation of the w/c ratio. A measuring point in the center of the specimens was chosen. The laser ultrasonic measuring sensitivity is sufficient for a through transmission of these strongly absorbing systems.

In the course of the curing, both experimental mixtures show an increase in the ultrasonic pulse. The cement paste with a lower w/c ratio shows a significantly stronger increase in velocity. In contrast, increasing the amount of water will lead to a delayed and much smaller increase. In Fig. 5, the development of the first amplitude of the longitudinal wave is shown as the surface displacement on the detection side. The cement paste with a lower w/c ratio shows an earlier and steeper increase when compared to the one with the higher w/c ratio. This parameter allows a continuous evaluation of hydration kinetics. As the microstructure continues to develop, the influence of shrinkage processes on the coupling conditions becomes clear.

### 4 Ultrasonic pulse velocity vs. hydration time for cement pastes with different w/c ratios

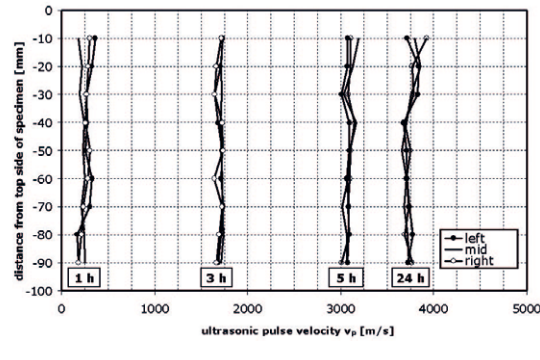


### 5 Evolution of longitudinal wave first amplitude for cement pastes with different w/c ratios

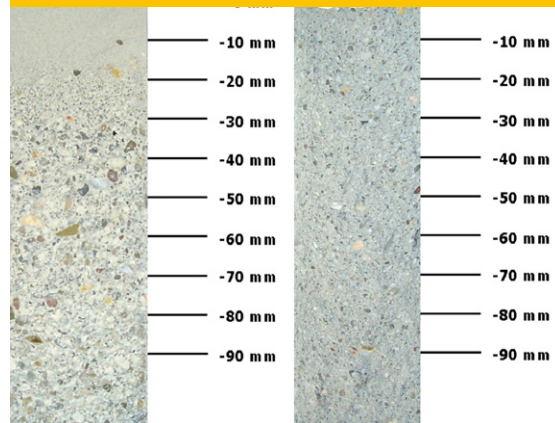
### Local Distribution of Elastic Parameters

In Fig. 6, the distribution of the ultrasonic pulse velocity of a cement paste with a w/c ratio of 0.31 at varying points of time after the beginning of the hydration is shown. At every point in time, similar sound velocities were determined over the whole specimen. Therefore, it can be assumed that there are no differences in the hydration progress or in the mixture composition and that the specimen is homogeneous (Fig. 7, right). The comparison of the ultrasonic pulse velocities with time allows an evaluation of the hydration kinetics.

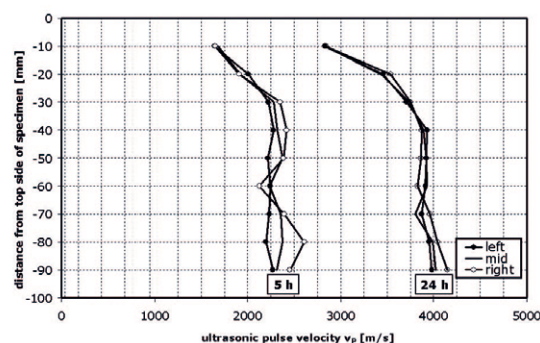
The distribution of the ultrasonic pulse velocity of a mortar sample at 5 h and 24 h after mixing is shown in Fig. 8. Over the test piece's height there are significant differences in the ultrasonic pulse velocities. In the bottom part of the specimen higher sound velocities are reached which can be explained by a higher aggregate content. This is due to insufficient mortar sedimentation stability. Before stiffening, a settling of the coarse components of the aggregate takes place and an enrichment of fine mortar in the upper part. This is confirmed by the visual examination (Fig. 7, left). Thus, by means of the laser-based ultrasonic transmission method, a non-destructive evaluation of local structure differences vertical to the through-transmission direction can be achieved.



**6** Distribution of ultrasonic pulse velocity over a cement paste sample. The narrow distribution in velocity across the sample at any given point in time indicates that the sample is homogeneous



**7** Mortar M1 with sedimentation phenomena (left) and homogeneous mortar M2 (right) with the heights of the measuring points



**8** Spatial distribution of ultrasonic pulse velocity in a mortar sample. The trend from lower velocities at the top of the sample to higher velocities at the bottom indicates an inhomogeneous sample



## Summary

The experimental results using laser ultrasonic inspection on cement pastes and mortars show that ultrasonic through-transmission can be used for a non-destructive, contactless investigation of setting and hardening of building materials. In order to describe the evolution of the material properties, the time-dependent and local changes of the ultrasound parameters can be used. The ultrasonic pulse velocity and the velocity amplitude of the longitudinal wave allow a continuous evaluation of the hydration kinetics. Using the ultrasonic pulse velocity, it is possible to show local variations of the mixture composition of the investigated cement pastes and mortars vertical to the transmission direction. This can be used to evaluate the sedimentation stability of such mixtures. The experimental setup described here enables

detection of vibration velocity only in the out-of-plane direction. Further investigations using a 3-D Scanning Vibrometer which measures the complete displacement vector (out-of-plane as well as in-plane) have revealed that the velocity of propagation of transverse vibration components (shear waves) can be simultaneously acquired during the hydration. This is an interesting approach that allows for a more comprehensive assessment of the evolution of the material's elastic parameters including Young's modulus and Poisson's ratio.

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