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CHANGES OF ACOUSTIC EMISSION AND ULTRASONIC P–WAVE VELOCITY IN SEDIMENTARY ROCK SAMPLES DURING CYCLIC HEATING

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ABSTRACT. Samples of sedimentary rocks subjected to thermal stresses show an effect of thermal memory. As the time goes, this effect disappears which is assumed to be related to the process of rock deformation.

Changes of acoustic emission caused by thermal stresses are accompanied by changes of time of propagation of longitudinal waves. The investigations were carried out basing on samples of Carboniferous sandstones of the Upper Silesian Coal Basin. The obtained velocities of wave propagation, in comparison with memory fading and with the values of cumulated count numbers, showed that velocities in samples are clearly connected with processes of memory fading. Together with the cooling of the sample and closing of the cracks the velocity comes back to its original value and the memory effect in the course of AE gradually disappears.

1. INTRODUCTION

Cyclic mechanical and thermal loading of rock samples have shown the existence of memory effects in the course of acoustic emission (AE). Research carried out in the Dept. of Applied Geology, Faculty of Earth Sci., University of Silesia on the effect of thermal memory in AE have indicated that this effect is gradually decaying with time [Żogala 1992] and it shall be supposed that it is related to the process of rock deformation [Żogala et al. 1992; 1995; Zuberek 1994].

It is assumed that the changes in the course of AE under the influence of thermal stresses shall be associated with corresponding changes of the P–wave propagation time. Combined observations of that effect can explain the mechanism of the memory effect occurrence.

2. CHANGES OF ACOUSTIC EMISSION UNDER THE INFLUENCE OF THERMAL STRESSES

The research carried out in the last years had proved that solid rocks indicate the memory effect in the course of AE not only during cyclic mechanical loading of rocks but also during cyclic thermal stresses [Chen, Wang 1980; Żogala 1991; Żogala, Zuberek 1992; Żogala et al. 1995]. During heating the rocks are microfracturing and fracturing what can be observed as the discrete elastic impulses called acoustic emission [Warren, Latham 1970].

In magmatic rocks as well as in sedimentary ones a certain critical temperature threshold exists above which one can see evident increase of acoustic emission [Chen, Wang 1980; Atkinson et al. 1984; Żogala 1992; Żogala et al. 1992]. That temperature threshold seems to be independent on the heating rate, but the heating rate is influencing significantly the number of acoustic emissions. With its increase the acoustic emission rate is evidently increasing [Żogała, Zuberek 1992; Żogala et al. 1995]. With temperature increase, the level of acoustic emission is clearly stimulated by confining pressure. At constant temperature, the level of acoustic emission is decreasing with the increase of confining pressure [Carlson et al. 1990].

During cyclic heating of rock samples, it has been found, that occurs the discrete memory effect of the maximum temperature from the previous cycle, called the thermal memory effect [Żogala 1992]. It means that the significant increase of acoustic emission rate can be observed above the maximum temperature achieved in the previous cycle. The research have proved that with time this effect is gradually decaying what can be observed just after one week of the seasoning time of samples. It has been shown also the increase of heating rate causes faster decay of the maximum temperature memory effect [Żogala et al. 1995].

Maximum temperature memory effect can be explained with microfracturing and fracturing of rocks. During the heating, the developing thermal stresses are causing new microfractures and fractures and the growth and opening of existing ones to the value specific for the given temperature. Therefore in the next cycle clear increase of acoustic emission is observed above the maximum temperature achieved in the previous cycle [Żogala 1992; Zuberek 1994]. On the other hand the decay of the thermal memory effect can be explained by the process of "fracture recovery", it means slow recovery of rock their former properties. It may be assumed that during heating the existing in rock fractures are deformed mainly under shearing due to various thermal expansion of specified mineral grains.

During heating of the rock samples, due to various thermal expansion of mineral grains the existing fractures and microfractures are mainly going to open (the volume of rock is increasing) significantly decreasing their shear strength and then the recorded AE count number is the lowest. Increasing the seasoning time after cooling of the samples, the gradual closure of the fractures is taking place with fitting their inner surfaces together (the volume is decreasing) and due to this the rock is recovering its former properties what is connected with the increase of AE rate during following heating cycle. It will manifest itself as a gradual decay of the memory and as a decrease of the temperature threshold above which the significant increase of AE is observed. With higher heating rate mainly outer fractures are opening in the sample. They also are closing sooner and therefore the memory is decaying sooner [Zuberek 1994]. Therefore it results that the AE generation process during heating is closely related to the course of rock deformation and first of all with its volumetric strain.

3. MEMORY EFFECT IN THE COURSE OF ROCK DEFORMATION AND IN THE PROPAGATION TIME OF LONGITUDINAL WAVES

The volumetric strain of rocks is appearing during their mechanical and thermal loading. Precisely measured volumetric strain during loading and unloading has demonstrated a distinctive hysteresis loop (Fig. 1a) [Holcomb 1981]. With the increase of the differential stress the volumetric strain of the rock indicates during mechanical loading initially fast, close to linear increase what is connected with appropriate increase of the propagation time of the longitudinal waves. The both hysteresis loops will close not before the total unloading of the sample. On the Fig. 1a the rock sample was loaded in several cycles always to the same differential stress value. In the last cycle the sample was fully unloaded and due to this the both hysteresis loops were closed. In the following unloading cycles (I – III) the hysteresis loop has always indicated the same pattern only it was shorter. The total closing of the both hysteresis loops manifest that in the deformation course as well as in the velocity of P–waves the memory effect of the maximum differential stress exist. D.J. Holcomb (1981) has found that the memory refers to the "local" maximum of the differential stresses and is not referred to the "global" maximum. Realising during loading a small loop (Fig. 1b) the rock is returning to the former course passing the last local maximum differential stress and this is not the global one.

In the hysteresis loop are memorised not only maximum values but also the minimum values of the differential stress what causes that the composed hysteresis loop will look as on the Fig. 2. It has been observed [Holcomb 1981] that crossing the threshold of the maximum differential stress from the previous loading cycle is associated with distinct occurrence of AE. It means that the memory effect is connected with fracturing and damaging of rock structure and as a result the rock during cyclic loading will indicate the evident increase of AE not before the maximum value of the differential stress to which it was loaded before.

4. THE INFLUENCE OF THE CYCLIC HEATING ON THE CHANGES OF THE PROPAGATION TIME OF THE P–WAVES

The research were carried on the carboniferous sandstone samples with standard dimensions subjected to four heating cycles. The propagation time of the ultrasonic P–wave was measured each time before heating and just after the end of the heating. The propagation times were determined with the oscilloscope Tektronix type 2225 with 1 μs accuracy. Independently, during heating the AE (cumulated count numbers) were measured. The obtained results have confirmed that the memory effect of the maximum temperature in the course of AE exists which gradually decays with time (Fig. 3a). The velocities were calculated on the basis on the measured times of wave propagation. It has been found that the wave velocity before sample heating is about 10 % higher than the velocity after heating (Fig. 3c). The maximum absolute measurement error was estimated as 5 %.

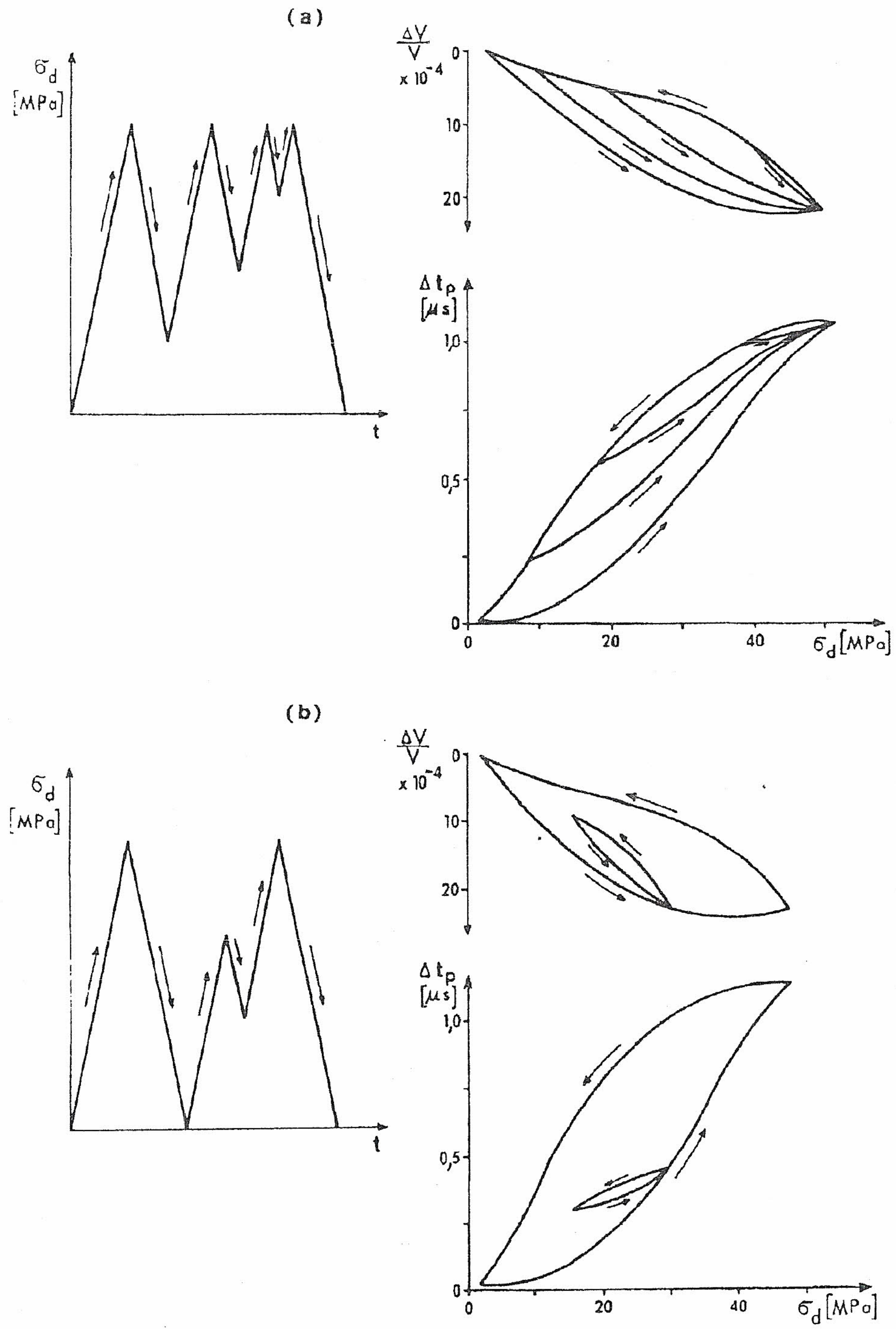

FIG. 1. Cyclic triaxial loading of granite sample (after Holcomb 1981)
– schema of the progress of the differential stress $\sigma_d(t)$ (a) and (b)
– course of the volumetric strain $\frac{\Delta V}{V}$ (compression down)
– course of the changes of the propagation time of the longitudinal waves Δt_p

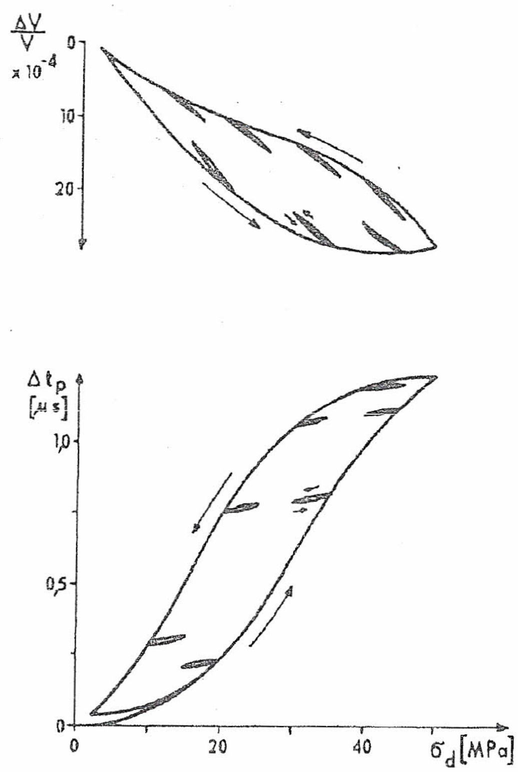

FIG. 2. Cyclic triaxial loading of the granite sample (after Holcomb, 1981); description as on Fig. 1.

It has been noted that the velocity measured before heating is the lowest before the II heating cycle, it means directly after cooling of the sample. Increasing the seasoning time of the samples the velocity is gradually increasing and before the beginning of the IV cycle is very close to its primary value. It may indicate that with the seasoning time the sample recovers its primary elastic properties (Figs. 3a, 3b, 3c).

Analysing the velocities determined directly after the end of the following heating cycles one can note that the largest velocity decrease has occurred after the end of the II and the III heating cycle. The II cycle has been started after approx. 1 hour from the end of the I cycle and the III cycle after 24 hours from the end of the II cycle. At the same time the difference between velocity in the heated and cooled sample is clearly increasing. The velocity measured after the end of the IV cycle is very close to the velocity of the III cycle. It can be observed that the velocities measured directly after the heating also suggest that the sample recovers its primary properties with the increase of time (Fig. 3c).

5. CONCLUSIONS

Comparing the obtained acoustic velocities values with the decay of the temperature memory effect in AE and with the recorded cumulated count numbers in

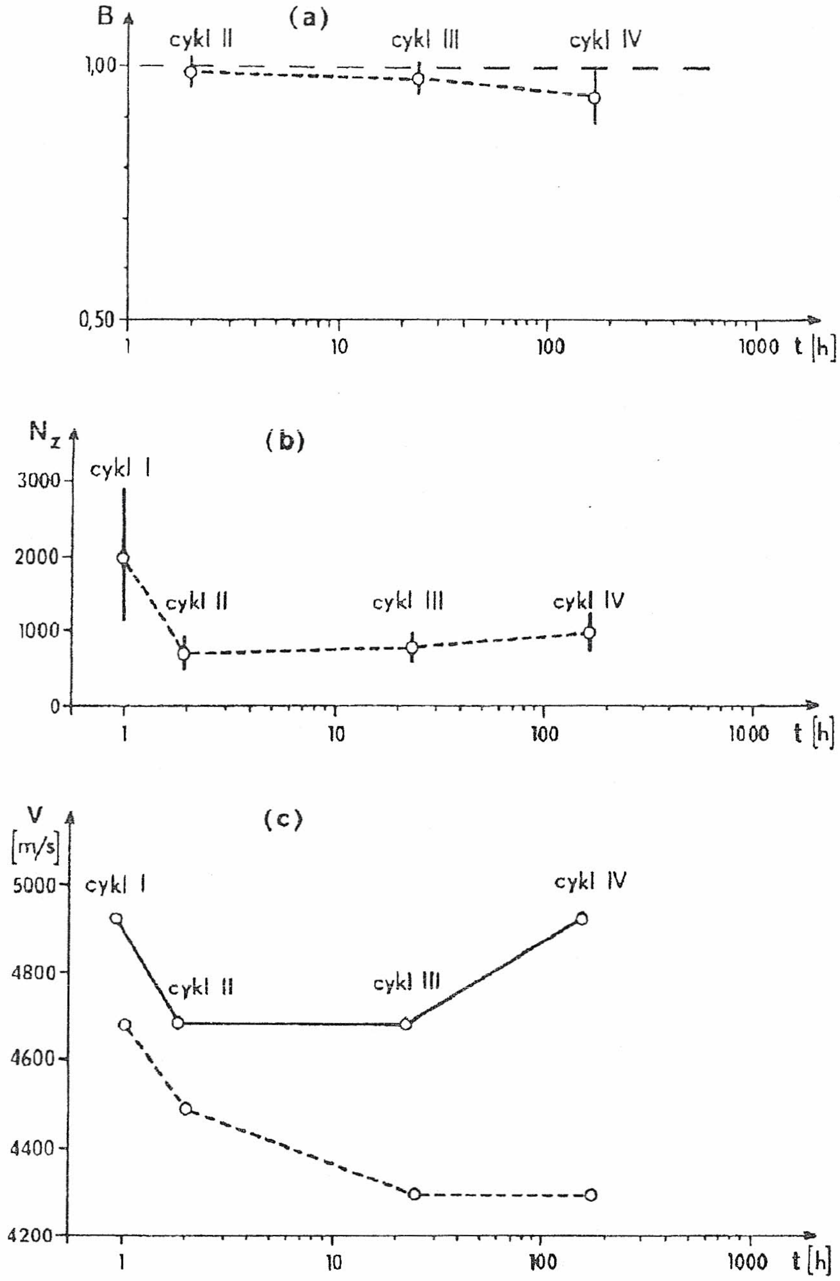

FIG. 3. The comparison of the changes of the thermal memory coefficient B in AE with the cumulated AE count numbers N_Z and velocity V in carboniferous sandstone samples versus seasoning time t after heating.
Coefficient B is defined as a ratio of temperature determined from AE to the maximum temperature achieved in the previous heating cycle.
At Fig. 3c – continuous line denotes velocity before heating, dashed line – velocity after heating.

AE during heating one may conclude that the changes in velocities are evidently related to the process of the memory decay. Thus the velocity measurements have confirmed the postulated earlier hypothesis that the temperature memory effect in AE is related to the deformation of fractures and microfractures in heated rock. As the sample is cooled, the fractures are closing, the velocity returns to its primary value and the memory effect in AE is gradually decaying.

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