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THE MANAGEMENT OF SURFACE QUALITY OF METAL WITH NANO AND SUBMICROCRYSTALLINE STRUCTURE DURING MACHINING

Розглянуті особливості поведінки нано- та субмікрокристалічних металів, отриманих методом інтенсивної пластичної деформації, під впливом температурного чинника, виникаючого у процесі механічної обробки заготівок. Представлена послідовність дій для отримання раціональних умов обробки, які забезпечать збереження вихідної структури металу та високу якість поверхневого шару після механічної обробки. Запропоновані раціональні умови обробки для деяких металів з нано та субмікрокристаллічною структурою.

Рассмотрены особенности поведения нано- и субмикрокристаллических металлов, полученных методом интенсивной пластической деформации, под воздействием температурного фактора, возникающего в процессе механической обработки заготовок. Представлена последовательность действий для определения рациональных условий обработки, которые обеспечат сохранение исходной структуры металла и высокое качество поверхностного слоя после механической обработки. предложены рациональные условия обработки для некоторых металлов с нано- и субмикрокристаллической структурой.

The behaviour features of the nano- and submicrocrystalline metals affected by the temperature factor incipient during cutting are considered. The metals are processed by methods of severe plastic deformation. The operations consistency in order to get the rational machining conditions is presented. The rational machining conditions will ensure the conservation of the initial metal structure and high workpiece surface quality after cutting. The rational machining conditions for the same metals with nano- and submicrocrystalline are suggested.

From the broad spectrum of all nanomaterials only bulk nano- and submicrocrystalline metals are considered in this paper. These metals are processed by methods of severe plastic deformation (SPD) [1].

Some research [1-5] has shown that the mechanical characteristics of the nanocrystalline metals essentially differ from macrocrystalline metals. The practical interest is the high strength properties of nanostructure metals, such as strength, microhardness, increased damping capacity etc.

The bulk nanocrystalline and submicrocrystalline metals are used in medical, aircraft and auto engineering industries [1, 6].

The nano- and submicrocrystalline metals, got by SPD, differ in instability structures. The observed grain growing can be explained by high internal tensions. The sources of tension are nonequilibrium of a boundary grain and a crystalline lattice distortion [1]. The temperature of a grain growth beginning (0,2-0,3Tm [7, 8]) in nano- and submicrocrystalline metals is lower than in macrocrystalline metals. Complex structured changes occur with the development of the processes of the return, recrystallization, growing grain and loss of high physical-mechanical properties in the nanocrystalline metals at heating [1, 9]. The intensity of the recrystallization process, resulted in grain growing, is determined by degree and time of the thermal action.

Usually, manufactured parts are made by means of the cutting.

Cutting is a complex process of plastic deformation. It is accompanied by intensive heat generation with significant stress in zone of the contact "instrument – work material" [10].

The physical state (structure, properties) and surface tension of a part are result of elastic-plastic deformation and local heating in a cutting zone. The heat occurs during plastic deformation and external friction of working surfaces of the cutting tool on the work material. The heat has a great influence on the physical state of the surface.

Large contact area on the front surface of the tool is characterized for fine metals. This leads to the considerable efforts of friction. Small value of a shear gives the increase of cutting speed and temperature in the cutting zone. The temperature in the cutting zone for technically fine nickel, titan and copper are 973, 873 and 573 K respectively [11].

It can be hypothesised that temperature in the cutting zone and time of the temperature influence, will cause the grain growth and reduction of physical-mechanical properties of the nano- and submicrocrystalline metals.

The experimental data have confirmed the influence of the temperature and the time factor on grain growth and change of the physical-mechanical properties of the nano- and submicrocrystalline metals. The change of the physico-mechanical properties results in deterioration of performance of the nano- and submicrocrystalline metals.

The main requirement for the formation of the parts is the preservation of the initial submicrocrystalline or nanocrystalline structure of the workpiece. The properties of the metal shouldn’t change under the influence of deformation-thermal phenomena during machining.

The force and temperature are main physic factors influencing changes in the structure of the nano- and submicrocrystalline metals. The role of these factors is necessary to determine to find the rational conditions of machining of the nano- and submicrocrystalline metals.

The operations consistency of surface integrity management of metals with nano- and submicrostructure has been developed.

The consistency of workpiece surface quality consists of the following stages:

1. The workpiece with the known initial grain size is chosen.
2. The maximal temperature in the workpiece, time of influence of this temperature and penetration depth of the maximal temperature is determined. For this purpose the model of calculation of the thermal fields is used. The

necessary data are a tool material, cutting conditions and number of cutter passes. (The maximal temperature arises in the workpiece and causes structural changes of metal. The time of the maximal temperature influence defines intensity of grain growth and depends on the feed value).

The finite-element modelling of the allocation of temperature fields in a workpiece is performed using the program package ANSYS 8.0.

The value of the heat flow coming from the instrument in the workpiece and the heat transfer coefficient of the workpiece with the environment is found. These data are calculated based on the algorithm for calculating heat flows proposed A. N. Reznikov [12].

The intensity of heat current, heat-transfer coefficient and the thermal characteristics of work metal (thermal conductivity, specific heat) are put in the model. The allocation of temperature fields in a workpiece and the intensity of heating the workpiece to a depth of the surface layer are found by finite-element modelling.

3. The coarsening transport coefficient is determined. The values of coefficient lie in an interval of the calculated boundaries considering nano– and submicrocrystalline metal from a position of crystal and amorphous properties.

The rate constant of coarsening (k) is derived by supposing the grain boundary is crystalline (1):

$$k_c \cong A\frac{T_m}{T}\exp\left(-B\frac{T_m}{T}\right), \tag{1}$$

with $A = (1.3 \pm 0.5)\ 10^{-4}$ (m^2/s), $B = p + z$, with $p = 14$ (bcc), $p = 17$ (fcc and hcp) and $p = 21$ (for dc, such as Ge, Si)), while z - the valence of the metal, T_m - melting point of metal (K).

The equation parameter k, supposing that the grain boundary is fully amorhopous (2):

$$k_a = (8.5 \pm 3)10^{-9}\frac{V_m^{1/3}\cdot T_m}{M^{1/2}\cdot T^{1/2}}\exp\left[-(2.34 \pm 0.20)\frac{T_m}{T}\right], \tag{2}$$

with the molar volume (3) expressed as [13]:

$$V_m = V_m^o\left[1+\beta(T-T_m)\right] \tag{3}$$

with M - , atomic mass (kg/mol); Tm - melting point of the metal (K), V_m^o - the molar volume of the metal (m3/mol).

The decision region is found using the calculated and experimental [1, 5, 14, 15] values of the coarsening transport coefficient for five fine metals (Ti, Ni, Fe, Nb, Cu). The decision region is limited straight lines. Straight lines connect the points obtained by calculating the coarsening transport coefficient for the grain boundaries with crystal (c) and amorphous (a) properties. The decision regions are shown in Figure 1.

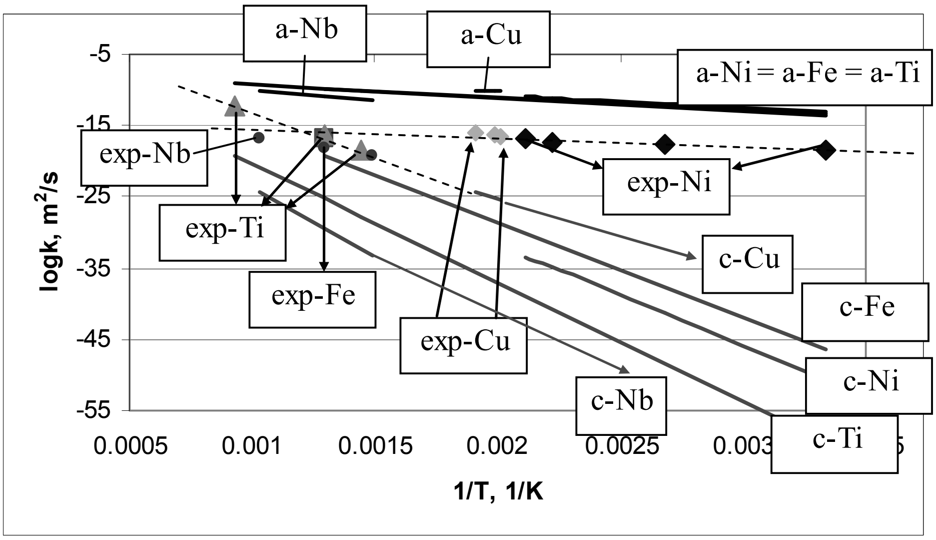

Figure 1 – Comparison of experimental and calculated intervals for k for Ti, Ni, Fe, Nb, Cu

The semi-empirical dependences for Ti, Ni, Fe, Nb and Cu have been received to simplify the calculation of the coarsening transport coefficient (Figure 2).

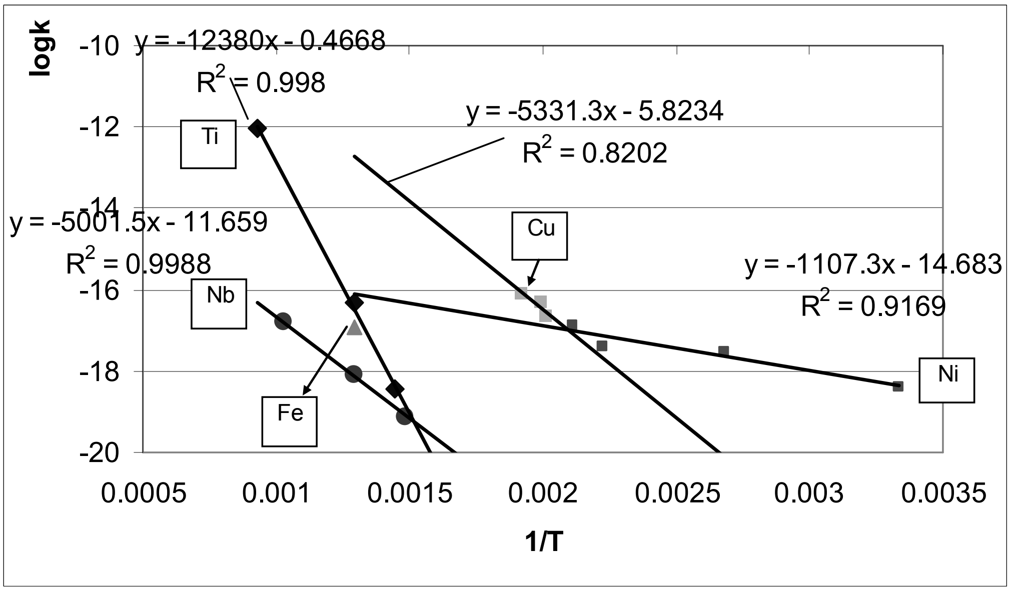

Figure 2 – Semi-empirical correlation between log k and 1/T for Ti, Ni, Fe, Nb, Cu

The following equations (4-7) can be used:

For Ni:

$$k = 10^{-14.683 - \frac{1107.3}{T}} \qquad (4)$$

For Ti:

$$k = 10^{-0.4668 - \frac{12380}{T}} \qquad (5)$$

For Cu: $$k = 10^{-5.8234 - \frac{5331.3}{T}} \tag{6}$$

For Nb: $$k = 10^{-11.659 - \frac{5001.5}{T}} \tag{7}$$

with T temperature (K).

4. The grain size of the workpiece after machining is determined using equation (8):

$$D = \sqrt{(D_0)^2 + 2 \cdot k \cdot t}\,, \tag{8}$$

with D0–the initial grain size (m), k–the coarsening transport (m2/s), t– time (s).

The value of the grain size after the growth process allows to predict the physical and mechanical characteristics of the workpiece surface layer (microhardness, breaking point, yield strength, etc.). The prediction is carried out to the experimental data [1-6, 14, 15].

Table – The rational machining condition of a number of fine metals at turning

Fine metal	Initial grain size, µm	Tool material	Cutting speed, m/min	Feed, mm/r	Cutting depth, mm	Lubricant-cooling agent
1	2	3	4	5	6	7
Copper	0,1	S6-5-2 (Euro), M2 or T1 (USA)	40-50	to 0,12	to 3	Aqueous solutions
	0,25		70-80	0,2-0,3	to 5	
	0,3		70-80	0,2-0,3	to 5	
Nickel	0,1	S6-5-2 (Euro), M2 (USA)	20-30	0,1-0,2	to 3	Aqueous solutions
	0,15		40-50	0,1-0,3	to 3	
	0,25		60	0,1-0,3	to 4	
			40-50	0,1-0,3	to 4	-
Niobium	0,1	S6-5-2 (Euro), M2 or T1 (USA)	60-70	0,05-0,1	to 3	Aqueous solutions
	0,2		80-95	0,2-0,3	to 5	
	0,3		80-95	0,2-0,3	to 5	-
Titan	0,1	K20	to 40	to 0,1	to 5	-
	0,25		40-50	0,1-0,15	to 5	
	0,3		to 60	0,1-0,15	to 5	
	0,1	synthetic diamond	to 80	to 0,1	to 5	
	0,25		100-120	0,1-0,15	to 5	
	0,3		100-120	0,1-0,15	to 5	

The model of workpiece surface integrity can be used for fine metals including copper, armco iron, and niobium.

The rational machining conditions for a number of fine metals have been found using the work of the algorithm. The rational machining conditions are presented in Table

The consistency includes the given model of grain growth intensity under the influence of time-temperature factors and the model of temperature distribution in the workpiece. The master data for modeling includes: the workpiece material, the initial grain size, the cutting tool material, the cutting conditions (speed, feed, cut depth, lubricant-cooling agent) and application conditions.

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