ON THE ISSUE OF IMPROVING THE STRUCTURE OF TOOL STEELS

Igor Stepankin[1], Dmitry Kuis[2], Abdrakhman Naizabekov[3],
Evgeniy Panin[4], Evgeniy Pozdnyakov[1], Sergey Lezhnev[3]

[1]Pavel Sukhoi State Technical University of Gomel
Oktyabrya av. 48, Gomel, 246746, Belarus
[2]Belarusian State Technological University
Sverdlova str. 13a, Minsk, 220006, Belarus
[3]Rudny industrial Institute, 50 let Oktyabrya str. 38
Rudny, 115000, Kazakhstan
E-mail: sergey_legnev@mail.ru
[4]Karaganda Industrial University, Republic av. 30
Temirtau, 101400, Kazakhstan

Received 08 September 2021
Accepted 12 November 2021

ABSTRACT

The effect of carbide liquation on the local strength of T11302 and X165CrMoV12 ledeburite steels was studied. The features of the interaction of large carbide inclusions and a solid solution of alloys during the destruction of a composite material in which the lines of inclusions were located along and across the line of action of the tensile force, as well as at an angle of 45 degrees to it, were revealed. It is shown that in the manufacture of large matrices with a complex forming surface, the arbitrary orientation of carbides limits the durability of the tool in the manufacture of its working surface by methods of electro-erosion treatment. The use of triple reforging as a preliminary operation for processing the workpiece significantly increases the operational characteristics of the material by reducing the influence of carbide liquation.

Keywords: tool steel, carbide liquation, triple reforging, stamp tool.

INTRODUCTION

The structural components of alloy steels include solid solution crystals that are in a mechanical mixture with various chemical compounds, most of which are carbides. The main carbide of iron-carbon alloys is cementite. Strong carbide-forming elements of alloy steels significantly change the stoichiometry and other characteristics of the excess phases. Compounds of the MeC, Me_2C, Me_6C_3 and $Me_{23}C_7$ types can be formed by chromium, molybdenum, tungsten, vanadium and other metals located to the left and below iron in the periodic table of D.I. Mendeleev [1]. These complex carbides are characterized by increased hardness and heat resistance, but, like cementite, they exhibit high brittleness, which increases with increasing crystal sizes of these phases. The distribution of carbide liquation in the alloy steel billet depends on the level of alloying of the alloy, the size of the billet and the degree of processing of its structure in the metallurgical processing of the ingot. In the vast majority of cases, machine-building and tool production has to deal with a billet, the macrostructure of which is formed during the rolling process. After it, as a rule, there is a characteristic line-by-line liquation of the carbide phase, accompanied by anisotropy of the properties of both the workpiece and the future part. The noted effect is quite strongly manifested in the manufacture of heavy-loaded die and other tools from tool steels of the ledeburite class. The viscosity and strength of local volumes of metal is significantly reduced in the central-axial zones of the rolled workpiece.

One way to reduce the anisotropy of high-alloy steels and increase the local strength of the metal is to reforge workpieces, which increases the complexity of manufacturing a particular product, but increases the mechanical properties of the material. The expediency of using preliminary thermo-mechanical treatment is the subject of constant discussion. This state of affairs is due to the ambiguous result of reforging in relation to high-alloy tool steels containing chromium, tungsten and other elements capable of intensive burnout during processing. An additional negative factor is the rather high labor intensity of the forging operation, the productivity of which depends on the skill of the blacksmith.

The noted disadvantages are often the justification for refusing to carry out reforging in favor of using steels with a pronounced textural morphology. Such approach is promising in terms of the application of possible options for surface hardening of the alloy with the formation of a modified layer zone on its outer surface. However, the positive effect of the modification is limited only by the thickness of the formed layer, which does not always meet the requirements of the scale factor in terms of the stress-strain state of the working surface of the part. This aspect is most relevant for such parts, the working surface of which is affected by pulsating contact stresses. Under such conditions, contact fatigue cracks will originate in the sub-layer (under the hardened layer), and the presence of inclusions will provoke their formation [2 - 4]. This makes it relevant to research aimed at studying the relationship of the metal texture with its fracture mechanism and properties, as well as evaluating the significance of the three-to five-fold reforging process for the possibility of improving the operational characteristics of the material, especially in terms of its ability to resist the nucleation and propagation of cracks.

EXPERIMENTAL

Objects and methods of research

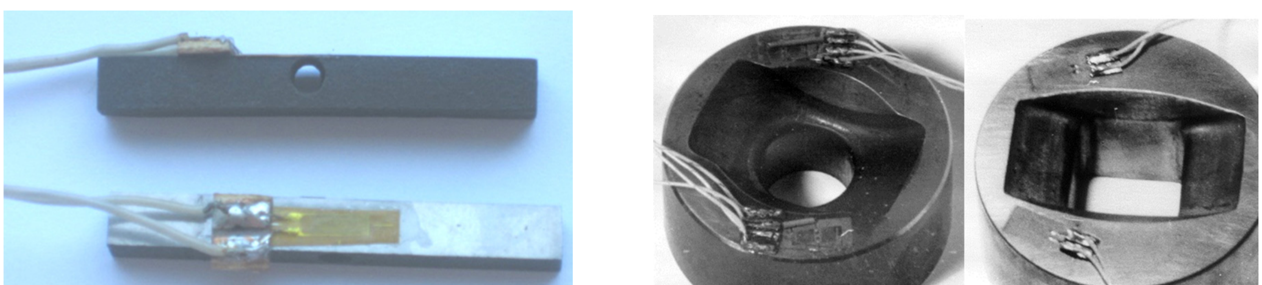
The objects of research were high-speed T11302 and semi-heat-resistant stamped X165CrMoV12 ledeburite steels. To identify the influence of structural features on the characteristics of these alloys, laboratory samples and cold-shrink matrices were tested (Fig. 1).

Prismatic samples were cut from a blank with a diameter of 70 mm. The carbide inhomogeneity of the metal corresponded to a 4 - 5 point according to GOST 19265-73 and GOST 5950-2000. The longitudinal axis of the samples was oriented so that it was located along the lines (0 degrees), across the lines (90 degrees) and at an angle of 45 degrees to the lines of carbide inclusions. The hole in the central part of the sample is designed to create a stress concentration in thin layers between the inner surface of the hole and the outer surface of the sample.

Experimental studies were carried out on the INSTRON 5000 test stand according to the scheme shown in Fig. 2. Cylindrical pads made of T11302 steel with a diameter of 2 mm were used as supports. The hardness of the supports was 63HRC. The lower supports were fixed on the surface of the samples at the same distances from the center of the hole. The load application was carried out over the center of the hole. To eliminate the possibility of uncontrolled displacement of the linings, they were fixed with glue. As a result of bending of the sample when an external load is applied, an almost flat strain state occurs on its lower surface (Fig. 3). In order to study the destruction nature on the surface of one of the samples, a coordinate grid with a step of 100 microns was applied in each batch after polishing. Load cells were placed on the remaining samples, the measuring base of which was located parallel to the long sides of the sample.

RESULTS AND DISCUSSION

The studies from [5] show that the orientation of the carbide lines in relation to the load application line has a significant effect on the strength of the studied steels (Fig. 4). The density of the distribution of inclusions and their dimensions depend on the diameter of the workpiece from which the tool is made. According to GOST 19265-



a) b)

Fig. 1. Objects of research: a - samples for the stress-strain state study of the surface layers of ledeburite steels; b - matrices for cold landing of the head of railway bolts.

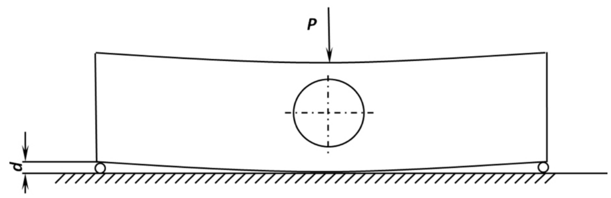


Fig. 2. Scheme of deformation of the experimental sample.

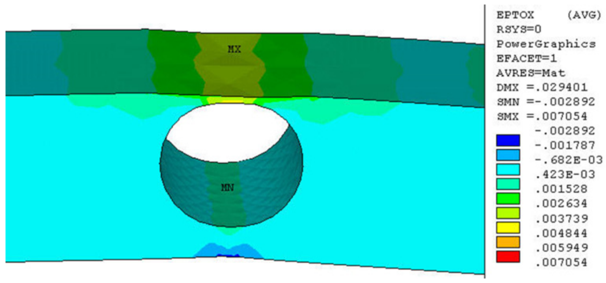


Fig. 3. Distribution of linear deformations on the studied surface of the experimental sample (numerical simulation).

73 and GOST 5950-2000, which regulate the carbide inhomogeneity score of the most famous representatives of the ledeburite steels T11302 and X165CrMoV12, the production of a die tool from blanks with a diameter of more than 40 mm leads to the preservation of large carbide particles in the tool structure. Their length is about 20 micrometers, and the size in diameter is 2 - 3 micrometers. In the manufacture of matrices with a complex profile surface, the most convenient method is electro-erosion treatment, the orientation of carbide particles at the place of their exit to the engraving is characterized by an arbitrary arrangement (Fig. 5). Numerical modeling has shown that the most dangerous orientation is the location of inclusions at angles of 0, 45 and 90 degrees to the outer surface of the material undergoing stretching [6].

Experimental results of evaluating the strength of T11302 steel with different orientation of texture formations (Fig. 6) showed that the highest strength (1660 MPa) was obtained by samples with a longitudinal orientation of carbide stitches. The value of the destructive stress in the plane stress state differs significantly from the one given in [5], obtained during the bending test, which is 2300 MPa. The destructive stress of the samples with a transverse arrangement of carbide stitches was about 1380 MPa, and 1420 MPa when the carbide stitches were arranged at an angle of 45 degrees.

The change in the orientation of the carbide stitches has a significant effect on the interaction of the carbide

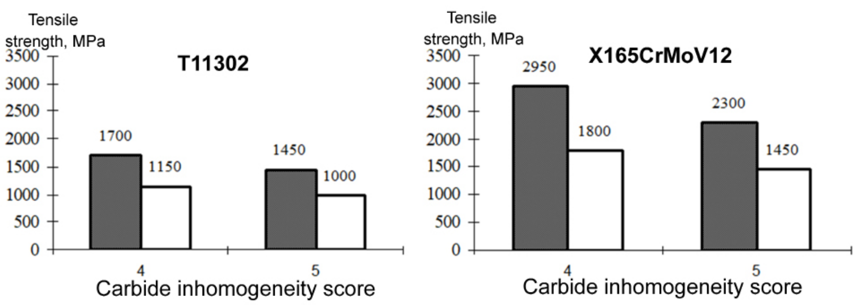
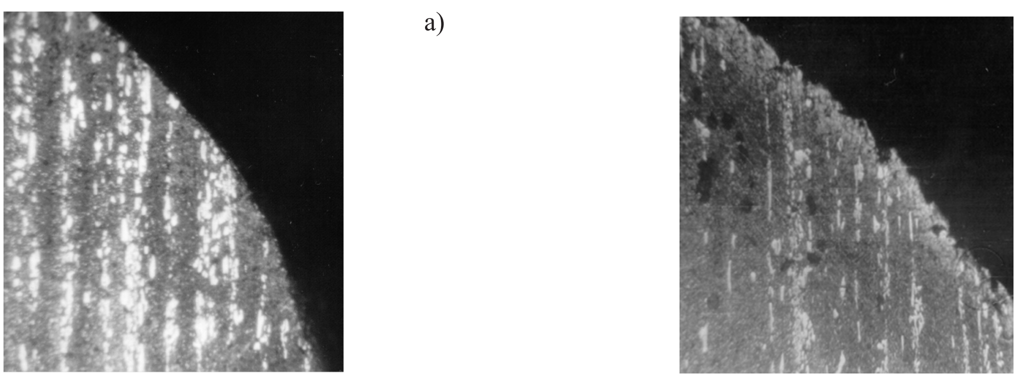


Fig. 4. Influence of the carbide inhomogeneity score on the tensile strength of high-alloy steels during bending: ■ - longitudinal arrangement of fibers, □ - transverse arrangement of fibers.



a) b)

Fig. 5. Microstructure of the surface layer of cold-shrink matrices, the forming surface is obtained by the electro-erosion method from ledeburite steels, magnification x100: a - X165CrMoV12; b - T11302.

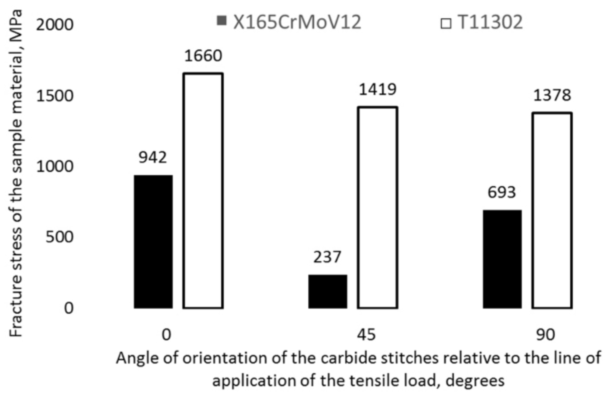


Fig. 6. Dependence of the destructive stress on the orientation of the carbide lines with respect to the horizontal surface of the test sample.

phase and the metal matrix of the alloy. With the transverse arrangement of the textural lines of the carbide phase, the destruction of the material occurs as a result of the propagation of a peppered crack (Fig. 7(a)), which slightly deviates from the original direction during growth (Fig. 7(b-c)). The crack passes along the border of the accumulation of carbide particles (Fig. 7(d)). Its progress is not accompanied by a pronounced intra-crystalline plastic deformation in a solid solution of steel.

With a different arrangement of the carbide lines, it was found that the process of crack nucleation is preceded by the intensive formation of sliding lines due to dislocation processes in the solid solution surrounding the carbide inclusions. Local foci of concentration of sliding lines are located in the vicinity of carbide lines located at an angle of 45 degrees (Fig. 8(a)). The initial cracks originate at the boundaries between the two phases, and only at the moment of their progress in the sample material begin to separate it in cross-section (Fig. 8(b)).

The destruction of samples with carbide lines located parallel to the outer boundary of the material occurs by separation along the cross section. Numerous sliding lines, whose density increases as they approach the edge of the main crack, fill the entire space of the matrix material between the zones of accumulation of carbide inclusions (Fig. 9). The distribution of local deformations of the material is much more uniform than in the cases discussed above. This feature emphasizes the ability of all structural components of

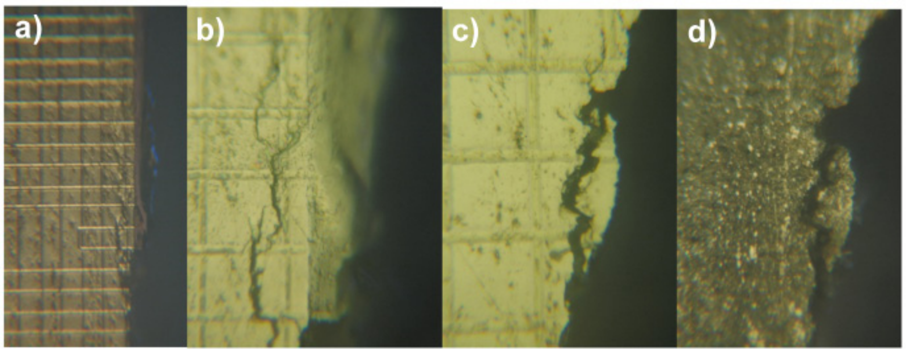


Fig. 7. Destruction nature of T11302 steel samples with a transverse arrangement of carbide stitches relative to a horizontal surface.

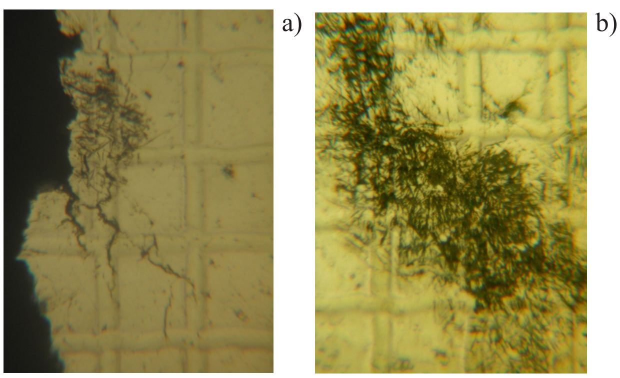


Fig. 8. Sliding lines in the vicinity of carbide inclusions located at an angle of 45 degrees to the line of application of an external tensile load: a - accumulation of sliding lines in the area of carbide stitches, b - initial cracks in the samples.

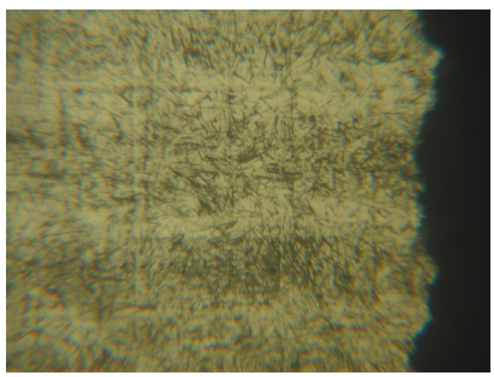


Fig. 9. Sliding lines on the surface of the T11302 steel sample in the vicinity of the fracture.

the material to realize greater resistance to external tensile load, which provides an increase in local strength up to 1660 MPa. This value is significantly inferior to the strength limit given in [5], which is due to the difference in the methods for determining the strength characteristics.

An analysis of the test results of X165CrMoV12 steel using a similar method showed that the strength of this alloy is significantly lower than that of high-speed steel T11302. This trend, which was also noted in [5], was clarified regarding the comparison of the strength characteristics of two metals in which the lines of carbide inclusions are located at an angle of 45 degrees to the line of application of external tensile stress. In particular, the test results show that samples made of X165CrMoV12 steel are destroyed at a voltage of about 237 MPa, while for high-speed steel this indicator was 1419 MPa, almost 6 times more. In our opinion, this difference can be explained by the different degree of alloying of the solid solution of these alloys [7]. This feature has increased the textural influence on the local strength of the material and the mechanism of its destruction. As can be seen from Fig. 10, a sufficiently large initial crack, the length of which significantly exceeds the critical value of such a defect from the standpoint of linear mechanics of destruction of tool materials [8], occurs in the direction of the textural pattern of the alloy and then develops in the cross section. The obtained results are an experimental confir-mation of the conclusions of numerical modeling given in [6]. Therefore, the use of alloy steels for the manufacture of large die tools should take into account the influence of textural features of the material on its local strength. Such an intermediate conclusion dictates the need for increased attention to technological alterations of die steel blanks, in which a significant reduction in the size of carbide inclusions is achieved, as well as the elimination of scribbling in their location. Currently, there are two main technologies for solving this problem. One of them is based on the principles of powder metallurgy and providing high uniformity of the workpiece significantly increases the cost of the material. The second technology is a traditional thermo-mechanical processing – three-five-fold reforging, which is widely used in many enterprises in the conditions of basic procurement production, and does not require significant additional costs.

Based on the formulated concept, two batches of cold-shrink dies were made for stamping bolts of railway fasteners (Fig. 1(b)). The initial structure of the blanks of this tool, made of X165CrMoV12 and T11302 steels by the method of electro-erosion treatment, is shown in Fig. 5. The score of carbide inhomogeneity is characteristic of the initial blanks of matrices with a diameter of 80 mm. To clarify the influence of the possibility of increasing the performance characteristics of the tool due to thermo-mechanical processing of the material of the workpieces, a three-fold reforging was carried out, which provided a significant change in the texture pattern of the alloy.

Industrial testing of the tool showed a two-or more-fold increase in durability in the manufacture of bolts of railway fasteners M22x50, M22x70, M22x140 (GOST 16016-79) on the BV-6 automatic machine of the company “NEDSCHROEF” (Belgium). The analysis of the structure of the surface layer of the tool after failure showed that the main cracks originating at the boundary between the carbide inclusions and the metal matrix became the causes of its destruction (Fig. 11). However, in the case of using a reforged workpiece, small carbides created a lower stress concentration, which provided an increase in the durability of the tooling.

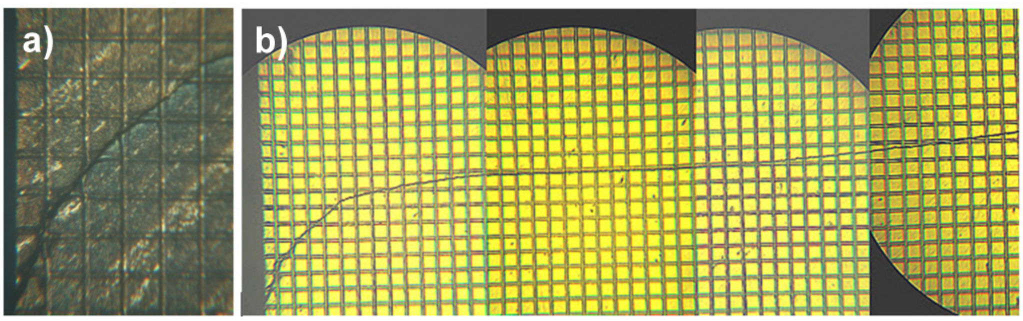


Fig. 10. Zone of origin (a) and propagation (b) of a crack in samples made of X165CrMoV12 steel with the orientation of the carbide lines at an angle of 45 degrees to the line of action of the destructive stress.

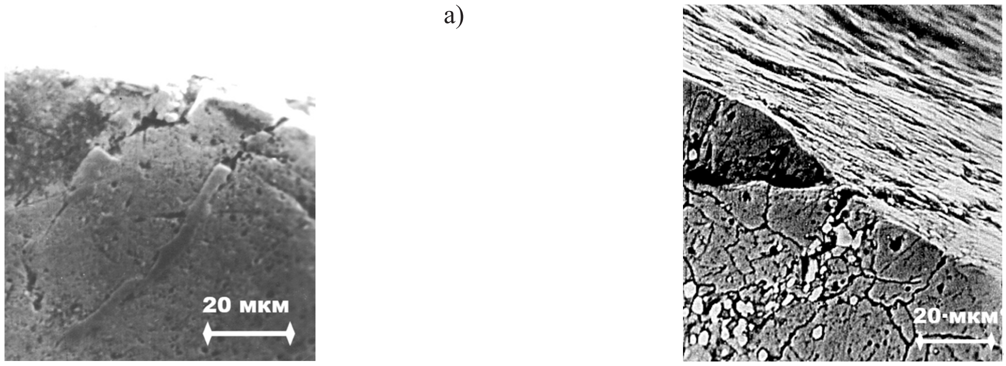


Fig. 11. Microstructure of the surface layer of cold-shrink matrices made of T11302 steel, the forming surface is obtained by the electro-erosion method from rolled (a) and reforged (b) billet.

The obtained results indicate the prospects of using reforging of tool steels to increase the durability of die tooling. Based on the studied features of the destruction of composite steels, it can be concluded that it is possible to significantly increase the resistance of a wide range of die tooling, including by manufacturing it from steels with a lower content of carbide-forming alloying elements. This approach will reduce the influence of carbide liquation and the textural structure of the starting material with minimal reforging costs, compared with high-speed and semi-heat-resistant steels that are quite labor-intensive for this operation.

CONCLUSIONS

Experimental studies of the effect of the texture of T11302 and X165CrMoV12 ledeburite steels on their local strength have been carried out. It is shown that the line arrangement of large carbide particles in blanks with a diameter of 80 mm or more, obtained by rolling, has a significant softening effect on the material. The results of the experiment explain the low durability of a large die tool, the engraving of which was obtained by methods of electro-erosive processing without preliminary alteration of the workpiece material. Using the example of T11302 steel, it is shown that the use of three-fold reforging of the material at the procurement stage allows to eliminate the main reason for the decrease in the local strength of the alloy - the output of large carbide inclusions on the working surface of the tool and increases its durability by more than two times.

Acknowledgements

This study was funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant № AP09259236).

REFERENCES

1. A.P. Gulyaev, Metal Science, Moscow, Metallurgy, 1986, (in Russian).
2. L. Chunhui, Modeling the Behavior of Inclusions in Plastic Deformation of Steels, Doctoral Thesis, Royal Institute of Technology, Stockholm, 2001.
3. D. Nelias, M.L. Dumont, F. Champiot, A. Vincent, D. Girodin, R. Fougeres, L. Flamand, Role of inclusions, surface roughness and operating conditions on rolling contact fatigue, Journal of Tribology, 121, 2, 1999, 240-251.
4. A. Beheshti, M.M. Khonsari, On the prediction of fatigue crack initiation in rolling/sliding contacts with provision for loading sequence effect, Tribology International, 44, 2011, 1620-1628.
5. V.M. Scheinerman, Steels for cold-forming dies, Riga, Latvian republican institute of scientific-technical information and propaganda, 1969, (in Russian).
6. V.M. Kenko, I.N. Stepankin, On the issue of taking into account the structural features of tool steels in the manufacture of cold-shrink tooling matrices, Casting and Metallurgy, 4, 2004, 110-116 (in Russian).
7. I. Artinger, Tool steels and their heat treatment, Moscow, Metallurgy, 1982, (in Russian).
8. L.S. Kremnev, Critical coefficient of stress intensity and fracture toughness of high-strength tool materials, Metal Science and Heat Treatment, 38, 1, 1996, 33-37.