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Anisotropy properties of the quartzite from Jegłowa, Poland

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ABSTRACT:

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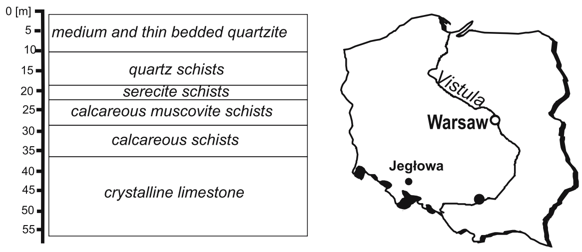
Results of the dielectric spectroscopy, thermal and dilatometric measurements of the quartzite rock are presented. Based on the dielectric measurements performed in a wide range of the frequency ($10^1 – 5 \cdot 10^7$ Hz) at temperature of 300K the piezoresonance in quartzite was found. A chemical composition of quartzite was examined by XRF. The anisotropy of the thermal conductivity was observed. The thermal conductivity coefficient changes from 13.2 [W/Km] to 5.6 [W/Km] for the [100] and [001] direction, respectively. Based on the thermal expansion measurement the thermal expansion coefficient of quartzite was estimated to be $\alpha_Q = 8.0 \cdot 10^{-6}$ [K^{-1}] $\pm 0.7 \cdot 10^{-6}$.

Key words: Quartzite anisotropy; Thermal conductivity of quartzite; Thermal expansion of quartzite.

INTRODUCTION

Quartzite samples used in measurements were kindly provided by the Jegłowa Mine. The Jegłowa Mine is situated in Poland, near Wrocław, in the Strzelin Hills (see the location in Text-fig. 1). Quartzite is a metamorphic rock (Powell 2009), which is a result of a process of the sandstones and mudstones almost exclusively constructed from fragments of quartz at temperatures greater than 150 to 200 [°C] and pressures of 1500 bars (Blatt *et al*. 1996). The quartzite occurring in the foothills of the Sudeten Block was already described in the XIX century (Chmura 1967). Most of the geological properties of quartzite were described in the paper (Chmura 1967). Quartzite is a rock with the temperature of the fire resistance T=1710 [°C]. The spectral analysis of the quartzite chemical composition using XRF method shows the quartzite content of about 98.7% of SiO_2 and 0.71% of Al_2O_3 (see Table 1). The piezoresonance caused by the quartz grain vibration occurring in the quartzite samples was also observed (Marciniszyn *et al*. 2012). In the twentieth century, the quartzite was used mostly to build the Martin furnace (Piech 1999). Nowadays, the quartzite or quartzite schist is also used in the construction industry (stone interior accessories, road metalling, etc.). Most of the papers are focused on a description of the tectonic or lithographic characteristics of rocks. Except for a few parameters such as the quartz grain size in the quartzite and a chemical composition, there is no significant physical information on quartzite.

A knowledge of wide-temperature electrical and mechanical properties of quartzite is required to understand and in consequence to control a number of processes in the earth's crust. For geological materials, the best procedure is usually to measure an electrical properties as a functions of frequency and all variations of relevant environmental parameters as temperature, water content, etc. It is well known that electrical properties of rocks are used in the induced polarization, resistivity, and electromagnetic methods of the mineral exploration, in the



Text-fig. 1. Location of the Jeglowa Mine (50°43'5" N, 17°9'14" E) and the lithological profile for an area dependent of the depth

	Compound	[%]
spectral analysis by XRF	SiO_2	98.7
	Al_2O_3	0.71
	Fe_2O_3	0.05
	CaO	< 0.01
	MgO	< 0.01
	Cr_2O_3	< 0.01
	MnO	< 0.01
	K_2O	0.19
	P_2O_5	< 0.01
	SO_3	< 0.01
	Na_2O	< 0.01
	TiO_2	0.03
	ZrO_2	< 0.01

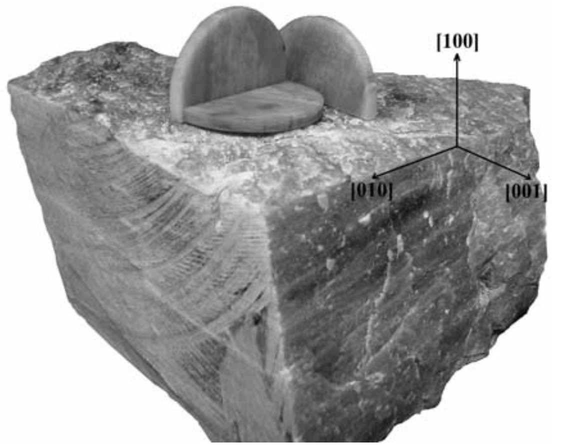
Table 1. Chemical composition of quartzite sample

crustal sounding and in other applications. A deep analysis of electrical properties of quartzite may supply an important information, for example for the electrical resistivity method widely used in the geologic investigation. Thermal properties of quartzite as the thermal expansion and the thermal conductivity are important parameters describing this material. These physical properties say about the thermal stability of quartzite which is very important from the application point of view.

SAMPLE PREPARATION AND EXPERIMENTS

The quartzite rock has no crystal structure. Nevertheless, mezostructure of the quartzite is a layer type with well visible highlighted direction of microcrystals (quartz grains). The microcrystals have a filamentous arrangement. For this reason, the perpendicular and parallel directions towards the filamentous arrangement were established at [001] and [100], respectively (Text-fig. 2). As indicated in Text-fig. 2, the quartzite block was cut out from the wall along [001] direction.

For the dielectric measurements, samples with dimensions of 5×25×5 [mm] in three perpendicular directions were cut out from the quartzite block (according to Text-fig. 2). Additionally, quartzite samples were mechanically polished and the silver paste was used for making a good electrical contact. Dielectric spectroscopy measurements were performed using automatic Novocontrol Alpha impedance analyzer at frequency range from 10^1 to 5×10^7 [Hz] at temperature of 300 K.



Text-fig. 2. Directions maked at the quartzite sample

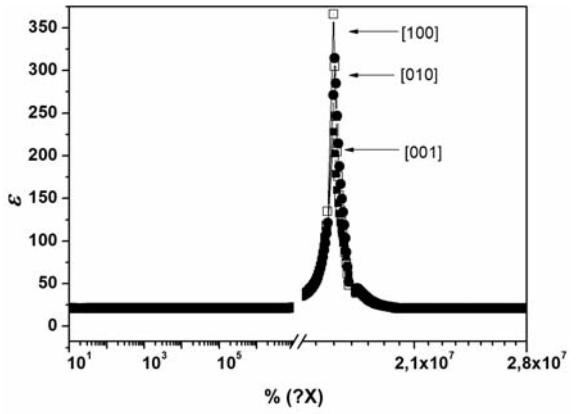
For the thermal conductivity measurements, three perpendicular rings with 70 [mm] diameter and 5 [mm] thickness were prepared. The method is based on the heat flow through the sample located between a heater and a heat receiver up to the moment of the thermal equilibrium – it means that the heat transfer by the heater is equal to the heat wasted by the side and the upper surface of the heat receiver. Additionally the thermal paste was used for removing available air between the sample, the receiver and the copper radiator.

For the thermal deformation measurements, the precision quartz capacitance dilatometer of the original design was used (Dziedzic *et al.* 1983). The samples performed along [100], [010] and [001] directions with the same dimension of 5×5×4.95 [mm] were cooled down with the rate of approximately 0.5 K/min at range of 400K–150K.

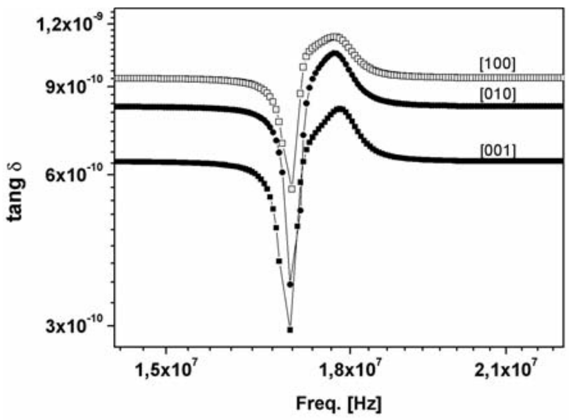
RESULTS

Basic electrical measurements

The complex dielectric permittivity in the wide range of frequencies was measured in order to determine the influence of the direction on the resonance occurring in the quartzite. The real part of the dielectric permittivity as the function of frequencies for the quartzite samples in the [100], [010] and [001] directions has been shown in Text-fig. 3. It is worth emphasizing, that the frequency



Text-fig. 3. Frequency dependence of the real part of the dielectric permittivity in three directions



Text-fig. 4. Loss tangent dependence of the frequency in three directions

corresponding to the maximum of the permittivity is direction independent and it is appointed as 17[MHz]. The maximum of the real part of the permittivity *(ε')* and the dielectric loss *tanδ* are depent on the direction. The largest value of the *ε'* and *tanδ* occurs in the [100] direction (*ε'*350, *tang - 9*10^-9*) and the lower values are observed in the [001] direction (*ε'*208, *tang - 9*10^-9*).

Thermal conductivity measurements

In order to estimate the thermal conductivity coefficients, the heat flow (caused by a temperature gradient) through the sample was measured. Assuming that the heat flux is perpendicular to the surface of the quartzite sample and the heat from the edges of the sample is negligible due to the sample thickness, the thermal conductivity coefficient is given by equation:

$$\lambda = \frac{m \times c \times n \times d_1(r+2d)}{2 \times \pi \times r_1^2 \times \Delta T(r+2d)} \qquad (1)$$

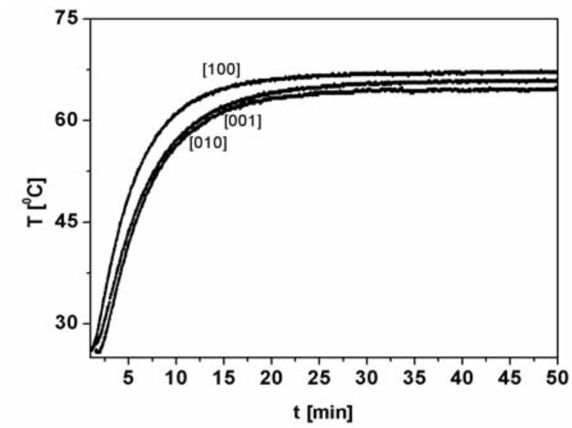
where *m* is the mass of the heat receiver (0.654kg), *c* is the specific heat of cooper (385 J/Km), *r* is the radius (70 mm) and *d* is the thickness of the receiver. d_1 is the thickness (5mm) and r_1 the radius (70mm) of the measured sample. A temperature difference in the thermally stable state between the radiator and the receiver was marked as *ΔT* [K].

Based on the equation (1), the thermal conductivity coefficient was estimated. The measurement results are presented in Table 2. It is well visible, that the quartzite shows the anisotropy of the thermal conductivity coefficient. Additionally it is well known, that the quartz crystals describe the anisotropy and the thermal conductivity changes from 6 to 9, depending on the direction (Horai 1971). Therefore, we suppose that the biggest value λ=13 [W/Km] in the [100] direction can be caused by the ordering of the quartz grain in the [100] direction. Additionally, the bigger thermal conductivity coefficient for quartzite when compared to that for the pure quartz can be caused by the Al_2O_3 dopant (λ [W/Km]) (Shigetaka Wada at al. 2005) in quartzite.

direction	λ [W/(Km)]
[100]	13.2
[010]	8.7
[001]	5.6

Table 2. Thermal conductivity of the quartzite rock

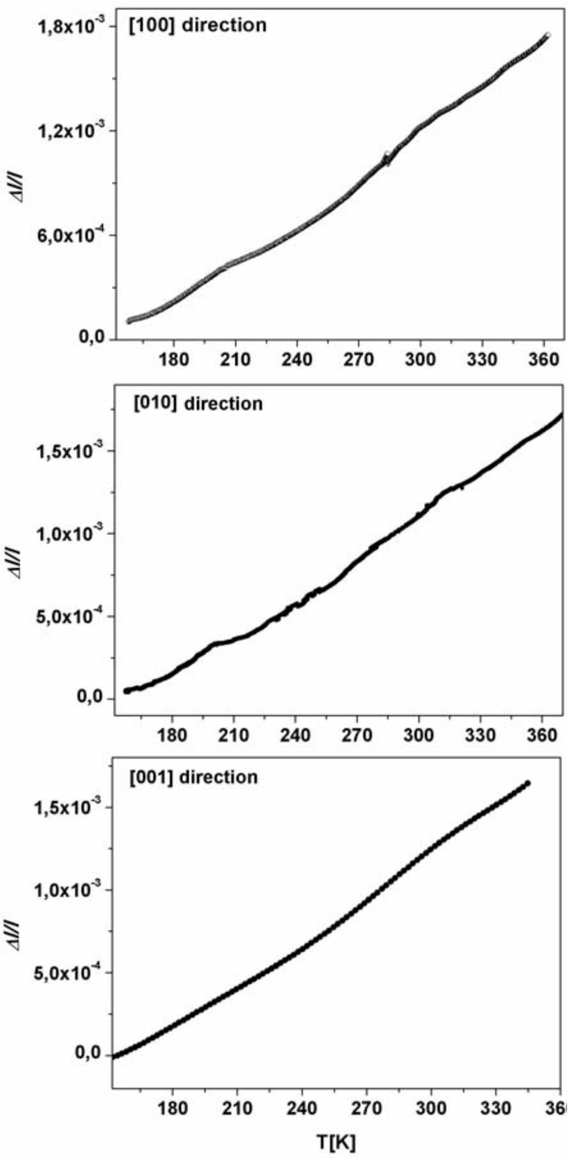
In order to confirm the anisotropy of the thermal conductivity in quartzite, measurements of the thermal wave penetration of quartzite were performed. For this reason, a cube quartzite sample (a=50 [mm]) was prepared. Holes with depth of 20 [mm] were drilled on the three perpendicular walls of the cube. A thermocouple was placed in the drilled hole. The measurements relied upon the determination of the temperature difference between the radiator and the samples interior in the time regime. The quartzite temperature as a function of time was created (Text-fig. 5) from data of the measurements. The speed of the penetration of the thermal wave



Text-fig. 5. Temperature of the sample interior as a function of time for three directions in a quartzite cube sample in the initial ten minutes was also calculated. The value was estimated at 4.9 [K/min] for the [010] [001] and at 6.5 [K/min] for the [100] direction.

Thermal expansion measurements

In Text-fig. 6, the temperature dependence of the thermal deformation for three directions is presented. Based on Text-fig. 6, the thermal expansion coefficients of quartzite are dependent on the direction and they were calculated and presented in Table 3. It should be noted that there is no significant change in the values of the thermal expansion coefficients which are related with the direction. Therefore, the results were averaged and



Text-fig. 6. Thermal deformation versus temperature for quartzite along the [100], [001] and [010] directions

direction	$\alpha_Q \cdot 10^{-6}[K^{-1}]$
[100]	9
[001]	7
[010]	8

Table 3. Mean value of the thermal expansion coefficient of quartzite for the three directions in the temperature range of 150-360[K]

Sample	$\alpha \cdot 10^{-6}[K^{-1}]$
Migmatite	5.4
Amphibolites	3.1
White Marble	2.0
Basalt	5.3
Granite	7.9
Sandstone	11.6
Quartz	6÷9

Table 4. Thermal expansion coefficient of selected rocks

estimated at $\alpha_Q = 8.0 \cdot 10^{-6}$ [K^{-1}] $\pm 0.7 \cdot 10^{-6}$ [K^{-1}]. In order to compare the thermal expansion coefficient of quartzite $\alpha_Q = 8.0 \cdot 10^{-6}$ [K^{-1}] with that for other rock materials, adequate data are given in Table 4.

CONCLUSIONS

The paper presents the results of the measurements of selected physical properties (dielectric, thermal expansion and thermal conductivity) along different directions. It is expected that this information will facilitate an assessment of future research needs in the thermomechanical and thermoelectrical characterization of quartzite, and for example it will be of an immediate use for scientists involved in the modeling of geological phenomena.

The dielectric measurements show that the resonance peak occurs at frequency of $f = 1.7 \cdot 10^7$[Hz]. Additionally, the frequency corresponds to the maximum of the real part of the permittivity and it is direction independent in quartzite.

The thermal conductivity coefficients of the quartzite samples were estimated from the thermal measurements. It is worth noting, that the thermal properties of quartzite demonstrate the anisotropic behavior. The thermal conductivity equals $\lambda_{[100]} = 13.2$ [W/(Km)], $\lambda_{[010]} = 8.7$ [W/(Km)] and $\lambda_{[001]} = 5.6$ [W/(Km)]. The penetration speed of the thermal wave occurs also as the anisotropy. The value equals 4.9 [K/min] for the [010] [001] and 6.5 [K/min] for the [100] direction. The anisotropy in the thermal properties can be caused by the position of the quartz grains occurring in the quartzite. It can be assumed that the ordering grains is present along the [100] direction.

The thermal expansion coefficient of quartzite for the three particular directions shows a small dispersion with an average value of $\alpha_Q = 8.0 \cdot 10^{-6}$ [K^{-1}] ± $0.7 \cdot 10^{-6}$ [K^{-1}]. The thermal expansion coefficient of quartzite is of the same order as that of most isolating rock materials.

Results of the studied material show that the quartzite with good thermal conductivity coefficient and low thermal expansion coefficient can be used as tiles e.g. for the floor heating or Stone Roofing. Furthermore, the eclectic properties are very interesting in a view of the piezoresonance potential application. Therefore, further studies of the resonance phenomena in the material are required.

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REFERENCES

Blatt, H. and Tracy, R.J. 1996. Petrology, Igneous, Sedimentary and Metamorphic, W.H. Freeman and Company, 2nd edition, pp. 1–529. New York; Basingstoke.

Chmura, K. 1967. Lithology of the Jegłowa quartzite series. *Rocznik Polskiego Towarzystwa Geologicznego*, **27**, 301–350. [In Polish]

Dziedzic, J., Poprawski, R. and Bronowska, W. 1983. A modified dilatometer technique for phase transition study in crystals over a wide range of temperature, *Acta Physica Polonica*, A **63**, 45–52.

Horai, K. 1971. Thermal conductivity of rocks for minerals, *Journal of Geophysics Research* **76**, 1278–1308.

Marciniszyn, T. 2012. The study of the thermal conductivity of quartzite and amphibolites, Interdisciplinary scientific research 2012, pp. 307–311. [In Polish]

Marciniszyn, T., Sieradzki, A. and Poprawski, R. 2013. Resonance phenomenon in the quartzite from Jegłowa/Poland, *AGH Journal* of *Mining and Geoengineering* (paper in press).

Piech, J. 1999. Refractory linings of furnaces and heating equipment, pp. 1–311. AGH; Krakow. [In Polish]

Powell, D. 2009. Quartzite, Mineral Information Institute. http://www.mii.org/Minerals/photoquartzite.html. Retrieved 2009-09-09.

Shigetaka, W., Bongkoch, P., Nakorn, P., Wasanapiarnpong, T. and Jinawath, S. 2005. Thermal Conductivity of Al_2O_3 Ceramics: The Inconsistency between Measured Value and Calculated Value Based on Analytical Models for a Composite, *The Journal of Scientific Research Chula University,* **30**, 109–120.

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