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LINEAR AND NONLINEAR ULTRASONIC TECHNIQUES FOR INVESTIGATIONS OF CEMENT COMPOSITES OF DIFFERENT AGES

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ABSTRACT

Concrete is the most preferred construction material. Besides the aggregates and sands, the cement is one of its primary constituents. During hydration, cement composite is developed over a period of time after going through various chemical reactions. In the present study, ultrasonic testing is carried out in the cement composite in transmission mode. Acoustic signal was actuated using the ultrasonic transducer excited at different frequencies and the received signal was acquired on the other side of the specimen. Different frequencies of the input signal helped to choose the most responsive frequency range for the cement composite inspection. The non-destructive testing and evaluation (NDT&E) was carried out on different days of curing. The obtained signals were processed to analyze the change in signal characteristics during different stages of curing. It is interesting to observe that the peak frequencies obtained from the Fast Fourier Transform (FFT) were not very distinctive. However, more sophisticated signal processing tools like S- Transform and Hilbert Huang Transformation (HHT) showed promising results. Nonlinear ultrasonic method which is very efficient for providing information on minor damages (which cannot, generally, be done using linear ultrasonic techniques), was also tried out. It was found that the nonlinear ultrasonic technique called side band peak count (SPC) which is derived from the frequency spectra of FFT exhibits clear distinction among the cement composite specimens with different ages of curing. The present study shows that the S- Transform, Hilbert Huang Transformation and SPC can provide appropriate parameters to characterize the cement composite.

Keywords: linear and nonlinear ultrasonic techniques, cement composite, signal processing

1. INTRODUCTION

Cement composites are commonly used in civil structures. Often it is the preferred building material over steel or other composite materials since it is durable, cost effective and easy to handle. Generally, cement along with the coarse and fine aggregates are used for concrete construction. After adding water to cement, cement composite is formed over a period of time through various chemical reactions. Cement composite (also called as cement matrix) acts as the binding agent and connects the other aggregates present in concrete. Thus, the heterogeneous structure of concrete is formed over the period of curing. Based on the state of development of cement matrix, concrete offers strength and stiffness. Therefore, cement composite plays a vital role on the properties of concrete.

Characterization of cement composite is performed by many methods, ranging from highly sophisticated physico-chemical studies to the mechanical tests. Assessment of cement composite using non-destructive methods is always a challenging task with huge practical importance. Reported studies show that considerable amount of work has been carried out for assessment of cement composites using different types of nondestructive testing and evaluation (NDT&E) methods such as ultrasonic pulse velocity (UPV) test, rebound hammer test, pulse-echo method, ground penetrating radar method, electro-mechanical impedance (EMI) technique, Infrared thermography, acoustic emission, Terahertz spectroscopy, etc. Further, recent endeavors are also reported on the use of linear and nonlinear ultrasonic techniques for NDT&E of different types of structures and materials [1-7].

In the present study, ultrasonic testing is carried out on the cement composite in transmission mode. Both linear and nonlinear ultrasonic techniques are used to extract the features from the cement composites during different stages of curing. The present study focuses on identifying the sensitive features from the ultrasonic tests which can help in characterizing cement composites.

2. MATERIALS AND METHODS

For developing the cement composite, water to cement ratio was set at 0.3. Prism specimens with dimensions 100 mm×100 mm×500 mm were cast using the cement composite mix. Metal mold was used during casting and it was removed after one day of casting.

Acoustic signal was generated using waveform generator and was amplified by an amplifier and fed into the specimen through actuating transducer. The transmitted ultrasonic signal was received on the opposite side of the specimen and was recorded by a digital oscilloscope. Experimental setup is shown in Fig. 1. The tests were performed with different frequencies of the input signal varying from 25 kHz to 100 kHz which helped to identify the most responsive frequency range for the cement composite inspection. Ultrasonic tests were performed on 3rd day, 6th day, 14th day, 21st day and 45th day of curing. The acquired signals were processed in both frequency and time-frequency domains to exact the distinctive features.

Figure 1: ULTRASONIC TESTING ON CEMENT COMPOSITE SPECIMEN

3. RESULTS AND DISCUSSION

As explained earlier, the data acquisition is done in transmission mode. Responses for all samples are recorded and processed. Transient signals are normalized to 1 for better comparative studies. Transient signals recorded from the specimen on different days of curing are shown in Fig. 2.

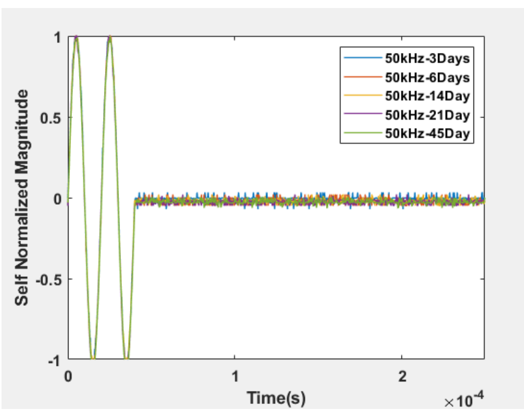

Figure 2: TRANSIENT SIGNAL OF 50 kHz SAMPLES

3.1. Fast Fourier Transform

A fast Fourier transform (FFT) is an algorithm that samples a signal over a period and divides it into its frequency components. Frequency spectra of the transient signals is shown in Fig. 3 and the signature is found to be not distinctive.

3.2. S- Transform

The S-Transform is a combination of Short Time Fourier Transform and Continuous Wavelet Transform.

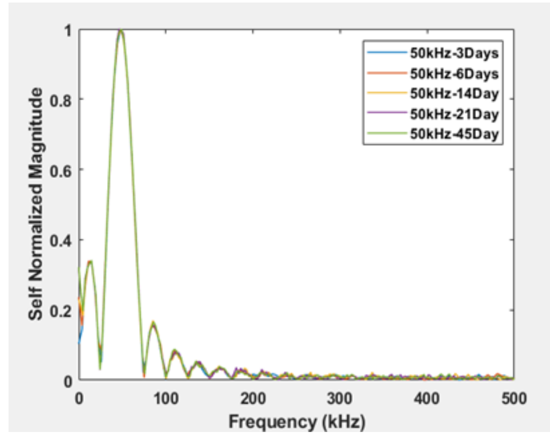

Figure 3: FFTS OF 50 KHZ SAMPLES

The S-Transform of a signal can be seen as a modified Short Time Fourier Transform with a Gaussian window of varying width and height as a function of frequency. It can also be interpreted as a modified wavelet transform (WT) with the phase correction in the mother wavelet. However, this modified wavelet ignores the wavelet's admissibility criterion of having the zero mean and hence, it cannot be considered as a Continuous Wavelet Transform.

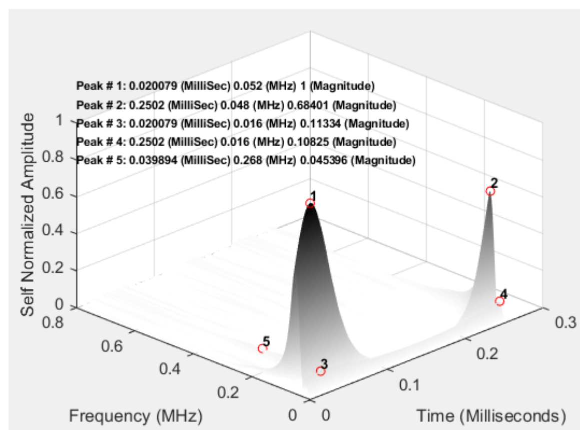

Figure 4: S-TRANSFORM PLOTS OF 50 kHz SAMPLES

3.3. Sideband peak Count

The non-linear analysis of the samples is performed using sideband peak count (SPC). The SPC technique counts the number of peaks in the FFT plots for given threshold values [10]. In general, a linear material shows fewer peaks compared to a non-linear material. Therefore, SPC values for linear and nonlinear materials should be different. The composite plates examined in this study show some non-linear behavior to start with. Increasing impact energy causes more damage in the material, and makes the material more non-linear. Obtaining sideband peak count or SPC values requires relatively simple signal processing tools that are implemented to count the number of peaks observed for a given threshold value. First, the total number of peaks in the FFT plot are counted for all signals. Then, a threshold is set, and the number of peaks below the threshold are counted. Finally, the number of peaks above the threshold are calculated by subtracting the number of peaks below the threshold from the total number of peaks. Fig. 5 exhibits that the number of sideband peaks changes with the age of curing of cement composite.

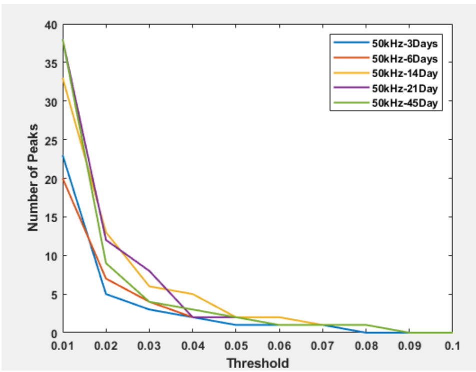

Figure 5: SPC OF 50 kHz SAMPLES

3.4. Hilbert Huang Transform

HHT has emerged as a reliable and powerful damage detection tool. In this technique, for a given signal a complex signal is first obtained by performing a Hilbert transform on the recorded signal. The Hilbert transform only shifts the phase keeping the magnitude same. Hilbert Huang Transform generates intrinsic mode functions (IMFs). These IMFs can be used to further analyze the signal/transient characteristics like its phase [8-9], frequency spectra etc. From Fig. 6, it is evident that the unwrapped phase angles calculated from the IMFs are very sensitive to the age of cement composite.

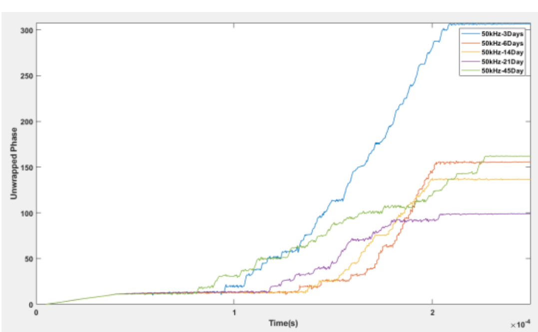

Figure 6: UNWRAPPED PHASE 50 kHz SAMPLES

4. CONCLUSION

In the present study, linear and nonlinear ultrasonic investigations are carried out on the cement composites of different ages. From the range of input frequencies, the frequency band of 50-100 kHz is found to be responsive for the cement composite studied here. Though the S-Transform was not able to provide any distinct information, sideband peak count (SPC) and the unwrapped phase are found to be capable of providing different wave signatures from the specimens of different ages.

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