Acoustic Method for Testing of High-Temperature-Degraded Cement-Based Composite Materials

Daniela ŠTEFKOVÁ *, Kristýna ŠAMÁRKOVÁ-TIMČAKOVÁ *, Zdeněk CHOBOLA *
* Brno University of Technology, Faculty of Civil Engineering,
Department of Physics, Žižkova 17, 602 00 Brno, Czech Republic
Contact e-mail: stefkova.d@fce.vutbr.cz

Abstract. The present paper deals with the applicability of Impact-echo acoustic method to testing of cement-based composites prepared from a mix of cement mortar and quartz sand, which were intentionally degraded by high-temperature treatment (in the temperatures range from 200°C to 1200°C). Changes in the bulk density and the flexural tensile strength were monitored during the degradation for comparison.

The test specimens of dimensions 40 x 40 x 160 mm were made from a cement mortar whose water-cement ratio was w/c = 0.46. The mortar preparation mixture contained CEM I 42,5R cement from Českomoravský cement, a.s., of Mokrá, and mortar preparation mixture test quartz sand from Filtrační písky, s.r.o., in a ratio of 1 to 3. In compliance with ČSN 721200 standards, 3 gradings of sand, namely, 0-1, 1-3, and 3-4 mm were used in all cases, to be blended in weight ratio 1:1:1.

Having been made from the cement mortar, all specimens were aged at a temperature of 22°C and a relative humidity of 55% for 24 hours. Subsequently, the specimens were placed in a water bath for 27 subsequent days. Thereafter, the specimens were dried at a temperature of 60°C for two days. Subsequently, the specimens under investigation were heated in a furnace to temperatures of 200°C, 400°C, 600°C, 800°C, 1000°C and 1200°C at a rate of 5°C/min and with a dwell of 60 minutes at the maximum temperature to find out the effect of high temperature on them. This having been done, the specimens cooled down spontaneously to the laboratory environment temperature.

To generate the signal, a hammer of a mass of 12 g, originally suspended from a hanger, was released to fall down on the specimen from a height of 4 cm. The response was picked up by an MIDI type piezoelectric sensor, whose output voltage was fed into a TiePie engineering Handyscope HS3, which is a two-channel, digital, 16 bits oscilloscope. Subsequently, a special smoothing algorithm was used to determine dominant frequencies for each of the output signals. Each measurement run consisted of 10 separate measurements, from which an average was calculated.

A shift of the predominant frequencies and a change in the damping coefficient were observed to occur during the degradation process.

Introduction

The present paper examines the potential applicability of the Impact-echo method for analysing the specimens made from a mix of cement mortar and quartz sand, which were intentionally degraded by high-temperature treatment (the temperatures ranging 200°C to 1200°C).

Impact-echo method is a non-destructive acoustic technique. Its principle is based on that the mechanical characteristics of a specimen affect its spectral properties [1-3]. The source of a signal is an impact of a small object (e.g. a calibrated hammer), which induces mechanical vibration to the specimen. The time development of the oscillations is sensed by accelerometers attached on the pre-determined spot of the specimen. In theory, the impact resembles a delta-function containing all possible frequencies. During wave propagation, each frequency component is affected by the geometry of the sample, the material properties, defects, non-homogeneities, cracks or any other structural characteristics [4-7]. The frequency spectrum of the gathered signal calculated using Fourier transform is a good measure of the condition of the specimen.

Keywords: Impact-echo, mortar, EVA polymer, rubber aggregates, high-temperature degradation

Experimental

1.1 Materials

The test specimens of dimensions 40 x 40 x 160 mm were made from a cement mortar whose water to cement ratio was w/c = 0.46.

Mortars were produced using a type CEM I 42,5R (Českomoravský Cement - Heidelberg Cement Group of Mokrá) and mortar preparation mixture test quartz sand from Filtrační písky, s.r.o., in a ratio of 1 to 3. In compliance with ČSN 721200 standard, 3 gradings of sand, namely, 0-1, 1-3, and 3-4 mm were used in all cases, to be blended in weight ratio 1:1:1. Having been made from the cement mortar, all specimens were left in the moulds for 24 hours, then cured in water for 27 days and finally air-cured for 32 days at laboratory temperature (25±2 °C).

After initial curing, the specimens were dried at a temperature of 60 °C for two days. Subsequently, the specimens were heated in a furnace at 200 °C, 400 °C, 600 °C, 800 °C, 1000 °C and 1200 °C with a temperature increase rate of 5 °C/min. A dwell of 60 minutes at the maximum temperature was provided, in order to find out the effect of high temperature on them. After heat treatment, the specimens were left to cool down spontaneously at laboratory conditions.

1.2 Tests

In order to generate the acoustic signal, a hammer of 12 g mass, originally suspended from a hanger, was released to fall down on the specimen from a height of 4 cm. The response was picked up by an MIDI type piezoelectric sensor, whose output voltage was fed into a TiePie engineering Handyscope HS3, which is a two-channel, digital, 16 bits oscilloscope. Subsequently, a special smoothing algorithm was used to determine dominant frequencies for each of the output signals. Each measurement run consisted of 10 separate measurements, from which an average was calculated [8, 9].

Results and discussion

Fig. 1 shows a record of the frequency spectrum measurement taken for a reference specimen (this specimen has not been subjected to any elevated-temperature load test). The sensor was placed at the centre of the specimen shorter side. The hammer tapped the specimen at the opposite side in the longitudinal centre line direction. The measurement run was labelled U0- S0. The measurement was repeated 10 times. The result average is shown in Fig. 1 Two dominant frequencies can be observed, namely, f_l = 6080 Hz and f_2= 13860 Hz. Taking into account the length of the armature, we get the wave propagation velocity to equal 4340 ms $^{-1}$.

Fig. 2 shows a record of the signal time behaviour as picked up by the reference specimen sensor prior to the thermal degradation start. The response signal duration is t_{20}= 26 ms. The value of the damping coefficient, λ, in the exponential function $A = A_o.\ e^{-\lambda T}$ was determined from the curve shape. When calculating the damping coefficient, variations in the envelopes obtained from maximum deviation squares of the reference signal were used. The damping coefficient is λ_0=540 $s^{-1\ T}$ for the reference specimen.

Fig.3 shows a frequency spectrum record for the specimen which underwent thermal stressing at a temperature of 1000°C. It is seen that the predominant frequencies shifted down towards the lower frequency region, namely, to f_l=4480 Hz and f_2= 10244 Hz. It means that f_l went down by 26%, whereas f_2, by 26%. After the 1000 °C - induced thermal stress, the damping coefficient equalled λ_{1000}=410 s^{-1} t (Fig. 4) and the signal duration was t_{1000}= 24 ms.

Fig. 5 shows a frequency spectrum record for the specimen which underwent a thermal stress by a temperature of 1200°C. It is seen that the predominant frequencies shifted upwards towards the higher frequency region, namely, to f_l=5953 Hz. It is evident that a structural change, accompanied with the creation of new crystal phases, takes place in the specimen at temperatures of about 1200°C After the 1200°C - induced thermal stress, the damping coefficient equalled λ_{1200}=558 $s^{-1\ T}$ (Fig. 4) and the signal duration was t_{1200}=23 ms.

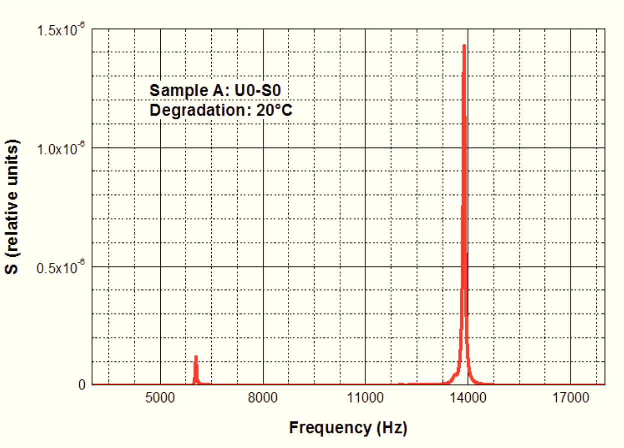

Fig. 1 Frequency spectrum for the sensor placed at the end of the joist and the hammer blow at the opposite end in the longitudinal centre line direction. The specimen was not stressed by elevated temperature. Reference specimen. Temperature, 20°C.

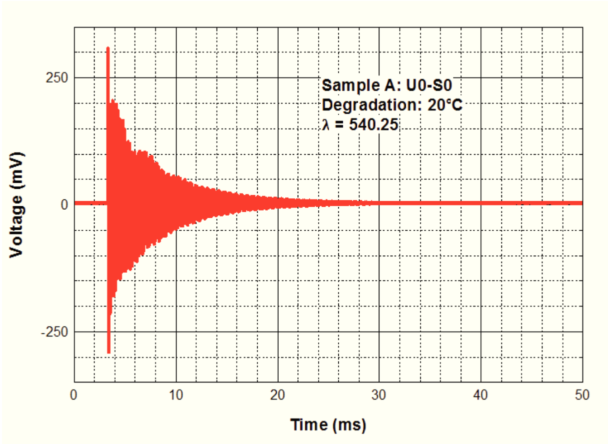

Fig. 2 Recorded signal time response for the specimen, which has not been stressed by elevated temperature. Temperature, 20°C.

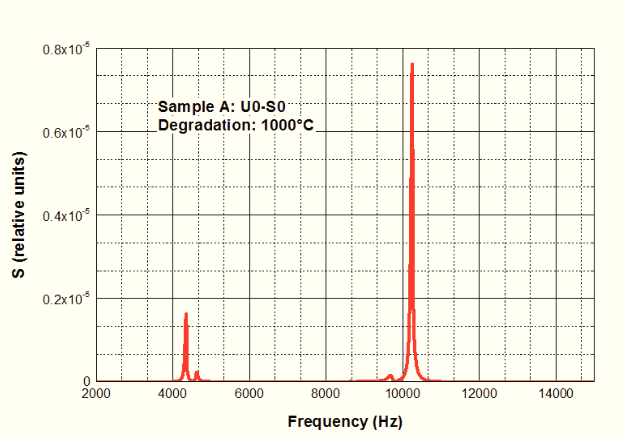

Fig. 3 Frequency spectrum for the sensor placed at the end of the joist and the hammer blow at the opposite end in the longitudinal centre line direction. The specimen was stressed by an elevated temperature of 1000°C.

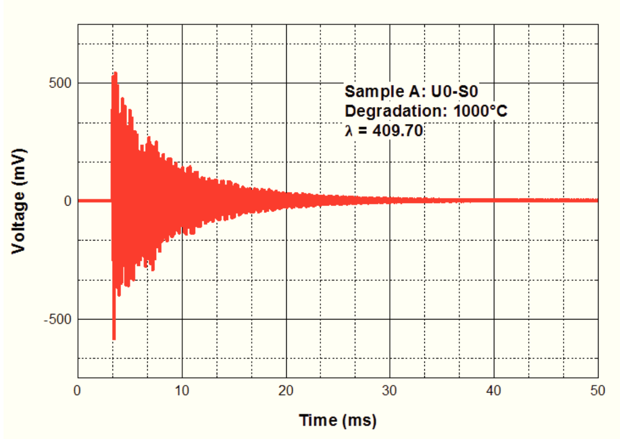

Fig. 4 Recorded signal time response for the specimen, which has been stressed by an elevated temperature of 1000°C.

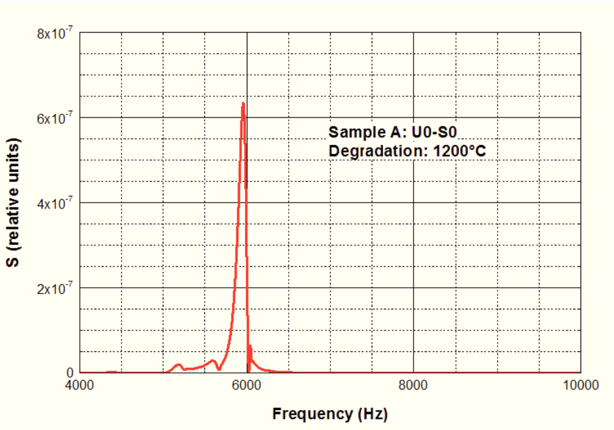

Fig. 5 Frequency spectrum for the sensor placed at the end of the joist and the hammer blow at the opposite end in the longitudinal centre line direction. The specimen was stressed by an elevated temperature of 1200°C.

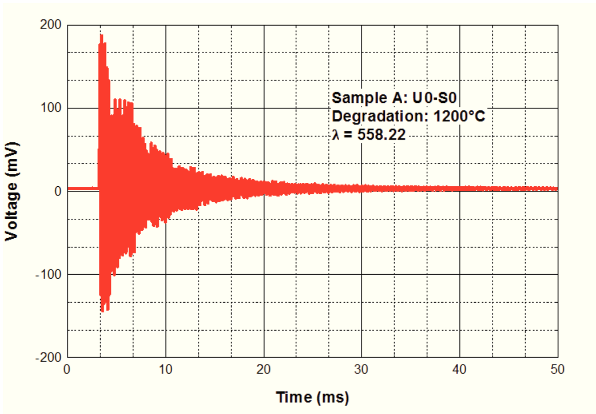

Fig. 6 Recorded signal time response for the specimen, which has been stressed by an elevated temperature of 1200°C.

Fig. 7 illustrates the change in predominant frequencies f_1, f_2, it is seen from Fig.1, 3, 5, versus the specimen stressing temperatures. Both predominant frequencies are shifting towards to the lower frequency range in the course of the degradation, namely, for f_1 from 6080 Hz to 4480 Hz when the temperature changes from 20 °C to 1000 °C. At the same temperature difference is changing the predominant frequency f_2 of the value of 13860 Hz to 12244 Hz. The decrease is rather slow at temperatures of up to 600°C, to speed up above this temperature. This is due to the phase transformation of quartz at 573°C. The predominant frequencies are growing up at temperatures above 1000°C. This is due to the specimen structural changes, because new crystalline phases are arising.

Fig. 8 shows the damping coefficient λ versus the stressing temperature plot. Its value increases from $\lambda_{20} = 540\ s^{-1T}$ at 20°C up to $\lambda_{1000} = 556\ s^{-1T}$ at 1000°C. At temperatures over 1000°C, it drops to $\lambda_{1200} = 554\ s^{-1T}$ at 1200°C.

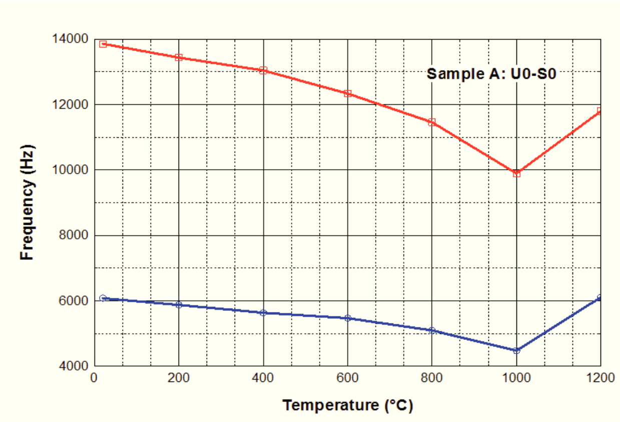

Fig. 7 Specimen degradation induced predominant frequency shift caused by elevated temperature. The red curve shows the trend of frequency f_2, the blue curve shows the trend of frequency f_1.

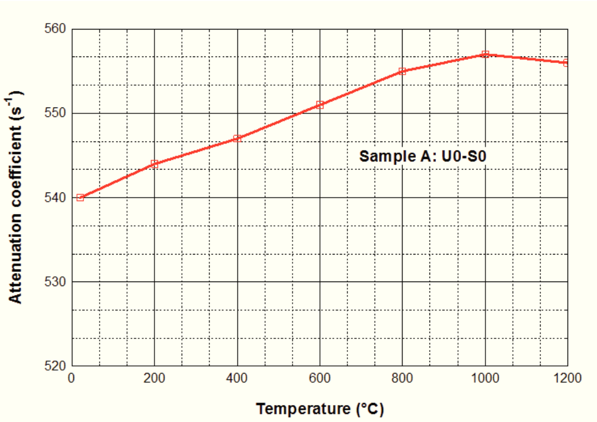

Fig. 8 Specimen degradation induced damping coefficient change caused by elevated temperature.

Figs. 9 and 10 show similar plots as Figs. 7 and 8, but the sensor is placed in the middle of the specimen face, perpendicularly to it (in S1 position). The results are similar to those of the preceding measurements. It follows that there a predominant wave mode propagating through the specimen, namely, the progressive wave mode.

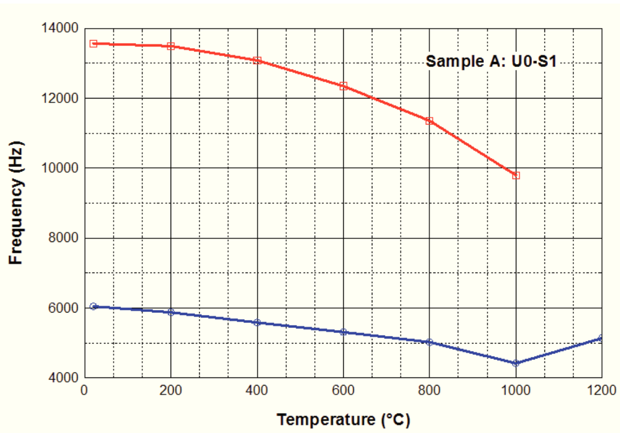

Fig.9 Specimen degradation induced predominant frequency shift caused by elevated temperature. The hammer hit the specimen in the longitudinal centre line direction, perpendicularly to the signal propagation direction.
The upper curve shows the trend of frequency f_2, the bottom curve shows the trend of frequency f_1.

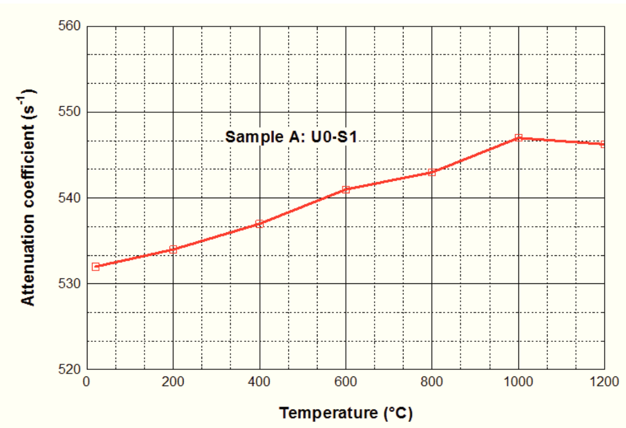

Fig.10 Specimen degradation induced damping coefficient change caused by elevated temperature. The hammer hit the specimen in the longitudinal centre line direction, the sensor was placed in the middle of the specimen face, perpendicularly to the signal propagation direction.

Conclusion

The paper deals with analysing the feasibility of composite material testing by means of Impact-echo acoustic method.

The specimens were made of cement composites, which in turn were prepared from a mixture of cement mortar and quartz sand.

The specimens were intentionally degraded by application of elevated temperatures of 200°C to 1200°C. A shift of the predominant frequencies and a change in the damping coefficient were observed to occur during the degradation process.

The results showed that the frequency inspection carried out by means of the Impact-echo method consists a convenient tool to assess the quality of the composite materials studied, after their exposure to elevated temperatures.

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ACOUSTIC METHOD FOR TESTING OF HIGH-TEMPERATURE-DEGRADED CEMENT-BASED COMPOSITE MATERIALS

Author: Daniela ŠTEFKOVÁ , Kristýna ŠAMÁRKOVÁ-TIMČAKOVÁ , Zdeněk CHOBOLA

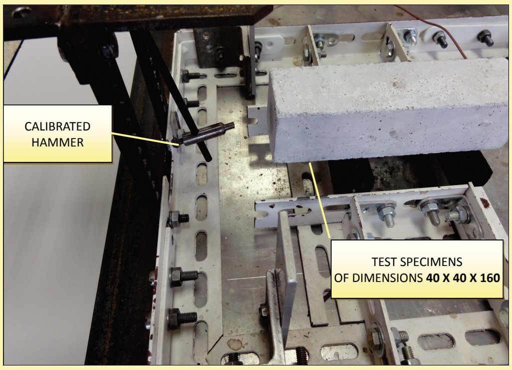
Brno University of Technology, Faculty of Civil Engineering, Department of Physics, Žižkova 17, 602 00 Brno,

Contact e-mail: stefkova.d@fce.vutbr.cz

THE MAIN AIM OF THE WORK:

- **TESTING OF CEMENT - BASED COMPOSITES PREPARED FROM A MIX OF CEMENT MORTAR AND QUARTZ SAND, WHICH WERE INTENTIONALLY DEGRADED BY HIGH-TEMPERATURE TREATMENT (IN THE TEMPERATURES RANGE FROM 200°C TO 1200°C).**
- **APPLICABILITY OF IMPACT-ECHO ACOUSTIC METHOD**

1. FUNCTIONAL MODEL



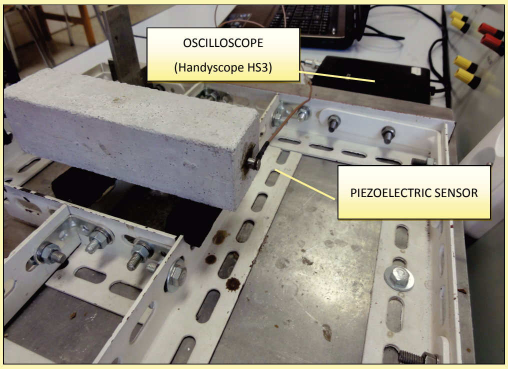


FIG.1, FIG. 2 IN ORDER TO GENERATE THE ACOUSTIC SIGNAL, A HAMMER OF 12 G MASS, ORIGINALLY SUSPENDED FROM A HANGER, WAS RELEASED TO FALL DOWN ON THE SPECIMEN FROM A HEIGHT OF 4 CM. THE RESPONSE WAS PICKED UP BY AN MIDI TYPE PIEZOELECTRIC SENSOR, WHOSE OUTPUT VOLTAGE WAS FED INTO A TIEPIE ENGINEERING HANDYSCOPE HS3, WHICH IS A TWO-CHANNEL, DIGITAL, 16 BITS OSCILLOSCOPE. SUBSEQUENTLY, A SPECIAL SMOOTHING ALGORITHM WAS USED TO DETERMINE DOMINANT FREQUENCIES FOR EACH OF THE OUTPUT SIGNALS.

2. COMPARISON OF MEASUREMENT RESULTS

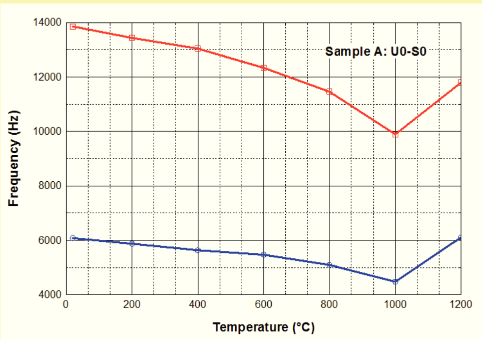


Fig.3 Specimen degradation induced predominant frequency shift caused by elevated temperature.

The red curve shows the trend of frequency f_2, the blue curve shows the trend of frequency f_1.

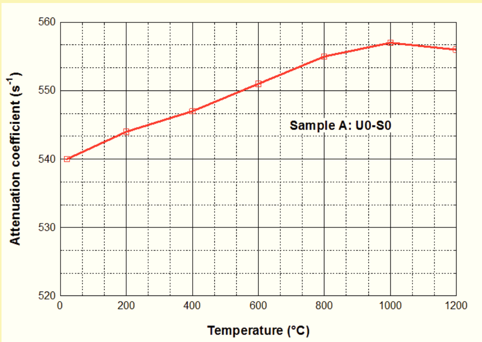


Fig.4 Degradation induced damping coefficient change caused by elevated temperature.

THIS FIG. 3 ILLUSTRATES A CHANGE IN PREDOMINANT FREQUENCIES F_1, F_2 AS A RESULT OF TEMPERATURE CHANGE. BOTH DOMINANT FREQUENCIES ARE SHIFTED TOWARD LOWER VALUES. THIS SHIFT SLOWLY TAKES PLACE FOR TEMPERATURES BELOW 600°C. ABOVE 600°C THIS CHANGE IS MORE RAPID. HOWEVER WHEN THE TEMPERATURE EXCEEDS 1000°C THE FREQUENCY VALUES HAVE INCREASING TENDENCY.

FIG. 4 SHOWS THE DAMPING COEFFICIENT Λ VERSUS THE STRESSING TEMPERATURE PLOT. THIS VALUE IS INCREASING FOR TEMPERATURES BELOW 1200 °C AND DECREASING FOR TEMPERATURES ABOVE 1200 °C.

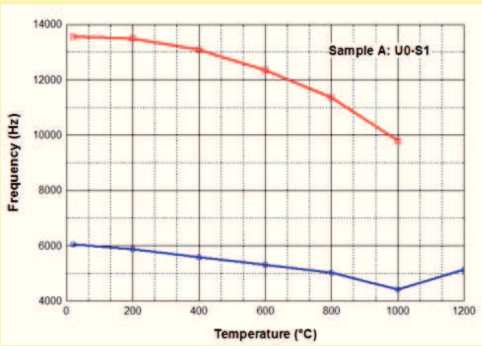


Fig.5 Specimen degradation induced predominant frequency shift caused by elevated temperature. The hammer hit the specimen in the longitudinal centre line direction, perpendicularly to the signal propagation direction. The upper curve shows the trend of frequency f_2, the bottom curve shows the trend of frequency f_1.

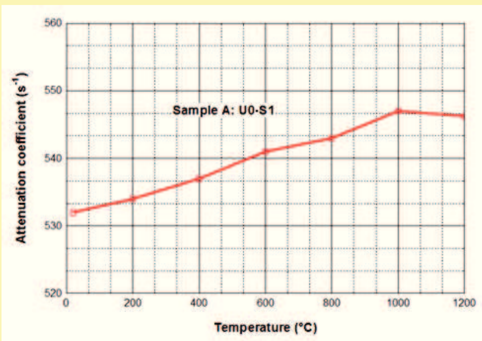


Fig.6 Specimen degradation induced damping coefficient change caused by elevated temperature. The hammer hit the specimen in the longitudinal centre line direction, the sensor was placed in the middle of the specimen face, perpendicularly to the signal propagation direction.

FIG. 5 AND 6 SHOW SIMILAR PLOTS AS FIG. 3 AND 4, BUT THE SENSOR IS PLACED IN THE MIDDLE OF THE SPECIMEN FACE, PERPENDICULARLY TO IT (IN S1 POSITION). THE RESULTS ARE SIMILAR TO THOSE OF THE PRECEDING MEASUREMENTS. IT FOLLOWS THAT THERE A PREDOMINANT WAVE MODE PROPAGATING THROUGH THE SPECIMEN, NAMELY, THE PROGRESSIVE WAVE MODE.

3. CONCLUSION

- THE RESULTS SHOWED THAT THE FREQUENCY INSPECTION CARRIED OUT BY MEANS OF THE IMPACT-ECHO METHOD CONSISTS A CONVENIENT TOOL TO ASSESS THE QUALITY OF THE COMPOSITE MATERIALS STUDIED, AFTER THEIR EXPOSURE TO ELEVATED TEMPERATURE.

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