ULTRASONIC TESTING DEVICE FOR MORTAR

ULTRASCHALLMESSEINRICHTUNG FÜR MÖRTEL

DISPOSITIF DE TEST ULTRASONIQUE POUR MORTIER

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SUMMARY

The testing principle of our ultrasonic testing device for mortar is an ultrasonic through-transition measurement with the evaluation of wave velocity and transmitted energy with the result of continuous monitoring of the setting and hardening process. Since the signals are recorded continuously in certain intervals, it is possible to observe the behaviour of the material at any time by the changes in these parameters. This method is not only capable of identifying different mortar mixes, but also of controlling the effectiveness of concrete admixtures.

ZUSAMMENFASSUNG

Das Ultraschallmessverfahren basiert auf dem Prinzip der Durchschallung. Ausgewertet werden die Ultraschallgeschwindigkeit und die übertragene Energie. Anhand der zeitlichen Änderung dieser Parameter kann das Materialverhalten beim Erstarrungs- und Erhärtungsprozeß genau verfolgt werden. Das Verfahren eignet sich nicht nur für die Untersuchung diverser Mörtelmischungen. Es kann auch die Wirksamkeit von Betonzusatzmitteln kontrolliert werden.

RESUME

Le test ultrasonique est basé sur la mesure continue des ondes parvenant à la face arrière de l'échantillon et l'évaluation de la vitesse de propagation et de l'énergie transmise. La variation de ces paramètres permet de suivre l'évolution de la prise et du durcissement du matériau. Ce procédé permet non seulement d'analyser différents mortiers, mais également de contrôler l'efficacité d'adjuvants.

KEYWORDS: ultrasonic, testing device, mortar, setting, hardening, penetration

1. INTRODUCTION

Concrete is a construction material based on mineral binders and, for many years, the material is the most frequently used in the world. Its origins go back to cultures even before the roman architects when it was named opus caementicium [Koch, 1994]. However, the material as applied today has little to do with the one used in the roman empire. In our days, we are talking of high performance concretes, reaching strength values of steel. We are even capable of manufacturing concretes that do not require any compaction energy anymore.

Despite the progress in concrete technology we are using testing techniques for quality control that were developed decades ago. Everybody is talking about quality management, but in no other engineering field, the technologies of materials and testing techniques are so far apart. With current testing methods, only some rather subjective parameters like initial and final set can be determined. A continuous monitoring of the setting and hardening process is not possible.

Scope of the research project presented here is the development of a testing method that is capable of replacing the old standardized methods by providing reliable parameters for a state assessment of cementitious materials.

In the following paragraphs some standardized methods for testing cementitious materials are shown as well as the physical background of our testing device. Measuring results are given and will be discussed.

2. NECESSITY OF TESTING AND PHYSICAL BACKGROUND

Modern concrete technology faces several challenges. First, the design engineer asks for high-strength concrete, high-performance concrete or fibre reinforced concrete. Also the contractors are demanding for highly workable concrete, self-levelling concrete, slip formed concrete and retarded mixes.

Another important point is the availability of less workmanship on the construction site. And last but not least, there is increasing quality required for durable concrete structures in an aggressive environment.

The materials producers have a basket full of admixtures and additions which are deemed to affect the fresh or the hardened state of concrete in a beneficial way. The user is sometimes inclined to combine various products in order to achieve the maximum success. However, not all mixtures lead to the expected result.

An advanced process technology needs proper control by reliable and - as much as possible - objective measurements.

What can be achieved by the actual standard testing methods? Only a few techniques are able to give control of the setting and hardening process. The Vicat-needle test [Deutsches Institut für Normung, 1990] is suitable for examining cement-water mixtures without any aggregates. An other testing procedure is the penetrometer test [Bunke, 1991]. With the penetrometer it is also possible to test concrete, i. e. mixtures with aggregates. However, the extracted material being tested is a mortar which is sieved out of a concrete!

With both methods the penetration resistance is measured and as a result the setting times (initial and final set) are defined. That means, not the true setting and hardening properties can be observed with these testing procedures.

Merely the last mentioned method is able to catch a portion of the time dependent process, but only at the very early stage of the hardening process. An example of a testing result from such a penetrometer test is shown in Figure 1.

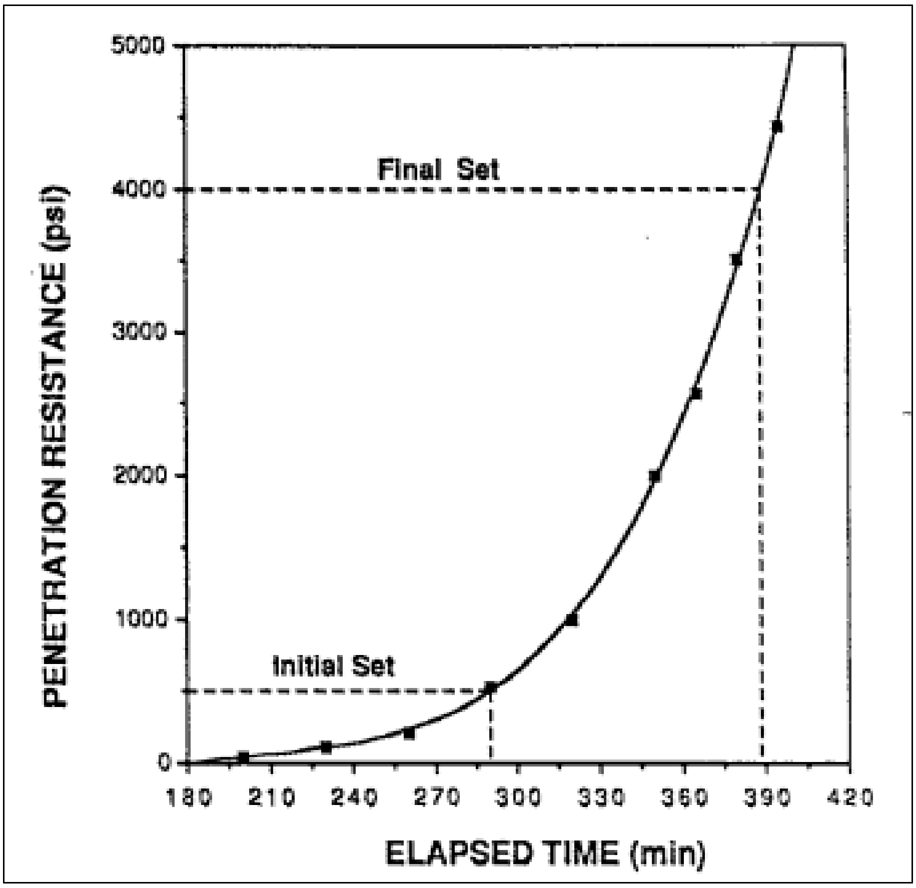

Fig. 1. *Penetrometer test [Bunke, 1991]*.

To solve the problem of observations during the whole hardening process the ultrasound technique can be applied where amplitude, velocity and frequency variations depending on the age of the mortar are recorded. The property of cementitious materials is changing from a suspension to a solid during the stiffening process caused by the hydration of the cement-matrix. Biot’s theory [Biot, 1956] describes the physical properties of this class of materials in an adequate way as was shown by own measurements [Bohnert, 1996]. Based on this approach, using wave propagation theory, it became obvious that ultrasound experiments measuring elastic waves in through-transmission are able to characterize the material during the stiffening process. Although the whole waveform is representing the material properties, for quantitative analysis techniques some parameters have to be extracted from the signals recorded by a measuring device.

Parameters that are easy to determine are the velocity (from the onset time of the signals knowing the travel path of the wave), the energy (calculating the integral of the wave amplitudes) and the frequency content (using Fast-Fourier-Transform techniques). One has to keep in mind that there are, of course, also several other parameters that can be used. Even though one single wave parameter could be sufficient to characterize the material, the reliability of the method is increased by evaluating more than one.

In the following the application of the method is shown.

3. OPTIMIZATION FOR MORTAR MEASUREMENTS

The ultrasonic testing device *freshmor 1* was developed at the University of Stuttgart, Institute of Construction Materials. It enables the observation of the setting and hardening process of mortar by means of ultrasonic through-transmission. Ultrasonic velocity and transmitted energy are the parameters that are evaluated. The testing device consists of a personal computer with an A-D-conversion card, an ultrasonic generator, a mould with an ultrasonic emitter/transducer pair and cables and connectors. Figure 2 shows the mould which contains the testing material.

Since mortar does not contain aggregates being lager than 4 mm in diameter, the size of the mould could be reduced significantly compared to former measurements on concrete materials [Reinhardt et al., 1999a]. The advantages are a better handling of the mould, especially the cleaning of the PMMA walls, a smaller amount of material lost during the measurement, as well as less waste causing additional costs. Also the shape of the mould was redesigned to be more robust for easy handling and fast replacement of specimen material. The suppression of interfering waves through the walls of the container and the mounting for piezoelectric transducers with reproducible coupling to the tested material have been additional problems to be solved.

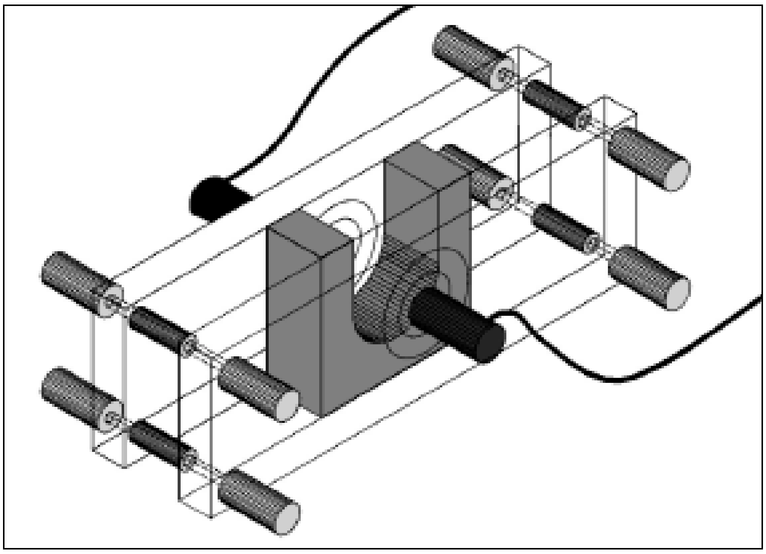

Fig. 2. *Set-up for the mortar experiments showing the mould (rubber foam and PMMA walls) and the transducers.*

An emitter-receiver pair of broadband conical transducers were chosen which are sensitive in a frequency range of 20 to 300 kHz. The conical shape of the transducers enables the possibility of point-to-point measurements.

The signals measured during the stiffening process are recorded by an A/D-conversion device consisting of a fast A/D transientrecorder PC card controlled by an IBM compatible PC. On the emitting side, the signals are produced by an US generator via the conical transducer in time intervals defined by the user.

Apart from the hardware, a lot of effort was made to bring the software in a user-friendly laboratory-suited state. The software consists of three parts including the control and monitor software used during the data acquisition, the extraction of wave parameters used for the material characterization and the data analysis software.

The patent specification [Reinhardt et al., 1999b] contains a more detailed description of the ultrasonic testing device *freshmor 1*.

4. EVALUATION OF THE US SIGNALS

To determine automatically the onset times of the compressional waves and therefore the velocities with highest reliability, a special picking algorithm must be used. Well-known algorithms using the crossover of signals above a given threshold are not applicable in this case, because, for the given data, they were tested with high error rates in relation to the onset times. We have developed a software called *FreshCon* which uses a combined energy-frequency approach solving this problem. The algorithm was extensively tested in numerous applications and gives reasonable results even if the signal-to-noise ratio is low. An example is shown in Figure 3. A description of the software can be found in [Grosse et al., 1999].

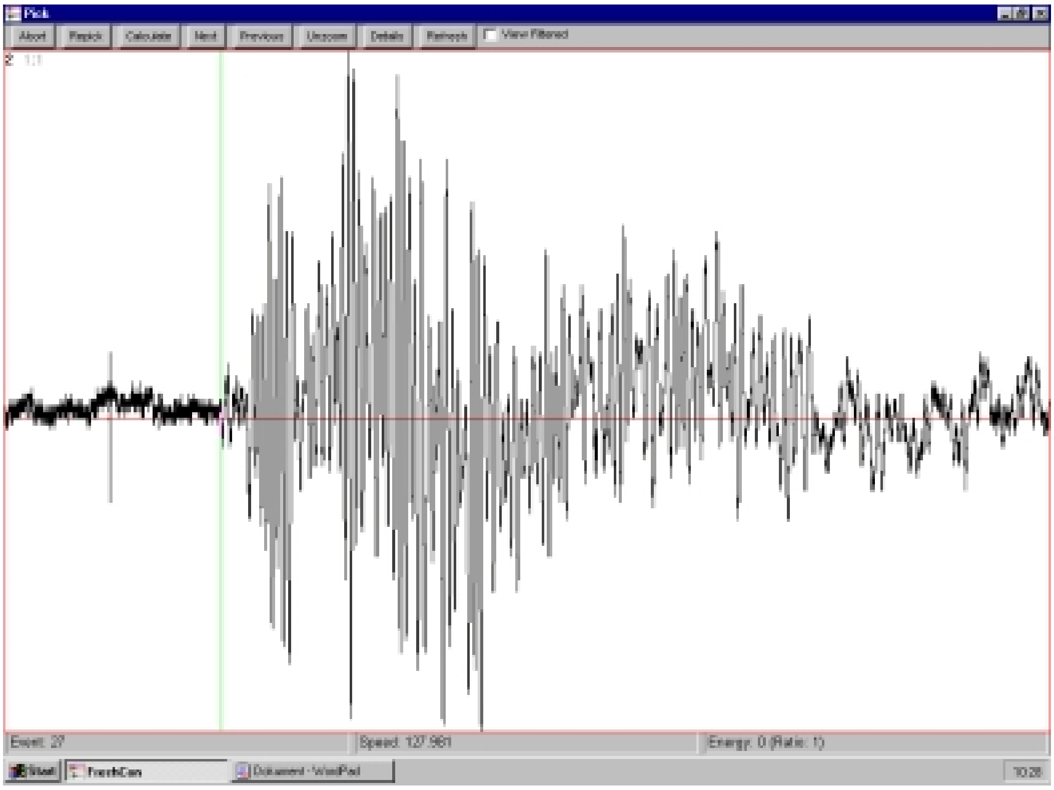

Fig. 3. *Example of an unfiltered US signal in FreshCon using the semiautomatic picking mode.*

For the final data analysis a commercially available software tool is used, which was considerably modified with import filters, templates, and macros. In this program the calculated compressional wave velocity and the transmitted energy, both depending on the age of mortar, are plotted to get a suitable presentation of the measurement results.

5. RESULTS FROM DIFFERENT MORTAR MIXTURES

Exemplary, the results of two different measurement series are shown in the following. In the first one there is a mortar observed consisting of cement CEM I 42.5 and standard sand (German “Normsand”) under variation of the water-cement ratio between 0.50 and 0.60. The second series differs only by the cement grade, namely a CEM I 52.5.

Both the standard sand and the mixing process are according to DIN EN 196-1, including a compaction time of two minutes. During the vibration of approximately 0.7 mm horizontal amplitude, the mould was slowly be filled – we learned that the devaporation of the material is important for proper and reliable results. Due to the time necessary for compaction and connection to the US device, the first data can be recorded after approximately 10 minutes. Choosing standard settings for these test measurements, the repetitive data acquisition interval was set to 10 minutes.

In the early age of the mortar, the velocity of the US waves, shown in the two figures is very low and slowly increasing. After two or three hours the velocity increases faster. In the later trend of the curves the increment of the velocity drops again.

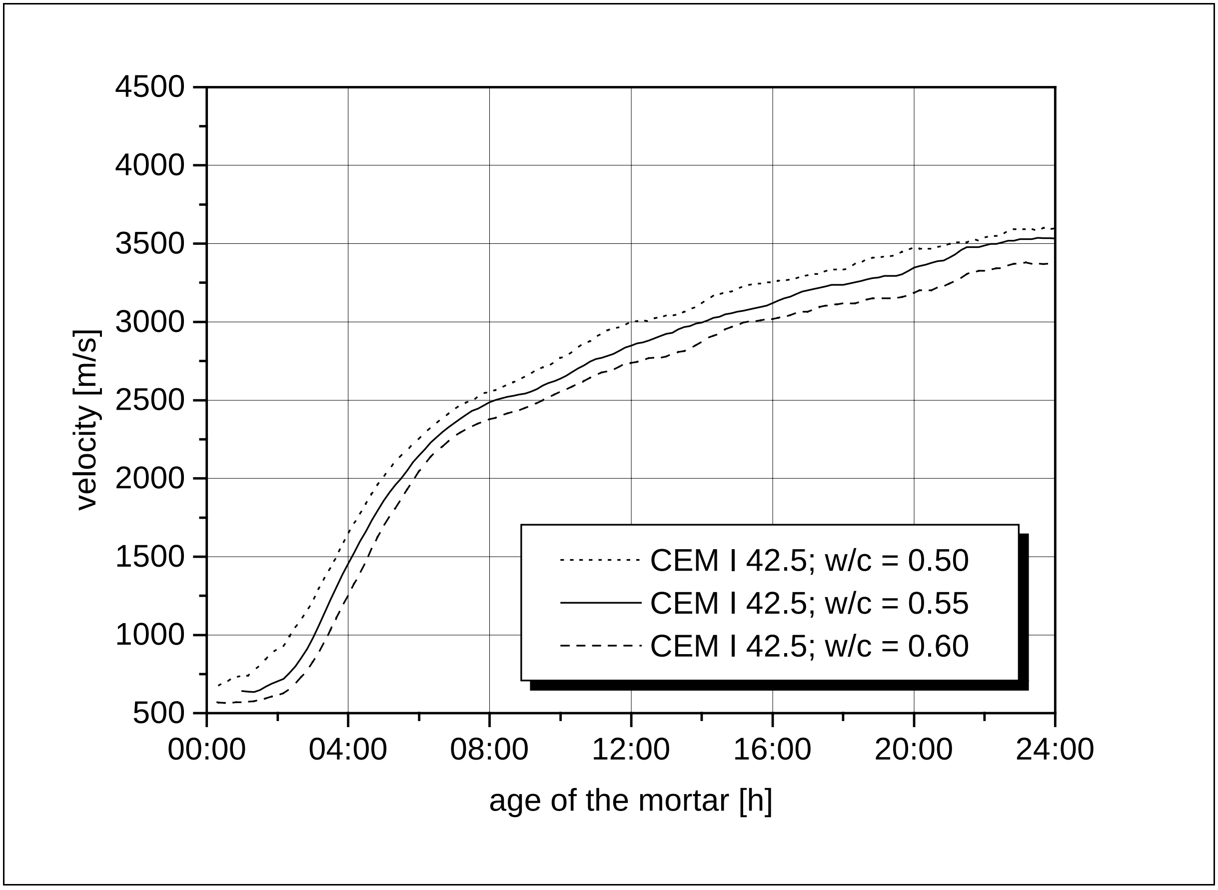

Fig. 4. *Velocity of the US wave depending on the age of a mortar with CEM I 42.5 with variation of the water-cement ratio.*

In both diagrams an effect can be observed depending on the water-cement ratio, i. e. the velocity develops differently. According to the stiffness and the expected compressive strength, the curves are reaching a different value of the velocity at a certain time. Having regard to this effect while comparing the two diagrams, the higher absolute velocity from the curves shown in Figure 5 becomes acceptable, because the overall quality of the cement has an influence on the compressive strength of the mortar.

The test results presented should give an impression about the capabilities of this technique to investigate and classify a hardening material. Special mixtures as well as newly designed admixtures are able to be characterized in a new and promising way.

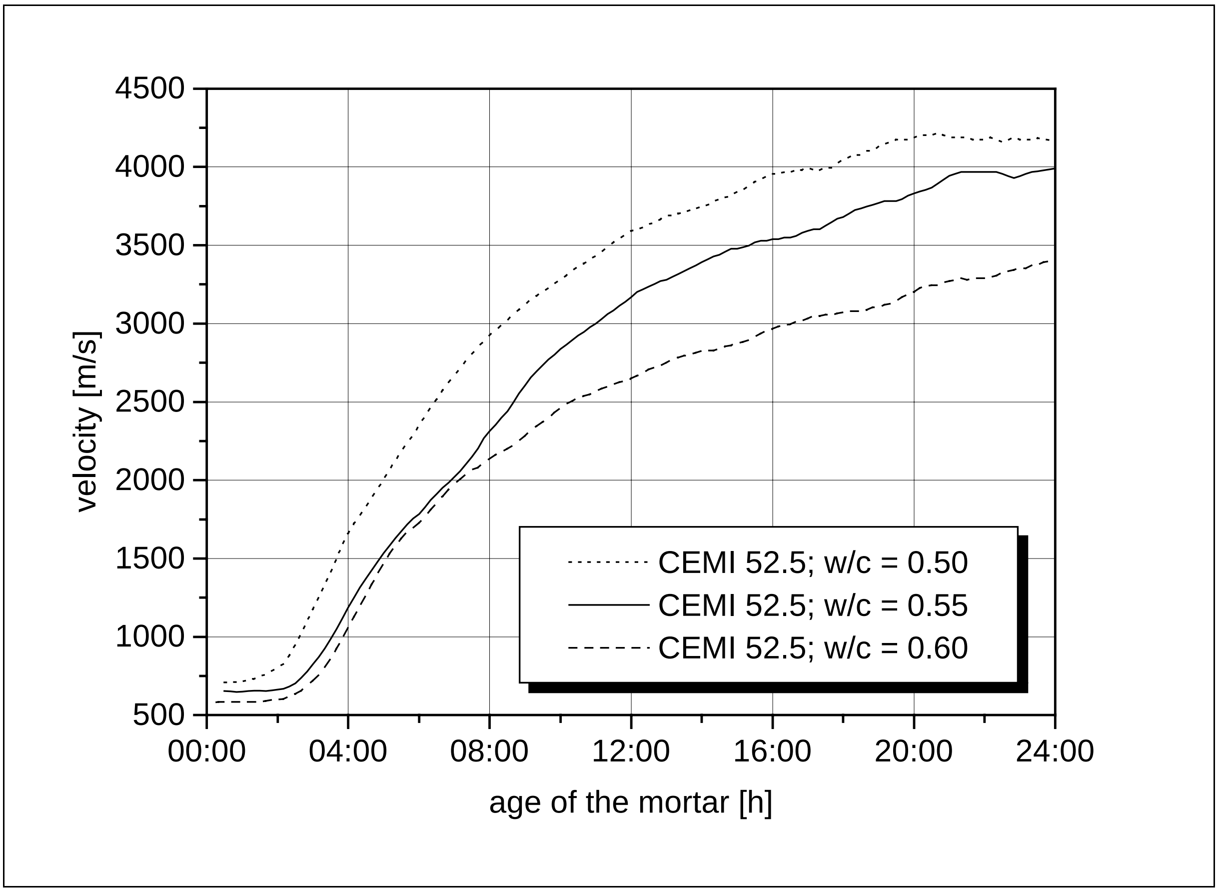

Fig. 5. Velocity of the US wave depending on the age of a mortar with CEM I 52.5 with variation of the water-cement-ratio.

6. CONCLUSIONS AND OUTLOOK

The ultrasonic device presented in this article is able to extract automatically certain parameters of US waves recorded continuously during setting and hardening of cementitious mortars. The resulting curves describe the material behaviour and are related closely to the hydration process of the mortar. These curves are linked to the elastic properties and give a comprehensive picture of the stiffening process in a way that was not accessible before. Future applications in industrial laboratories will show what kind of benefits are brought up by recording the material properties of suspensions during hardening. Anyway, it is obvious that this technique gives a clearer and more detailed insight into the material properties than the standard procedures that are measuring only one single parameter at a certain age.

It is expected that the industrial use of this method will fertilize the further improvement of the technique presented. On the basis of these experiences, the existing apparatus for concrete investigations will also be improved to enable measurements in-situ. It should be concluded that, apart from this, the US device will be modified for measurements on different other materials such as polymers, ceramics or even starch.

7. ACKNOWLEDGEMENT

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