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Effect of Adhesion Transfer on the Surface Pattern Regularity in Nanostructuring Burnishing

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Abstract. In the paper the influence of friction-induced adhesion of metal to the tool on the formation of surface topography under nanostructuring burnishing was studied. A comprehensive approach, including both experimental (optical microscopy and profilometry) and theoretical (computer-aided simulation) methods was used. The results showed a direct connection between values of adhesion strength of materials in contact with the workpiece surface pattern quality caused by the tool movement. Results of the experimental and theoretical study are in good agreement and allow us to identify the reason of regular profile forming during surface burnishing.

INTRODUCTION

One of the crucial tasks in engineering is obtaining both minimal roughness and work-hardened metal surfaces using a nanostructuring burnishing [1–3]. Earlier we described a conception that allows controlling the nanostructuring burnishing process where two critical process parameters were identified such as friction force and loading repetition factor [4, 5]. The loading repetition factor depends on the transversal feed and number of the tool runs over the surface. However, the role played by friction-induced adhesion of metal to the tool is not disclosed with the above mentioned conception. It is known from both tribology and metal cutting that adhesion transfer may result in a build-up and then greatly affect the surface quality. The transfer process is greatly depended on the burnishing speed and sliding conditions.

The objective of this work is to identify the effect of adhesion transfer on the burnished surface topology using both experimental and numerical methods.

EXPERIMENTAL DATA

The 78 mm diameter disk for nanostructuring burnished was machined from M1 copper bar. The tool for dry condition nanostructuring burnishing was 2 mm radius half-spherical synthetic diamond. The normal force was 1600 N, transversal feed 0.01 mm/rev and burnishing speed 100 m/min. Integral load repetition factor of the elementary volume for 1 tool run depends on the geometry of the contact spot length l_c and transversal feed f_b as follows:

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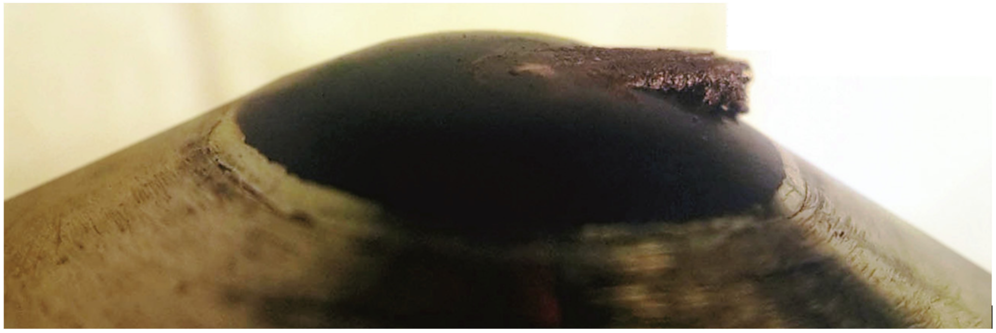


FIGURE 1. The build-up on the burnishing tool tip on the fifth run over the coper disk surface

$$n_l = \frac{l_c}{f_b}. \quad (1)$$

It was shown that when using the above noted burnishing process parameters the contact area length was 509 μm, what corresponded to the loading repetition factor $n_l = 50$ and $N_l = 250$ per one tool run and for the entire cycle, respectively.

The irregularities of the burnished surface pattern have been noticed on completing the fifth run of the tool over the surface (Fig. 1). These irregularities originated from the build-up on the tool working tip (Fig. 2):

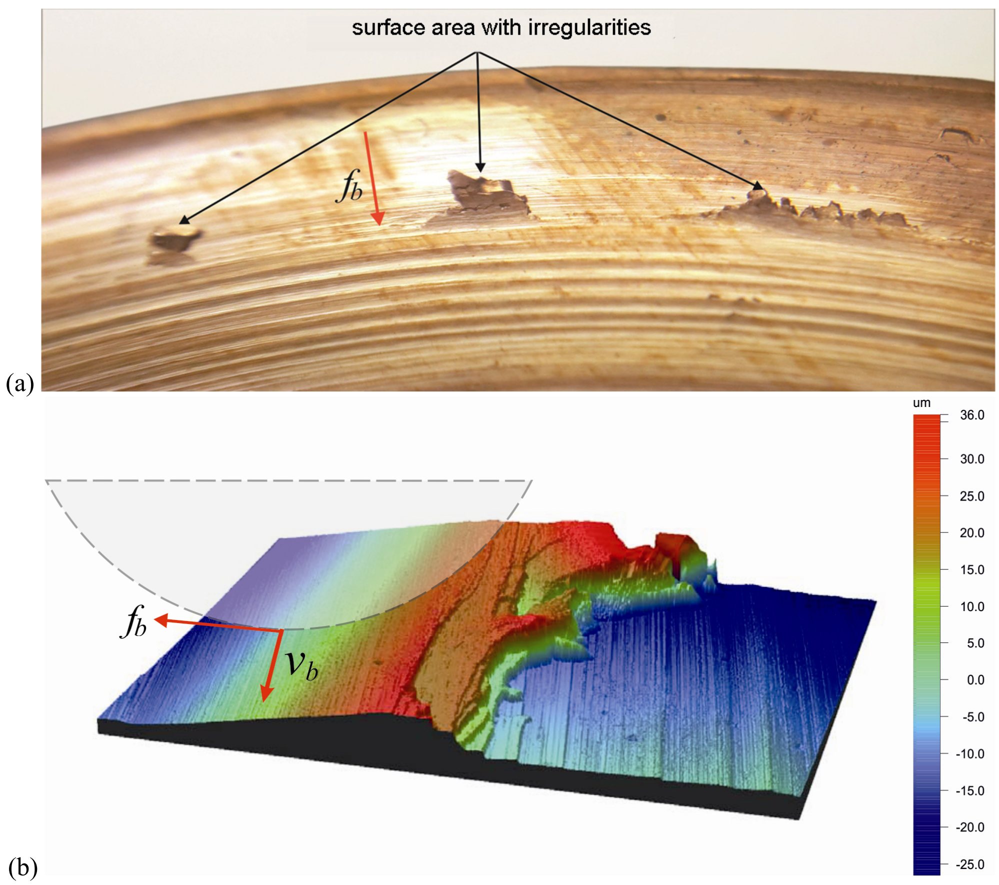
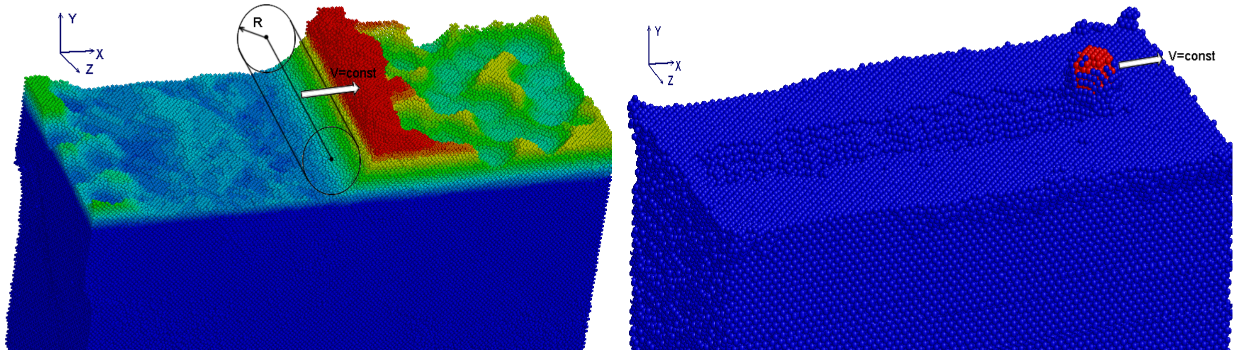


FIGURE 2. The burnished surface area with irregularities (a) and 3D topography image of the irregularity (b)



(a) (b)

FIGURE 3. The modeled surface structures resulted from burnishing by the force field (a) and material object (b)

The irregularity direction is opposite to that of the transversal feed therefore we may suggest that they form on the trail side of the tool under the action of friction force component transversal to the direction of burnishing due to shear instability of thermal softened copper at high burnishing speed and loading repetition factor.

Adhesion-assisted transfer of metal depends on several factors such as affinity of materials, burnishing process parameters, in particular burnishing speed which is the main factor for increasing the temperature in the contact area and loading repetition factor. Formation of the build-up on the tool's surface will have detrimental effect on the workpiece roughness since this build-up will be work-hardened and able to indent the surface burnished.

NUMERICAL MODELING

The adhesion transfer of metal to the tool's surface and its effect on the resulting burnished surface pattern has been analyzed using the results of molecular dynamics modeling. For this purpose the contacting between workpiece and two types of tools has been modeled. The first type of tool was presented in the form of a specially shaped force field, which corresponded to zero adhesion force. The second type tool was a material object with non-zero adhesion forces determined by an interatomic potential action. The workpiece was modeled using a copper crystallite. Such an approach was dictated by our expertise both in modeling on that material and using the earlier verified interatomic potential reconstructed in the framework of the embedded atom method [6, 7]. The calculation procedure was accomplished using the multi-processor cluster "Skif Cyberia" and LAMMPS program package [8]. The full number of atoms was 1500000. The modeled crystallite axes [100], [010] and [001] were oriented to coincide with coordinate axes *X*, *Y* and *Z*. The crystallite's dimensions with respect to coordinate axes were $40.1 \times 30.2 \times 16.6$ nm and $40.13 \times 17.9 \times 16.3$ nm for the force field and material object, respectively. The tool speed over the workpiece was 10 m/s for both cases.

The results of modeling are shown in Fig. 3 for two above described configurations. In case of force field, the atoms located inside the cylindrical surface with the axis along *Z* have been subjected to the action of radial forces. The magnitude of this force is determined by the expression as follows: $F(r) = -K(r-R)^2$, where *K* is the constant, *r* is the distance from the cylinder axis to the atom, *R* is the cylinder radius, here $r > R$, $F(r) = 0$. The tool radius was varied and thus changed the leading bulge size. Simultaneously, flat surface pattern was formed behind the trail side of the tool (Fig. 3a).

The profile of the leading bulge formed by the force field is shown in Fig. 4. Different colors of atoms identify the atoms belonged to different subsurface layers of the workpiece before the burnishing. It is observable that the bulge consists of not only the superficial atoms but also includes far off atoms shown by the blue color. The leading bulge structure is typical with those obtained as a result of intense inhomogeneous deformation including bending and shear. In other words the leading bulge may be considered as a folded structure formed under the condition of triaxial stress state and constraint deformation [9, 10].

The second example of burnishing implies spherical material object in the form of bcc iron single crystal (Fig. 3b). The adhesion between iron tool and copper workpiece resulted in adhesion transfer of copper onto the iron single crystal surface. The burnished surface pattern looks irregular due to adhesion transfer. So the numerical modeling confirmed the feasibility of adhesion transfer during nanostructuring burnishing and its negative effect on the surface pattern regularity.

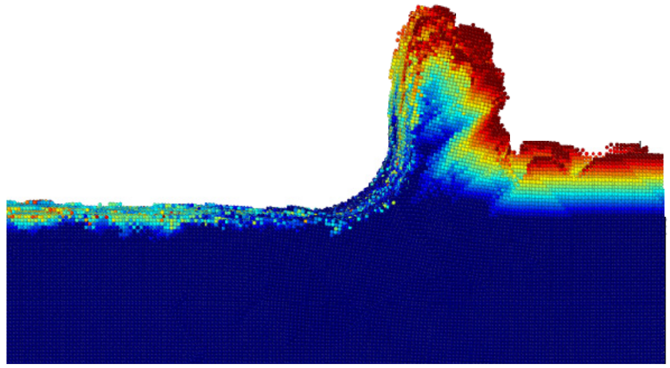


FIGURE 4. The leading bulge profile resulted from burnishing by the force field

CONCLUSION

The results of modeling support the consideration derived from the experimental data on the effect of adhesion transfer on the workpiece surface pattern quality. It was shown that the workpiece metal is transferred onto the tool's surface and strongly affects the regularity of the roughness pattern burnished.

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