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STUDY BERYLLIUM MICROPLASTIC DEFORMATION

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Investigation of the physical characteristics of the material behavior in the microstrain provides information on trends and mechanisms of the elastic-plastic transition and subsequent plastic flow until deformation about 10^{-4}. This information can not be obtained using traditional methods of testing and analysis of materials macrodeformation. Investigation of deformation processes in microplasticity help to better understand and explain some of the features of plastic flow of the material, such as the formation of planar dislocation pileups that occur before the start of the macroscopic flow processes and fracture, dislocation pinning by point defects and inelastic behavior of brittle materials under tensile loads, etc. The currently available experimental data on the microscopic deformation processes beryllium insufficient and contradictory [1], so the behavior of metals (beryllium, in particular) in microplasticity requires further study. This article presents the results obtained by the authors on the study of the early stages microflow and influence of structural factors and heat treatments (such as thermal cycling) on the microplasticity characteristics of different beryllium grades.

EXPERIMENTAL

For research of precision characteristics by a method of a mechanostatic hysteresis in this work used microsample testing machine for static tension designs KIPT. Grips movement speed was 5.4 10^{-6} s^{-1}, thereby provided the necessary permission measured characteristics microplasticity.

As a weighting device used cylindrical elastic element with tensoresistive loading measurements. For measurement of deformation of samples used resistance sensors of type 2 PKB-20-200 with 20 mm base, equal to the sample working length. The error of definition of loading didn't exceed ±1%, strains ±2 10^{-7} units relative deformation (u.r.d.).

The microplasticity test samples were cut by electric spark method. Their dimensions are: length 20 mm the working part, the cross-section 3,5 mm^2. This size ratio of the flat samples satisfies the conditions to ensure high sensitivity to strain using strain gauges with the corresponding base.

In experiments determined the following values which characterize the behavior of materials in microstrain (10^{-7}…10^{-3} u.r.d.):

— microscopic elastic limit $\boldsymbol{\sigma_E}$ — tension at which the deviation from linear elastic behavior of a material is found when loading;

— microscopic yield strength $\boldsymbol{\sigma_A}$ — tension at which the first residual deformation is observed $\boldsymbol{\varepsilon}$ =2 10^{-7};

— residual deformation $\boldsymbol{\varepsilon}$ after each cycle of loading of a sample;

— Young modulus $\boldsymbol{E}$ in microplasticity.

MICROPLASTICITY DIFFERENT GRADES OF BERYLLIUM

At present, almost all of the metal beryllium received by powder metallurgy. Properties of the metal is largely depend on production technique of powder, particle size and chemical composition.

Compaction of material produced mainly by two methods: vacuum hot pressing (HP) and cold or hot isostatic pressing (CIP-HIP). Sample which are received by the CIP-HIP method, have two important advantages in comparison with hot-pressed sample. Firstly, CIP-HIP sample have higher degree of isotropy of structure and properties. Secondly this method can produce products rather complicated form, which does not require further substantial mechanical processing.

Therefore focused on beryllium powder, compacted using CIP-HIP technology.

Microplastic properties of beryllium compressed by CIP- HIP from different purity powder and obtained by casting and rolling, are given in Table. 1.

Table 1

Characteristics of beryllium microplasticity obtained by different technological schemes

Metal grade	Obtaining Method	E, GPa	σ_E, MPa	σ_A, MPa	σ, MPa, with $\varepsilon=10^{-6}$	σ, MPa, with $\varepsilon=10^{-5}$
CIP-HIP	CIP-HIP technical grade powder	359	11.6	35.3	73	–
CIP-HIP Sph	CIP-HIP milled spherical powder	348	11.4	34.0	68	–
HIP Sph	HIP spherical technical purity powder	340	17.2	41.0	49	113
HIP Sph D	HIP spherical distilled metal powder	385	–	–	6.3	20
Cast rolled	vacuum melting distilled metal, casting, extrusion, rolling	327	28.5	52.4	61	117

The main factors that determine the level values σ_E, σ_A and strain microflow are: particle size, the chemical composition of the powder, and technology for producing metal [2].

As seen from Table 1, beryllium grades CIP-HIP and CIP-HIP Sph show almost the same values σ_E s σ_A in microstrain. Although these materials have approximately the same grain size (accordingly 8 and 10 microns), they are different in chemical composition of the initial powders. Sort beryllium CIP- HIP contains significantly less impurities, and therefore must have a lower value σ_E and σ_A. Observed match these characteristics can be related to differences in the microstructures of these materials and the internal stress level. This assumption is confirmed by distinctions in impact on microplasticity characteristics at thermocyclic processings of these grades of beryllium.

Increasing the purity of the material by reducing the material content *BeO, Fe, Al* and other impurities leads to a significant reduction microplastic characteristics. For example, when $\varepsilon = 1\cdot10^{-6}$ $\sigma = 73$ MPa for isostatically pressed metal technical grade and $\sigma = 6$ MPa for beryllium grade HIP Sph D, which is molded from distilled metal. At the cast and rolled distilled beryllium this tendency doesn't remain: microplasticity characteristics of these grades significantly increased due to a low temperature hardening during extrusion and rolling. Increase in compaction temperature and particle size leads to the observed decrease microplastic characteristics.

EFFECT OF LONG-TERM STORAGE UNDER NORMAL CONDITIONS, ON THE MICROPLASTIC CHARACTERISTICS OF BERYLLIUM

Determination parameters change nature of microplastic deformation at long storage is one of ways to determine structure stability and properties of metal. Results of these studies allow to estimate with high precision influence of technology of receiving a material and various preliminary heat treatments on dimensional stability of products .

Effects of prolonged storage under normal conditions on the characteristics of microplasticity ($\boldsymbol{\sigma_E}$ and σ_A) and hardenings for microdeformation in the range from $2\ 10^{-7}$ to $1\ 10^{-4}$ studied on samples of four beryllium grades different composition and production technology: CIP-HIP, CIP-HIP Sph, HIP Sph and HIP Sph D. Storage duration of beryllium samples ranged from 283 to 647 days [3].

Table 2 presents the microplastic deformation characteristics of beryllium samples of various grades in the initial state and after prolonged storage.

Table 2 shows that after prolonged storage at grades CIP-HIP and CIP-HIP Sph value $\boldsymbol{\sigma_E}$ does not change significantly. At the same time, the parameters $\boldsymbol{\sigma_A}$ microplastic flow stress and significantly decreased compared with the initial state in the range of considered microstrain area (Fig. 1). Therefore, storage materials for $1.5\ 10^4$ hours reduces the values $\boldsymbol{\sigma}$ from 2 to 5 times with $\boldsymbol{\varepsilon} = 2\ 10^{-6}$ and twice during deformation $\boldsymbol{\varepsilon} = 5\ 10^{-6}$.

Table 2

Microplastic deformation characteristics of different varieties of beryllium samples in initial state and after long-term storage

Material	Storage time, thousands of hours	σ_E, MPa	σ_A, MPa	σ, MPa with ε	
				$2\cdot10^{-6}$	$5\cdot10^{-6}$
CIP-HIP Sph	initial state	11.4	34.0	158	229
	15.5	8.1	12.1	27	120
CIP-HIP	initial state	11.6	35.3	117	258
	14.8	11.9	29.9	53	150
HIP Sph D	initial state	-	6.3	8.4	13
	11.8	-	9.1	18	23
HIP Sph	initial state	17.2	41.0	56	80
	11.8	16.4	44.6	79	112

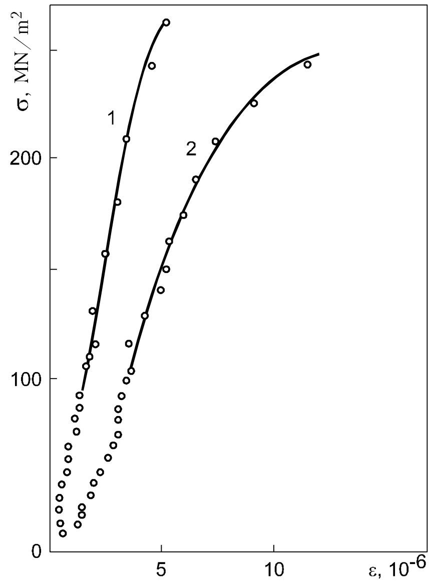

Fig. 1. Influence of a storage time on characteristics of microplasticity of CIP-HIP beryllium: curve 1 – initial state; 2 – after exposure at normal 1,5 10^4 hours

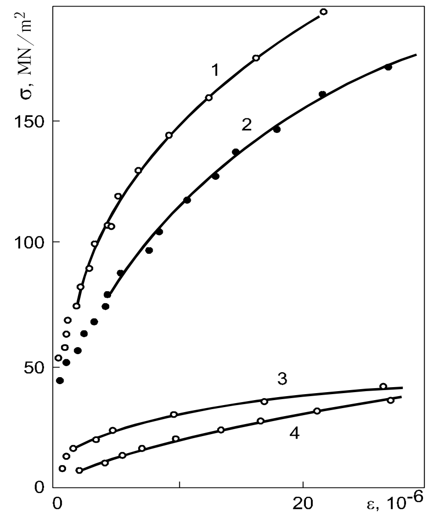

Fig. 2. Influence of a storage time on microplasticity characteristics HIP Sph and HIP Sph D beryllium: curve 1 – HIP Sph after 1,1 10^4 h.; 2 – HIP Sph initial state; 3 – HIP Sph D after 1,1 10^4 h.; 4 – HIP Sph D initial state

Material softening (CIP-HIP Sph, CIP-HIP) in microstrain, probably due to the relaxation of microstrains during long-term storage of materials at room temperature.

For materials with low resistance microplastic deformation (grades HIP Sph, HIP Sph D), which have a low content of impurities as compared with the beryllium grades CIP-HIP and CIP-HIP Sph, long-term storage does not reduce stress microflows. In contrast, long-term storage is accompanied some increase $\boldsymbol{\sigma}$ in comparison with an initial state. Besides, there is a slight increase in the value σ_A and hardening in the investigated strain range. It is also found that the degree of hardening is more significant, since the total concentration of impurities in the material higher. The cleanest of the studied group of metals beryllium grade HIP Sph D has low value σ_E and σ_A, minimum flow resistance in microstrain range (Table 2) and a relatively high plasticity, which depends weakly on the storage time.

The increase in hardening observed at these grades of beryllium (Fig. 2), is result probably of aging during long storage.

EFFECT OF THERMAL CYCLING ON THE CHARACTERISTICS OF BERYLLIUM MICROPLASTICITY

Thermocycling treatment (TCT) beryllium samples grade CIP-HIP and CIP-HIP Sph performed as follows: heating to temperature of the upper loop (433…523 К), выдержка at this temperature for 4 minutes followed by cooling in liquid nitrogen. The rate of the sample heating and cooling was 30 degree/s. In preparing the samples for tests performed four consecutive heat cycle.

Samples were subjected to thermal cycling processing in the initial state and after annealing. Samples were placed in wrapping and molybdenum annealed in vacuum (2 10^{-3} Torr) at 1273 K for 2 hours. Tables 3 and 4 shows the results of measuring the characteristics of beryllium grades microplasticity CIP-HIP and first increase, approaching the maximum values in the temperature range after heat treatment under various conditions.

From Tables 3 and 4 shows that with increasing the top temperature TCT, values σ_E and σ_A first increase, approaching the maximum values in the temperature range 473 K (for CIP-HIP Sph grade) and 523 K (for CIP-HIP grade).

The maximum increase σ_E and σ_A for CIP-HIP Sph beryllium is 55 and 10%, and for ХИП CIP-HIP beryllium up to 75 and 60%, accordingly. Further increase of the top temperature TCT reduces the stress microflows. Thus, when the top temperature TCT 673 K value $\boldsymbol{\sigma_E}$ and $\boldsymbol{\sigma_A}$ for beryllium grade CIP-HIP reduced by 23 and 40% compared to initial state.

Table 3

Microplastic characteristics CIP-HIP Sph beryllium after various thermal and thermocyclic treatments

Heat treatment	σ_E, MPa	σ_A, MPa	σ, MPa	
			$\varepsilon=2\cdot10^{-6}$	$\varepsilon=5\cdot10^{-6}$
Initial state	11.4	34.0	158	229
Annealing at 1273 K, 2 hours	12.5	25.5	64	115
TCT 77↔433 K	13.8	35.4	90	155
TCT 77↔473 K	17.8	35.9	124	198
TCT 77↔523 K	17.2	37.6	87	170
TCT 77↔673 K	14.5	23.2	40	53

Table 4

Microplastic characteristics CIP-HIP beryllium after various thermal and thermocyclic treatments

Heat treatment	σ_E, MPa	σ_A, M Pa	σ, MPa	
			$\varepsilon = 2\cdot10^{-6}$	$\varepsilon = 5\cdot10^{-6}$
Initial state	11.6	35.3	117	258
Annealing at 1273K, 2 hours	10.2	33.0	115	181
TCT 77↔433 K	14.4	51.3	150	235
TCT 77↔523 K	26.0	73.6	155	241
TCT 77↔573 K	10.9	25.2	7	120
TCT 77↔673 K	8.8	20.7	55	68
TCT 77↔873 K	10,7	15.0	32	43

Annealing of the samples at 1273 K for 2 hours, lowers the elastic and plastic characteristics.

In this paper, a detailed study of the dependence of the stress microflows σ от from residual deformation $\boldsymbol{\varepsilon}$ beryllium in the range of deformation 2 10^{-7} to 10^{-5} (Figs. 3, 4).

The top temperature TCT affects the hardening beryllium.

So, at the top temperatures 433…523 K at CIP-HIP beryllium grade at the initial stage of microstrain ($\boldsymbol{\varepsilon}$=2 10^{-6}) a slight hardening.

Analysis of the results suggests that the values of the characteristics of raw materials microplasticity determined by thermal stresses, that arise due to the anisotropy of the thermal expansion coefficient due to the cooling of the extrusion temperature.

It is known that thermal microtension arising from rapid temperature changes, interact with internal microstresses, and the result of this interaction determines the integral internal stress in the metal [4]. So the observed increase in resistance to microplastic deformation after TCT from the top temperature to 523 K mainly due to the fast relaxation processes microstressing in a more intense regions of the material during thermal changes.

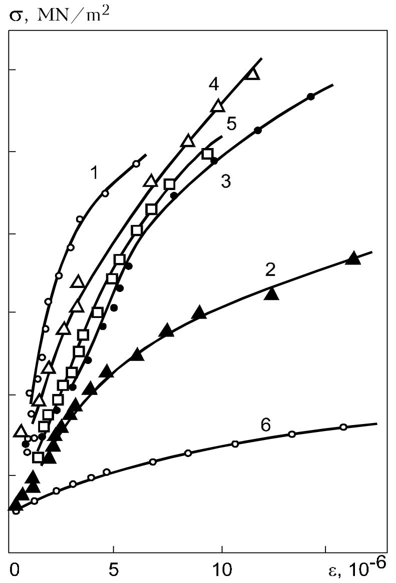

Fig. 3. Dependencies microflows stress σ from the residual deformation for CIP-HIP Sph beryllium after various thermal and thermocyclic treatments: curve 1 – initial state; 2 – annealing at 1273 K for 2 hours; 3 – TCT 77…433 K; 4 – TCT 77...473 K; 5 – TCT 77...523 K;6 – TCT 77...673 K

At the same time the mobility of dislocations in grain volume is controlled by content and distribution of the defects (impurities) in the crystal lattice.

At the top temperatures TCT exceeding 573 K, microstressing relaxation accompanied by intense deformation of a significant part of the grain, which is confirmed by metallographic studies. Existence of the easy mobile dislocations generated during plastic deformation of grains during TCT, defines, possibly observed decrease microplastic deformation characteristics of the material.

Dependency analysis $\sigma(\varepsilon)$ for beryllium grade CIP-HIP (Fig. 5) allows to determine the evolution stages microflows defined thermal pretreatment.

It can be seen that for the initial metal and after TCT from the top cycle temperature in the range of 433 to 523 K, dependence $\sigma(\varepsilon^{1/2})$ has three stages. By increasing the top temperature TCT to 573…873 K second stage microflows slowly disappearing at the same time duration of the first stage decreases.

In range of residual strain $(1…1.8)\cdot10^{-6}$ second stage microflows present and is associated with plastic deformation within individual grains with a favorable orientation of the basal planes. With increasing stress microflows more grains with less favorable orientation of the basal planes involved in the process of plastic deformation. This mechanism the second stage of development is confirmed by the linear dependence σ from deformation ε.

Regarding the third stage, its development is known to be associated with cooperative plastic deformation of the grains [5].

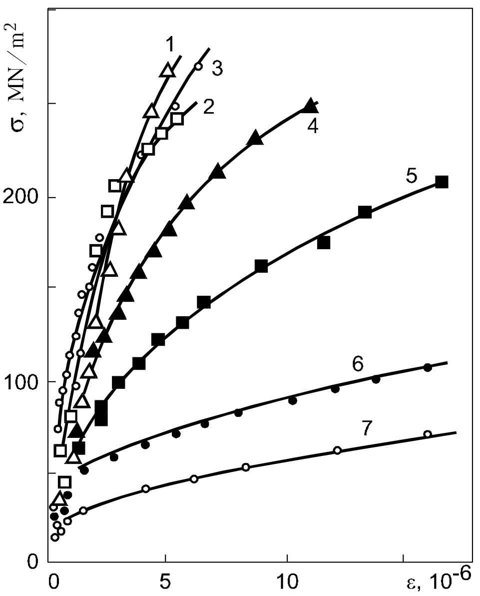

Fig. 4. Dependencies microflows stress σ from the residual deformation for CIP-HIP Sph beryllium after various thermal and thermocyclic treatments: curve 1 – initial state; 2 – TCT 77…433 K; 3 – TCT 77…523 K; 4 – annealing at 1273 K for 2 hours; 5 – TCT 77…573 K; 6 – TCT 77…673 K; 7 – TCT 77…873 K

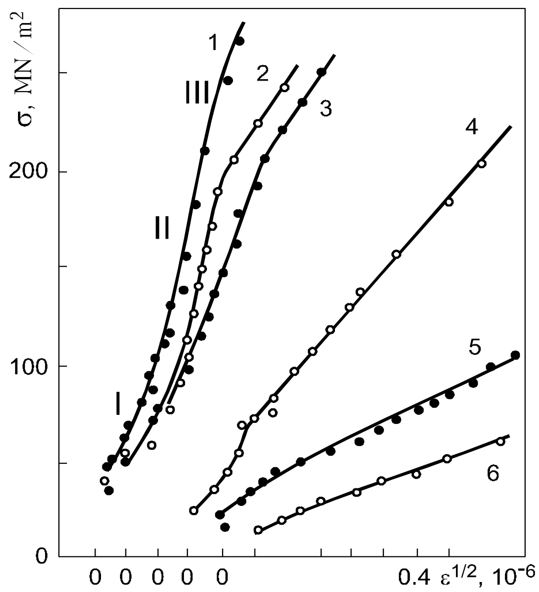

Fig. 5. Stress dependence (σ)from deformation ($\varepsilon^{1/2}$) in microdeformed range CIP-HIP beryllium in the initial state and after various TCT modes: curve 1 – initial state; 2 – TCT 77…433 K; 3 – TCT 77…523 K; 4 – TCT 77…573 K; 5 – TCT 77…673 K; 6 – TCT 77…873 K

Hereby, the upper temperature interval selected TCT significantly effect on the microflows nature and hardening at different stages of flow. This effect is determined by the features to beryllium structure change, which is caused by different parameters the heat treatment.

We also conducted a study of the influence TCT on the properties of cast rolled beryllium. Distilled metal ingot 50 mm diameter extruded and then rolled to a sheet 2.5 mm thickness. Samples for microplastic testing were cut along the rolling direction. The grain size of the samples in the initial state was ~ 30 μm.

The effects of heat treatment on the characteristics microplasticity cast beryllium rolled are shown in Table 5.

Table 5

Effect of different thermal and thermocyclic cycling treatments on microplastic properties of cast rolled beryllium

Heat treatment	σ_A, MPa	σ, MPa with ε		
		$1\cdot10^{-6}$	$1\cdot10^{-5}$	$2.5\cdot10^{-5}$
Initial state	52.4	61	117	163
Annealing at 993 K, 0,5 hour	36.3	51	80	97
Annealing at 923 K, 2 hours	76.8	108	164	198
TCT 77…873 K, 5 cycles	94.8	105	153	186
TCT 293-873 K, 5 cycles	90.6	112	150	176
TCT 293…873 K, 5 cycles + annealing at 923 K, 2 hours	107.2	137	182	206

In contrast to the powdered beryllium, TCT cast rolled beryllium in the temperature ranges 77…873 K and 293…873 K raises characteristics of microplasticity and stress microflows at comparable residual deformations. At the initial stage microflows (up to 3.10^{-6} residual deformation) in thermocyclic materials have seen an increase hardening coefficient in comparison with the initial state of the metal.

Aging cast rolled beryllium (after TCT on the regime 293…873 K, 5 cycles) at 923 K during 2 hours approximately doubled the value σ_A. Characteristics of microflows stress at comparable residual strains also increased.

Increased performance microplasticity at the microflows initial stage for samples cast beryllium rolled after TCT, probably due to the thermal relaxation microstressing by twinning [3]. Furthermore, it should consider the possible acceleration of the aging process beryllium during TCT [6]. This is confirmed by the similar nature of the dependence $\sigma(\varepsilon)$ for samples after TCT processing and aging (Fig. 6).

The proposed mechanism of hardening TCT confirmed by experimental data on the influence of recrystallization annealing on metal microplasticity. Recrystallization annealing (993 K for 0.5 hours) reduces a limit of microflowing and deformation of a microflow also as well as coefficient of deformation hardening at early stages of a mikroflowing.

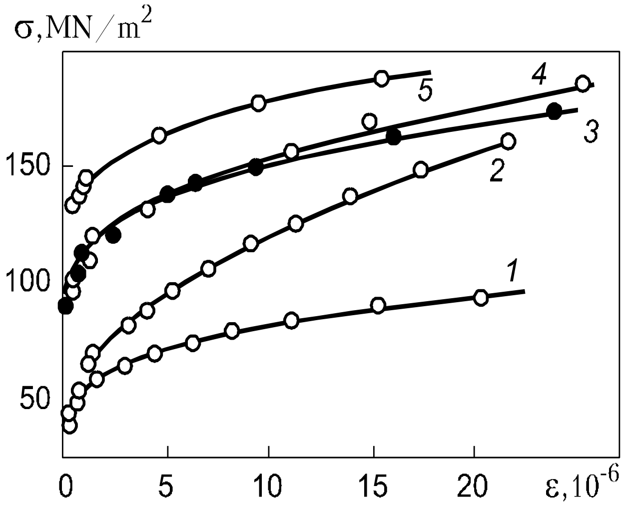

Fig. 6. Microflows dependence of the stresses of residual deformation ε for cast rolled beryllium at different thermal pretreatment: curve 1 – recrystallization for 0,5 hour at a temperature 993K; 2 – initial state; 3 – TCT 293...873 K; 4 – TCT 77...873 K, 5 cycles; 5 – TCT 293...873 K, 5 cycles, annealing at 923 K, 2 hours

So it can be concluded that the behavior of a metal at TCT is largely determined by its production technology, which leads to differences in the level of initial mechanical properties and thermal microstressing. Using the methods of powder metallurgy beryllium can be obtained with high values σ_E and σ_A, but it does not guarantee high stability. This is due to the fact that the level of thermal microstresses grows with microplasticity durable materials. Although these stresses can be removed by TCT, but high top temperature of such treatments may not be appropriate for real application designs.

EFFECT OF GRAIN SIZE ON BERYLLIUM MICROPLASTICITY

Effect of grain size on the stress microflows was studied on cast polycrystalline high purity beryllium. Relative residual electrical resistance of the metal was $\delta = R_{300K}/R_{77K} = 30$. Samples cut from the sheets and annealed at a temperature 1173 K for 27, 600 and 3600 seconds. This allowed to receive samples with grain 10 to 143 μm.

Characteristically dependence of the flow stress on the deformation in the range of beryllium microplasticity with different grain sizes are shown in Fig. 7. In the deformations range less than 10^{-6} and more than 10^{-5} observed two stages of material hardening. Hardening in the first step is not very strong ($n = d\log\sigma / d\log\varepsilon \approx$ 0.04…0.05) and weakly depends on the grain size. The quantity of hardening in the second step is increased to n =0.14…0.20. Fig. 8 shows the dependence of the flow stress on grain size for various values of microstrain (on the graph shows the scatter of measured values).

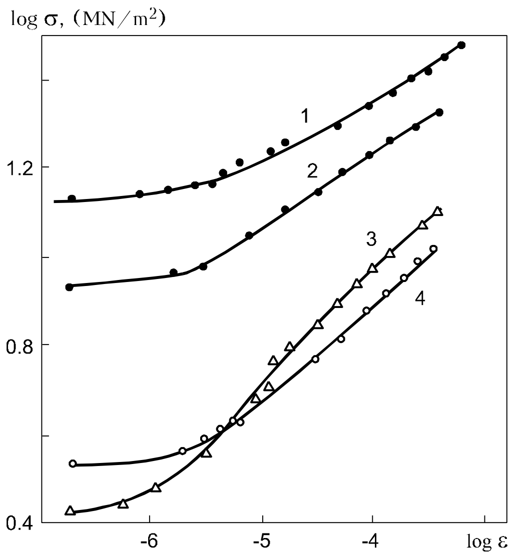

Fig. 7. Typical curves for beryllium microstrain with different sizes: the curve 1 – d=10 μm; 2 – d=20 μm; 3 – d=77 μm; 4 – d=147 μm

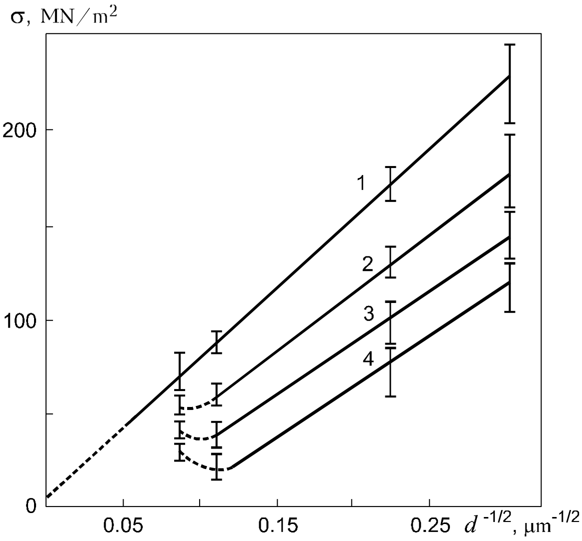

Fig. 8. Dependence of the yield stress on the grain size in the range of microplasticity: curve 1 – ε =1 10^{-4}; 2 – ε =1 10^{-5}; 3 – ε =1 10^{-6}; 4 – ε = 2 10^{-7}

Features of these relationships following:

1. Dependence of the Hall-Petch ($\sigma = \sigma_o + kd^{1/2}$, where σ_o and k – const, d – grain size) satisfactorily performed in the range of grain size 10…77 μm for all values of residual deformation (ε) including at ε= 2 10^{-7}, stress in this case is the limit of the microflow σ_A.

2. Deviation from this dependence is observed at the grain d=143 μm and is the stronger, the smaller the amount of deformation. So when residual deformation $\varepsilon=10^{-4}$ deviation is virtually absent, and at ε=2 10^{-7} value is maximum.

3. The angle of inclination in dependence of the Hall-Petch (coefficient k) growing with increasing deformation:

ε	$2\cdot10^{-7}$	$1\cdot10^{-6}$	$1\cdot10^{-5}$	$1\cdot10^{-4}$
k, MN/m^2	530	540	610	720

Anomaly curves of the Hall-Petch relationship in the range of microplasticity at large grain sizes, as well as negative values σ_o at $d\to\infty$, possibly caused by a large concentration of impurities in the beryllium matrix, dissolution of which occurred during high-temperature annealing: reduction σ with increasing grain size is compensated by its increase due to impurities dissolution.

To test the above assumption about the influence of impurities on beryllium microplasticity, have investigated the properties of the two samples with the same grain size (20 μm), but, after various heat treatment: in temperature region of dissolving impurities (1173 K, 27 s) and in the region below the solubility limit (973 K, 1 hour). The results of these studies are shown in Fig. 9. Seen that for the same grain size high temperature (1173 K) of annealing is accompanied by an increase in yield strength up to 40 MPa (curve 1), in contrast to annealing at 973 K (curve 4). Aging at a temperature 873 K within 24 hours (temperature, which is accompanied by precipitation of the solid solution impurities, and refining matrix) samples that were annealed at 1173 K, reduces the yield stress (curve 3), while aging of samples annealed at 973 K, has almost no influence on the measurement results (Fig. 9, curve 2). With an equal grain size in the material transition impurities in solid solution, really accompanied by a significant change in the stress microflows and annealing at a temperature below the solubility limit or aging accompanied by stress relaxation.

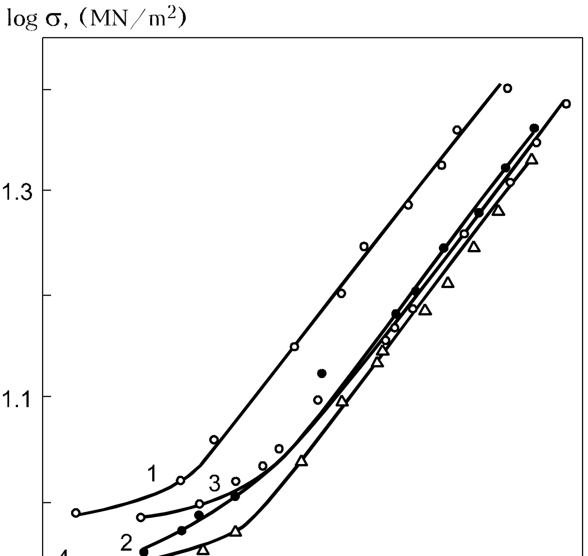

Fig. 9. Effect of heat treatment on the characteristics of beryllium microplasticity (d=20 microns). Modes of heat treatment (temperature and duration) curve 1 – 1173 K, 27 s; 2 – 1173 K, 27 s + 87 3K, 24 hours; 3 – 973 K, 1 hour + 873 K, 24 hours; 4 – 973 K, 1 hour

Similar results were obtained with aging (873 K for 24 hours) samples having a grain size of 77 and 143 μm.

CONCLUSIONS

Microplastic characteristics isostatically pressed beryllium decreased with increasing particle size of the powder, increasing pressing temperature, higher purity metal according to *BeO*, *Al*, *Fe* and other impurities.

High initial values of micro elasticity limit and microflow in some cases due to increased levels of internal stresses of thermal origin and over time they can show slow relaxation.

During long-term storage of beryllium materials with high initial resistance values microplastic deformation microflow limit and stress microflows reduced considerably, due mainly to the relaxation of thermal microstressing.

Long-term storage of beryllium with relatively low resistance value microplastic deformation is accompanied by some increase in the mikroflow limit and intensity of strain hardening.

Temperature range TCT determines the behavior and stages of the microflows process and beryllium hardening in the field of microstrain.

Behavior of beryllium at TCT determined mainly by the production technology, which leads to differences in the levels of initial characteristics microplasticity and thermal microstressing.

TCT causes significant structural changes in beryllium, if the top temperature of TCT is higher 523 K. In this case, the integral deformation and internal stress relaxation processes occur with the formation of linear and point defects. The main effect of TCT begins to appear after consecutive two or three cycles of heating-exposure-cooling. Development of intergranular plastic deformation at TCT is not only a consequence of structural anisotropy, but also arise in the material temperature gradients.

TCT 77↔873 K cast distilled beryllium improves microplastic characteristics and hardening coefficient in the first stage of microflows, due to thermal relaxation microstressing due to twinning and accelerate the aging process in TCT .

TCT 300↔873 K hot-pressed beryllium with high initial resistance values microplastic deformation leads to a significant loss of strength in the field of microplasticity, while less durable hot-pressed beryllium influence of TCT on the characteristics of microplasticity is weak.

Analysis of the stress microflows beryllium on the grain size in the deformations $2\ 10^{-7}…10^{-4}$ showed that the Hall-Petch relationship is done in d =10…77 μm for all ε. Deviation from the Hall-Petch dependence is observed with a grain size above d = 143 μm and increases with the decrease of the strain amount.

Possible cause of the curves deviation $\sigma(d)$ from the Hall-Petch relationship at $d\to\infty$ is a process of dissolving the impurities in the beryllium matrix during high-temperature annealing.

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ИССЛЕДОВАНИЕ МИКРОПЛАСТИЧЕСКОЙ ДЕФОРМАЦИИ БЕРИЛЛИЯ

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Систематически изучены характеристики микропластического течения разных сортов бериллия. У изостатически прессованного бериллия они снижаются с увеличением размеров частиц порошка, увеличением температуры прессования и повышением чистоты металла. Высокие начальные значения предела микроупругости и микротекучести в ряде случаев обусловлены повышением уровня внутренних напряжений термического происхождения и с течением времени возможна их медленная релаксация. В процессе длительного хранения бериллиевых материалов с высокими начальными значениями сопротивления микропластическим деформациям предел микротекучести и напряжение микротечения заметно снижаются, что связано, главным образом, с релаксацией термических микронапряжений.

ДОСЛІДЖЕННЯ МІКРОПЛАСТИЧНОЇ ДЕФОРМАЦІЇ БЕРИЛІЮ

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Систематично вивчено характеристики мікропластичної течії різних сортів берилію. У ізостатично пресованого берилію вони знижуються зі збільшенням розмірів частинок порошку, збільшенням температури пресування і підвищенням чистоти металу. Високі початкові значення межі мікропружності і мікроплинності в ряді випадків обумовлені підвищенням рівня внутрішніх напружень термічного походження і з плином часу можлива їх повільна релаксація. У процесі тривалого зберігання берилієвих матеріалів з високими початковими значеннями опору мікропружним деформаціям межа мікроплинності і напруга мікроплинності помітно знижуються, що пов'язано, головним чином, з релаксацією термічних мікронапружень.