THIN-WALLED STEEL BILLETS PRODUCTION QUALITY MANAGEMENT

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ABSTRACT

This article analyzes the advantages of thin-walled steel cylindrical structures obtained by means of rolling and emphasizes the important role of technological heredity laws at all stages of their production. The authors estimate the state-of-the-art of thin-walled pipes production, analyze technical requirements for their quality and highlight the connection between the technological heredity and steel thin-walled pipes quality indicators. The initial ovality and curvature of steel billet axis, inherited from rolling or extrusion and fixing forces occurring under any technological influence cause billet deformation and a centering error before machining, assembling or controlling stages. Functioning of steel thin-walled cylindrical billets is substantially determined by the accuracy of their geometrical parameters, with wall thickness being the dominating one.

The results of the statistical analysis of key geometrical parameters' accuracy have shown that the outer diameter of thin-walled steel pipes has the lowest accuracy. Determination of error type by means of harmonious analysis has given grounds to assume that they are caused by technological system deformations. The research of technological system rigidity has shown that the billet and the mandrel are the "weakest" points, while billet axis' and walls' deformations play the dominating role in causing the overall processing error. Therefore the authors have experimentally investigated the rigidity of machines and devices. It has been established that form errors in longitudinal and cross sections are formed as a result of a joint deflection of steel thin-walled billet axis together with the mandrel. The billet wall deflection during machining also plays a significant role. Rigidity research of mandrels of various types has shown that billet form errors in the longitudinal direction are connected with the couplings in mandrels' structures. Another feature of mandrels' influence on the accuracy of processing is such a specific error as a non-uniformly focused ellipse in the cross-section. This phenomenon is explained by changing rigidity of the mandrel in various radial directions.

Keywords: quality management, thin-walled steel pipe, thin-walled cylinders machining, rolled pipe billet, form error, machining error, machines and devices rigidity, technological system.

INTRODUCTION

Thin-walled steel cylindrical structures obtained by rolling provide high strength and density of the layout and are widely used in a variety of industries and, most importantly, in the key areas of oil production, aircraft and rocket construction, cryogenic machinery and cool-ing systems, space and military industrial development.

In precision engineering, technical requirements for thin-walled steel pipes surface dimensions' accuracy, their shapes and mutual arrangement reach micrometers and micrometer fractions. For such parts, all manufacturing stages are important, and the laws of technological heredity play an important role in technological process

development. A.M. Dalsky, A.S. Vasiliev, A.G. Suslov, A.S. Yamnikov, V.V. Semin and other scientists have dealt with the issue of technological heredity [1, 2].

Hereditary ties both increase and decrease quality indicators, therefore it is important to take into account the influence of their heredity on the characteristics of the billet at every stage of thin-walled steel pipes' manufacturing [3]. The phenomenon of technological heredity makes it possible to form the best technological environments and to change the properties of the product as desired. Some of the most important factors affecting the quality of pipes are the initial errors (ovality and curvature of the axis), location scheme and billet fixing forces in machining attachment [4].

The main contradiction between the processing of thin-walled steel cylindrical billets and billet quality is that locating and fixing of the rolled pipe billet takes place under the conditions of ovality, axis curvature, variability of the wall thickness, and the low rigidity and surface hardness of the billet [5, 6]. The initial ovality and curvature of the billet axis inherited from the rolling or extrusion technology and the fixing force for any technological action affect the deformation of the billet and cause the centering error before machining, assembling or controlling stages [7]. For thin-walled pipe parts, these errors in some cases exceed the limit and can withdraw the part from precision category.

Pipe form errors still affect the subsequent technological processes. For example, at one of the machine-building enterprises an average of about 15 - 17 % of thin-walled pipe assemblies do not meet the draft requirement for a radial runout, despite the fact that all parts undergo quality control. Such assemblies are sorted and subjected to manual selection by a large number of high-skilled fitters. This increases labor intensity and reduces assembly performance. Applied technologies and equipment do not guarantee the accuracy of machining in obtaining parts from cold-drawn, progressive-shaped billets, having errors in the shape and the relative position of surfaces within the range of 15 - 16 degrees of accuracy. At another plant up to 6 % of assemblies do not withstand the specified excess pressure during hydrotests, and in 10 % of assemblies a one-sided gap in parts' joints is bigger than the permissible one when screwing them over a threaded tool joint.

National economy widely uses steel thin-walled cylindrical parts with a length-to-diameter ratio of 8 - 12

working under conditions of power and temperature impulse loads [8, 9, 10]. The papers of Russian and foreign authors consider functional effectiveness of such parts, which is largely determined by the accuracy of their geometric parameters, with the dominant influence of the wall thickness. Operation practice shows that, the destruction of parts occurs, mainly in places with the smallest wall thickness, regardless of the shape of the steel billet - cylindrical, or other type [11, 12]. These defects occur due to form errors at the external and internal surfaces and their relative location.

In this connection, we are interested in analyzing the production and processing of thin-walled cylinders and identifying the weakest links in the production cycle.

Research object and methods

A careful study of the accuracy of manufacturing thin-walled steel cylinders under conditions of effective mass production with single-cut processing and the results of a statistical analysis of basic geometric parameters accuracy have shown that the accuracy of the outer diameter is the lowest one. This can be caused by form errors in the longitudinal and cross sections [13]. The determination of error type with the help of harmonic analysis gave grounds to assume that they are caused by technological system deformation. Rigidity investigation of the technological system has shown that the "weakest" parts of the system are the billet and the mandrel, and billet axis and walls' deformations play the dominating role in causing the overall processing error.

Increasing the strength of thin-walled cylinders by increasing the wall thickness may not always be acceptable, as this leads to a sharp increase in metal consumption and product cost and, at the same time, to a reduction in other performance characteristics. Therefore, in critical cases in order to eliminate this contradiction, the steel billets are subjected to hardening heat treatment, usually by means of hardening followed by tempering.

The reliability of thin-walled cylinders, working only as pressure accumulators, is determined by the wall thickness accuracy. Fulfillment of this requirement is a condition sufficient for the normal operation of the product, therefore the accuracy of the remaining parameters is not regulated.

For cylinders having couplings with other structural elements at one surface, the requirements are set for the coupling surface and the minimum wall thickness.

For cylinders coupling with both surfaces, the requirements are set for the outer and inner surfaces and the minimum wall thickness.

In a number of cases, the operation of thin-walled cylinders takes place under conditions of nonstationary temperatures or axial rotation with large angular velocities. It is obvious that the wall thickness difference caused by form errors at the outer and inner surfaces and their mutual position leads to uneven temperature deformations, and also to the occurrence of a centrifugal force.

Enterprises that specialize in the mass production of thin-walled cylinders face certain difficulties due to the considerable length (L/D = 8 - 12) and low rigidity of such parts.

RESULTS AND DISCUSSION

Operation time distribution (Fig. 1) indicates that the maximum labor intensity is reached during the operations of roughing and finishing of the outer diameter.

Relatively little time is spent in operations 1, 5 and 8 due to the small length of the working stroke and joint transitions. A small period of time is spent on roughing of the outer diameter, compared with finishing time, due to the fact that the latter is carried out with the help of a double-edged adjustment and, naturally, with larger feeds than during the finishing.

During the finishing boring operation, high productivity is achieved by using a four-sided counter-bore together with smoothing elements. And, if the productivity of the above mentioned operations is high enough, the question of labor intensity reduction during the finishing

turning of the external surface remains open. All attempts to solve it to date have not taken effect yet.

But there are ways to increase productivity, namely:
 - reduction of the path of cutting tool and billet movement in relation to the working   feed;
 - reducing the number of transitions;
 - increasing feed and cutting speed [14].

The universal method for reducing the path of cutting tool relative movement is the use of multi-tool adjustments, i.e. an increase in the perimeter of simultaneously cutting blades participating in the work. When working on turning multi-cutting and hydrocopy semi-automatic machines the tools of the same type such as cutters are usually installed one after another at a certain interval along the generatrix of the billet. The operating conditions of thin-walled cylinders as a rule require them to be manufactured of alloyed steels that have undergone a hardening heat treatment. In these conditions, a significant increase in the cutting speed is possible only with the use of cutters equipped with modern abrasion resistant plates. Currently, for cutting the above said steels, tungsten-cobalt-based cutting materials continue to be widely used [14, 15]. The cutting process proceeds with intensive cooling [14, 16]. Otherwise, the heat released during cutting is concentrated in a small volume due to the thin wall of the part. This can lead to intense heating of the metal being processed and, as a result, undesirable changes in its structure.

Another way to increase the turning efficiency is to increase the feed rate. For finishing processes, this path is limited by the required surface roughness. In a number of cases, the use of cutters with a transitional
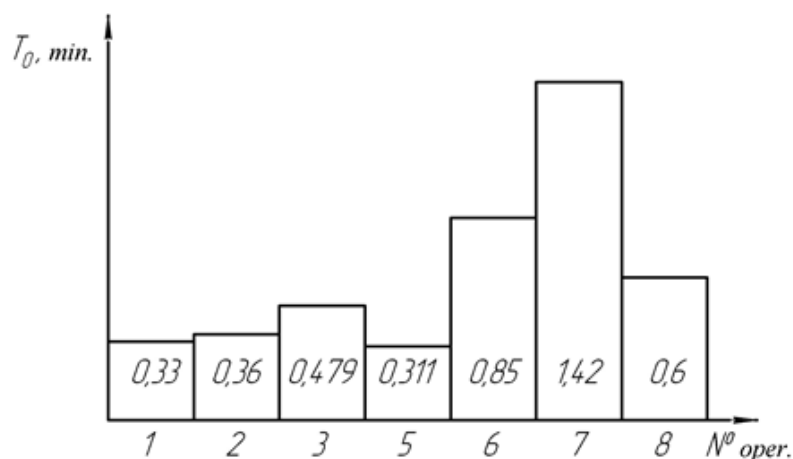

Fig. 1. Distribution of labor intensity of processing by operations.

cutting edge of a large radius or with a zero angle in the plan makes it possible to solve this problem [14, 17]. But, when processing thin-walled cylinders with low wall hardness an increase in the perimeter of the cutting edge and, as a consequence, the growth of cutting forces sharply reduces the accuracy of processing.

An attempt to reduce cutting forces due to the re-distribution of the allowance from finishing to roughing operations is also unacceptable for thin-walled cylinders. This is due to the fact that form errors, the magnitude of which reaches, and sometimes exceeds, the allowance for finishing occur during heat treatment as a result of warping.

When processing nonrigid parts, we must take into account a significant change in the strain values applied to different parts of the treated surface. Therefore, experimental studies of the errors that occur when machining nonrigid cylinders with a single-cut tool have been carried out. To assess the role of deformations of technological systems' main parts in the overall processing error, the rigidity of machines, devices and blanks was studied experimentally.
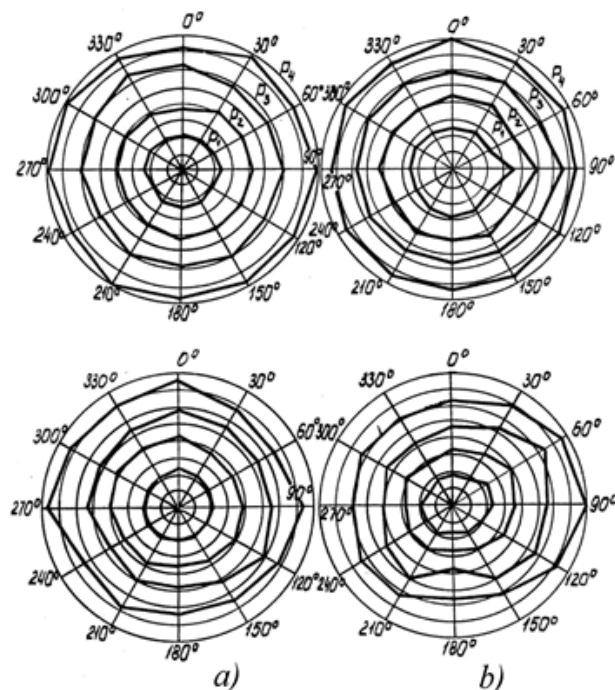
The static rigidity was measured by the traditional method in three machines having a different degree of wear of the front center, taking into account the temperature changes: at a temperature of 200°C; after 3 hours of operation of the machine at speeds of 1000 min^{-1}, when the temperature reached 600°C; and after 6 hours of operation, when the temperature reached 750°C.

The results of measurements showed:

a) the radial rigidity of the front and rear centers of the three machines under study is approximately the same, and the rigidity of the quill is on average four times less than the rigidity of the spindle (Fig. 2);

b) the change in the radial rigidity of the machine centers at various angular positions and the temperature of the headstock is insignificant;

c) the distribution of the rigidity of the longitudinal support along the length of the bed (Fig. 3) showed that in two machines at different positions of the transverse support the rigidity values near the headstock vary significantly. It is characteristic that it is at these points that the rigidity diagram has a pronounced nonlinear character. As a result of checking the gaps in the fastening points

Fig. 2. Polar diagrams of machine front (a) and rear (b) centers' deformation at P1 = 600 N, P2 = 1200 N, P3 = 1800 N, P4 = 2400 N; a) f1=0.008 mm, f2=0.016 mm, f3=0.024 mm, f4=0.032 mm; b) f1=0.040 mm, f2=0.080 mm, f3=0.120 mm, f4=0.160 mm.
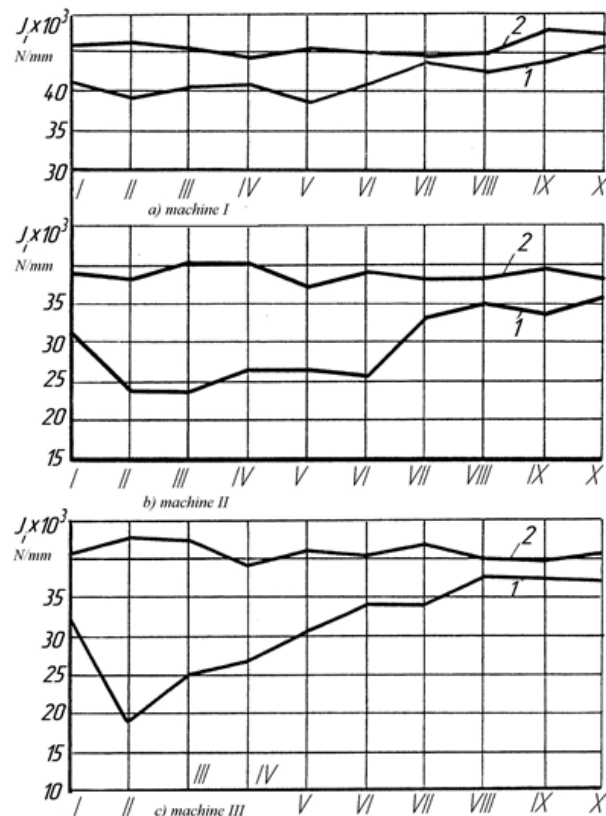

Fig. 3. Changing of the support group rigidity along the frame length.

between the support and the frame, it is established that for two machines the clearance under the rear clamping bars is variable for different positions of the support and varies from 0.03 to 0.08 mm. This phenomenon is explained by the considerable harmony in work of the guidepaths of the frame. In this case, the action of the cutting forces (with the maximum transverse support) creates a moment with respect to the front bearing part of the support.

An attempt to reduce the maximum gap led to the fact that in the extreme positions of the working stroke the support «jams» and the friction force in the rear guides increases sharply, which causes the twist of the support and sharply reduces the accuracy of the treatment.

When machining thin-walled cylinders of the class in question, standard expanding collet mandrel is used (Fig. 4).

The mandrels of type I (Fig. 4, a) are double-sided collets installed in the centers of the machine. The disadvantage of this design is that the billet contacts clamping elements in a narrow section at the ends where wall rigidity is minimal. This leads to errors connected with copying of the clamping elements' section. Therefore, such mandrels find application in the processing of rela-

tively rigid billets. To avoid this disadvantage, mandrels in which the billet contacts the clamping elements in the middle part of the billet are used. This is achieved by using mandrels with intermediate centers (Fig. 4b, c).

The desire to minimize the error associated with copying of the clamping elements' section leads to the creation of structures allowing the clamping force to be redistributed over a large area. Such mandrels are designed to have two or more double-sided collets.

Since the evaluation of the accuracy of the processing process requires consideration of mandrel deformation effect, it is necessary to have quantitative dependences of rigidity on the position of the applied force. In the papers of a number of authors, this problem is solved by considering the contact chain "body - collet - billet", where the body of the device is regarded as an absolutely rigid part. Such solutions may be acceptable for collet type I mandrels. But having intermediate elements in the construction, as is the case for mandrels of types II and III, the rigidity essentially depends on the number and quality of mandrel parts' joints, as well as their configuration and mutual position. Determining the rigidity of compound mandrels is theoretically a very laborious task, which at the same time gives approxi-
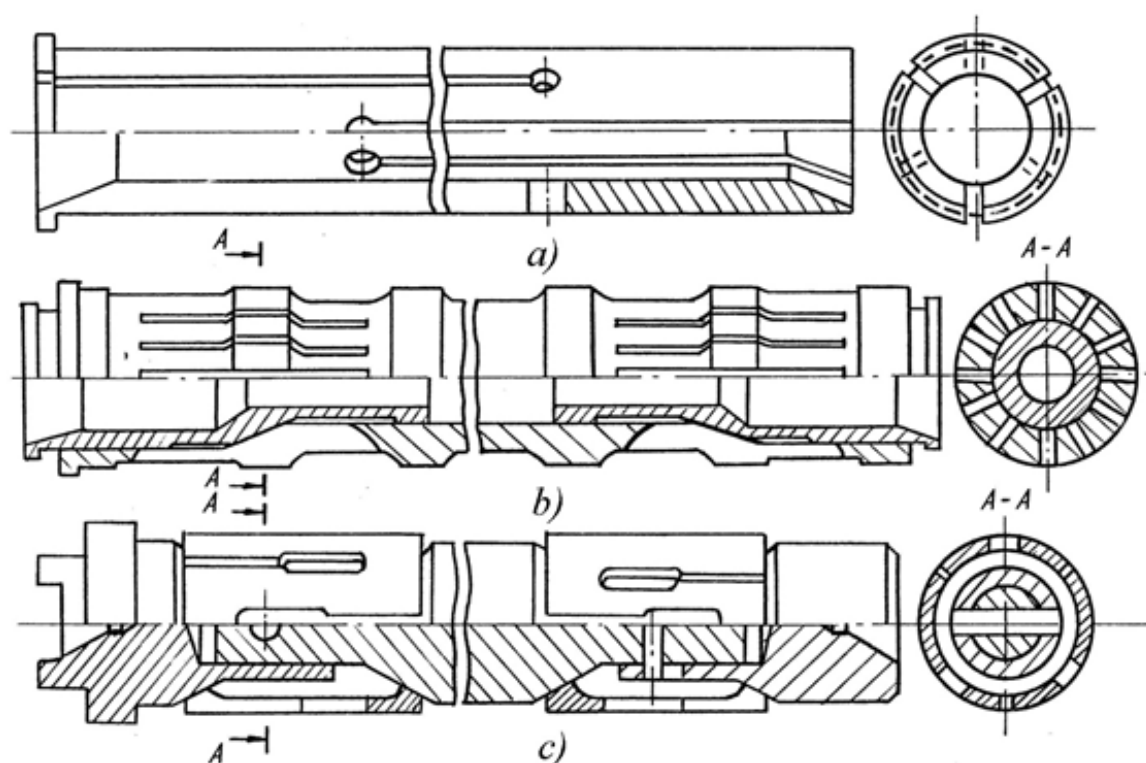

Fig. 4. Types of mandrels used for processing of thin-walled cylinders' outer surface.

mate results. Therefore, we experimentally studied the rigidity of mandrels of three types to obtain quantitative rigidity values and the character of their distribution in the longitudinal and cross sections. Three mandrels of each type were selected for measurement and rings with internal diameter equal to the diameter of the billet being fixed were put on the clamping elements. The mandrel was installed in the centers of the machine, then an axial force equal to the working force was applied, and rigidity was measured. Then the mandrel was rotated by 30°, and the measurement was repeated. Thus, the rigidity was determined in twelve radial directions. Similar measurements were carried out alternately in several sections along the axis of the mandrel.

Rigidity distribution along the axis is of a different nature and depends on mandrel type.

A characteristic feature for mandrels of types II and III is the presence of pronounced turning points, which can be explained by gaps in the junctions of structural elements. Thus, the nature of the rigidity distribution indicates that the size of the deflection of the mandrel along the length varies significantly and depends on the presence and nature of structure coupling. Elastic deformation of the mandrel parts in the investigated range of loads has practically no effect.

As shown by the results of the measurements, the deviation of rigidity in the radial directions has a significant value of 29 %, which can cause form errors in the cross section. On radial rigidity diagram it is easy to see local sections where the rigidity values have extreme deviations, both to the maximum and minimum values. Since such a pattern is observed only at the junctions of structural elements, this can be explained by coupling errors when the female or male part has a concavity or convexity. This phenomenon is explained by one of the most common form errors of billets with the cross section forming a non-uniformly focused ellipse.

Form errors analysis in the cross section shows that the existing mathematical tools of harmonic analysis do not allow us to identify the error of the "non-uniformly focused ellipse" as an independent one. In other words, the "non-uniformly focused ellipse" is the result of an ellipse and a trihedral summing. The section formed by the totality of the ellipse and the trihedral is similar to the section of the "non-uniformly focused ellipse", which can be described analytically only approximately using harmonic analysis.

CONCLUSIONS

On the basis of the conducted rigidity studies, form errors in the longitudinal and cross sections can be represented as a result of the joint deflection of the axis of the steel thin-walled billet together with the mandrel and deflection of the billet wall during processing.

Rigidity study of mandrels of various types has shown that billet form errors in the longitudinal direction takes place due to the presence of coupling in mandrel structures. Another feature of mandrel's influence on processing accuracy is such a specific error as a non-uniformly focused ellipse formed in the cross-section. This phenomenon is explained by the variable rigidity of the mandrel in different radial directions.

Data on the variation in rigidity along the length of the type I-III mandrel can be used to theoretically determine the processing errors and when turning with multi-cutters.

REFERENCES

1. A.G. Suslov, A.M. Dalsky, Scientific foundations of engineering technology, Moscow, Mashinostroenie, 2002, (in Russian).
2. A.M. Dalsky, A.S. Vasiliev, Technological heredity in machine-building production, Moscow: MAI Publishing House, 2000, (in Russian).
3. A.S. Yamnikov, O.I. Boriskin, O.A. Yamnikova, I.A. Matveyev, Technological inheritance of the properties of the initial billet in the accuracy parameters of extended axisymmetric parts, Chernye Metally (Ferrous metals), 2017, No 12, 50-56.
4. I.A. Matveyev, A.S. Yamnikov, O.A. Yamnikova, Accuracy of turning of the base surfaces of pipe-type thin-walled body parts, Journal of modern technologies, 2, 2. 2016, 56-62.
5. V.U. Grigorenko, S.V. Pilipenko, Variation in wall thickness of cold-rolled pipe, Steel in translation, 38, 9, 2008, 775-776.
6. M.A. Rozenbaum, I. Bazhukov, G.V. Shimov, A.V. Serebryakov, Study of residual stresses and surface hardening in tubes for nuclear steam generators, Solid State Phenomena, 2017, 265 SSP, 53-59.
7. Li S.B., Xie J.X., Fabrication of thin-walled 316L stainless steel seamless pipes by extrusion technology, Journal of Materials Processing Technology.

183, 1, 2007, 57-61.

8. S. Al-Mosawi, M.P. Saka, Optimum shape design of cold-formed thin-walled steel sections, Advances in Engineering Software, 31, 11, 2000, 851-862.

9. M.-C. Gwak, Y. Lee, K.-H. Kim, J.J. Yoh, Deformable wall effects on the detonation of combustible gas mixture in a thin-walled tube, International Journal of Hydrogen Energy, 40, 7, 2015, 3006-3014.

10. Z.-Q. Zhang, Prediction of maximum section flattening of thin-walled circular steel tube in continuous rotary straightening process, Journal of Iron and Steel Research, International, 23, 8, 2016, 745-755.

11. Y. Li, S. Liu, Analysis of theory fracture times of superplastic thin walled cylinder with internal pressure, Jixie Qiandu, 35, 3, 2013, 372-375.

12. J. Ma, Y. Le, Z. You, Axial crushing tests of thin-walled steel square tubes with pyramid patterns, Collection of technical papers - AIAA/ASME/ASCE/AHS/ASC structures, structural dynamics and materials conference, 2010, 2010-2615.

13. M. Razumov, A. Grechukhin, A. Maslennikov, Geometric parameters of cutting tools that can be used for forming sided surfaces with variable sections, Archives of Metallurgy and Materials, 2017. 62, 1, 2017, 33-40.

14. O.I. Boriskin, S.V. Zyabrev, G.A. Nuzhdin, S.Ya. Khludov, On the problem of designing progressive multifunctional cutting inserts, Fundamental and Applied Problems of Technics and Technology, 2-4, 2012, 13-19.

15. T. Kagnaya, C. Boher, L. Lambert, T. Cutard, M. Lazard, Microstructural analysis of wear micromechanisms of WC-6Co cutting tools during high speed dry machining, International Journal of Refractory Metals and Hard Materials, 42, 2014, 151-162.

16. Z. Wu, Y. Yang, C. Su, X. Cai, C. Luo, Development and prospect of cooling technology for dry cutting tools, The International Journal of Advanced Manufacturing Technology, 88, 5-8, 2017, 1567-1577.

17. H. Caliskan, P. Panjan, C. Kurbanoglu, Hard coatings on cutting tools and surface finish, Comprehensive Materials Finishing, 2016, 230-242.