MICROSTRUCTURAL ASPECTS OF LOCALIZATION OF DEFORMATION AND DESTRUCTION OF STRUCTURE–INHOMOGENEOUS MATERIALS

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ABSTRACT

Here are the results of the comprehensive researches of mechanical properties,destruction and the micromechanism of deformation of polycrystalline materials.The inhomogeneity of stress-strained states in microvolumes of different polycrystals in elastic and elastoplastic fields is investigated.Microstructural coefficients of stress and strain concentration are defined and their dependence on the degree of anisotropy properties and kind of stress is examined.The dependence of mechanical properties and destructions of polycrystalline alloys on the level of microheterogeneous deformation under the static tests,the impact tests and different temperature tests is established.

KEYWORDS

Micromechanism of deformation,inhomogeneity of stress-strained states,microstructure,mechanical properties,destruction.

INTRODUCTION

Polycrystalline metals are the typical structure-inhomogeneous materials,which are widely used in practice.The inhomogeneity of stresses and deformations in polycrystals,which depends on their microstructure(Kuksa,1979),plays a great role in the achievement of limit stress-strained states.The inhomogeneity of stresses and deformations in elastic field must be connected with the achievement of limit of yield in local microvolumes and, consequently,with the appearance of the first plastic yield and as for fragile metals,it has to be connected with the achievement of destruction stresses in single microvolumes.It is the consideration of microstructure stresses and deformation that must play the great role,especially,in places of concentration of stresses and in the mouth of the spreading crack.The inhomogeneity of the plastic deformation influences the plastic properties and promotes the quicker exaust of bearing capacity of the material,leading to the destruction.The comprehensive research of the inhomogeneity of stress-strained states in microvolumes of polycrystals in elastic and elasto-plastic fields permit to define microstructural coefficient of stress and strain concentration,to determine the role of the microheterogeneous deformation in the formation and prognostication of mechanical properties,to study the mechanism of accumulation of plastic microdeformations,leading to the destruction of the material.

METHODS OF RESEARCH

Stresses and deformations in the elastic field were defined on the basis of calculation of the statistic model of the polycrystal with the use of the method of finite elements(Kuksa, 1986),in that case the method of consideration of the polycrystal on different levels was used: 1) dimensions of the grain of the polycrystal; 2) a group of grain of the polycrystalline agregate,making the elementary volume,which may be endowed with the average properties; 3) the calculating element of the construction(body as a whole).The ground of sizes of the elementary volume was made on the basis of the research of the scale eФfect of elastic properties of polycrystals.

Fig.1 shows the change of standard deviation of the Young's modulus,depending on the number of grain characterizing the linear size of the elementary volume of polycrystal.

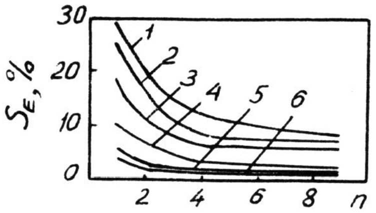

Fig.1. The scale effect of elastic properties of polycrystals. 1-Zn; 2-Cu; 3-Fe; 4-Ti; 5-Al; 6-Mg.

Different polycrystals have different anisotropy of elastic properties,it is reflected in the value of standard deviation depending on n .When n=6,the change of the standard deviation becomes negilible true for all examined polycrystals.It was taken into account that n=6.A separate grain of the polycrystal was broken into approximately 100 triangular elements.

When using the method of finite elements the creating of the system of equations (1) includes the calculation of matrix of the stiffness of the elementary cell (2) as the sum of corresponding members of the matrix of the stiffness of separate elements (3).

$$[K]\{\delta\} = \{F\}\ , \qquad (1)$$

$$K_{sl} = \sum_{1}^{n} K_{ij}\ , \qquad (2)$$

$$[K] = [B]^T[D][B]At, \qquad (3)$$

where $[K]$-the matrix of the stiffness of the model; $\{\delta\}$-the vector of transfers; $\{F\}$-the vector of loads; $[K]$-the matrix of the stiffness of separate element; $[B]$-some rectangular matrix, the elements of which depend on the type of finite element and coordinates of the point examined; $[D]$-the matrix of elastic properties; A, t -the area and the thickness of the element correspondingly.

The decision of the system of equations (1) permits to calculate the vector of deformations $\{\varepsilon\}$ and stresses $\{\sigma\}$ by the formulas

$$\{\varepsilon\} = [B]\{\delta\}, \qquad (4)$$

$$\{\sigma\} = [D]\{\varepsilon\}. \qquad (5)$$

After the definition of the vector of deformation is made by the formula (4) and the vector of stresses is found by the formula (5),we find the principal stresses σ_1 ,and deformations ε_1 for each element,and then calculate the microstructural coefficients of stress $K_{\sigma_1 max}$ and strain concentration $K_{\varepsilon_1 max}$:

$$K_\sigma = \sigma_{1max}/\bar{\sigma}, \qquad K_\varepsilon = \varepsilon_{1max}/\bar{\varepsilon}. \qquad (6)$$

We calculate the models of polycrystals,having different crystal latice: iron(volumecentric cubic lattice),cooper(facet-centric cubic lattice),titan and zinc(hexagonal lattice) for different kinds of the stress.

The inhomogeneity of plastic deformation was experimently investigated in samples,made of different polycrystalline alloys. Tensile test of mainly cylinder samples was made(initial diameter is 10mm and length of working part is 100mm).After the thermal processing,the surface of samples,which was prepared as metallographic polish,was subjected to the multiple electrolyte polishing with the subsequent etching in order to expose the microstructure.We made datum points on the surface along the axis of the sample of the diamond pyramid.It was made under the low load on the indentor(with the minimum base up to 10mcm) on the microhardnessmetre with automatic loading,which is placed on the independent foundation.The measurement of the deformation of samples on the microbases was fulfilled with the method, which is described in the work(Kuksa,1979).The general number of research microarea per each sample accounted from 200 to 400. The deforming was carried out in a series of consecutive steps. The average deformation of the sample on the step was 2...4%.

The deformation of i's microarea on the first and next steps was calculated in such a way:

$$\varepsilon_{i1}=[l_{i(1)}-l_{i(0)}]/l_{i(0)},\ \varepsilon_{i2}=[l_{i(2)}-l_{i(1)}]/l_{i(0)} \text{ and so on.} \qquad (7)$$

The parameter K_ε was defined for the building up of diagrams of the microheterogeneous plastic deformation

$$K_\varepsilon=\varepsilon_i/\bar{\varepsilon}\ , \qquad (8)$$

where

$$\bar{\varepsilon}=\sum_{i=1}^{n}\varepsilon_i/n \qquad (9)$$

When investigating two-phrase polycrystalline alloys(the steel with different content of carbon),we defined the criterions of the locality using structural components:ferrite K_F and perlite K_P :

$$K_F=\varepsilon_{Fmax}/\bar{\varepsilon},\qquad K_P=\varepsilon_{Pmax}/\bar{\varepsilon}. \qquad (10)$$

The quantity appraisal micro-nonheterogeneity of deformation as a whole was made with the help of the standard deviation and the variational coefficient.

RESULTS OF RESEARCH AND THEIR DISCUSSION

The Inhomogeneity of Stress-Strain States in the Elastic Field. The stress-strained states in grains of cubic and hexagonal polycrystals with different orientations were calculated on the basis of the elaborated method.It is stated the availability of the incorn inhomogeneity of stresses and strains,which was the result of elastic interaction of differently oriented grains to each other.The dependence of the inhomogeneity of stresses and on the level of the anisotropy of elastic property of separate crystallites was displayed.

The microstructural coefficients of stress and strain concentration,the meanings of which are displayed on fig.2,have to play a great role in the achievement of limit stress-strained states.

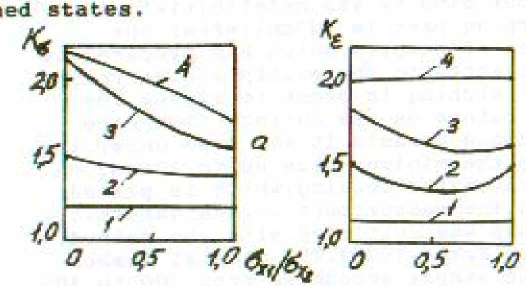

Fig.2. The change of the microstructural coefficients of stress and strain concentration: 1-Ti; 2-Fe; 3-Cu; 4-Zn.

The microstructural coefficients of concentration also depend on the degree of anisotropy of elastic properties and on the kind of the stresses states(in that case,it is estimated by the ratio of principal stresses σ_{x1}/σ_{x2}) and can count for much, for example $K_\sigma=2{,}15$, $K_\varepsilon=2$ -for zinc and $K_\sigma=2{,}1$, $K_\varepsilon=1{,}8$ -for copper under the direct stretching ($\sigma_{x1}/\sigma_{x2}=0$).These results testify the necessity of the consideration of the microstructural coefficients of stress and strain concentration.

The Role of Microheterogeneous Plastic Deformation in the Formation of Mechanical Properties and in Destruction of Two-Phase Polycrystal Alloys.The difference in properties of separate structure components and their percentage content in the polycrystal alloy play an important role for the two-phase and many-phase metals.Research,carried out on steels with various content of carbon shows that the increase of the content of the more hard but low-plastic component of perlite and decrease of the component of ferrite lead to the raising of criteria of the locality on ferrite K_F and on perlite K_P .

Fig.3 represents graphs of microheterogeneous deformation in microareas for samples made of steel containing carbon: a-0,045%; b-0,12% c-0,23%; d-0,42%; e-0,66%.The employment of base in 10mcm allows to distinguish sharp outbursts of local plastic deformation and in that case may be from 2 to more than 4 times.

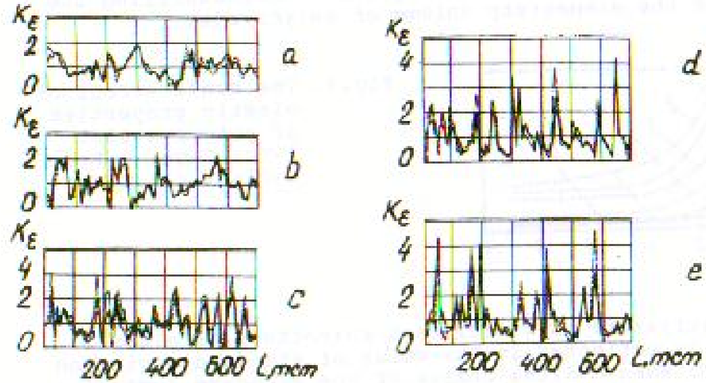

Fig.3. Graphs of microheterogeneous deformation.

Fig.4 shows the change of variational coefficient V ,of the criteria of locality on ferrite K_F and also change of mechanic characteristics of steel depending upon the contents of ferrite and perlite in the structure of alloy.Upon increasing the level of microheterogeneous deformation,which is estimated with the help of criteria of the locality according to the structure components of K_F, K_P and of variational coefficient V ,the plastic properties of steel are considerably decreasing.In that case there are two causes of properties of two-phase alloys:the change of the level of microheterogeneous deformation and plasticity of separate structure components.Simultaneously the increase of contents of perlite in comparison with ferrite results in increasing limit of yield σ_y ultimate stress σ_u .

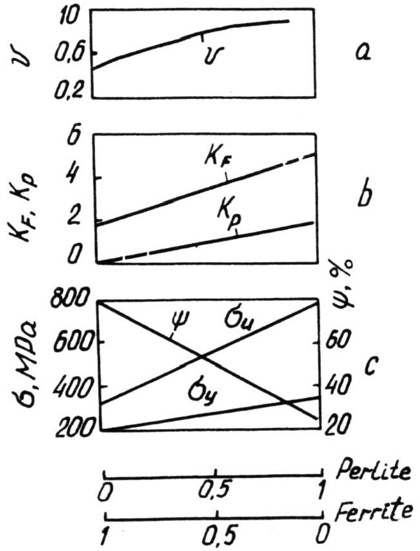

Fig.4. The change of the characteristics of microheterogeneous deformation and mechanical properties of carbon steels according to the contents of structural components.

A certain connection was determined between average real deformation of the sample before destruction, criteria of locality according to the structural components K_F and K_p and the plasticity of separate phases. The destruction of an alloy begins when one of the structural components achieves limit significance of plastic deformation $\varepsilon_{F max}$ or $\varepsilon_{p max}$.

<u>The Micromechanism of Forming Mechanical Properties of Steel According to Its Structure.</u> Micromechanism of forming of plastic and strength properties depending on the structure for average carbon steel (carbon content C-0,42%) was investigated in different states. Such states, were the result of the process of hardening: at t^o 900°C and cooling in water with further heating at the temperature from 100°C to 900°C.

The changes of the microstructure of steel are reflected in the change of properties of microvolumes, which are defined by the change of microhardness, and by the character of interaction of individual microvolumes in the process of deformation, evaluated by variational coefficient ν .

The consideration in common (Fig.5) of dependence of ultimate stress σ_u , real tear resistance σ_F , microhardness H , relative remaining extention δ , narrowing ψ , toughness KCU and variational coefficient ν on the temperature of heating after hardening testifies to their definite conformity. The change of ultimate stress σ_u corresponds to change of microhardness H , which serves as the indirect characteristics of strengthing properties of microvolumes (Fig.5a). The decrease of variational coefficient ν is accompanied by the increase of plasticity and toughness (Fig.5b,c).

The impact tests as well as static tests in microfields'cause extremely heterogeneous deformation. The toughness is a sensitive characteristic for the manifestation of microheterogeneity of deformation of polycrystal materials, changing when depending on its level more significantly, than the static characteristics

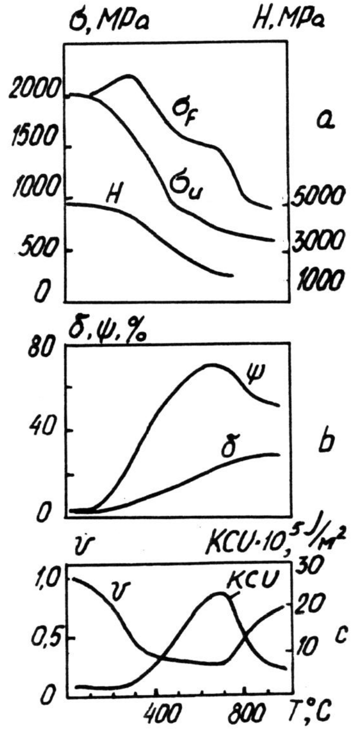

Fig.5. The change of mechanical properties of steel (C 0,42%) and variational coefficient in dependence on temperature heating after hardening.

of plasticity. The researches held allow to make the conclusion that the composition is the optimal structural one when under the highest strength properties of microvolumes it is possible to provide for the most favourable conditions of their interaction leading to the decrease of microinhomogeneity deformation.

<u>The Micromechanism of High Temperature Heterogeneous Deformation and Destruction of Heat-Proof Nickeliferrous Alloys.</u> The investigations conducted on the samples made of heat-proof nickeliferrous alloys, having complicated chemical composition, show the presence of heterogeneous deformation character on microfields under various temperature of deformation (20°C and 750°C). The level of microinhomogeneous deformation depends on temperature of test and speed of deformation. Under high temperatures of a test the level of microinhomogeneity of deformation decreases to some extent for the bodies of grains, but the localization of deformation on the boundaries of grains increases and forms microcracks, which take place with the decrease of the speed of deformation.

It is found the dependence of mechanical properties for heat-proof alloys on the level of microheterogeneous deformation at the temperature of 750°C and at the speed of deformation at $1\cdot10^{-6}$ c^{-1} for different regimes of heat treatment, distinguished by speeds of cooling after heating (Fig.6). The least value of variational coefficient ν corresponds to greatest value of characteristics of strength σ_u and plastic properties ψ (Fig.6, second regime of heat treatment). The destruction of the alloy in that case carries advantageously inside crystallite character (Fig.7b) opposite to the 1st and 2nd regimes, where the intercrystallite character of destruction prevails (Fig.7a,c) and it is possible to observe the shearing of processes in the zone of destruction under the 1st regime of treatment.

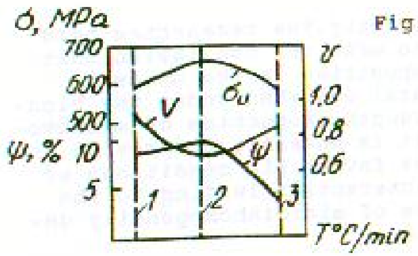

Fig.6.The change of mechanical properties and variational coefficient depending on the speed of cooling under different regimes of heat treatment of the heat-proof nickeliferrous alloy.

a b c

Fig.7.Micropicture of deformation in the zone of destruction of the heat-proof nickeliferrous alloy at 750°C,speed of deformation $1\cdot10^{-6}$ c^{-1}: a-the 1st,b-the 2nd,c-the 3d regimes of heat treatment,correspondingly.

CONCLUSIONS

It was found that there is an interconnection of the micromechanism of deformation with the mechanical properties and the destruction of polycrystal alloys.It is shown that the optimal structural composition is that one,when with the highest strength properties of microvolumes the most favourable conditions of interaction are ensured,what results in decreasing of microinhomogeneity of deformation.

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