ISSN 1062-8738, Bulletin of the Russian Academy of Sciences: Physics, 2018, Vol. 82, No. 7, pp. 786–788. © Allerton Press, Inc., 2018.
Original Russian Text © S.D. Victorov, A.N. Kochanov, A.A. Pachezhertsev, 2018, published in Izvestiya Rossiiskoi Akademii Nauk, Seriya Fizicheskaya, 2018, Vol. 82, No. 7, pp. 878–880.

Experimental Study of the Microstructural Characteristics of the Surfaces and Volumes of Granite Samples

S. D. Victorov[a], A. N. Kochanov[a, *], and A. A. Pachezhertsev[b, **]

[a]*Research Institute of the Comprehensive Exploitation of Mineral Resources, Russian Academy of Sciences, Moscow, 111020 Russia*

[b]*Center for Engineering and Technology for Hard-to-Recover Reserves, Moscow Institute of Physics and Technology, Dolgoprudny, 141700 Russia*

**e-mail: kochanov@mail.ru*

***e-mail: pachezhertsev.aa@cet-mipt*

Abstract—The microstructural characteristics of granite are studied experimentally by means of electron microscopy and X-ray microtomography. Images are obtained of the pores and microcracks on the surfaces and throughout the volumes of granite samples, allowing estimates of the sizes and distribution of microdefects inside them. The advantage of using experimental data in analyzing the structural characteristics of different materials is noted.

DOI: 10.3103/S1062873818070444

INTRODUCTION

Material failure is a physical process caused by the different external impacts. Its patterns have been studied in numerous works on the physics of strength and failure mechanics. The patterns of development and the final results of failure process are determined in many respects by a material's initial structure, which is characterized by grain shape and size, and by the presence of microdefects in the form of pores and microcracks. A material's initial structure and chemical composition determine its physical properties, including those of strength. In the case of rocks, reliable assessment of their structural and strength indices is a required tool for the safest and most effective exploitation of mineral resources. This includes avoiding catastrophic failure in the form of rock bursts and other hazardous dynamic phenomena.

An important element of a material's structure is microcracks and pores. Their presence or absence predetermines the behavior of deformation under an external action. Based on the available experimental results, the smallest microdefects in a solid body can range from ~0.01 to 0.1 μm in size, according to different estimates [1, 2].

In this work, we studied pores and microcracks as structural elements of natural polycrystalline granite using scanning electron microscopy and computer X-ray microtomography. The investigated samples were individual fragments of a granite block subjected to dynamic impact according to the scheme described in [3].

EXPERIMENTAL

Our study of the surfaces of the granite samples using electron microscopy to some extent continued the work of [4]. We obtained images of pores and microcracks on granite surfaces using a JEOL–JSM-5910LV microscope (Fig. 1). The formation of pores is usually determined by natural factors and results from geological processes during the formation of rocks. We can note two peaks in the size distribution of pores: the ones most numerous have sizes of ~1.0–2.5 μm, while the larger ones are 5.0 μm in size (Fig. 1a).

The formation of microcracks in our experiments was caused by dynamic impact on granite under laboratory conditions. Figure 1b shows the image of a fragment of a granite surface with microcracks as much as ~1000 μm long and ~50.0 μm wide in its individual mineral components (obviously quartz and feldspar) and along the boundaries of their grains.

The internal structure of the samples was examined via X-ray microtomography using a SkyScan 1272 scanner. The scanning mode had a resolution of 1.1 μm/pixel; the radiating source voltage was 90 kV; the duration of exposure was 4331 ms; the filter was 0.5 mm of Al + 0.038 mm of Cu; and the rotary step was 0.1°.

RESULTS AND DISCUSSION

X-ray microtomography is a reliable way of studying the internal structure of solid bodies, based on reconstructing the spatial distribution of the linear weakening of X-ray emissions via computer processing

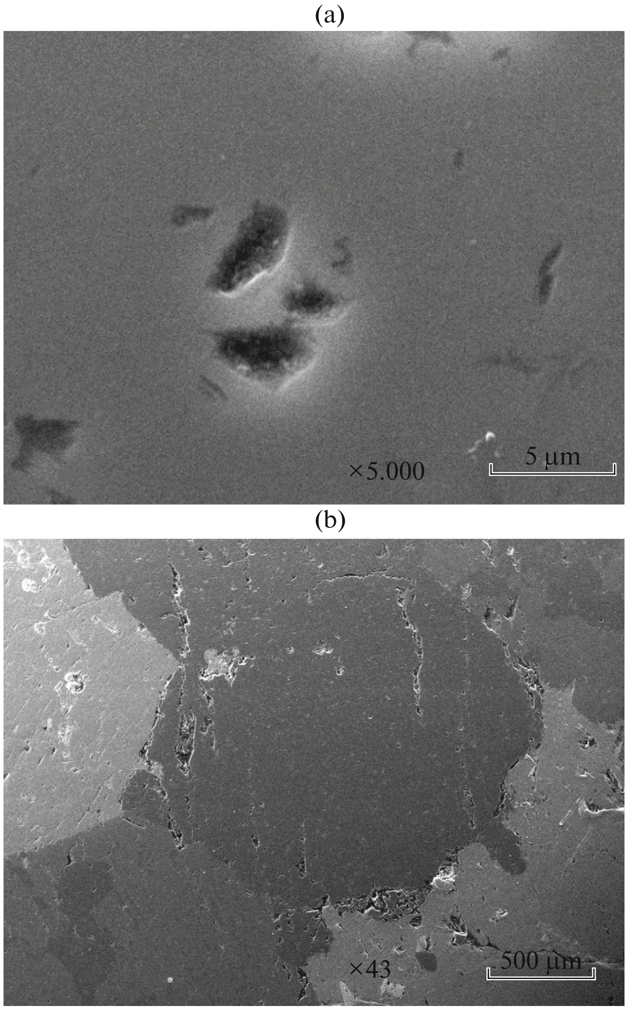

Fig. 1. Images of (a) pores and (b) microcracks on a granite surface, according to the data from electron microscopy.

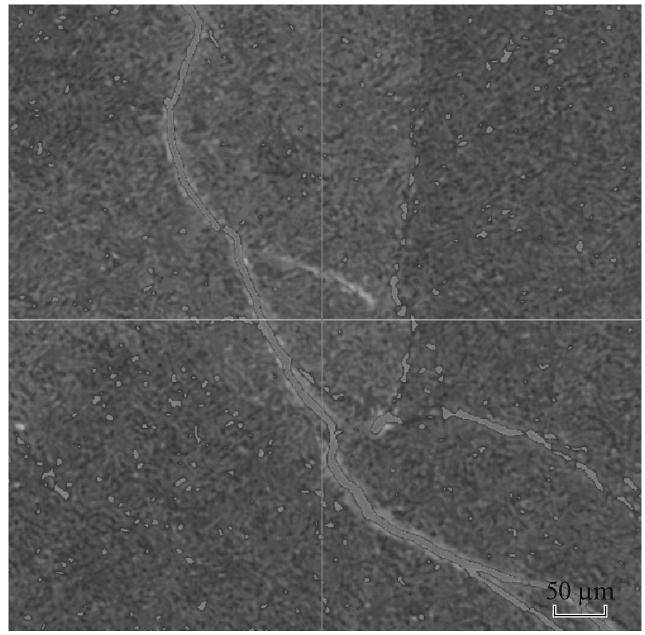

Fig. 2. Cross section of granite's internal structure showing microcracks and pores.

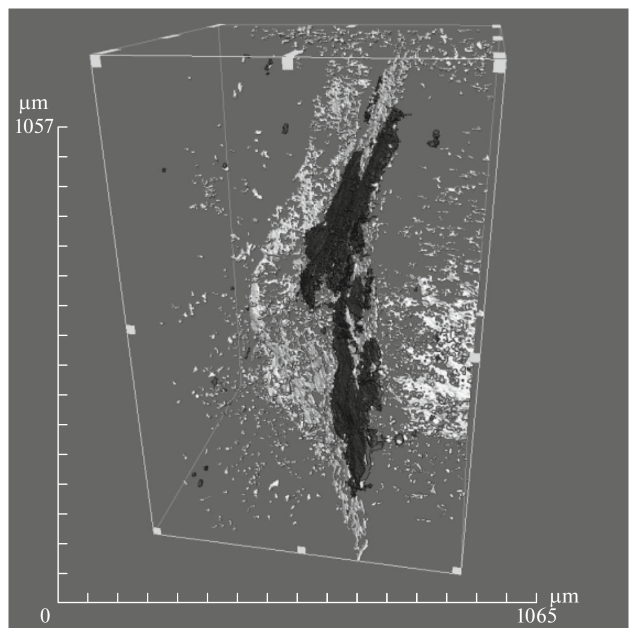

Fig. 3. Image of microdefects, according to the data from X-ray microtomography.

of shadow projections obtained in X-raying a material with components of different densities and chemical compositions. This allows us to scan a sample throughout its volume in different directions with a step of ~1 μm, letting us visualize the internal 3D structure of the samples. This technique is now widely used in studying structural elements in different materials, including rocks [5–7].

To study the internal structure of granite using a microtomograph, we prepared samples 2 × 1 × 1 mm in size. Scanning revealed micropores with diameters of 1.0 to 5.0 μm and microcracks 3–10 μm wide. Some cracks had voids filled with more compact minerals. Some microcracks interconnected and formed branched networks. Figure 2 shows a cross section of the internal structure of granite at the half-length level of the scanned sample. This image clearly shows individual pores and microcracks, with the widths of the latter ranging from 7 to 10 μm. Figure 3 presents a 3D image of microdefects (pores and microcracks). The size of the visualized volume is 800 × 800 × 800 μm^3. The white fragments of the microcracks (microdefects) are evidently not filled and form voids, while the black fragments are filled with more compact material.

The pores were distributed throughout the volumes of our granite samples nonuniformly. An area with an increased content of micropores is shown in Fig. 4, while there are local volumes in which they are not

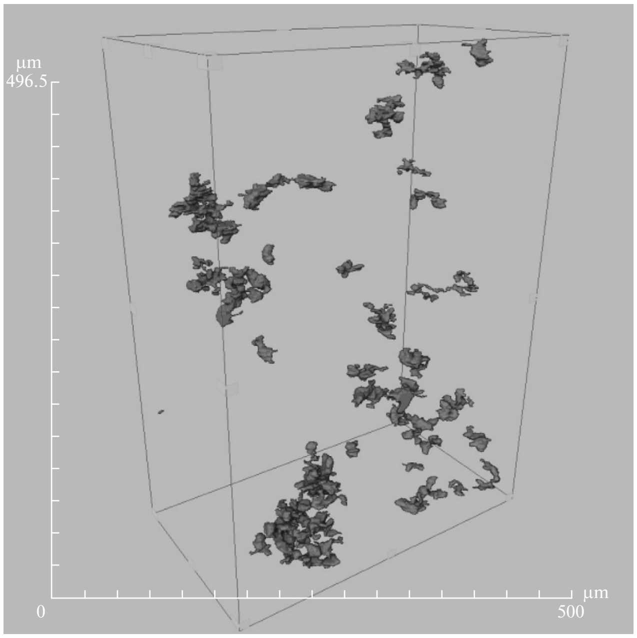

Fig. 4. Distribution of pores throughout the local volume of a sample, according to the data from X-ray microtomography.

observed. The visualized volume is in this case 500 × 500 × 200 μm^3. The total porosity of this sample was ~1.8%.

CONCLUSIONS

Scanning electron microscopy and X-ray microtomography were used to obtain images of pores and microcracks on the surfaces and throughout the volumes of granite samples, allowing us to estimate their sizes and determine the distribution of microdefects in local volumes of a sample. In analyzing the results, we noted that the distribution, morphology, and sizes of the pores on the surface and throughout the volume of a granite sample were to some extent identical. The parameters of the microcracks were slightly different because they were wider, while the surfaces were studied by means of electron microscopy. The results from our study, including those associated with the 3D visualization of microdefects, created prerequisites for the development of theoretical models in the physics of strength for predicting deformation processes and material failure. Integrated use of X-ray microtomography and electron microscopy would seem to be of great promise in the study of material structures.

ACKNOWLEDGMENTS

This work was supported by the Russian Science Foundation, grant no. 16-17-00066.

REFERENCES

1. Cheremskoi, P.G., Slezov, V.V., and Betekhtin, V.I., *Pory v tverdom tele* (Pores in Solids), Moscow: Energoatoimizdat, 1990.
2. Betekhtin, V.I. and Kadomtsev, A.G., *Phys. Solid State*, 2005, vol. 47, no. 5, p. 825.
3. Viktorov, S.D. and Kochanov, A.N., *Bull. Russ. Acad. Sci.: Phys.*, 2017, vol. 81, no. 6, p. 667.
4. Viktorov, S.D. and Kochanov, A.N., *Bull. Russ. Acad. Sci.: Phys.*, 2015, vol. 79, no. 6, p. 743.
5. Vaisberg, L.A. and Kameneva, E.E., *XXI Peterburgskie chteniya po problemam prochnosti* (Proc. XXI St. Petersburg Readings on Strength Problems), St. Petersburg, 2014, p. 3.
6. Nadev, A.N., Korobkov, D.A., Yakimchuk, I.V., et al., *Sb. mater. Vseross. konf. "Prakticheskaya mikrotomografiya"* (Proc. All-Russian Conf. "Practical Microtomography"), Kazan, 2013, p. 160.
7. Damaskinskaya, E.E., Panteleev, I.A., Gafurova, D.R., et al., *Sb. tezisov LVIII mezhdunar. konf. "Aktual'nye problemy prochnosti"* (Proc. LVIII Int. Conf. "Topical Strength Problems"), Perm, 2017, p. 77.

Translated by L. Mukhortova