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RESEARCH OF THE HETEROGENEOUS ALLOY PROPERTIES VIA INDENTATION AND FINITE-ELEMENT METHOD SIMULATION

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Research significance

Any activity with metals or alloys causes energy exchange processes; for example, the material is able to dissipate and reverse elastically some part of the energy under deformation (tension, compression, torsion). But if the input energy is too high, the material fails. Thus the development of the criteria to evaluate the dissipating energy capability and its load-carrying ability limits are important tasks in material science.

On the one hand, these limits differ for heterogeneous alloys in macro- and microscale testing. On the other hand, microscale testing gives the researches highly informative results about material features and even may substitute macroscale tests in some cases.

Background

Several methods of microtesting described in [1-4] may be used for energy exchange parameters determination. Firstly, it is microindentation (or instrumented indentation) technique, which has been widely used for determining mechanical properties of solids, especially the elastic modulus and hardness. The output usually has the form of a pair of load-displacement curve that forms hysteresis loop of the load and unloading branches. This loop gives an opportunity to measure dissipated energy etc. [1, 2].

Authors [3] studied the subsurface hardness investigation under the big Vickers imprint. For this purpose the sectioned plane through a Vickers indentation in an annealed copper specimen was done and then subsurface strain hardening was investigated. Subsurface strain contours showed the real shape of the hardened area, which appeared to be significantly elongated in the indenter load axis direction in cooper [3]. Due to procedural difficulties this research seems to be too complicated to carry out in case of hard materials (such as cemented carbides).

A very powerful technique is the finite-element method (FEM). The main advantage of the method is the determination of the load-displacement curve and also the interior stresses for thin film systems and brittle materials where analytical solutions are not available. FEM also gives an opportunity to investigate bulk volume on any plane in simulated specimens when the study is impossible in lab [1, 4, 5].

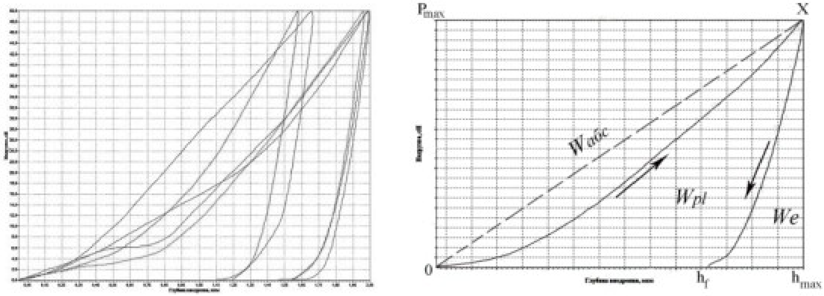
The goal of the research

The main goal of the recent study is to explore energy exchange processes of heterogeneous alloy via microindentation and FEM.

Results and discussion

Sintered powder alloy of 30%Co-70%WC (VK30) composition with hardness 79-79.5HRA and elastic modulus E=238 GPa was chosen as the material for the research. In order to achieve assigned task the study was divided into two stages.

Firstly, microindentation was conducted using Vickers pyramid. In fig.1 the set of load-displacements curves and scheme of the areas corresponding to the following energies: W_{pl} –energy dissipated (work-of-indentation) during the indentation cycle; W_e – elastically recovered energy; W_t – total energy (sum of the W_{pl} and W_e); W_{abs} – absolute energy (area $0Xh_{max}$). In fig. 1 h_{max} is the maximum penetration depth; h_f is the recovered imprint depth. The defined values are given in table 1.



a b

Fig.1 –Set of load-displacements curves (a) and scheme of the areas that are correspond to following energies (b), alloy VK30

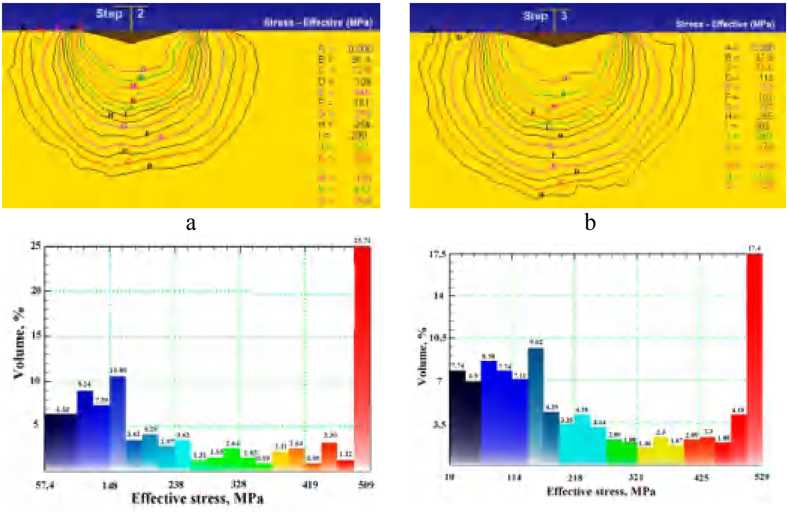
Absolute energy is defined as the maximum energy that may be dissipated during the indentation on the material surface [6]. While the total and elastic energies are related to the curvatures of the loading and unloading curves, respectively, W_{abs} is a half of potential energy of the weight used. The difference between W_{abs} and W_t lays in rage 28±9%. This value is caused by the difference between alloy strain rate at initial and further loading stages (fig. 1).

Table 1

Defined indentation energies

No.	h_{max}, µm	h_f, µm	d_1, µm	W_{pl}, nJ	W_e, nJ	W_t, nJ	W_{abs}, nJ	A, µJ/µm^3
1	2.04	1.52	14.29	309	58	367	500	78.01
2	1.63	1.15	11.41	198	60	258	399	122.31
3	1.72	1.24	12.01	300	66	366	420	110.49
4	2.05	1.59	14.33	289	66	355	502	77.56
5	2.02	1.51	14.11	259	59	317	494	80.04
Mean	1.89±0.2	1.40±0.2	13.22±1.42	271±45.4	62±4.1	332±46.7	463±49.8	93.68±21.42

Then simulation via finite-element method using Deform v10.2 was carried out. FEM was conducted with regard to following assumptions: the Vickers indenter was considered as absolutely rigid body; alloy was assumed to be homogeneous for convenience; the indenter movements are controlled by the stroke. In fact the VK30 alloy is characterised by signified heterogeneity that makes simulation process difficult. Therefore its mechanical properties were calculated as an arithmetic mean of Co and WC properties, so as bulk material was assumed to be homogeneous in macroscale. The results are given in fig.2.



a b

c d

Fig.2 – The effective stress filed under the imprint (a,b) and in bulk volume (c,d). Simulation step 1 (a,c) and step 2 (b,d)

It was shown that high effective stress may spread in almost 26% of deformed volume (fig.2 c,d) and this field lays directly under the imprint. The lower stress spreads much more regularly in volume. Low capability of VK30 to distribute load can explain its brittleness and low plasticity.

FEM results proved that shape of the hardened area tend to form a sphere. Main geometry constants were estimated in this regard (table 2): d_1 – diagonal of pyramidal imprint; d_{max} – the biggest diameter of deformed area (of the sphere) ; h_1 – depth of pyramidal imprint; h_2 – distance from section plane to sphere axis; h_3 – depth of hardened area.

The volume of deformed area can be calculated approximately to following equation:

$$V = \frac{\pi}{3}[4R^3 - (d_{max} - h_3)^2 \cdot (R + h_3)] = \frac{\pi d_1^3}{3}[0{,}5\beta^3 - (\beta - \gamma)^2(0{,}5\beta + \gamma)]$$

where β=2.3 and γ=1.43.

Table 2

Size proportions of deformed area

Alloy	according to FEM resultes					
	h_3/h_1	h_3/h_2	$\alpha=d_{max}/d_1$	d_{max}/d_2	$\gamma=h_3/d_1$	d_2/d_1
VK30	10.07	4.9	2.3	1.10	1.43	2.14

Specific work A that one has to do to deform surface of VK30 alloy may be estimate as:

$$A = \frac{W_{abs}}{V} = \frac{mgh_1/2}{1{,}4\pi d_1^3} = \frac{mg}{19{,}6\pi d_1^2}, J/\mu m^3$$

where m – weight, kg.

g – acceleration of gravity, g=9.8 m/sec^2.

Determined values of A are shown in table 1.

Since load-displacement curves have been obtained early, the depth of unrecovered imprint h_{max} was used instead of h_1 in calculations and the specific work A was the work needed for elasto-plastic deformation (i.e. total). Its magnitude lied in range A=93.68±21.42 μJ/μm^3. This value was obtained with regard to absolute energy, that is why 93.68 μJ/μm^3 may be interpreted as highest possible level of expenditure of energy for deformation.

Conclusions

To sum up, the energy transformation processes in heterogeneous alloy 30%Co-70%WC were studied via microindentation and FEM. The indentation shown that alloy dissipated 271±45.4 nJ of absolute possible 463±49.8 nJ and recovered 62±4.1 nJ.

The results of FEM proved that high effective stress may spread in almost 26% of deformed volume lays directly under the imprint what can explain its brittleness and low plasticity. It was also noted that shape of the hardened area tend to form a sphere.

Thus FEM simulation made possible to evaluate the specific work for elasto-plastic deformation of 1μm^3 alloy volume. The work A laid in range 93.68±21.42 μJ for 30%Co-70%WC alloy.

These values might be useful in estimation of alloy working capacity limits, its maximum capability to dissipate energy without fracture and became the materials selection criterion.

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