

Surface Processing Technology in Improving Operational Properties of Hot-Work Tool Steel

N. S. Ulakhanov

Department of Mechanical Engineering
East Siberia State University of Technology and
Management
Ulan-Ude, Russia
e-mail nulahanov@mail.ru

U. L. Mishigdorzhyn

Department of Metal Science and
Materials Processing Technologies
East Siberia State University of Technology and
Management
Ulan-Ude, Russia
e-mail druh@mail.ru

A. D. Greshilov

Department of Mechanical Engineering
East Siberia State University of Technology and
Management
Ulan-Ude, Russia
e-mail agreshilov@mail.ru

A. G. Tikhonov

Department of Mechanical Engineering Production
Technologies and Equipment
Irkutsk National Research Technical University
Irkutsk, Russia
e-mail tihonovalex90@mail.ru

I. N. Ryzhikov

Department of Mechanical Engineering
Technologies and Materials
Irkutsk National Research Technical University
Irkutsk, Russia
e-mail rin111@list.ru

Abstract— The present study is devoted to the surface processing technology of 3X2B8Φ hot-work tool steel and the effect on its operational properties. The surface processing included thermal-chemical treatment (TCT) and surface finishing. Boroaluminizing (joint diffusion with boron and aluminum) was chosen as a TCT method. Steel samples were covered by a treatment paste, containing boron carbide, aluminum and sodium fluoride powders. The exposure time was 2 hours and the treatment temperature - 950°C and 1050°C. The surface finishing was carried out by an elbow grinding tool to coordinate grinding on a vertical milling machine. The diffusion layers with a composite structure were formed on top of the steel as a result of TCT at 1050°C. Processing at 950°C resulted in a diffusion layer formation with layered structure. The surface roughness after boroaluminizing have increased from initial Ra 1.5 μm to Ra 4 μm after 950°C TCT and to Ra 7.7 μm after 1050°C TCT. The roughness increase was due to surface reactions with air components, such as oxygen and nitrogen, as well as their penetration to the upper zones. Applying surface finishing as a final mechanical operation (FMO) resulted in roughness reduction from the above mentioned values to Ra 0.09 μm to Ra 0.43 μm, respectively. In addition, the upper redundant zone of the layer was removed with no damage done to the inner zones by means of FMO. The provided surface quality ensures sufficient operational properties of the machine parts and details made of this particular steel.

Keywords— *thermal-chemical treatment, boroaluminizing, composite structure, roughness, surface finishing*

I. INTRODUCTION

The working surfaces of many tools in forging are subjected to complex stresses, such as abrasive and corrosive media influence, heat and shock loads. Customarily, alloyed and special steels are selected for these conditions. However, in particular circumstances, surface layers need to be additionally strengthened. Thus, one of the most important objectives in mechanical engineering is the development of methods aimed at improving functional properties of the surface layers by various methods of surface engineering.

There are several widely used methods of thermal-chemical surfaces treatment (TCT), such as nitriding, carburizing, boriding, which provide high functional properties. Complex diffusion treatment with boron and aluminum allows increasing wear resistance, oxidation at high temperatures, corrosion and other properties of forming tools' working surfaces [1-3]. Functional properties depend on many factors of the technological process, and they are configured during preliminary surface preparations, diffusion boroaluminizing and surface finishing. In most cases, grinding is used as a surface finishing operation to ensure the required roughness and accuracy of the surface. A complex solution of these problems is relevant from the standpoint of the theory of technological heredity [4, 5]. In this regard, the study on the possibility of creating functional properties of the working surfaces of die steel in a wider range by means of

boroaluminizing and final machining operation (FMO) is an important task.

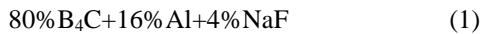
II. MATERIALS AND METHODS

Steel 3X2B8Φ (analogous to AISI H21 steel) was chosen as a testing sample. It is high quality hot work tool steel, alloyed with W, Cr, V, etc. The full chemical composition is given in Table 1. Steel 3X2B8Φ is used for manufacturing heavy-duty pressing tools (small inserts of final forming stream, dies and extrusion punches, etc.) during hot deformation of alloyed structural steels and high-temperature alloys, molds for injecting molding copper alloys.

TABLE I. CHEMICAL COMPOSITION OF STEEL 3H2V8F

C	Si	Mn	P	S	Cr	Ni	Cu	W	V
0.3 - 0.4	0.15 - 0.4	0.15 - 0.4	up to 0.03	up to 0.03	2.2 - 2.7	up to 0.35	up to 0.03	8.5 - 10.0	0.3 - 0.6

Boroaluminizing was carried out in treatment pastes containing powders of boron carbide, aluminum and sodium fluoride as an activator. The powders were pre-mixed on an organic glue to a paste-like composition. The ratio of B₄C / Al was 5: 1. The paste composition is given below:



Samples of tool steel 3X2B8Φ were placed in rectangular forms with paste. After tamping, the forms were removed, and the obtained briquettes were dried at a temperature of 50-100 °C for two hours in a drying chamber. After that, the briquettes were loaded into an oven preheated to the treatment temperature. The exposure time was 2 hours, the treatment temperature was 950 and 1050 ° C. The samples were cooled outside the oven in still air at room temperature.

FMO was carried out on a vertical milling machine with CNC Romi D800. The grinding tool is an elbor (cubic boron nitride) grinding head for multi-axis deep grinding with a diameter of 20 mm and grain size LKB60/250 (Fig. 1), made by means of vacuum diffusion welding of elbor grains. The cutting speed was 250 m/min, the feed was 0.08 mm/min and the cutting depth was 0.05 mm. The grinding scheme is shown in Fig. 2, where 1 is the workpiece, 2 is the elbor grinding tool, D_r is the main cutting movement, D_s is the feed movement.

The surface roughness before and after TCT, as well as after surfaces finishing was carried out on a Taylor Hobson Form Talysurf i20 profilometer in the research laboratory of high-performance technology of machining, shaping and hardening of machine parts of Irkutsk National Research Technical University.

The microstructure of the samples was examined on a METAM RB-34 metallographic microscope.

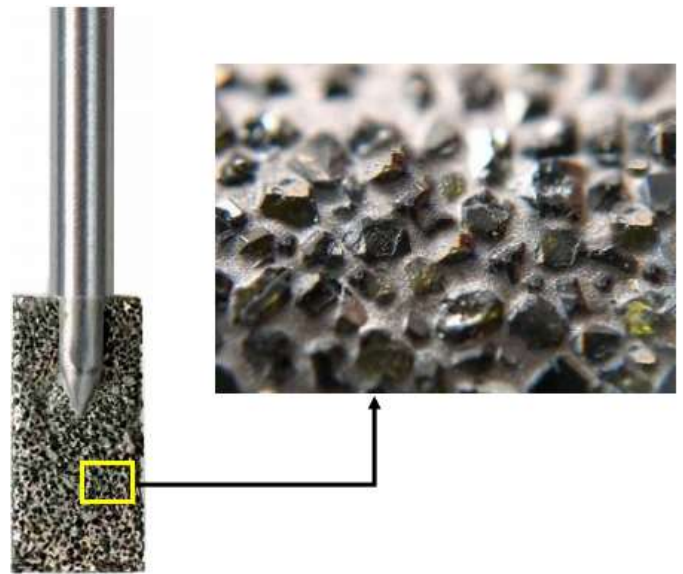


Fig. 1. Cylindrical elbor grinding tool

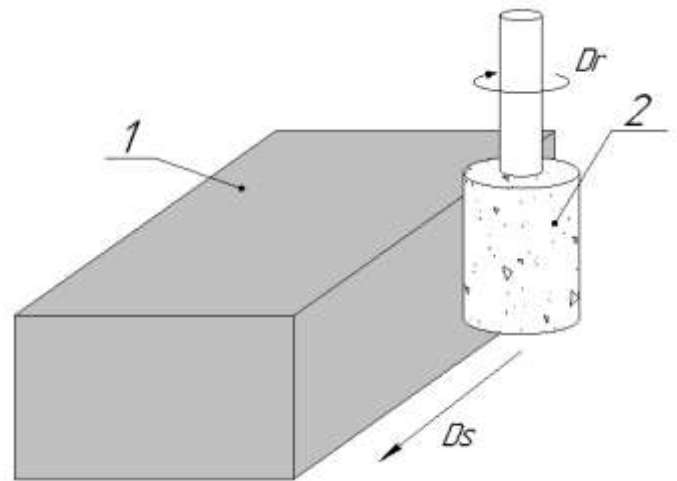


Fig. 2. Grinding scheme

III. THEORETICAL BASIS OF THE REQUIREMENTS TO THE ESTABLISHMENT OF OPERATIONAL PROPERTIES

A systematic approach is needed when the complex technological processes are being designed. This will allow to evaluate the role of each treatment in shaping the operational properties of the surface layer. The relationship between the output and input parameters of the processes can be represented in the form of the scheme, shown in Fig.3.

The main task of mechanical processing before TCT is the formation of the required working profile of the die, taking into account the machining allowance after diffusion boroaluminizing and subsequent surface finishing. It is also necessary to ensure the surface roughness of $Ra \leq 2.5 \mu m$, which provides its less intensive growth after TCT [6]. In most cases, it is practical to use milling as the pre-machining.

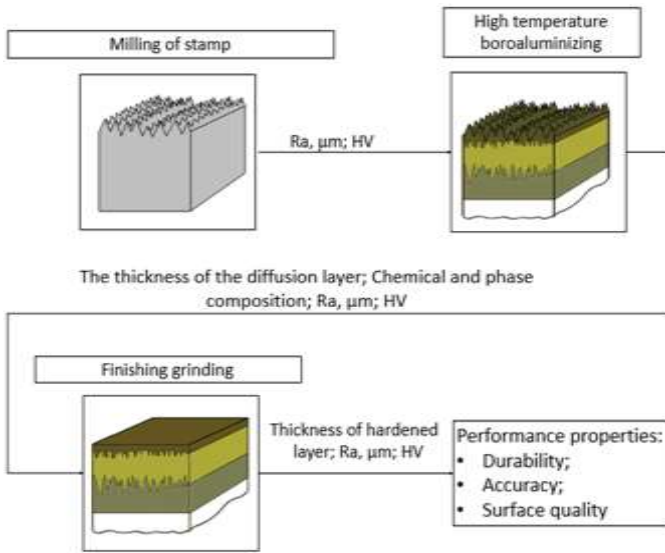


Fig. 3. Scheme of the formation of the operational properties

The die surfaces performance, made of 3X2B8Φ steel and usually used for hot forging processes, can be ensured by optimal values of the main parameters of the formed diffusion layer provided by the TCT (layer thickness, microhardness, phase composition and microstructure). The layout of the diffusion layer microstructure formed on the surface of die steel has been developed in accordance with the requirements for the surface properties, which can be represented as a schematic diagram (Fig. 4). I is a punch, II is a blank and III is a matrix, while 1,2,3 are diffusion layer zones.

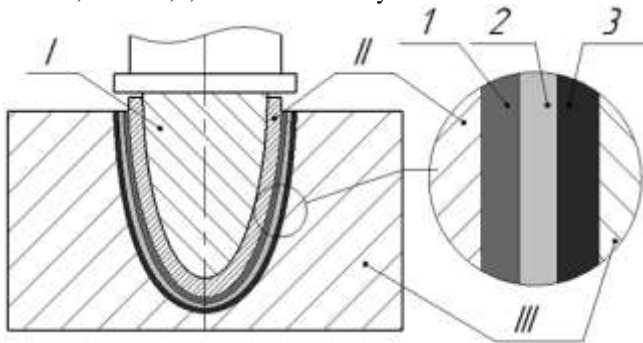


Fig. 4. Schematic diagram of the diffusion layer on the surface of the die

According to the concept, the diffusion layer contains several specific zones, each of which has its own functional purpose. Zone 3 is transition one, directly adjacent to the instrumental base metal. It should provide sufficient adhesive of the diffusion layer with the matrix material. The properties of the transition zone and the base metal should be as identical as possible in terms of their heat, physical and mechanical properties in order to avoid residual stresses and detachment of the diffusion layer. Zone 2 serves as a barrier, reducing the intensity of the heat flux in the matrix base, and also binds zones 1 and 3. Zone 1 carries out the main functions, contacting with the work pieces during the deformation process. It should have a high contact strength, plasticity, increased wear resistance and the required microgeometry

parameters (roughness). By varying the composition of the treatment mixture and the time-temperature parameters of the diffusion boroaluminizing, as well as the FMO modes, it is possible to obtain a surface with the required performance characteristics.

IV. RESULTS AND DISCUSSION

The experiments have shown that the use of treatment temperature of 950°C results in a predominantly aluminized layer formation with a layered structure (Fig.5). Aluminum, as a more active component of the mixture, reacts with an activator NaF faster than the boron carbide and forms AlF and AlF₂ fluorides. These components play role of the mass-transporters of active aluminum to the treated surface. The depth of the layer is 140 μm.

Boroaluminizing at 1050°C leads to the formation of layers with a composite structure, where solid structural components, for instance iron borides, are arranged in the form of isolated inclusions, and more viscous components form a matrix (Fig. 6) [7-9]. This type of structure provides high mechanical properties, in particular - wear resistance and plasticity (low brittleness).

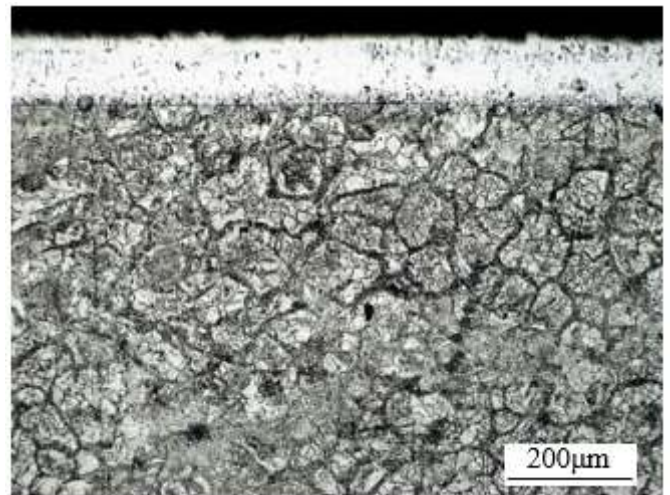


Fig. 5. Microstructure of 3H2V8F steel after boroaluminizing at 950°C.

In addition, treatment at 1050 °C allows to avoid the layered structure formation (phase heterogeneity through the layer depth), as well as to increase the layer thickness up to 380 μm.

The wear resistance and, consequently, the durability of die tooling is significantly affected by the surface roughness. The source [6] indicates that the boronizing process can be used as the final operation of tools and does not change the surface roughness. However, the mentioned study was devoted to the process of low-temperature liquid boronizing of carbon steels. Currently, there is no information about the surface quality of tool steels subjected to boroaluminizing. In order to reduce the roughness of the surface layers and remove the upper porous zone, grinding was carried out with elbore grinding heads. A study of the topography before and after grinding showed that the surface quality can be increased to

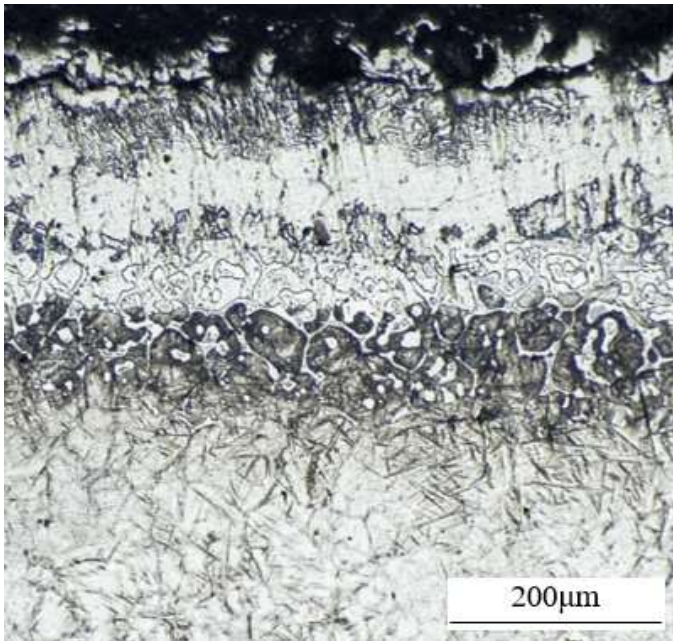


Fig. 6. Microstructure of 3H2V8F steel after boroaluminizing at 1050°C.

Ra = 0.4 µm for samples subjected to processing at a temperature of 1050°C and Ra = 0.08 µm for samples subjected to processing at temperature of 950°C. At the same time, functional properties are provided to the full extent by the remaining layer zones on the sample subjected to treatment above 1000°C. Figure 7 shows the changes in the surface roughness of the samples before and after boroaluminizing, as well as after grinding. It is obvious from the diagram that, the treatment temperature increase results in the surface roughness' growth. After grinding with elbore grinding heads according to the technological processing conditions mentioned above, the surface roughness decreases, and the effect of technological heredity is observed.

According to the scheme presented in Fig. 4, the TCT at 1050°C is more preferable for the formation of operational properties on the surface of the 3X2B8Φ steel used for the manufacture of die tooling for hot forming processes. The diffusion layer formed under these technological regimes has a greater depth, which makes possible to preserve the properties formed by boroaluminizing after the FMO.

Figure 8 shows the XRD pattern of the steel surface after boroaluminizing at a temperature of 1050°C. XRD analysis revealed the presence of typical for boroaluminizing phases, such as FeB and Fe₃Al. In addition to iron borides and aluminides, Fe₂O₃ and Fe₇W₆ are revealed in the diffusion layer. The presence of the first compound is due to the oxygen diffusion through the treatment paste, which leads to the formation of iron oxide in the upper zone of the layer. The ferrotungsten formation is probably the result of counter diffusion of alloying and initial elements. In addition, there is a displacement of carbide-forming elements from the surface

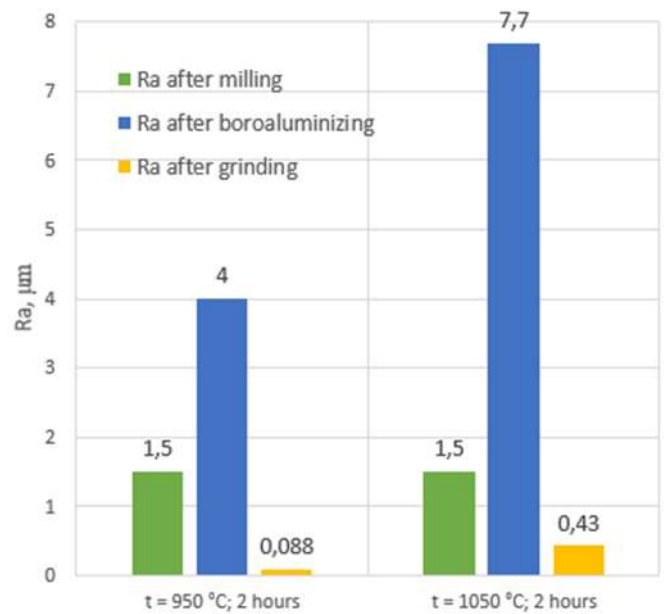


Fig. 7. Surface roughness of 3H2V8F steel after different treatments

occurring simultaneously along with diffusion process. The required concentration of tungsten is being reached for the formation of this compound due to the above mentioned processes. It was found that Fe₇W₆ has elevated hardness - more than 3000HV. Thus, this compound, together with iron boride, is capable of providing high mechanical properties of the layer, such as wear resistance under contact friction conditions.

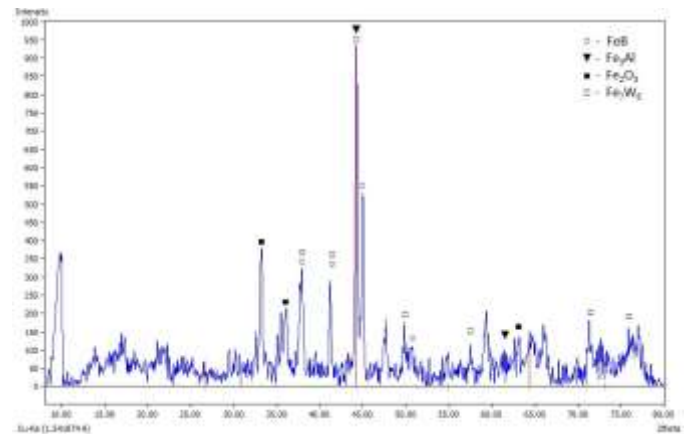


Fig. 8. XRD pattern of 3H2V8F steel after boroaluminizing at 1050°C.

The microhardness profiles differ significantly depending on the treatment temperature (Fig. 9). The lower treatment temperature results in only soft phases formation, so microhardness of the base metal is superior compared to the layer. The latter characterised by values between 300HV and 470HV, which is typical for the low-aluminum containing aluminides and solid solutions. The base metal microhardness is almost constant throughout the cross-section and its value is about 500HV.

A completely different profile has been obtained on the sample treated at 1050°C. High initial peak of 2200HV on the profile corresponds to the iron boride on top of the layer. Then, the microhardness drops to its minimum value of about 300HV. This drop can be attributed to the iron aluminide Fe₃Al zone. Despite of the presence of very hard compounds, such as Fe₇W₆, in the composite layer the average value is about 700-800HV between 100 μm and 600 μm from the surface. The microstructure complexity in this area of the layer thickness results in significant microhardness variations. The second high peak of 1400HV can be attributed to the carbide-rich zone. Beneath the carbide-rich zone the values go down from 1000HV to 600HV as gradual slope on the graph. Generally, the composite layer microhardness profile ranges significantly and characterised by sharp rises and drops, which indicates the phase and elemental composition diversity.

The base metal microhardness after TCT at 1050°C is slightly superior to the one after 950°C and correlates as 600HV against 500HV, respectively. The obtained values is in good agreement with the literature data, indicating 520HV after vacuum heat-treatment [10].

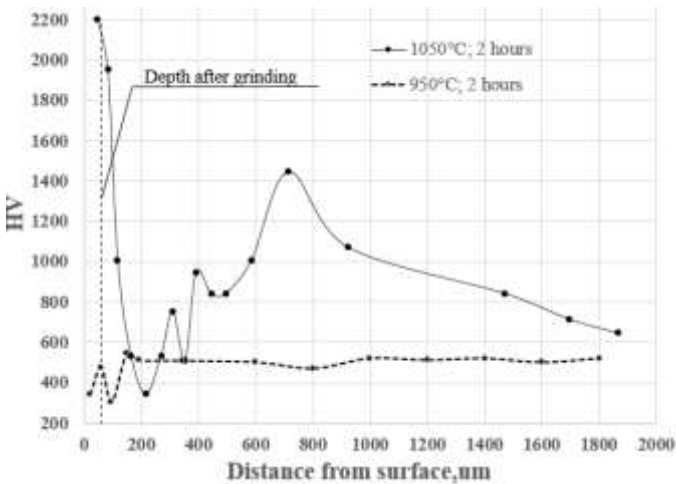


Fig. 9. Microhardness distribution of 3H2V8F steel after boroaluminizing.

V. CONCLUSION

A comprehensive solution to the problems of ensuring the required quality parameters of the surface layer (geometric, physico-mechanical and structural) makes it possible to form the most favorable modification of the structure of the surface layer, which ensures the minimum roughness of the diffusion layers after grinding, as well as forms the required performance properties

References

- [1] I.G. Sizov, U.L. Mishgidorzhiyn, C. Leyens, B. Vetter, and F. Furmann, "Influence of thermocycle boroaluminizing on strength of steel C30," Surf. Eng., vol. 30, pp.129-133, 2014.
- [2] M.G. Krukovich, B.A. Prusakov, and I.G. Sizov, Plasticity of boronized layers, Springer International Publishing: Switzerland, 2016; pp. 111-227.
- [3] G.V. Zemskov, and R.L. Kogan, Mnogokomponentnoye diffuzionnoye nasyshcheniye metallov i splavov [Multi-component diffusion saturation of metals and alloys], Metallurgiya: Moscow, USSR, 1981; pp. 208.
- [4] Yu.S. Chesov, E.A. Zverev, and A.V. Plokhov, "Operational properties of plasma coatings from wear-resistant powder material of the PG-S27 brand," Obrabotka metallov, vol. 47, (2), pp. 8-12, 2010.
- [5] Yu.S. Chesov, E.A. Zverev, A.I. Popelyukh, and P.V. Tregubchak, "Surface roughness of wear-resistant coatings after finishing machining", Obrabotka metallov, vol. 50, (1), pp.12-14, 2011.
- [6] A.A. Aliyev, V.P. Bulgakov, and B.S. Prikhodko, "Diffusion boronation of steel and surface roughness," Vestnik of Astrakhan State Technical University, vol. 25, (2), pp. 91-94, 2005.
- [7] Yu.M. Dombrovsky, and M.S. Stepanov, "Creation of composite diffusion boride coatings during microarc hardening in powder environments," Izvestia VSTU, vol. 160, (5), pp. 61-63, 2015.
- [8] A. Shmatov, "Composite structures formed by diffusion saturation of steel with several transition metals," Polzunovsky almanac, (2), pp. 78-84, 2015.
- [9] D. Mikołajczak, M. Kulka, N. Makuch, and P. Dziarski, "Laser borided composite layer produced on austenitic 316L steel," Archives of Mechanical Technology and Materials, pp. 35-39, 2016.
- [10] S. Chander, and V. Chawla, "Characterization and Industrial Performance Evaluation of Duplex-Treated AISI H21 Die Steel during Hot Forging Process," Materials Performance and Characterization, vol. 8, (1), pp. 197-210, 2019.