TESTING OF FRESH CONCRETE USING A MODIFIED VERSION OF THE PRISM TECHNIQUE

Abdelmalek BOUHADJERA, Mourad GRIMES, Fatima KEMIHA
NDT Lab, Jijel University, Algeria

In testing fresh cementitious materials using techniques based on ultrasound, many difficulties are encountered related to the setting of the whole measurement system and procedure, namely, the shape and preparation of samples, the choice of the right transducer and type of wave, the type of coupling medium, the choice of a data acquisition system, signal processing and displaying of results. The technique described in this paper addresses the above-mentioned issues by adapting a special technique - the so-called Prism Technique to the testing of fresh cementitious materials. The new system is able to test cementitious materials both during setting and hardening phases, using both compressional and shear waves. In addition, it is possible with this technique to carry out measurements in both reflection and transmission modes, and thus enabling the evaluation of several parameters, such as reflection coefficients, energy, and speeds of ultrasonic waves in a continuous manner. These parameters are directly related to the changing characteristics of the material under investigation. Practical measurements have been made on different mortar samples, and very encouraging results have been achieved.

Keywords
Ultrasonic testing, reflection coefficient, compressional waves, shear waves, concrete

1. Introduction

Concrete is a multi-phase material consisting of a coarse aggregate, a fine aggregate, sand and cement. The speed of sound in concrete depends on the relative concentration of the constituent particles, the degree of compaction, the moisture content and the nature and amount of defects present. Its coarse granular structure gives rise to high degree of acoustic scattering and, hence, attenuation, depending greatly on the testing frequency [1].

The ultrasonic testing of concrete is usually restricted to measurements of the transit times of pulses through the material and the determinations of the amplitudes of the received pulses. This is carried out using mainly compressional and shear waves. Among the applications is the evaluation of strength, homogeneity and age, together with the detection of the presence of defects.

Concrete is mixed in the fresh state. The fresh state is a suspension with high viscosity. In order to obtain a homogeneous compact material and get rid of air bubbles that greatly attenuate ultrasonic waves, concrete is vibrated after being poured in the final position. After mixing cement with water the hydration process takes place. Three phases characterize the development of this chemical reaction, namely, the dormant, the setting and the hardening phases. The dormant phase allows the working of fresh concrete. The setting stage comes at the end of the dormant stage. From a practical point of view it is quite important to be able to know the beginning and ending of the setting period. After the setting phase, the concrete is no more workable, since it hardens and forms a solid material [2]. Both compressional and shear waves as well as reflection coefficients could be used to evaluate the setting time of concrete.

There is unanimous agreement among engineers that the presently available test methods for nondestructive determination of concrete strength are, without exception, inadequate. Fifty years of research in this area could produce no better solution to the problem than empirical formulas obtained by elementary curve fitting for the calculation of the strength. In view of the complexities of the problem, it would appear to be overly optimistic to attempt to formulate an ultrasonic test method for the determination of concrete strength. However, considering the seriousness of the infrastructure problem and the magnitude of the cost of rehabilitation, major advancement is desperately needed to improve the current situation. For instance, it has been demonstrated repeatedly that the standard ultrasonic method using longitudinal (or L) waves for testing concrete can estimate the concrete strength only with ± 20 percent accuracy under laboratory conditions [3].

The same difficulties, or even more are encountered when testing concrete while it is in a fresh state, because the mix is in a transitional state and many additional parameters have to be taken into consideration [2].

For a better understanding of the development of microstructure during cement hydration as well as finding a better correlation between wave speeds and physical parameters such as strength, new approaches are required. In this article, we propose a new approach for testing concrete. It is based on the use of very simple equipment based on the prism technique that can be used by even unqualified personnel due to signal quality. The constituents of concrete (cement paste and aggregates) have to be tested separately in order to gather viable raw data. Final parameters in the actual concrete are derived from known percentages formulae (for wave speeds), or empirical relations that have to be developed based on practical measurements and computer simulations (for strength evaluation).

2- Basic principles of the method

A schematic diagram of the proposed method is shown in figure1.

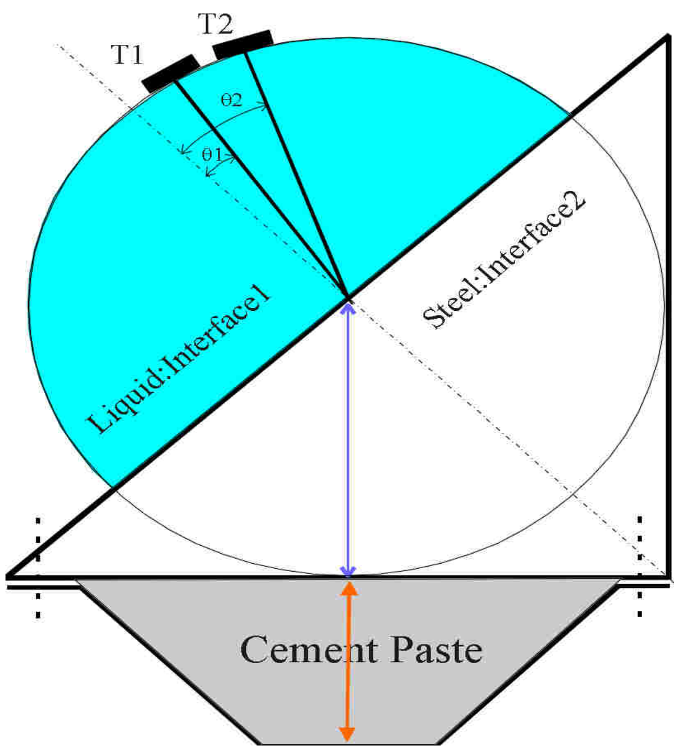


Figure1: Schematic diagram of the proposed prism-technique.

It must be emphasised here that this is a special adaptation of the original prism technique that was the subject of several publications [4-7]. In its turn, the proposed technique is also a subject of a patent application [8]. This new technique is particularly useful for testing samples in a visco-elastic state (liquid) when the sample is still in its mould, whereas the original technique is more useful with samples in elastic state (solid) when the sample is taken from the mould.
The new system looks different from the original prism technique shown in figure2.
In the latter, wave velocities for both compressional and shear waves are evaluated from the same formula:

$$Vc,s = \frac{2L2}{Tc,s - t_1} = \frac{\sqrt{2}R}{Tc,s - t_1} = \frac{a}{Tc,s - t_1} \tag{1}$$

Where Tc,s represents the time-of-flight of ultrasonic pulses within both the liquid interface and SUT when refraction takes place at oblique incidence for both waves; t1 is the time of flight of compressional waves within the liquid interface at normal incidence.

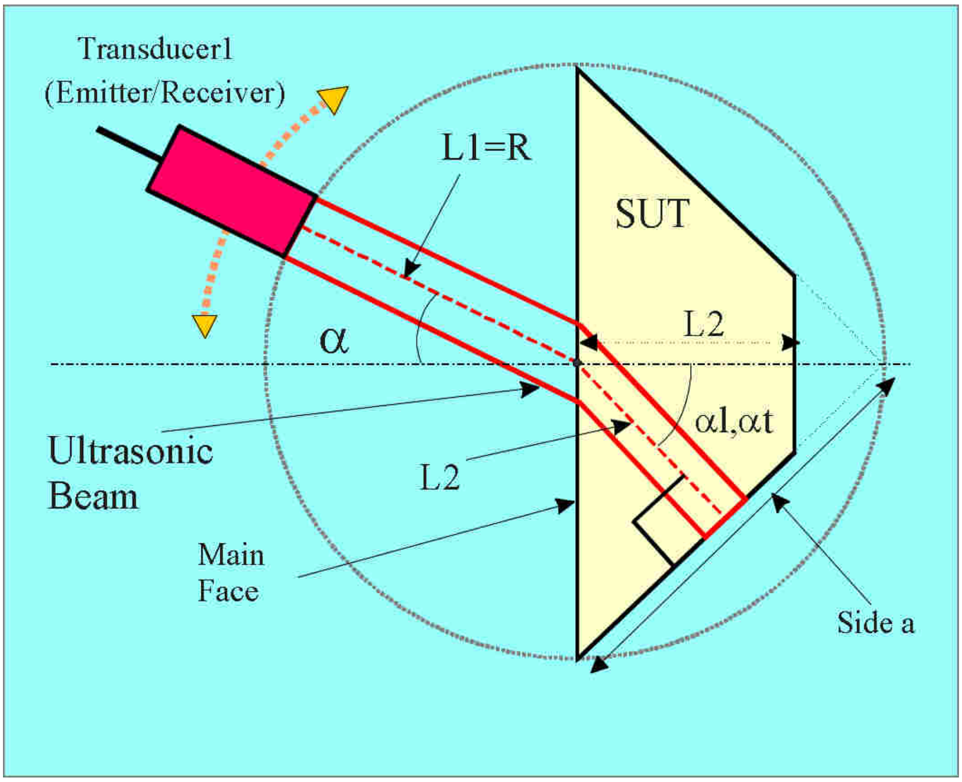


Figure2: General view of the original prism-technique

The same form of samples (trapezoidal prism) is used for both techniques and therefore samples can be tested at any time during setting and hardening, and could also be kept for future reference.
With the new technique it is possible to do the testing in both transmission and reflection modes using both compressional and shear waves. This is a unique feature of this technique, since it takes advantage of all existing methods. In addition it provides conditions for perfect coupling between the transducer and the sample under test (SUT).

Another very important feature is that the mould design allows for material shrinkage, which is inevitable during setting, and hence SUT does not get disconnected from the steel interface during measurements.
It is possible to evaluate all signal parameters linked to physical properties of the SUT, namely compressional and shear wave speeds, reflection coefficients, etc. This is done by carefully choosing the right amplitude for the driving pulse, selecting the right centre frequency for the transducer, and amplifying the received signal.
The use of a software interface allows for automated data acquisition and processing. By analysing the echoes present in the received signal, it is possible to determine with accuracy the position and amplitude of the echoes of interest, in relation to the driving pulse and to one another.

3- System description

The schematic diagram of the measuring system based on the new prism technique is shown in figure3. It is the same as the one used for the original prism technique except for the transducer cell. The system contains beside the latter the following parts: An ultrasonic pulser/receiver, a digital oscilloscope and a microcomputer with data acquisition software.

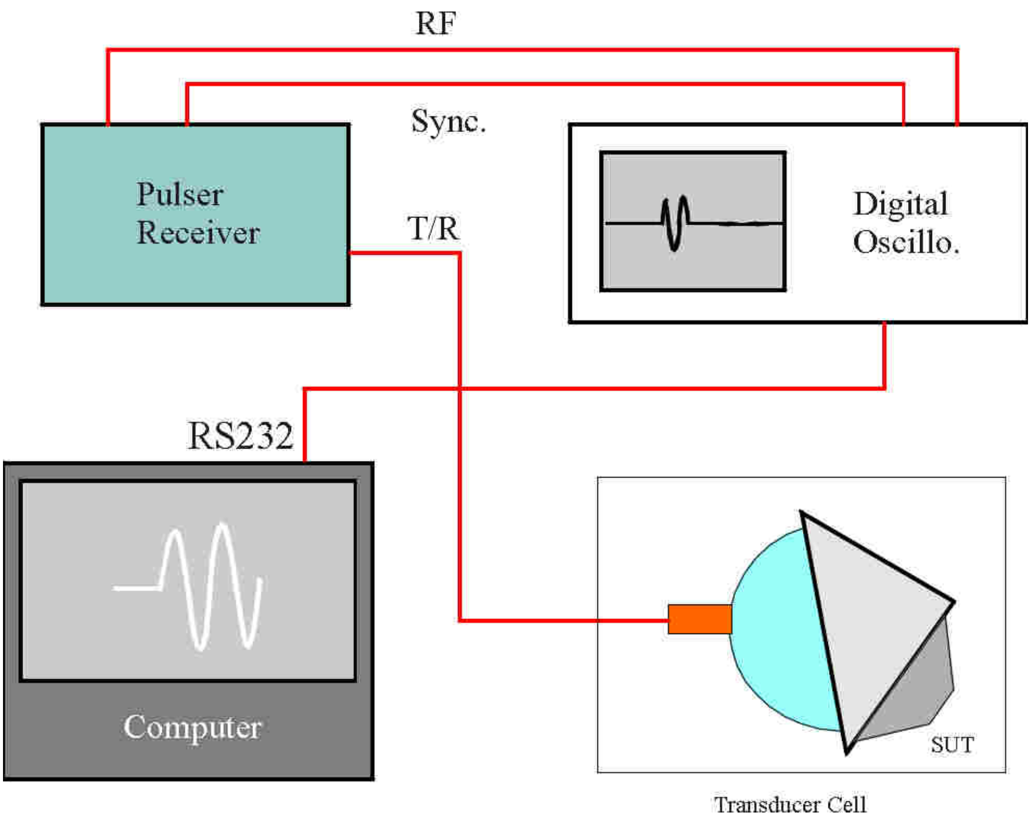
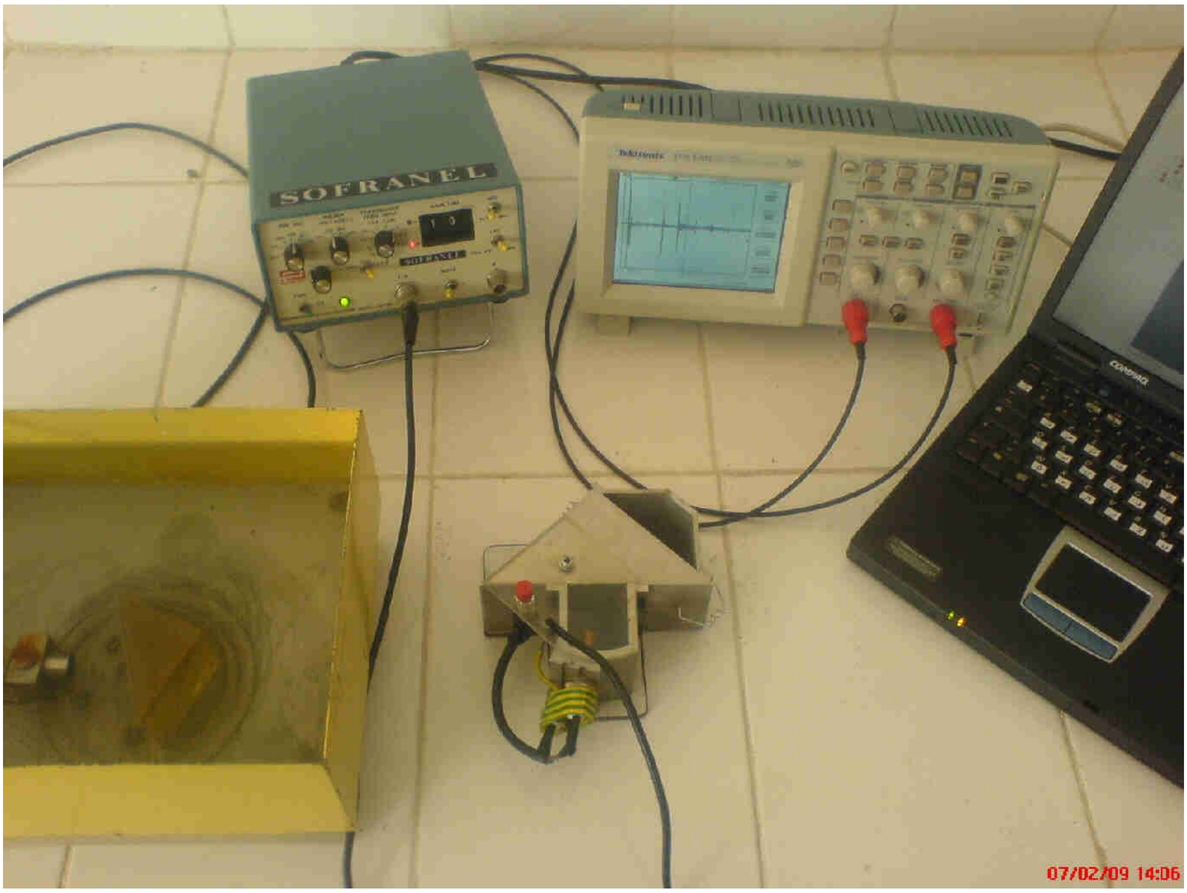


Figure3: Schematic diagram of the measuring system

A photograph of the whole system is shown in figure4 including the transducer cell for the original prism-technique (bottom left).



Figur4: General view of the measuring system

4- Results and discussion

In order to test the system during the setting phase, a mortar sample (S/C =1, W/C=0.6) was used. Figure5 shows a typical echo-signal from the mortar steel interface and the changing of the relative amplitude.

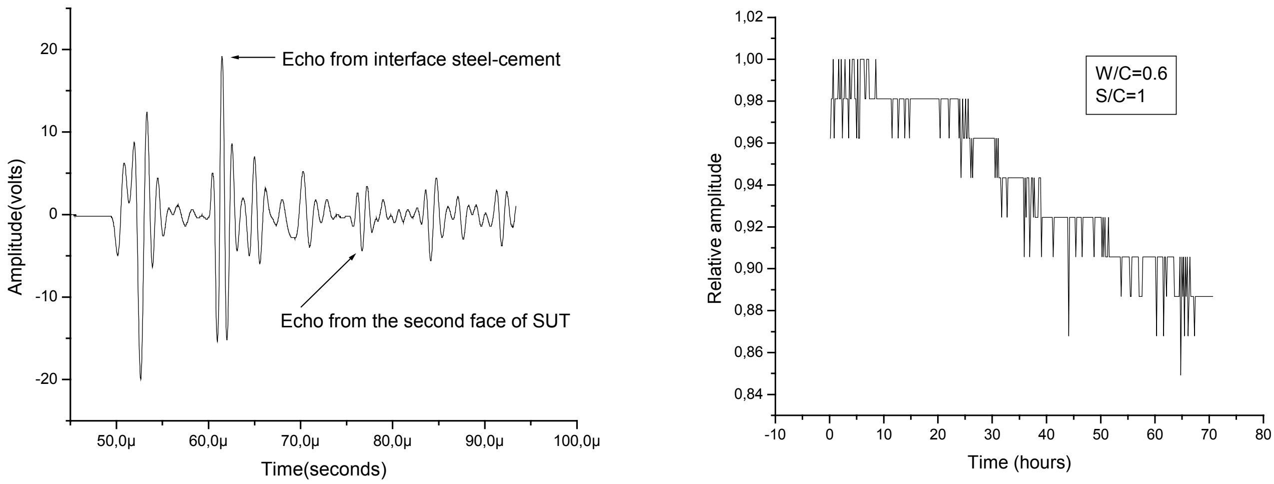


Figure5: Relative amplitude variation

This result shows clearly the predictable fall of the amplitude of the reflected echoes with time due to the start of the hydration process within mortar. The smoothing of this curve would certainly yield a clearer picture.

In order to prove that this system is also able to test effectively both cement paste in a hardened state as well as rock samples (used for making aggregates) two different mortar samples (W/C=0.5, W/C=0.6) were used and tested one month after making.

The signals obtained are shown from figure6 to figure8. Signals related to the first sample (W/C=0.5) are put on the left, and the ones related to the second sample (W/C=0.6) are represented on the right of the figures.

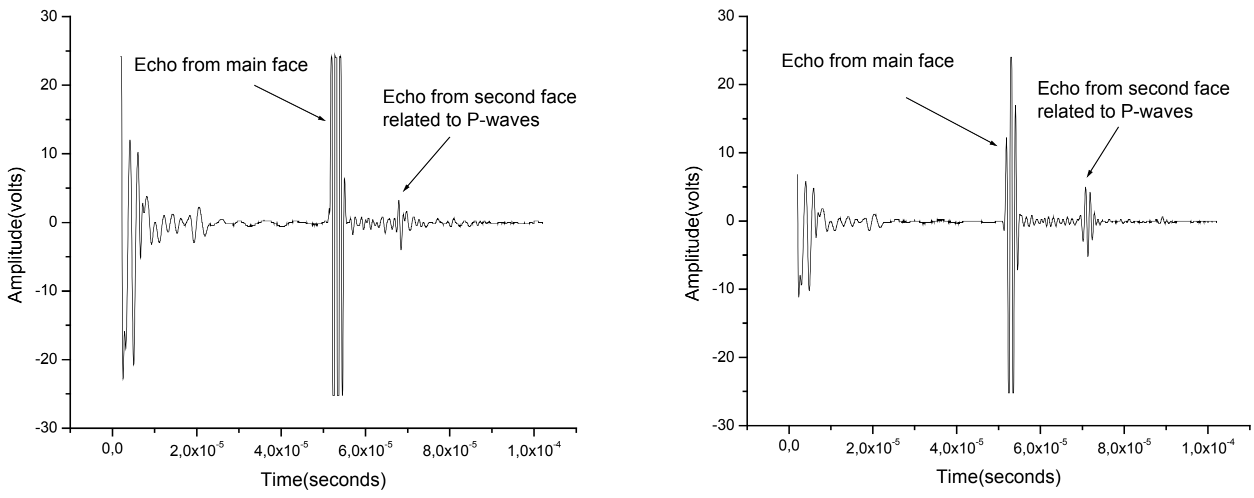


Figure6: Normal incidence of ultrasonic waves

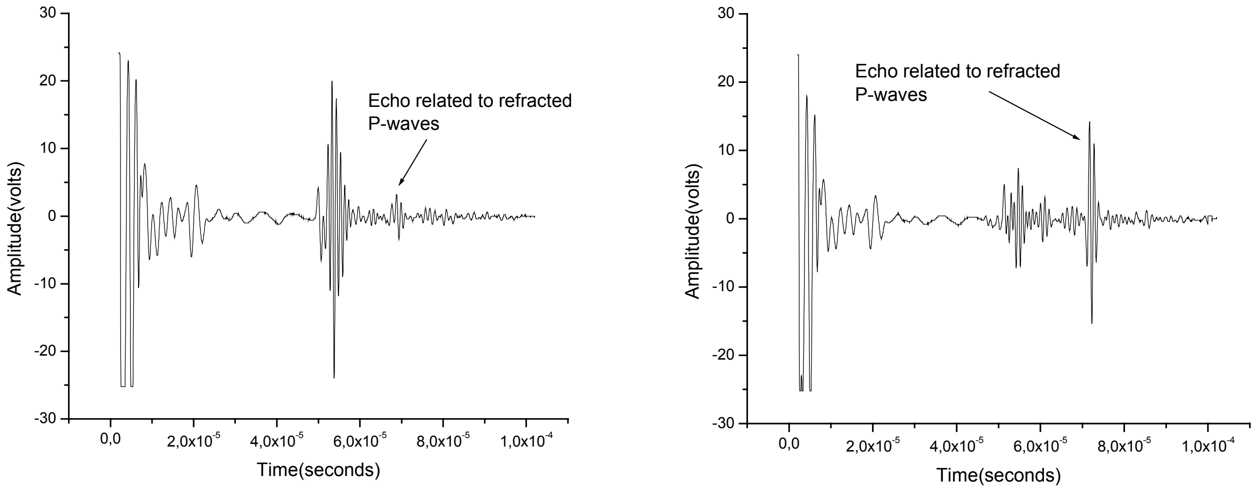


Figure7: Oblique incidence at first critical angle

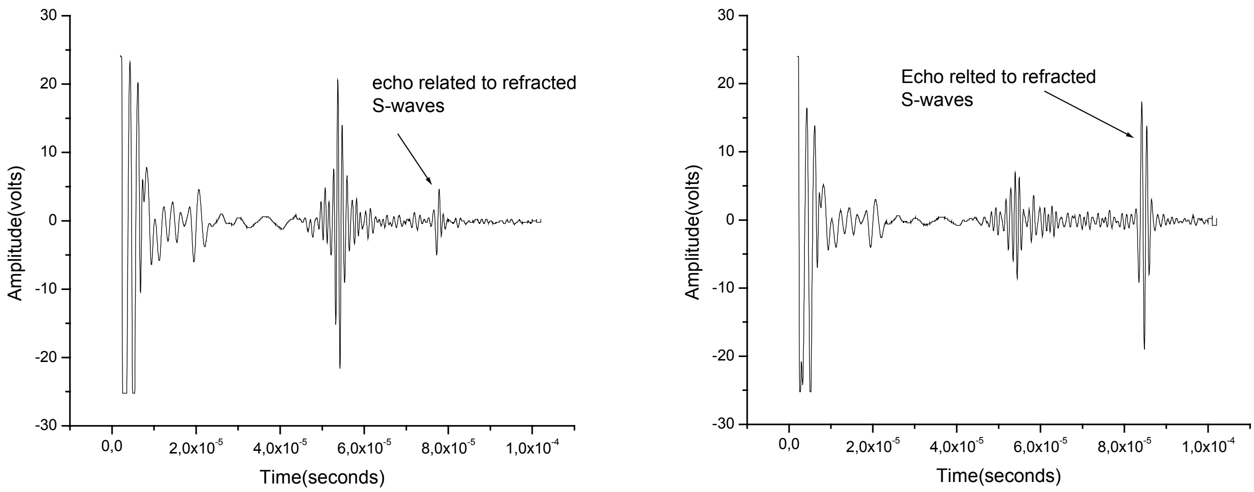


Figure8: Oblique incidence at second critical angle

It can be seen clearly that transit times could be measured easily (since the echoes are strong enough without hardly any signal conditioning) by carefully positioning the time cursors (of an oscilloscope) on the echoes of interest.

The results obtained for these two samples are shown in table1.

Transit times (µs)	Tc normal	Vc (m/s)	t1 in water	Tc oblique	Vc (m/s)	Ts oblique	Vs (m/s)
Sample1	68	3684	52.80	68.80	3500	77.60	2258
Sample2	70.40	3181	52.80	71.60	2979	84	1795

Table1: Results obtained

The speed of refracted compressional waves could be crosschecked with that of normal incidence as indicated in the table. They are quite close and could be taken as an assurance that the experiment is working properly.

It is predictable to get longer times for sample2 and hence smaller wave speeds, since it has bigger W/C ratio.

5- Conclusion

In this paper an attempt was made to use a new approach for testing cementitious materials. For that purpose two transducer cells were used with the prism technique. It was demonstrated that the first device could be used for studying the setting time of concrete by evaluating the reflection coefficient. Whereas, the second one could be used for studying the hardening concrete. Encouraging results were achieved related to two mortar samples by determining with considerable ease both the speed of compressional and shear waves.

These are just preliminary results, but the aim in the very near future is to test the constituents of concrete separately (cement, sand and aggregates), and not the mixed concrete as it is done usually, and using after that special percentages formula to predict the final properties of concrete.

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