The analysis of speed increase perspectives of nanostructuring burnishing with heat removal from the tool

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Abstract. The work deals with investigation of opportunities of speed increase of nanostructuring burnishing due to heat removal from the contact area of severe plastic deformation using friction via the tool. The work has analyzed changes of the structure, thickness and quality of the modified layer, while increasing treatment speed of the tool without heat removal and with heat-cooling system. It is established that the cooling system of the tool indenter with a cooling capacity of 10 W allows for the two-times increase of the critical speed of burnishing, and when exceeding this speed, the deformable material does not turn into a nanostructuring state. It is shown that heat removal provides for a stable maintenance of the indenter temperature, an increase in thickness of the nanostructured layer up to 5 µm and roughness up to Ra = 150 nanometers at processing speed up to 0.17 m/s.

1. Introduction

The linear speed of the nanostructuring burnishing and the temperature in the contact area of the tool have an essential effect on stability of structure dispersion and the surface layer quality. The work has investigated the influence of thermostrengthened steel processing speed on roughness and shear elasticity of the surface layer material [1]. The critical speed of nanostructuring burnishing was determined, at the increase of which an essential deterioration of processed surface layer roughness, loss of shear stability and material destruction occur. In works [2-4], it is shown that, at severe plastic deformation of constructional materials, the temperature increase in the area of deformation leads to a decrease in microhardness and in extent of structure dispersion.

The problem of nanostructuring burnishing speed increase at finishing processing of high-precision parts is connected with ensuring an economically reasonable processing rate and tool life

The objective of the research is aimed at identification of a possibility to increase speed of nanostructuring burnishing of quenched and tempered cemented 20Cr4 steel by means of heat removal from the tool indenter. The work solves the problem of experimental determination of dependence of structure refinement, thickness and quality parameters of the modified layer on the linear processing speed and indenter temperature in the conditions of dry friction and application of the tool with the heat-cooling system.

2. Methodology and experiment equipment

The experimental investigation is conducted when processing a disk-type specimen made from 20Cr4 steel (Fe rest; C 0.21; Cr 0.84; Ni 0.08; Mn 0.57; Si 0.27; Cu 0.18; P 0.017; S 0.019 (wt.%)) with a diameter of 80 mm and 12 mm thick. During preliminary preparation, the specimen underwent cementation, quenching, low tempering and turning. Quenching was carried out at a temperature of 850 °C, low tempering – at 120 °C. After chemical heat treatment, the material had a structure of lath martensite with the size of laths equal to 0.3…0.5 μm and the hardness of 64…65 HRC. The turning of specimen flat surfaces was carried out by a cemented metal carbide tips of Sandvik WNANOMETERSG 080408-SM at a speed of 80 m/min and feed of 0.06 mm/rev. After turning, the surface roughness amounted to Ra = 0.25 μm, and microhardness – 900…950 $HV_{0.5}$.

Nanostructuring burnishing in the conditions of dry friction was carried out on Takisawa EX-310 CNC turning center (Figure 1b) at normal force F_b on indenter 200 N and tool feed f_b=0.04 mm/rev. At this, spindle rotational speed n was maintained at 150 rpm. In proportion to the tool feed, linear processing speed v_b was changed within the range of 0.06…0.6 m/s. The indenters were used with semispherical tips from ultrafine grained cubic dense boron nitride (DBN) with a 2 mm radius and with working surface roughness equal to Ra=50 nm. Friction coefficient μ of the indenter in contact with the processed surface amounted to 0.3…0.34 and friction force F_{fr} equaled 60…68 N. One plane of the specimen was processed by the burnishing tool without the heatsink, another by the tool with a heat-cooling system.

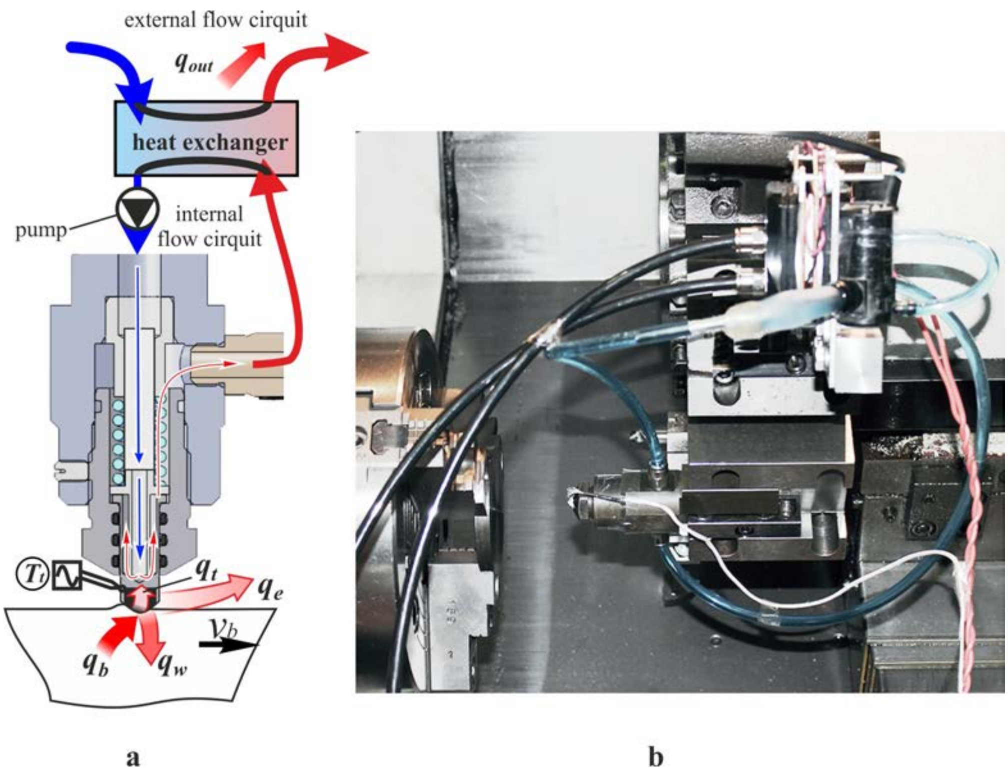

Figure 1. The heat flow diagram at nanostructuring burnishing by the tool with a two-circuit liquid cooling system (a) and the snapshot of the experimental set-up (b).

In the course of the nanostructuring burnishing of 20Cr4 steel with friction force of 60…68 N and speed up to 0.6 m/s, maximum heat capacity q_b amounted to 36…41 W.

A burnishing tool with a two-circuit liquid cooling system (Figure 1a) was used for heat removal q_t passing through the indenter [5]. In the first circuit due to coolant circulation by means of a pump, heat transfer occurs from the indenter into the heat exchanger. In the heat exchanger Peltier thermoelectric modules, which cool the coolant, are used. The cooling of Peltier thermoelectric modules is carried out by the coolant of the second circuit (Russian Federation Patent No. 150111). The cooling capacity of the cooling system reaches 10 W.

The measurement of the indenter tip temperature was carried out by the thermocouple of a K-type. The research of the surface layer structure after nanostructuring burnishing was conducted by means of microscopes JEOL JEM 200CX, JEOL JEM 2100 and Zeiss CrossBeam AURIGA by TEM and SEM methods. The measurement of surface microhardness was carried out by Vickers method using a microhardness tester Leica at loading of 0.5 N. The roughness was determined by optical 3D – profiler Veeco WYCO NT1100 by PSI method.

3. Results

The transmission electronic microscopy of the surface layer foils after processing by the tool with the heat-cooling system has shown that, at burnishing speed from 0.06 to 0.12 m/s, the nanocrystalline structure with grains of 40…100 nm in size (Figure 2a) is formed.

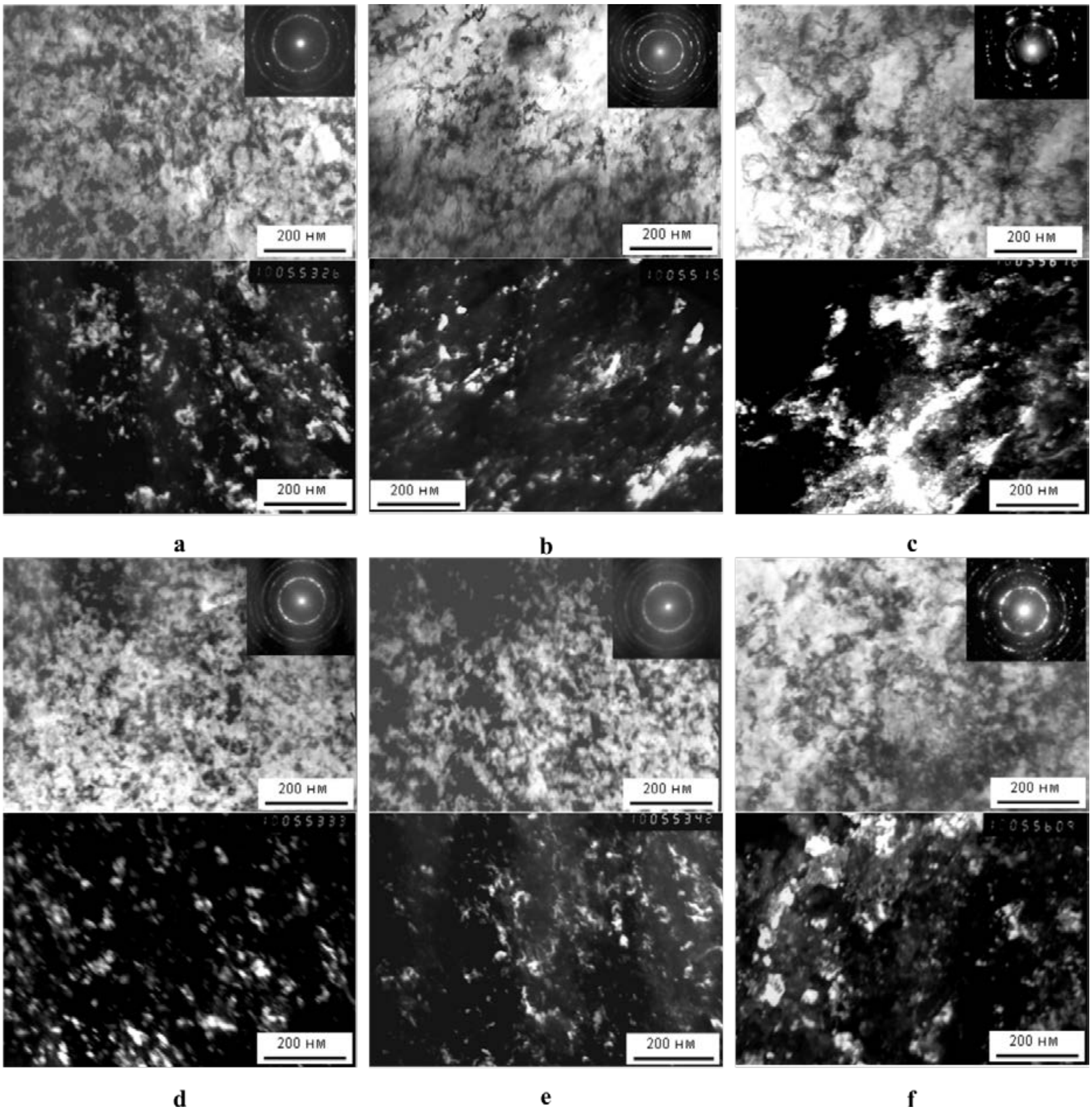

Figure 2. Light-field, dark-field images and diffractions (110α) of the specimen surface layer when processing by the tool without the heatsink at a speed of 0.1 m/s (a), 0.17 m/s (b), 0.2 m/s (c) and by the tool with the heatsink system at a speed of 0.1 m/s (d), 0.22 m/s (e) and 0.38 m/s (f).

At a speed increase up to 0.17 m/s, the grain sizes amounted to 50…300 nm (Figure 2b). The speed increase up to 0.22 m/s and higher leads to formation of a grain structure of 200…600 nm in size (Figure 2c). In the course of tool processing with the heatsink system at a speed from 0.06 to 0.22 m/s, formation of the nanocrystalline structure of 30...70 nm in size occurs (Figure 2d, e). At a speed increase up to 0.38 m/s, the sizes of grains reach 50...300 nm (Figure 2f). Further increase of speed leads to an increase in the grain size up to 200…600 nm and, practically, to the absence of the nanostructural state of the deformed material.

The scanning electron microscopy of the surface layer after nanostructuring burnishing by the tool without the heatsink system shows that, at a speed up to 0.12 m/s, the thickness of the modified layer equals 2...3 µm (Figure 3a). A speed increase up to 0.17 m/s leads to a decrease in thickness of the layer up to 0.8…1 µm (Figure 3b). At further speed increase, the modified layer is not observed (Figure 3c). While processing by the tool with the heatsink system at a speed up to 0.16 m/s, the thickness of the modified layer amounts to 4…5 µm (Figure 3d). The thickness of the layer decreases to 2 microns (Figure 3e) at a speed increase up to 0.27 m/s. The increase in speed up to 0.41 m/s leads to layer thickness reduction up to 0.7…1 µm (Figure 3f). At further speed increase the modified layer is not observed.

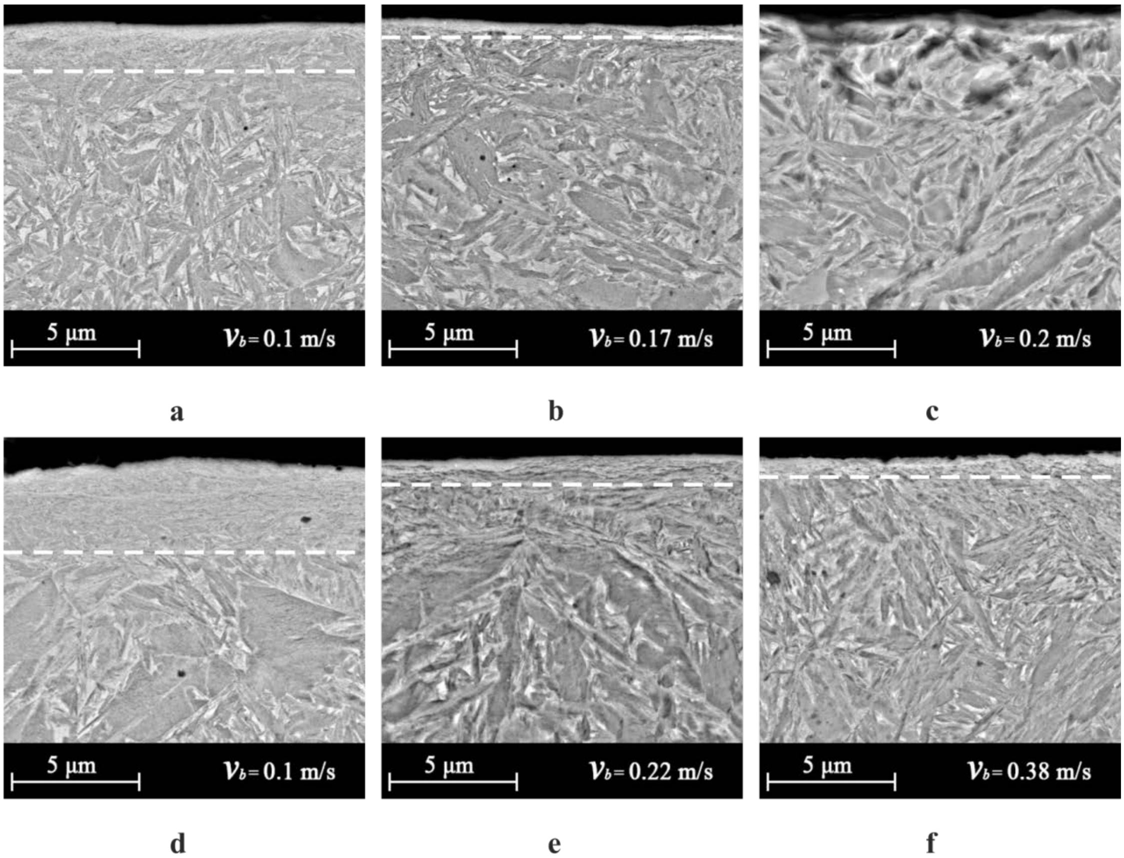

Figure 3. Scanning electron microscopy of the surface layer after nanostructuring burnishing: by the tool without the heatsink (a, b, c); by the tool with the heatsink system (d, e, f)

After nanostructuring burnishing without the heatsink, the microhardness of the processed surface amounts to 1120...1250 $HV_{0.5}$ (Figure 4a). When processing by the tool with the heatsink system, the microhardness equals 1160…1220 $HV_{0.5}$, which, taking into account the measurement accuracy, makes it possible to consider that it has an identical result. Besides, there is a decrease in the surface microhardness by 50...60 $HV_{0.5}$ at a speed increase up to 0.22 m/s when being processed by the tool without the heatsink.

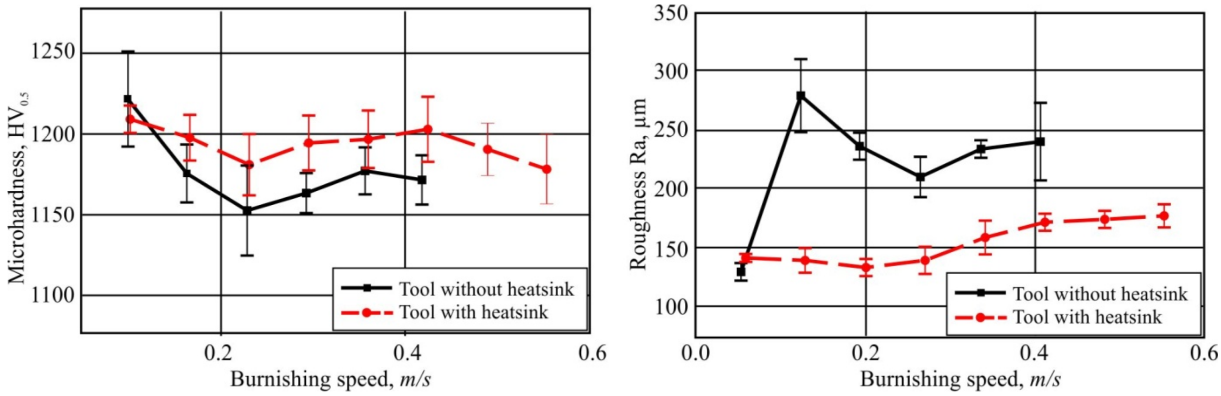

Figure 4. A change of the microhardness (a) and roughness (b) of the surface layer at an increase of nanostructuring burnishing speed.

When processing by the tool without the heatsink at a speed over 0.1 m/s, the roughness worsens from Ra = 100…150 nm to the level of Ra = 250... 300 nm, that is more than in the initial state of the specimen after turning (Figure 4b). At the same time, the surface roughness after treatment by the tool with the heatsink system amounts to Ra = 140…170 nanometers within all the range of the investigated speeds.

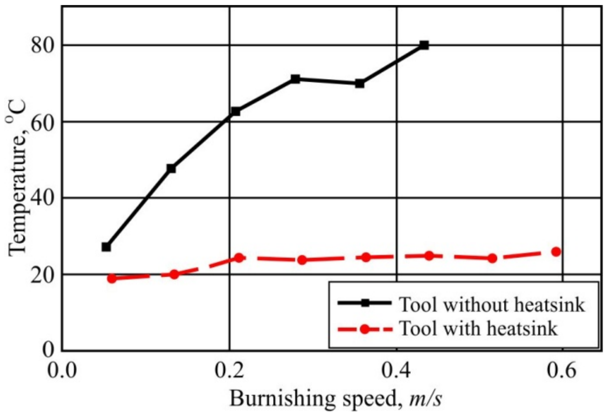

Figure 5. A change of the indenter tip temperature at increasing speed of nanostructuring burnishing.

The indenter tip temperature (Figure 5), when processing by the tool without the heatsink and when changing speed from 0.06 to 0.4 m/s, increases from 28 to 80 °C. The application of the tool with the heatsink system provides stable maintenance of the temperature at the level of 20…26 °C within all the range of the investigated speeds.

4. Discussion

According to the concept of a fast-moving source of thermal generation [6], an increase of nanostructuring burnishing speed leads to an increase in thermal flow resistance q_w in the specimen and to the reduction of the heated layer thickness in the contact area. The essential heating-up of the deformed material can lead to changes of the friction force in contact and of the rotational and shear nanostructuring mechanism.

The given research showed that at nanostructuring burnishing of 20Cr4 steel, the tool without the heatsink and with an indenter tip with the radius of 2 mm, the formation of the layer with a nanodimensional crystal structure 2…3 µm thick is possible only at heat generation capacity in the deformation center up to 8.2 W. This capacity corresponds to the burnishing speed of 0.12 m/s at friction force in contact of 68 N. The application of the tool with the two-circuit heat-cooling system allowed for increasing thickness of a nanostructured layer up to 4…5 μm at the abovementioned capacity of heat generation. The formation of a nanostructural state of the material in the surface layer 2…3 μm thick applying the tool with the heat-cooling system is provided at heat generation capacity up to 18.4 W that corresponds to the burnishing speed increase up to 0.27 m/s.

To form a nanocrystalline grain structure of the surface layer of parts from constructional materials at a burnishing speed of more than 0.3 m/s, it is necessary to increase, first of all, the efficiency of heat removal via the tool. To implement this, two ways are possible: 1) Coolant temperature decreases in the first circuit due to an increase in cooling capacity of the cooling system when using more powerful Peltier thermoelectric modules; 2) Contact thermal resistance decreases due to an increase of the contact area by increasing the radius of the indenter tip.

5. Conclusion

Heat removal from the contact area via the tool allows for ensuring stability of the nanocrystalline grain structure formation in the surface layer of constructional steels at the increase in a linear processing speed in the conditions of dry friction.

The application of the tool cooling system with a cooling capacity of 10 W allows for increasing the critical speed of nanostructuring burnishing of 20Cr4 steel from 0.12 to 0.27 m/s.

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References

[1] Kuznetsov V P, Tarasov S Yu and Dmitriev A I 2015 *J. of Mater. Process. Techn.* **217** 327–335
[2] Vorhauer A, Kleber S and Pippan R 2005 *Mater. Science and Engineer. A* **410-411** 281–284
[3] Kamikawa N and Tsuji N 2012 *Materials Transactions* **53(1)** 30–37
[4] Dedyulina O K et al 2014 *IOP Conf. Series: Materials Science and Engineering* **63(1)** 012054
[5] Kuznetsov V P, Skorobogatov A S and Gorgots V G 2015 *Appl. Mech. and Mater.* **770** 449–455
[6] Laraqi N, Bairi A and Segui L 2004 *Applied Thermal Engineering* **24(17–18)** 2567–2581