

MECHANISMS OF INTERGRAINAL FAILURE DURING PLASTIC DEFORMATION

Nugmanov Ikrom Nugmanovich

Almalyk State Technical Institute, Almalyk, Uzbekistan

Candidate of Technical Sciences, Professor

E-mail: nugmanovikrom43@gmail.com

Isroilov Diyorbek Abdunasim o'g'li

Almalyk State Technical Institute, Almalyk, Uzbekistan

Student of the 7A-23 MT group, Mechanical Engineering

E-mail: diyorbekisroilov468@gmail.com

Annotation. The article investigates fracture occurring during plastic deformation. It is noted that the fracture begins in two ways – due to the formation of wedge-shaped (V-shaped) cracks, which usually form at the intersection points of three grain boundaries and tend to grow along the boundaries perpendicular to the direction of the applied stress. Such V-shaped cracks can be observed in many pure metals as well as in engineering alloys such as nickel alloys and stainless steels.

Keywords: intergranular fracture, wedge-shaped cracks, main cracks, GB sliding (grain boundary sliding), V-shaped cracks, lattice dislocations.

Аннотация. В статье исследуется разрушение при пластической деформации. Указано, что оно начинается двумя путями – за счёт образования клинообразных

(V-образных) трещин, которые, как правило, формируются в точках пересечения трёх границ зёрен и стремятся расти вдоль границ, перпендикулярных направлению действующего напряжения. Такие V-образные трещины можно наблюдать у многих чистых металлов, а также у технических сплавов, таких как никелевые и нержавеющей стали.

Ключевые слова: Межзеренное разрушение, клиновидные трещины, магистральные трещины, ЗГП - зерно-границное проскальзывание, V - образные трещины, решеточные дислокации.

Annotatsiya. Maqolada plastik deformatsiya jarayonida yuzaga keladigan yemirilish jarayoni o'rganilgan. Unda yemirilish ikki yo'l bilan boshlanishi ko'rsatilgan: birinchisi — klinasimon (V-shaklli) yoriqlar hosil bo'lishi hisobiga. Bunday yoriqlar odatda uchta don (zarra) chegarasi kesishgan nuqtalarda paydo bo'ladi va ta'sir etuvchi kuchlanish yo'nalishiga perpendikulyar bo'lgan chegaralar bo'ylab o'sishga intiladi. Bunday V-shaklli yoriqlar ko'plab sof metallarda, shuningdek nikel qotishmalari va zanglamaydigan po'lat kabi texnik qotishmalarda ham kuzatilishi mumkin.

Kalit so'zlar: donalararo yemirilish, klinasimon yoriqlar, magistral yoriqlar, ЗГП – don chegaralari bo'ylab sirpanish, V-shaklli yoriqlar, kristall panjara dislokatsiyalari.

Wedge-shaped V-shaped cracks, forming at triple grain boundary junctions, weaken the cross-section of the material. Cluster of lattice dislocations in front of the boundary weakens the grain's cross-section. Slip along the boundary with steps creates stress concentrations, which in turn cause localized vacancy flows. Vacancies coalesce into complexes, which, by absorbing new vacancies, grow into pores. Pores (O-shaped cracks) can be elliptical in cross-section; they gradually increase in number and size. The massive formation of pores and their influence leads to a main crack and ultimately to complete failure of the material [1,2].

Fracture initiates in at least two ways: through the formation of wedge-shaped cracks and more or less spherical pores. Wedge-shaped (V-shaped) cracks typically form at the intersections of three boundaries (Fig. 1) and tend to grow along grain boundaries normal to the direction of the applied stress (1).

This type of crack typically occurs during low-temperature plasticity and high stresses. Its occurrence is associated with grain boundary slip, which, due to stress

concentration, can lead to crack opening at the intersection of three boundaries in several ways. Such V-shaped cracks can be observed in a wide range of pure metals and in technical alloys, such as nickel (Fig. 3) or stainless steel (Fig. 2) [3, 4].

Wedge-shaped cracks, forming at triple grain boundary junctions, weaken the cross-section of the material. This accelerates the formation of new microcracks at other boundaries. The massive formation of microcracks leads to their coalescence into main cracks and ultimately to complete failure of the material (2).

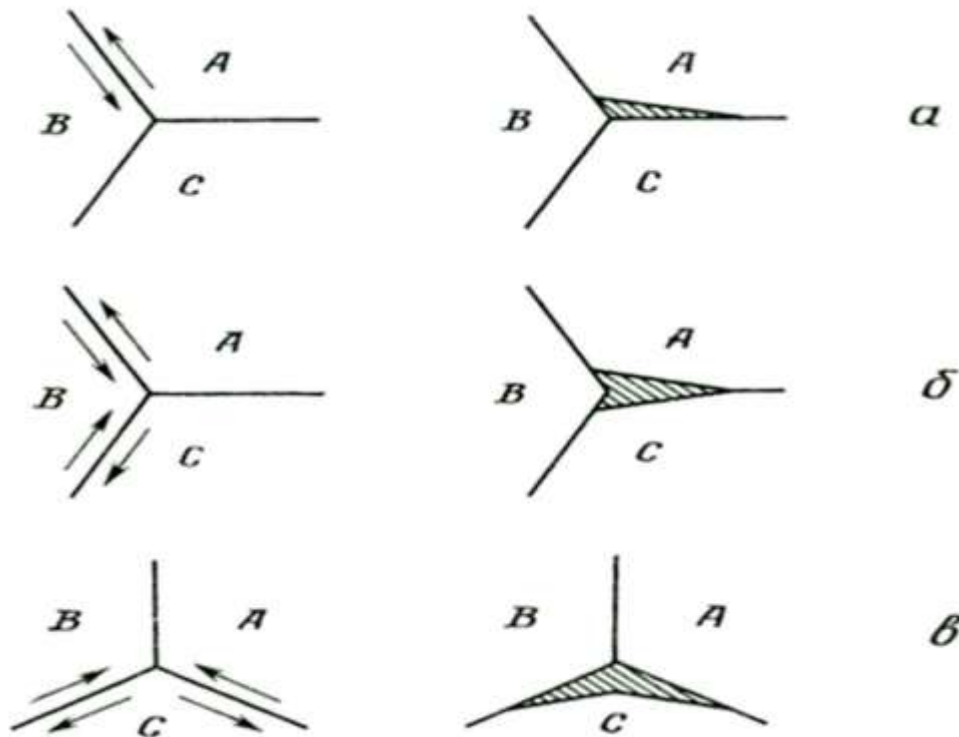


Figure 1. Mechanisms of crack formation at the intersection of three boundaries

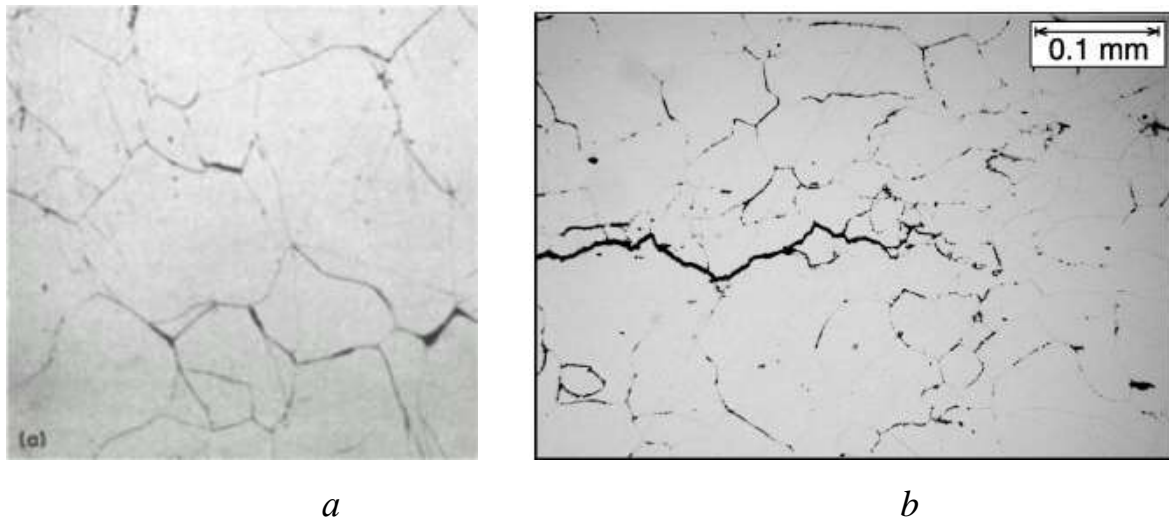


Figure 2. Primary wedge-shaped cracks in stainless steel (316N) (a) and their merging into a main crack (b).

The second pathway for grain boundary crack formation was first observed by Greenwood et al., who discovered small spherical pores at grain boundaries in a number of metals and alloys at the onset of the third stage of creep. These pores (O-shaped cracks) can be circular or elliptical in cross-section; they gradually increase in number and size during the third stage of plasticity (Fig. 2) [5, 6].

At low temperatures, observations show that the pores are typically spaced approximately $1 \mu\text{m}$ apart and have a diameter of no more than $1 \mu\text{m}$.

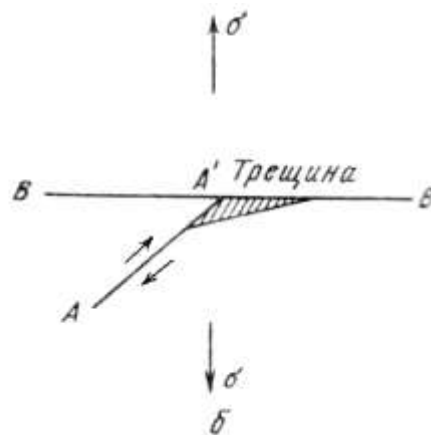


Figure 3. Wedge-shaped cracks resulting from creep of Ti alloy (a) and the diagram of their formation (b)

There may be several causes for the formation of pores at boundaries. Clusters of lattice dislocations in front of a boundary and sliding along stepped boundaries create stress concentrations, which in turn trigger localized vacancy flows. Vacancies form complexes, which, by absorbing new vacancies, grow into pores.

Let's consider the influence of some important factors on these two types of fracture.

The influence of temperature. Since grain boundary sliding increases with increasing temperature, it is expected that the tendency for intergranular cracks to form will also increase. Moreover, at high temperatures, a transition from V-shaped cracks to O-shaped cracks occurs. With increasing temperature, the number of pores per unit boundary length also increases; this has been shown to be related to the degree of development of the grain boundary fracture [7, 8].

Some experiments have found that the distribution density of pores located along grain boundaries decreases at very high temperatures; this is the result of grain boundary migration, which thus moves away from the pores that formed previously at them.

The influence of stress. It is often difficult to separate the effects of stress and temperature, but in general, at a constant temperature, a decrease in stress favors the formation of pores to a greater extent than V-shaped cracks. The greater the stress at a given temperature, the shorter the time required for intergranular fracture—this is a general rule for the behavior of metals during plasticity. Since high stresses promote V-shaped fracture, it follows that this type of crack grows faster than fracture by pore coalescence [10, 11].

The type of stress significantly influences pore formation and the region where they arise. Experiments with bicrystals show that stresses normal to the boundary

surface do not cause pore formation, as in this case the boundary is not subjected to shear stress, and thus, slip along the boundary does not occur. On the other hand, if slip occurs along a grain boundary, the imposed tensile stress often promotes pore formation [12].

CONCLUSIONS: Pore formation during tensile creep testing occurs primarily along boundaries located at angles of 60° to 90° to the tensile axis. However, in some cases, they form at boundaries located at smaller angles, and sometimes even parallel to the tensile axis. Compressive stresses generally help reduce the number of cracks that form, but do not completely eliminate their occurrence. Under hydrostatic compression imposed on the tensile specimen, pore formation is greatly hindered.

REFERENCES

- [1]. Кайбышев О.А., Валиев Р.З., Граница зерен и свойства металлов. М.Металлургия, 1987, 212с
- [2]. Астанин В.В., Кайбышев О.А., Салищев Г.А. Роль зернограницного проскальзывания и миграции границ зерен в сверхпластической деформации сплава Zn-0,4% Al. Изв. Вузов, Цветная металлургия, 1975.
- [5]. A. Djuraev, B.N. Davidbaev, A.S. Jumaev. Improvement of the design of the belt conveyor and scientific basis for calculation of parameters. Global Book Publishing Services is an International Monograph & Textbook Publisher. Copyright 24 may 2022 by GBPS. 10.37547/gbps – 03. 1211 Polk St, Orlando, FL 32805, USA. – 151 p.
- [3]. И.Н. Нугманов, Х.Х. Бобоев, З.С. Тураева Использование эффекта сверхпластичности в обработке металлов давлением// Композиционные материалы. 2022. №1. С. 79-81.
- [7]. Djuraev, A., Jumaev, A.S., Abduraxmanova, M.M. Analysis of the results of physical and mechanical experimental studies of the modernized belt conveyor. Journal of

- Physics: Conference Series, 2023, 2573(1), 012012.
<https://iopscience.iop.org/article/10.1088/1742-6596/2573/1/012012>
- [4]. Хоником В.Р. Пластическая деформация металлов. М: Мир 1972,408с.
- [8]. A. Djuraev, Sh. S. Khudaykulov, A. S. Jumaev. [Development of the design and calculation of parameters of the saw cylinder with an elastic bearing support jin.](#) International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-5, January 2020. <https://www.ijrte.org/portfolio-item/E6952018520/>
- [9]. Jumaev, A., Istablaev, F., Dustova, M. Development of the theory of calculation of constructive and rational parameters of belt conveyor roller mechanisms. AIP Conference Proceedings, 2022, 2467, 060025.
https://api.scienceweb.uz/storage/publication_files/9737/26397/666af69e34968
- [10]. Djuraev, A., Jumaev, A.S., Ibragimova, N.I., Turdaliyeva, M.Y. Analysis of the dynamics of a belt conveyor with composite guide rollers and elastic elements. Journal of Physics: Conference Series, 2023, 2573(1), 012026.
https://api.scienceweb.uz/storage/publication_files/9737/26378/666ad94ba5c1b
- [11]. Tilabov, B., Jumaev, A., Sherbutaev, J., Normurodov, U., Salimov, G. Testing of heat-treated surfaced samples and machine parts for hardness and wear resistance. E3S Web of Conferences, 2024, 548, 03014. https://www.e3s-conferences.org/articles/e3sconf/abs/2024/78/e3sconf_agritech-x_03014/e3sconf_agritech-x_03014.html
- [12]. Jumayev A.S., Abduraxmanova M.M. [Modernizatsiya qilingan tasmali konveyyer rolikli mexanizmlarining tajribaviy tadqiqot natijalari tahlili.](#) Scientific Journal of Mechanics and Technology. ISSN 2181-158X, volume 6, Issue 1, 2025.
- [13]. Djuraev, A. Jumaev. [Providing the development of new designs for the design of the roller mechanism transmitting rotational motion in belt conveyors.](#) International

Journal of Emerging Trends in Engineering Research. ISSN 2347 – 3983. Volume 8.
No. 9, September 2020.

- [14]. A.S. Jumaev, A. Djuraev, M.M. Abduraxmanova. [Analysis of the influence of the properties of oil products on the performance of belt conveyor guide roller mechanisms](#). Harvard Educational and Scientific Review International Agency for Development of Culture. Vol.2. Issue 2 Pages 44-52. 2020.
- [15]. A.S. Jumaev, A. Djuraev, A.N. Pushanov. [Development of models of recession of defactory states of components as a result of external loads of belt conveyor drums](#). Harvard Educational and Scientific Review International Agency for Development of Culture. Vol.2. Issue 2 Pages 36-43. 2020.
- [16]. A.D. Djuraev, A.S. Jumaev. [Study the influence of parameters of elastic coupling on the movement nature of support roller and rocker arm crank-beam mechanism](#). International Journal of Advanced Research in Science, Engineering and Technology Vol. 6, Issue 6, June 2019.
- [17]. A. Jumaev, Dj. Khusanova, I. Turabov. The influence of the properties of oil products on the operation of belt conveyor guide roller mechanisms in mining industry enterprises. World international conference on science, technology and education. Volume-1, Issue-2, 2026.
<https://www.globalconferencehub.org/index.php/ste/article/view/279>
- [18]. Dj. Khusanova, A. Jumaev, I. Turabov. Development of a new design of a belt conveyor guide roller mechanism and calculation of vibration amplitude. International conference on science, innovation and global development. Volume-1, Issue-2, 2026.
<https://www.globalconferencehub.org/index.php/sigd/article/view/278>

- [19]. A. Jumaev, M. Abdurakhmanova, A. Shakirbekov. Analysis of vibration phenomena of belt conveyor roller mechanisms. International conference on science, innovation and global development, Volume-1, Issue-2, 2026.
<https://www.globalconferencehub.org/index.php/sigd/article/view/224>
- [20]. A. Jumaev, M. Abdurakhmanova, M. Abduraximova. Prospects for creating and improving resourcesaving design solutions for the main elements of a belt conveyor. International conference on science, innovation and global development, Volume-1, Issue-2, 2026.
<https://www.globalconferencehub.org/index.php/sigd/article/view/223>
- [21]. A. Jumaev, M. Abdurakhmanova, D. Abdullaev. Creation of modern technologies for strengthening the working surface of the details of the belt conveyor roller mechanism. International multidisciplinary science conference. Volume-1, Issue-2, 2026.
<https://www.globalconferencehub.org/index.php/ms/article/view/213>
- [22]. A. Jumaev, M. Abdurakhmanova, I. Esenbaev. Development of a method for determining and calculating loads appearing on belt conveyor guide roller mechanisms. World international conference on science, technology and education. Volume-1, Issue-2, 2026.
<https://www.globalconferencehub.org/index.php/ste/article/view/215>
- [23]. A. Jumaev, M. Abdurakhmanova, B. Umirzoqova. Vibration analysis event of guide roller mechanisms from belt conveyors. Global scientific conference on multidisciplinary research. Volume-1, Issue-2, 2026.
<https://www.globalconferencehub.org/index.php/mr/article/view/214>
- [24]. A.S. Jumaev, A.B. Uralov, Sh.A. Karimov. Determination and calculation of gravity stresses arising in the working zones of belt conveyor drums during the

interaction with the belt. Universal journal of technology and innovation. ISSN 2992-8842. Volume 4, Issue 32 January 2026.

<http://sr-journals.org/index.php/UJTI/article/view/804>.

[25]. A. Jumaev, R. Rakhimova. Design and calculation of parameters of gear transmissions with variable parameters and flexible elements. World international conference on science, technology and education. Volume-1, Issue-2, 2026.

<https://www.globalconferencehub.org/index.php/ste/article/view/122>

[26]. A. Jumaev, R. Rakhimova. Improvement of the design and justification of the parameters of mechanisms of composite guide rollers of belt conveyors. International conference on science, innovation and global development. Volume-1, Issue-2, 2026.

<https://www.globalconferencehub.org/index.php/sigd/article/view/121>

[27]. A.S. Jumaev, G.I. Salimov, M.M. Musayeva. Analysis of the changes in drum angular velocity and driver load in a belt conveyor system in connection with technological resistances. Universal journal of academic and multidisciplinary research. ISSN 2992 – 8788. Volume 4. Issue 32. January 2026.

<http://sr-journals.org/index.php/UJAMR/article/view/784>

[28]. A.S. Jumaev, G.I. Salimov, I.T. Polatova. Calculation of vibrations of belt conveyor roller mechanisms and their mathematical model. Universal journal of technology and innovation. ISSN 2992-8842. Volume 4. Issue 32. January 2026.

<http://sr-journals.org/index.php/UJTI/article/view/783>