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THE MEMORY OF PROPAGATION VELOCITY OF LONGITUDINAL WAVES AFTER CYCLIC HEATING OF SEDIMENTARY ROCK SAMPLES

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ABSTRACT. Carboniferous sandstone samples were heated up to 200 °C during 5 cycles twice for each sample increasing seasoning time between sequent cycle. The longitudinal wave propagation time has been estimated before and after every heating. It has been considered that thermal loading of sedimentary rocks is connected with the increase of longitudinal wave propagation time. It can be explained by volumetric strain. Seismoacoustic measurements and changes of longitudinal wave velocity confirm the hypothesis that the maximum temperature memory effect is connected with deformation of cracks and microcracks in heated rock sample. With cooling of sample and increasing of seasoning time the cracks gradually close, velocity comes back to its previous value and the maximum temperature memory effect gradually decays.

1. INTRODUCTION

Elastic properties of sedimentary rocks are mainly conditioned by their effective porosity ratio, mineral composition, consolidation, mineral binding type and also by density of microcracks and cracks. These factors significantly exert an influence on the longitudinal wave velocity. P–wave velocity varies from 300 m per second for incoherent argillaceous sandstones to 6000 – 7000 m per second for carbonate and coherent terrigene rocks [Plewa, Plewa 1992]. It means that with rock consolidation increase P–wave velocity also increases.

In anisotropic rocks the longitudinal wave velocity in large extent depends on direction of wave radiation. The velocity is higher if measured perpendicularly than measured parallel to rock bedding for given value of effective porosity ratio. Considering sedimentary rocks, the greatest changes of P–wave velocity value are observed in sandstones with high porosity and argillaceous binding. The shape of pores may also be significant. For example the rocks with flat, lengthened pores are susceptible to normal stresses because the normal stress increase is connected to the elastic wave velocity increase whereas round pores do not influence on the changes of elastic wave velocity very much [Winkler, Murphy III 1995]. P–wave velocities are higher in rocks with siliceous and carbonate binding than in rocks with argillaceous binding. Research carried out by M. Plewa and S. Plewa (1992) proved that the increase of rock temperature is connected to 200 m per second decrease of the longitudinal wave velocity.

Rock Deformations Generated by Thermal Stresses

The internal stresses in structure are generated in rocks subjected to thermal loading. The internal stresses are the result of different thermal and elastic properties of particular minerals, their different thermal expansion or local changes of temperature gradient. These factors may cause the opening and enlargement of already existing microfractures and fractures as well as development of new ones [Chen, Wang 1980; Montoto et al. 1989]. Thus the changes of temperature generate the volumetric strain of rocks. Temperature increase generates the extension of volume and temperature decrease or increase of seasoning time after cooling generate the reduction of volume. It is related to gradual closing of cracks and adjustment of particular mineral grains surfaces [Żogała, Zuberek 1996; Żogała 1996].

One may assume, on the analogy of cyclic mechanical loadings of rocks [Holcomb 1981] that cyclic thermal loadings also indicate the hysteresis loop of the volumetric deformation and propagation velocity of the P–waves [Zuberek, Żogała 1996].

3. The Changes of P–wave Velocity Generated by Cyclic Heating

The research was carried on carboniferous sandstone samples. Samples were heated in 5 cycles, twice in each cycle, increasing the seasoning time between particular cycles (Fig. 1). The P–wave propagation times were estimated before and after every heating using Tektronix oscilloscope type 2225 with accuracy 0.5 ms. Next the P–wave velocities were estimated. The average values for 10 samples are presented in Table 1 and Fig. 2a.

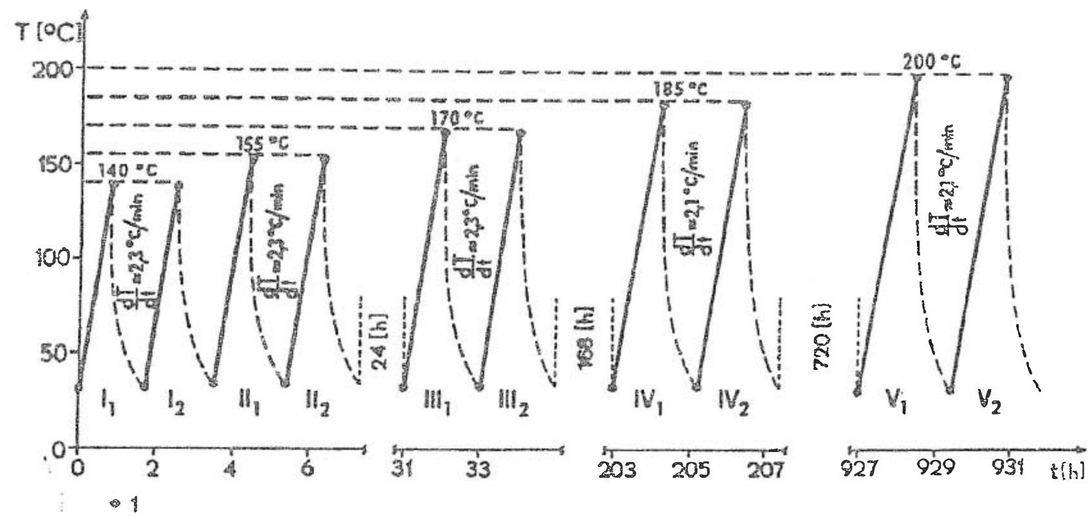

FIG. 1. Scheme of the Cyclic Thermal Loading of Sandstone Samples (roman numbers denote heating cycles)
1 – points of P–wave velocity measurements.

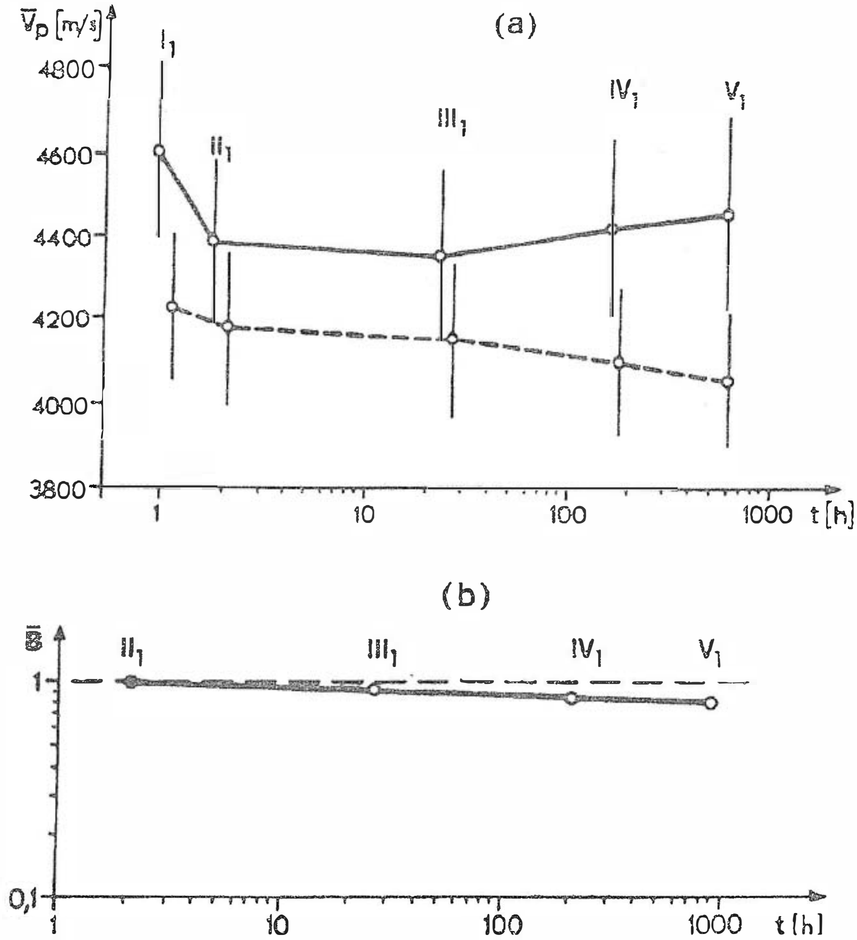

FIG. 2. The Comparison of the changes of the Average values of:
– FIG. 2a. Average P–wave velocity V_p before heating (full line) and after heating, (dashed line); vertical bars – standard deviations,
– FIG. 2b. The Thermal Memory Coefficient B in AE (the log–log scale).

Acoustic emission measurements were also carried out during every heating and then the thermal memory coefficient was determined (Fig. 2b). Thermal memory coefficient close to 1.0 denotes that the memory exists and the deviations from this value denote that maximum temperature memory decays [Żogała et al. 1995; Żogała et al. 1996]. Fig. 2 shows that the changes of P–wave propagation velocity are correlated to memory decay process in the course of acoustic emission.

P–wave velocity measurements confirm the previous hypothesis that the memory effect of maximum temperature from the previous heating cycle is related to deformation of microcracks and cracks. With the cooling of samples the cracks and microcracks get closer, the velocity comes back to its previous value and the memory effect gradually decays [Zuberek et al., in press].

TABLE 1. Average values of P–wave velocities for 10 sandstone samples
V_z – velocity before heating
V_g – velocity after heating

	cycle I		cycle II		cycle III		cycle IV		cycle V	
	I_1	I_2	II_1	II_2	III_1	III_2	IV_1	IV_2	V_1	V_2
V_z	4607	4412	4386	4351	4353	4314	4419	4228	4451	4169
σ_{n-1}	444.5	382.5	399.9	401.1	415.4	401.0	427.4	412.2	452.3	353.4
V_g	4254	4256	4181	4173	4154	4135	4103	4089	4055	4025
σ_{n-1}	347.5	360.9	369.5	375.0	365.6	353.0	357.2	369.1	296.7	304.4

4. SUMMARY

The highest P–wave velocity always occurred before the heating cycle I_1. The velocity estimated just after the heating ("hot sample") was approx. 8 % smaller and gradually decreased after the first heating in successive cycles (Fig. 2a). It seems that observed changes of velocity could be the result of volumetric strain. Average values for 10 samples, excluding the second heating, showed that the lowest velocities were estimated before cycle II that means after 24 hours of seasoning. The velocities before cycle III were 5 – 6 % lower than the maximum velocities. With increasing the seasoning time between successive cycles the velocity gradually get higher and for cycle V after 1 month seasoning was approx. 3 % lower (Fig. 2a).

It seems that with time the rock samples recover their original elastic properties and the volumetric strain generated by thermal stresses also declines.

Acknowledgements

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