18. Kolokoltsev V. M., Petrochenko E. V., Molochkova O. S. Structure and properties of heat- and wear-resistant white cast irons of the Cr–Mn–No–Ti system. *Chernye metally.* No. 3. 2016. pp. 42–48.
19. Petrochenko E. V. Features of forming of structure and properties of complex-alloyed white irons depending on different types of heat treatment. *Chernye metally.* No. 1. 2012. pp. 10–14.
20. Gurevich Yu. G. Wear-resistant composite material: titanium carbide — white iron. *Chernye metally.* No. 4. 2010. p. 14.
21. Petrochenko E. V. Features of crystallization, forming of the structure and properties of wear-resistant and heat-resistant irons in different cooling conditions. : thesis of a doct. of techn. sciences. Magnitogorsk. 2012. 310 p.
22. Molochkova O. S. Choice of the composition and investigation of the structure, properties of heat- and wear resistant complex-alloyed white cast irons: thesis of a cand. of techn. sciences. Magnitogorsk. 2012. 123 p.

UDC 669.13 DOI: http://dx.doi.org/10.17580/cisisr.2018.01.03

DESTRUCTION MECHANISM OF CASTING GRAPHITE IN MECHANICAL ACTIVATION

I. E. Illarionov[1], T. R. Gilmanshina[2], A. A. Kovaleva[2], O. N. Kovtun[2], N. A. Bratukhina[2]

[1] *Chuvash state university (Cheboksary, Russia)*
[2] *Siberian federal university (Krasnoyarsk, Russia)*
E-mail: gtr1977@mail.ru

AUTHOR'S INFO

I. E. Illarionov, Dr. Eng., Prof.,
T. R. Gilmanshina, Cand. Eng., Associate Prof.,
A. A. Kovaleva, Cand. Eng., Associate Prof.,
O. N. Kovtun, Cand. Eng., Associate Prof.,
N. A. Bratukhina, Associate Prof.

Key words:

graphite, mechanical actication, destruction, plastic deformation, slipping plane, twinning, cast iron, burn-in, non-stick coating.

ABSTRACT

Development of the technologies allowing to improve the quality of initial materials is considered as the actual problem of casting and foundry production at present time. This tendency is connected with working and depletion of existing and operating deposits. Natural graphites are subjected to crushing, comminution, concentration and other operations during their preparation. Each of these operations is realized using special equipment, and their transition to the higher technological level requires additional expenses. Thereby, mechanical activation seems to be the most prospective method that does not need to include additional equipment in the technological chain of materials preparation. This process is accompanied by varying of crystal lattice energy in the processing material and is connected with forming of different structural defects (such as dislocations and vacancies), leading to forming of the new separation surfaces. The energy is reserved in such way and then it is spent for strengthening of chemical and physical-mechanical reactions during consequent fabrication of products (including non-stick coatings) on the base of activated materials, and it was proved convincing in the works. Many investigations in this field have examined only varying of parameters depending on activation time, without any discussion about the destruction mechanism of the particles. This work was aimed on examination of the destruction mechanism of natural graphite during mechanical activation from the point of view of crystallography. Natural crystalline graphite from Zavalyevskoe deposit has been chosen for investigations. The destruction mechanism has been studied on large oval graphite plates with maximal diameter 1.5 mm. Graphite activation was realized in the AGO-2 mill of planetary-centrifugal type. The activation procedures are discussed in the paper. Metallographic analysis via transmission electronic microscope UEVM-100K was used for determination of the mechanism of crack origination in graphite particles.
Natural crystalline graphite from Zavalyevskoe deposit containing of oval graphite plates with maximal diameter 1.5 mm and small particles (about 10%) with more complicated and elongated form has been chosen for investigations. Size and total surface of particles, their distribution on fractions has been determined by the method of light laser screening in Novosibirsk institute of solid state chemistry and mechanochemistry on PRO-7000 unit.
The form and micro-shape of particles has been determined using transmission electronic microscope UEVM-100K. It was established that destruction of particles during graphite mechanical activation occurs via the mechanism similar to destruction during usual forging. At the same time it was noted that two main types of plastic deformation (slipping and twinning) are observed in mechanical activation owing to strong deformation of graphite crystals under the effect of balls. Fracture planes coincide with slipping planes, while fracture is caused by the defined stress value perpendicular to the fracture surface.

Introduction

Creation of the technologies, allowing to improve the properties of initial materials, and fabrication of non-stick coatings on the base of these materials, allowing to improve quality of cast products, remains the actual problem of casting production at present time [1–3].

Carbon-containing materials, i.e. natural graphites are subjected to crushing, comminution, concentration etc. operations during their preparation [4–8]. Each of these technological stages is conducted using special equipment, and their transition to the higher technological level requires additional energy consumption and labour efforts [9–12].

Mechanical activation is considered as one of the most prospective methods that does not need introduction of additional equipment in the technological chain for materials preparation [11, 13–16].

Usage of this technology is accompanied by varying of crystal lattice energy of the processing material; it can be connected with forming of different defects of the structure (dislocations, vacancies) that result in forming of the new separation surfaces [11, 16–19]. Energy reserved in such way is consumed on increase of chemical and physical-mechanical reactions during consequent manufacture of products, i.e. non-stick coatings, on the base of activated material.

The paper [20] presents the results of examination of the effect of time activation on geometrical parameters of natural crystalline graphite. It was displayed in this case that the most mass destruction occurs after activation during 20 min, while the average size decreases from 102 to 14 μm and total surface increases from 1,600 to 10,000 cm^2/cm^3.

However, destruction mechanism was discussed in this work only from the point of view of varying geometrical and other parameters. This investigation was devoted to study of destruction mechanism of natural graphite during mechanical activation from the position of crystallography.

Technique of the experiment

Natural crystalline graphite from Zavalyevskoe deposit has been chosen for examination. Destruction mechanism was studied on large oval graphite plates with maximal diameter 1.5 mm.

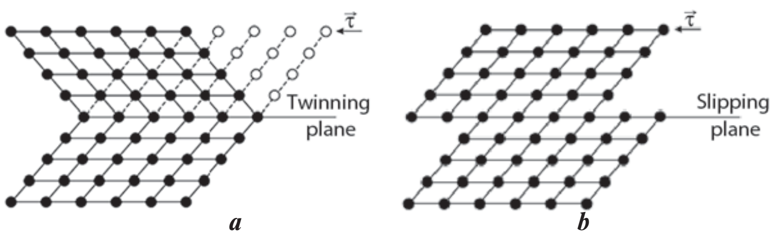
Graphite activation was realized in the AGO-2 mill of planetary-centrifugal type. The activation procedures are discussed in the paper [20,21].

Metallographic analysis via transmission electronic microscope UEVM-100K was used for determination of the mechanism of crack origination in graphite particles.

Obtained results

It was noted that two main types of plastic deformation (slipping and twinning) can be observed in mechanical activation owing to strong deformation of graphite crystals under the effect of balls (see **fig. 1**) [22,23].

Graphite crystals can be easily subjected to deformation via shift along the planes (0001) due to structure layering. It was connected with the fact that the minimal Bürgers vector a/3 $11\bar{2}0$ is located in the basic close-packed plane (0001). In this case, there are three slipping systems for one plane and three directions (except slipping in the basic plane): in prism planes $(10\bar{1}0)$, in 1st kind pyramid plane $(10\bar{1}1)$ and 2nd kind pyramid plane $(11\bar{2}2)$ (**fig. 2**).



a *b*

Fig. 1. Plastic deformation (*a*) deformation via slipping (*b*) [23]

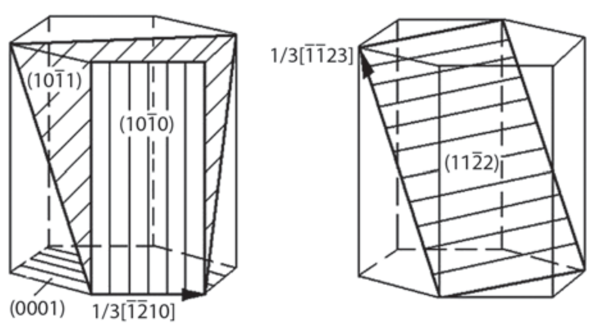


Fig. 2. Slipping systems [24]

Full dislocations slip in the basic and prism planes 1/3 $[\bar{1}210]$, dislocations 1/3 $[\bar{1}\bar{1}23]$ slip in the 2nd kind pyramid planes, and both dislocations slip in the 1st kind pyramid planes [24].

Twinning is connected with slipping caused by pressure, arising during mutual hitting of graphite particles and grinding bodies (balls). Twins can interact with dislocations moving in the slipping planes, but they brake near the boundaries of twins, arising appearance of steps on these boundaries; otherwise they transform in twinning dislocations originating new twins [24].

As soon as the value and density of dislocations approach to the critical points, ductility reserve decreases together with strength elevation. When above-mentioned critical points are achieved, the cracks originate in the areas with maximal stresses [25].

Crack propagation during mechanical activation is considered similar to destruction process during usual forging, based on the Maurice theory [26] (see **fig. 3**), i.e. suggestion about maximal stresses in the periphery of a flattened particle is the most trustworthy ductile materials (such as graphite). It is connected with the fact that fracture of the surface layers of the substance occurs after their mutual hitting with grinding bodies. As a result, the stressed state in the center and in the periphery is different, while in the center it is close to the state of all-around hydrostatic compression and in the pe-

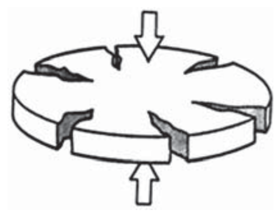
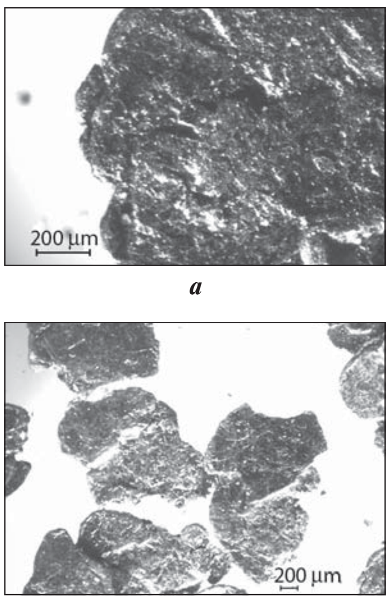


Fig. 3. Destruction routes in forging [26]



a

b

Fig. 4. The crack in graphite particle, activation during 10 (*a*) and 20 (*b*) min

riphery it is characterized by maximal anisotropy of stresses and deformation.

Thereby, the edge surface of graphite particles is the place of the most possible cracks origination (see **fig. 4**).

The fracture planes are the most dense in the lattice and coincide with the slipping planes. Destruction is caused by the determined stress value perpendicular to the fracture surface, not by the acting stresses in the fracture plane [25].

Thereby, defects of slipping and twinning are accumulating in graphite during mechanical activation. These defects support increasing of graphite reaction ability in consequent chemical and physical-chemical reactions: in manufacture of anti-stick coatings and in creation of reducing atmosphere in a moulds hollow owing to more intensive oxidation.

Conclusions

It was established that mechanical activation of graphite is accompanied by destruction of the particles via the mechanism similar to destruction process during usual forging. It was noted that two main types of plastic deformation (slipping and twinning) are observed during mechanical activation due to strong deformation of graphite crystals under the effect of balls. The fracture planes coincide with the slipping planes. This fracture is caused by the determined stress value perpendicular to the fracture surface. Thereby, graphite destruction leads to its comminution and, respectively, to quality improvement of non-stick graphite-based coatings.

REFEFRENCES

1. Dmitriev A. V. Rupture of Cryptocrystalline Graphite Ore Pieces. *Solid Fuel Chemistry*. 2010. Vol. 44. No. 1. pp. 36–39.
2. Jie-Ren Shie. Optimization of Dry Machining Parameters for High-Purity Graphite in End-Milling Process by Artificial Neural Networks: A Case Study. *Materials and Manufacturing Processes*. 2006. No. 21. pp. 838–845.
3. Leushin I. O., Chistyakov D. G. Graphite phase forming in crystallization of cast iron for its consequent thermal cyclic loads. *Chernye metally*. 2016. No. 2. pp. 23–27.
4. Mamina L., Gil'manshina T., Koroleva F. Promising methods of graphite enrichment. *Lieinoe proizvodstvo*. 2003. No. 2. pp. 16–18.
5. Crespo E., Luque F. J., Barrenechea J. F., Rodas M. Influence of grinding on graphite crystallinity from experimental and natural data: implications for graphite thermometry and sample preparation. *Mineralogical Magazine*. 2006. Vol. 70(6). pp. 697–707.
6. Bogatyreva E. V. Development of theory and practice of efficient application of mechanical activation in the technology of hydrometallurgical development of oxygen-bearing rare earth raw materials : thesis of a cand. of techn. sciences. Moscow. 2015. 331 p.
7. Gilmanshina T. R., Lytkina S. I., Khudonogov S. A., Kritskiy D. Yu. Cryptocrystalline graphite properties study following treatment by different methods. *Obogashchenie rud*. 2017. No. 1. pp. 15–18.
8. Udalov Yu. P. New crystalline forms of carbon. Up-to-date state of manufacturing technology and application of coal-graphite materials: a package of information materials. St. Petersburg. TsNTI "Progress". 2000. pp. 1–13.
9. Sreejith P. S., Ngoi B. K. A. Dry machining: machining of the future. *J. of Materials Processing Technology*. 2000. No. 101. pp. 287–291.
10. Babkin V. G., Leonov V. V. , Gilmanshina T. R., Stepanova T. N. Phase transformations in graphite coatings and their effect on surface cleanness of castings. *Chernye metally*. 2017. No. 10. pp. 54–59.
11. Mamina L. I. Theoretical grounds of mechanical activation of forming materials and development of the resource-saving technological materials and processes in casting production : thesis of a doct. of techn. sciences. Krasnoyarsk. 1989. 426 p.
12. Gilmanshina T. R., Koroleva G. A., Baranov V. N., Kovaleva A. A. The Kureyskoye deposit graphite mechano-thermochemical modification technology. *Obogashchenie rud*. 2017. No. 4. pp. 7–11.
13. Boldyrev V. V., Avvakumov E. G. Fundamental grounds of mechanical activation, mechanical synthesis and mechanical-chemical technology. Novosibirsk : Siberian branch of the Russian academy of sciences. 2009. 343 p.
14. Possible physical-chemical effects of mechanical activation. Available at: http://msd.com.ua/vse-o-penobetone/vozmozhnye-fiziko-ximicheskie-effekty-mexanoaktivacii/
15. Khodakov G. S. Fine comminution of building materials. M. : Stroyizdat. 1972. 240 p.
16. Avvakumov E. G. Mechanical methods of activation of chemical processes. Novosibirsk : Nauka. 1986. 333 p.
17. Kurdyumov A. V., Malogolovets V. G., Novikov N. V. Polymorphic modifications of carbon and boron nitride. M.: Metallurgiya. 1994.
18. Ubbelode A. V. Graphite and its crystalline compounds. M. : Nauka. 1965. 256 p.
19. Veselovskiy V. S. Coal and carbon construction materials. M. : Nauka. 1966. 225 p.
20. Baranov V. N. Activation of graphite with different crystalline-chemical structure for refractories and paints in casting production : thesis of a doct. of techn. sciences. Krasnoyarsk. 2005. 131 p.
21. Mamina L. I., Anikina V. I., Lytkina S. et. al. Influence of the activation time on the parameters of a graphite structure. *Russian Journal of Non-Ferrous Metals*. 2016. Vol. 57. No. 1. pp. 52–56.
22. Egorov-Tismenko Yu. N. Crystallography and crystallochemistry. M. : KDU. 2005. 589 p.
23. Slipping and twinning deformation. Available at: http://dssp.petrsu.ru/p/tutorial/ftt/Part4/part4_4_1.htm.
24. Nikolaeva E. A. Shifting mechanisms of monocrystals plastic deformation. Perm : Izdatelstvo Permskogo gosudarstvennogo teknicheskogo universiteta. 2011. 51 p.
25. Deformation, fracture and hardening of crystals. Available at: https://ufn.ru/ufn28/ufn28_6/Russian/r286d.pdf.
26. Parameters of mechanical activation and methods of their evaluation. Available at: http://www.crystallography.ru/MA/control.html.