Formation of a narrow hard layer in the AlMg6 alloy near the contact surface after extrusion through a conical die

E O Smirnova1,*, A S Smirnov1 and S E Alexandrov2

1Institute of Engineering Science, UB RAS, 34 Komsomolskaya St., Ekaterinburg, 620049, Russia
2Institute for Problems in Mechanics, RAS, 101-1 Vernadskogo Ave., Moscow, 119526, Russia

*evgeniya@imach.uran.ru

Abstract. A technique for determining the thickness of a deformed layer obtained at the contact with a rough deforming tool is verified by means of kinetic indentation. The AMg6 aluminum alloy is investigated after extrusion through a conical die with a semi-angle of 1.5°. The analysis of the experimental data has shown the existence of a 200 µm deformed layer near the contact surface.

1. Introduction
As a result of severe shear deformation, a hard layer appears near the friction boundary between the tool and the metal material being processed [1–4]. This layer allows one to generate unique mechanical and tribological properties of the material. To describe the evolution of the deformed (distorted) layer, mathematical models were developed in [5–7] to show the existence of a gradient contact layer after the interaction of a hard tool with a softer material.

In order to study the formation of a distorted layer near the contact surface between a ductile material and a tool, as well as to construct and verify mathematical models describing this formation, it is necessary to develop and verify experimentally the procedure of determining the thickness of the distorted layer. The aim of this study is to define the applicability of the results of kinetic indentation to the determination of the thickness of the distorted layer in materials subjected to friction treatment.

2. Result and discussion
To make a deformed layer at the contact between two dissimilar materials, a cylindrical specimen was pushed through a non-polished steel die with half the apex angle equal to 1.5°. As a result, favorable conditions for additional shear deformation near the friction surface were achieved.

The AMg6 deformable aluminum alloy (one of the Al-Mg system) is studied. The chemical composition of the AMg6 alloy (92.3 Al, 6.47 Mg, 0.25 Fe, 0.14 Si, 0.026 Cu, 0.63 Mn, 0.04 Ti, 0.08 Zn, 0.0017 Be, wt%) was determined on a Spectro Maxx metal analyzer. Figure 1 shows the dimensions of the specimen used for the experiments.
Experiments on pushing the specimen through a hard-alloy die were made by an Instron 8801 universal testing machine at room temperature. Before the tests, the AMg6 alloy specimens were vacuum-annealing at 350 °C for 2 hours, in order to remove work-hardening and transfer them to the soft annealed state, and then furnace-cooled.

Figure 2 shows 3D profiles of the specimen surface before and after pushing through the die. In the initial state, the surface microrelief is a set of irregularities in the form of alternating convexities and cavities resulting from machining, see figure 2a.

In the contact between the deforming tool and the specimen, the microscopic irregularities on the specimen surface are rumpled completely or partially due to high pressure. As a result, a new surface microrelief is formed, with the roughness decreasing sharply (see figure 2b). After extrusion through the die, the root-mean-square surface roughness $R_q$ decreases from the initial value of 2.1 µm to 1.1 µm.
Figure 3. An EBSD image of the microstructure in the region close to the lateral surface of the annealed AMg6 alloy specimen.

The first indent was made at a distance of about 10 to 15 µm from the edge. Figure 3 depicts the dependence of hardness distribution on the distance from the contact surface for both the initial and deformed specimen. The experiments have shown that surface hardening is achieved for the AMg6 alloy specimen with an initial average hardness of 1.7 GPa. Figure 4 demonstrates that the hardness increases in a narrow layer near the friction surface and that the increase starts at a depth of 200 µm from the surface edge. The maximum hardness value is 2.3 GPa at a depth below 15 µm.

Figure 4. Hardness ($H$) distribution as dependent on the distance from the contact surface edge of the AMg6 alloy specimen: ▲ – the initial specimen; ● – the deformed specimen.

3. Conclusion
Pushing specimens through a conical die with a small semi-angle allows one to form a thin hardened layer in metal materials. The results of the experimental investigation have shown that, when the AMg6 alloy specimen is pushed through a conical die with a semi-angle of 1.5°, the thickness of the hardened layer is 200 µm.
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References
[1] Savrai R A, Makarov A V, Malygina I Yu, Rogovaya S A and Osintseva A L 2017 Diag. Resour. Mech. Mater. Struct. 5 43-62
[2] Peat T, Galloway A, Toumpis A, McNutt P and Iqbal N 2017 Appl. Surf. Sci. 396 1635-48
[3] Savrai R A, Makarov A V, Malygina I Yu and Volkova E G 2018 Mater. Sci. Eng. A. 734 506-512
[4] Savrai R A, Makarov A V 2018 Mater. Sci. Eng. A. Elsevier 734 513-518
[5] Alexandrov S, Richmond O 2001 Int. J. Non. Linear. Mech. 36 1-11
[6] Alexandrov S E, Goldstein R V 2015 Dokl. Phys. 60 39-41
[7] Brovman M J 1987 Int. J. Mech. Sci. 29 483-489