Materials Physics and Mechanics 40 (2018) 274-284 Received: March 20, 2018

THEORETICAL AND EXPERIMENTAL STUDY OF PLASTIC ANISOTROPY OF Al-1Mn ALLOY TAKING INTO ACCOUNT THE CRYSTALLOGRAPHIC ORIENTATION OF THE STRUCTURE

F.V. Grechnikov[1,2], Ya.A. Erisov[2], S.V. Surudin[2], V.V. Tereshchenko[3*]

[1]Samara Scientific Center of the Russian Academy of Sciences, Student lane, 3A, Samara, Russian Federation

[2]Samara University, Moskovskoye shosse, 34, Samara, Russian Federation

[3]Peter the Great St. Petersburg Polytechnic University, Polytechnicheskaya Street, 29, St. Petersburg, Russian Federation

*e-mail: teretshenko_vv@spbstu.ru

Abstract. The paper establishes a relationship between the indicators of plastic anisotropy (coefficient of transverse deformation) and the parameters of the structure of the material. It was also investigated the change of crystallography of the structure and anisotropy parameters on the example of rolling of Al-1Mn alloy (grade 1400). In general, the results of studies indicate a fairly good convergence of the calculated and experimental data, therefore the developed models of plastic flow of anisotropic material, taking into account the crystallographic orientation of the structure, adequately describe the anisotropy of the deformation characteristics of sheet materials. Crystallographic orientations contributing to an increase in the coefficients of transverse deformation are established and also leads to the creation of transverse isotropy. The conducted studies confirm the principal possibility of forming a given crystallographic structure in the sheets which provides an increase in the deformation capabilities of the material in the molding process.

Keywords: plastic anisotropy, crystallographic orientation of the structure, the plasticity criterion, the coefficients of transverse deformation, rolling, data storage systems

1. Introduction

A characteristic feature of aluminum alloys is the tendency to form a structure with an unfavorable crystallographic orientation in the sheets during rolling, which causes a significant anisotropy of deformation characteristics [1]. With the subsequent formation of products from such materials occurs the predominant development of deformation in the thickness of the sheet and its destruction, the shape and size of the products are distorted, occurs formation of metal projections on the edge of the product, the wall thickness of a mechanical component appears different at different heights, which ultimately leads to an overestimation of dimensions of a work piece and to increasing of constructions weights [2-4]. The proposed solutions to these problems are, as usual, reduced to the mechanical account of the anisotropy factor in technological calculations and to the recommendations for appropriate adjustment of the shape and size of a work piece and tool [5-8,17].

On the other hand, the above disadvantages of aluminum alloys can be eliminated if the rolling purposefully form the crystallography of the structure, taking into account the requirements of the subsequent forming processes of blanks in a particular stress-strain

http://dx.doi.org/10.18720/MPM.4022018_16

state [1,9,24]. However, to solve this problem in technological calculations it is necessary to use indicators quantitatively characterizing the crystallographic orientation of the structure.

To characterize the direction of the predominant development of deformations in the plastic flow, deformation anisotropy indicators are widely used, which include Poisson's ratios in the plastic region or the coefficients of transverse deformation, which is the ratio of logarithmic deformation in width to the deformation along the length of the sample at its uniaxial tension [1,18-21]. As can be seen from the definition, although the transverse deformation coefficients characterize the plastic anisotropy of the material, they do not take into account the physical basis of the anisotropy of the properties, i.e. the crystallographic orientation of the structure [25]. That means these indicators do not allow to solve the inverse problem, i.e., based on the requirements of plastic forming blanks, to determine the most effective composition of the components of the texture, which must be formed in the production of structural materials [22].

In connection with mentioned above, in this paper the relationship between the values of the transverse deformation coefficients and the parameters of the preferred crystallographic orientation of the structure is established, as well as the change in the crystallography of the structure and anisotropy parameters is studied by the example of the rolling of the Al-1Mn alloy [15,16,23].

2. Theoretical thesis

Let us use the criterion of plasticity, in the basic equations of which the parameters of the structure of materials are introduced [9]:

$$\sigma_i = \frac{1}{\sqrt{2}}\left\{ \eta_{12}\left(\sigma_{11}-\sigma_{22}\right)^2 + \eta_{23}\left(\sigma_{22}-\sigma_{33}\right)^2 + \eta_{31}\left(\sigma_{33}-\sigma_{11}\right)^2 + \right.$$
$$\left. +4\left[\left(\frac{5}{2}-\eta_{12}\right)\sigma_{12}^2 + \left(\frac{5}{2}-\eta_{23}\right)\sigma_{23}^2 + \left(\frac{5}{2}-\eta_{31}\right)\sigma_{31}^2\right]\right\}^{1/2}, \tag{1}$$

where σ_i – stress intensity; σ_{ij} – the components of the stress tensor; (*i, j* = 1, 2, 3; 1 – the direction of rolling, 2 – transverse direction; 3 – the direction of the thickness of the sheet); η_{ij} – generalized anisotropy indicators:

$$\eta_{12} = 1 - \frac{15\left(A'-1\right)}{3+2A'}\left(\Delta_1 + \Delta_2 - \Delta_3 - \frac{1}{5}\right);$$
$$\eta_{23} = 1 - \frac{15\left(A'-1\right)}{3+2A'}\left(\Delta_2 + \Delta_3 - \Delta_1 - \frac{1}{5}\right); \tag{2}$$
$$\eta_{31} = 1 - \frac{15\left(A'-1\right)}{3+2A'}\left(\Delta_3 + \Delta_1 - \Delta_2 - \frac{1}{5}\right);$$

A' – the parameter of anisotropy of the crystal lattice:

$$A' = \frac{S'_{1111} - S'_{1122}}{2S'_{2323}}; \tag{3}$$

S'_{ijkl} – elastic constants of the crystal lattice;

Δ_i – parameters of crystallographic orientation of the structure:

$$\Delta_i = \sum_{\{hkl\}\langle uvw\rangle} p^{\{hkl\}\langle uvw\rangle} \Delta_i^{\{hkl\}\langle uvw\rangle}; \tag{4}$$

$p^{\{hkl\}\langle uvw\rangle}$ – weight fraction of *i*-th component $\{hkl\}\langle uvw\rangle$; $\Delta_i^{\{hkl\}\langle uvw\rangle}$ – orientation factor of ideal crystallographic orientation $\{hkl\}\langle uvw\rangle$:

$$\Delta_i^{\{hkl\}\langle uvw\rangle}=\frac{h_i^2k_i^2+k_i^2l_i^2+l_i^2h_i^2}{\left(h_i^2+k_i^2+l_i^2\right)^2}; \tag{5}$$

h_i, k_i, l_i – Miller indices determining the *i*-th direction in the crystal relative to the coordinate system associated with the sample.

Using the criterion of plasticity (1) and associated flow rule, the equations of connection between linear deformations ε_{ij} and stresses σ_{ij} taking into account the parameters of the structure of the material have the form:

$$\begin{aligned}
\varepsilon_{11}&=\frac{1}{2}\frac{\varepsilon_i}{\sigma_i}\left[\eta_{12}\left(\sigma_{11}-\sigma_{22}\right)+\eta_{31}\left(\sigma_{11}-\sigma_{33}\right)\right],\\
\varepsilon_{22}&=\frac{1}{2}\frac{\varepsilon_i}{\sigma_i}\left[\eta_{12}\left(\sigma_{22}-\sigma_{11}\right)+\eta_{23}\left(\sigma_{22}-\sigma_{33}\right)\right],\\
\varepsilon_{33}&=\frac{1}{2}\frac{\varepsilon_i}{\sigma_i}\left[\eta_{23}\left(\sigma_{33}-\sigma_{22}\right)+\eta_{31}\left(\sigma_{33}-\sigma_{11}\right)\right],
\end{aligned} \tag{6}$$

where ε_i – strain intensity:

$$\begin{aligned}
\varepsilon_i=\sqrt{2}\Bigg\{&\left(\frac{1}{\eta_{12}}+\frac{1}{\eta_{23}}+\frac{1}{\eta_{31}}\right)^{-2}\left[\frac{1}{\eta_{12}}\left(\frac{\varepsilon_{11}}{\eta_{31}}-\frac{\varepsilon_{22}}{\eta_{23}}\right)^2+\frac{1}{\eta_{23}}\left(\frac{\varepsilon_{22}}{\eta_{12}}-\frac{\varepsilon_{33}}{\eta_{31}}\right)^2+\right.\\
&\left.+\frac{1}{\eta_{31}}\left(\frac{\varepsilon_{33}}{\eta_{23}}-\frac{\varepsilon_{11}}{\eta_{12}}\right)^2\right]+\frac{1}{4}\left[\frac{\varepsilon_{12}^2}{\frac{5}{2}-\eta_{12}}+\frac{\varepsilon_{23}^2}{\frac{5}{2}-\eta_{23}}+\frac{\varepsilon_{31}^2}{\frac{5}{2}-\eta_{31}}\right]\Bigg\}^{1/2}.
\end{aligned} \tag{7}$$

Let's determine the dependence of the ratio of the transverse strain directions in the plane of the sheet. Consider stretching a sample which was cut at an angle to the rolling direction. In this case, the transverse deformation coefficient is expressed as follows:

$$\mu_\alpha=-\frac{\varepsilon_{\alpha+90^\circ}}{\varepsilon_\alpha}, \tag{8}$$

where $\varepsilon_{\alpha+90^\circ}$ – transverse plastic deformation of compression under linear tension of a flat sample; ε_α – longitudinal plastic strain of the stretching. Index μ_α varies from 0 to 1.

The stresses and strains that occur when the specimen is cut at an angle α to the rolling direction are related to the following dependences with stresses and strains in the main anisotropy axes [10]:

$$\begin{aligned}
\sigma_{11}&=\sigma_\alpha\cos^2\alpha,\\
\sigma_{22}&=\sigma_\alpha\sin^2\alpha,\\
\sigma_{12}&=\sigma_\alpha\sin\alpha\cos\alpha,
\end{aligned} \tag{9}$$

$$\varepsilon_\alpha=\varepsilon_{11}\cos^2\alpha+\varepsilon_{22}\sin^2\alpha+\varepsilon_{12}\sin\alpha\cos\alpha, \tag{10}$$

where σ_α – yield point at linear tension of the sample cut at an angle α to the rolling direction.

Substituting the expression (10) in (8), taking into account the dependencies (9) and (7) after the transformation, we obtain:

$$\mu_\alpha = 1 - \left[\eta_{23}\sin^2\alpha + \eta_{31}\cos^2\alpha\right]\Big[(\eta_{12}+\eta_{23})\sin^4\alpha + \\ +(\eta_{12}+\eta_{31})\cos^4\alpha + 6\left(\frac{5}{3}-\eta_{12}\right)\sin^2\alpha\cos^2\alpha\Big]^{-1}. \quad (11)$$

Using the dependence (11), it is possible to determine the value of the transverse deformation coefficient in any direction of the sheet plane, if the generalized anisotropy of the material is known. In this case, the expressions for the transverse deformation coefficients in the rolling direction, at an angle of 45° to the rolling direction and the transverse direction are written as follows:

$$\mu_{21} = \frac{\eta_{21}}{\eta_{21}+\eta_{31}};$$
$$\mu_1 = \frac{4\eta_{12}+\eta_{23}+\eta_{31}-10}{4\eta_{12}-\eta_{23}-\eta_{31}-10}; \quad (12)$$
$$\mu_{12} = \frac{\eta_{12}}{\eta_{12}+\eta_{23}}.$$

3. Methods of the experiment

The studies were conducted on the bullions with a thickness of 400 mm of Al-1Mn alloy, which was treated by different thermo-mechanical regimes. Schematic of rolling, indicating the mode of annealing, temperature of heating for rolling and degrees of compression during hot and cold rolling are shown in Fig. 1. Other parameters were corresponded to the conventional rolling technology. At each stage of production samples were selected for x-ray structural analysis and mechanical tests.

Texture measurements in the form of construction of pole figures were carried out on samples cut from the middle planes on the thickness of the sheet (one sample for each thickness). The plane of shooting of pole figures was parallel to the plane of rolling. Texture in the form of incomplete pole figures {111}, {200}, {220}and {311} were measured by the method of "reflection" using x-ray diffractometer "Dron-7" (Russian name "Дрон-7") in CoKα-radiation. The orientation distribution function (ODF) is calculated from experimental pole figures. Based on the obtained ODF, the inverse pole figures were calculated for three mutually perpendicular directions in the sample (the normal direction to the rolling plane; the rolling direction; the transverse direction).

Primary crystallographic orientations and their volume fractions were determined by the results of cross-section analysis. The criterion for the adequacy of the selection of a set of such orientations was the minimum value of the standard deviation between the experimental and calculated by the sum of the individual ODF orientations. The orientational factors of the texture were then calculated using formulas (4) and (5). Based on the results of texture analysis, calculations were performed using the formulas (12) to find the calculated values of the transverse deformation coefficients.

To study the plastic anisotropy, 3 samples were cut for each direction at angles of 0°, 45° and 90° to the rolling direction. The sizes of samples were chosen according to GOST 11701-84 (in Russian "ГОСТ 11701-84") and GOST 1497-84 (in Russian "ГОСТ 1497-84") depending on the thickness of the sheet. Tests were carried out on an electromechanical testing machine Zwick/Roell Z005 with a speed of stretching of 1 mm/min. The Coefficients of transverse deformation was calculated in accordance with formula (8).

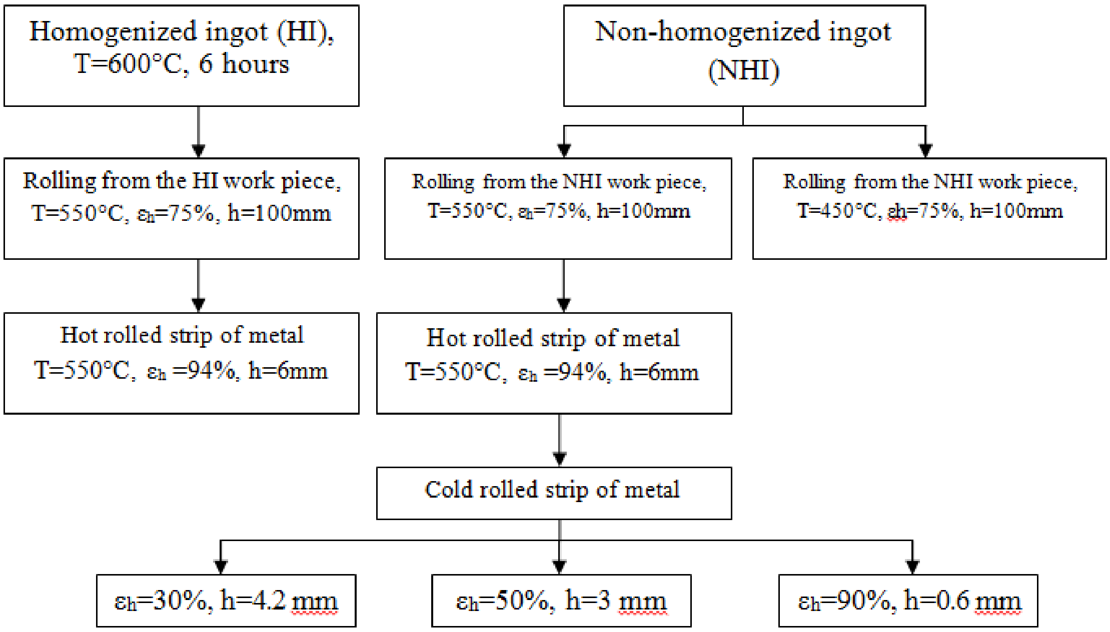

Fig. 1. Scheme of rolling ingots of Al-1Mn alloy

4. Results and their discussion

As a result of texture analysis, it was found that the heterogeneity of the texture thickness is observed in the roll of the Al-1Mn alloy. For the central layer of the non-homogenized ingot is characterized by ideal orientation $\{139\}\langle 123\rangle$, $\{233\}\langle 133\rangle$, $\{110\}\langle 110\rangle$ (table 1). In the surface layer is dominated by orientation type $\{127\}\langle 123\rangle$, $\{139\}\langle 123\rangle$, $\{100\}\langle 100\rangle$. The texture is significantly affected by the condition of the ingot before rolling. Thus, in the Central layer of the roll, obtained from the non-homogenized ingot, there are mainly orientations $\{133\}\langle 110\rangle$, $\{133\}\langle 233\rangle$, $\{124\}\langle 123\rangle$, and in the central layer of the homogenized ingot - $\{139\}\langle 123\rangle$, $\{233\}\langle 133\rangle$, $\{110\}\langle 110\rangle$.

Table 1. The change of the preferential crystallographic orientation during rolling of ingots of Al-1Mn alloy

The condition of the material	Basic orientations $\{hkl\}\langle uvw\rangle$	Weight fractions of orientations $p^{\{hkl\}\langle uvw\rangle}$	The coefficients of transverse deformation of the orientations, μ_{ij}^{cal} (defined by formulas (12))		
			μ_{21}	μ_1	μ_{12}
The homogenized ingot (HI), T=600°C, 6 hours	{931}<123>	0.1664	0.166	0.204	0.284
	{321}<111>	0.1032	0.500	0.614	0.380
	{521}<012>	0.0860	0.378	0.487	0.476
	{100}<010>	0.0780	0.500	0.142	0.500
	{311}<233>	0.0730	0.336	0.570	0.272
	{110}<001>	0.0675	0.500	0.391	0.857
Non-homogenized ingot (NHI) (center)	{321}<139>	0.1380	0.500	0.480	0.715
	{320}<233>	0.0915	0.386	0.602	0.340
	{521}<113>	0.0792	0.452	0.447	0.483
	{953}<132>	0.0792	0.446	0.571	0.463

	{332}<203> {100}<010>	0.0732 0.0704	0.550 0.500	0.603 0.142	0.659 0.500
Rolling from the HI work piece, T=550°C, εh=75%, h=100 mm (center)	{139}<123> {233}<133> {110}<110> {130}<139> {113}<233> {125}<311>	0.1040 0.0949 0.0663 0.0660 0.0657 0.0440	0.284 0.541 0.857 0.421 0.336 0.452	0.523 0.640 0.391 0.387 0.570 0.447	0.284 0.567 0.500 0.489 0.272 0.483
Non-homogenized ingot (NHI) T=550°C, ε_h=75%, h=100 mm (center)	{133}<110> {133}<233> {124}<123> {110}<223> {110}<100> {113}<233>	0.1053 0.1014 0.0988 0.0739 0.0704 0.0294	0.819 0.474 0.414 0.663 0.500 0.336	0.447 0.635 0.552 0.561 0.391 0.570	0.522 0.432 0.414 0.425 0.857 0.272
Non-homogenized ingot (NHI) T=450°C, ε_h=75%, h=100 mm (center)	{100}<100> {139}<123> {113}<233> {233}<113> {126}<124> {110}<100>	0.1276 0.1040 0.1012 0.0657 0.0646 0.0585	0.500 0.284 0.336 0.574 0.415 0.500	0.142 0.523 0.570 0.551 0.458 0.391	0.500 0.284 0.272 0.727 0.404 0.857
Hot rolled strip of metal from the HI work piece, T=550°C, εh=94%, h=6 mm	{100}<100> {113}<233> {123}<139> {139}<123> {233}<230> {223}<110>	0.0968 0.0968 0.0936 0.0832 0.0671 0.0507	0.500 0.336 0.500 0.284 0.550 0.727	0.142 0.570 0.480 0.523 0.603 0.551	0.500 0.272 0.715 0.284 0.659 0.574
Hot rolled strip of metal from the NHI work piece, T=550°C, ε_h =94%, h=6 mm	{233}<110> {100}<100> {123}<139> {112}<111> {111}<123> {110}<111>	0.1506 0.1343 0.1150 0.0650 0.0624 0.0546	0.727 0.500 0.500 0.500 0.619 0.500	0.551 0.142 0.480 0.614 0.619 0.614	0.574 0.500 0.715 0.380 0.619 0.380
Cold rolled strip of metal from the NHI work piece, ε_h =30%, h=4.2 mm	{100}<100> {100}<110> {139}<123> {113}<233> {230}<223> {110}<533>	0.1364 0.0936 0.0936 0.0880 0.0854 0.0546	0.500 0.142 0.284 0.336 0.536 0.375	0.142 0.500 0.523 0.570 0.558 0.627	0.500 0.142 0.284 0.272 0.387 0.431
Cold rolled strip of metal from the NHI work piece, ε_h=50%, h=3 mm	{100}<110> {113}<233> {123}<111> {233}<133> {110}<111> {139}<123>	0.1100 0.1056 0.0832 0.0657 0.0624 0.0520	0.142 0.336 0.500 0.541 0.500 0.284	0.500 0.570 0.614 0.640 0.614 0.523	0.142 0.272 0.380 0.567 0.380 0.284
Cold rolled	{123}<139>	0.1352	0.500	0.480	0.715

strip of metal from the NHI work piece, ε_h=90%, h=0.6 mm	{100}<100> {233}<110> {139}<123> {113}<125> {359}<130>	0.1044 0.0730 0.0728 0.0636 0.0616	0.500 0.727 0.284 0.548 0.549	0.142 0.511 0.523 0.384 0.401	0.500 0.575 0.284 0.514 0.658

Comparing the components of the roll texture obtained at 450 and 550°C, it should be noted that the highest rolling temperature contributes to the formation of a clearer texture. This is evidenced by a smaller number of preferential orientations in the roll, rolled at 550°C, and their higher weight fractions The set of orientations is also different. So in the roll, obtained at 450°C, there was a strong orientation $\{100\}\langle 100\rangle$. The transverse deformation coefficients change accordingly (Table 1). The maximum values of the transverse deformation coefficients are observed where the proportions of such orientations prevail, as $\{110\}\langle 110\rangle$, $\{123\}\langle 110\rangle$, $\{110\}\langle 100\rangle$, $\{111\}\langle 123\rangle$, $\{123\}\langle 135\rangle$, $\{123\}\langle 134\rangle$. If the material is dominated by the orientation of the type $\{100\}\langle 100\rangle$, $\{100\}\langle 011\rangle$, $\{139\}\langle 123\rangle$ $\{139\}\langle 134\rangle$, $\{113\}\langle 110\rangle$, $\{113\}\langle 233\rangle$, then, as can be seen from Table 1, the transverse deformation coefficients take minimum values. Alignment of anisotropy coefficients in the plane of rolled products is promoted by orientations $\{111\}\langle 123\rangle$, $\{130\}\langle 139\rangle$, $\{233\}\langle 230\rangle$, $\{233\}\langle 133\rangle$, $\{125\}\langle 113\rangle$, $\{124\}\langle 123\rangle$, whereas orientations $\{100\}\langle 100\rangle$, $\{100\}\langle 110\rangle$, $\{110\}\langle 001\rangle$, $\{139\}\langle 123\rangle$, $\{139\}\langle 134\rangle$, $\{133\}\langle 110\rangle$, $\{123\}\langle 135\rangle$, $\{230\}\langle 233\rangle$ causes an increase in the plane anisotropy of the properties.

Further deformation of the roll with a degree of compression of 94% leads to the disappearance of orientations $\{110\}\langle 110\rangle$ and dominance $\{100\}\langle 100\rangle$ in a strip of the homogenized ingot. In the strip of metal obtained from the non-homogenized ingot in addition to orientation $\{100\}\langle 001\rangle$ there is also a strong orientation $\{112\}\langle 111\rangle$ and $\{233\}\langle 110\rangle$. In accordance with this, the anisotropy parameters also change. So, for the hot rolled strips of metal obtained from the homogenized ingots coefficient μ_1 smaller than μ_{21} and μ_{12}, whereas for the hot rolled strips of metal obtained from the non-homogenized ingots the picture is reversed (Table 2).

Table 2. Comparison of calculated and experimental values of the transverse deformation coefficients of the Al-1Mn alloy

Research material		The coefficients of transverse deformation					
		defined by formula (12)			defined by formula (8)		
		μ_{21}^{cal}	μ_1^{cal}	μ_{12}^{cal}	$\mu_{21}^{\exp}$	$\mu_1^{\exp}$	$\mu_{12}^{\exp}$
Rolling from the HI work piece, T=550°C, ε_h=75%, h=100 mm	surface	0.410	0.528	0.365	0.388	0.476	0.496
	center	0.493	0.518	0.433	0.428	0.516	0.466
Rolling from the NHI work piece, T=550°C, ε_h=75%, h=100 mm	surface	0.388	0.503	0.377	0.371	0.451	0.377
	center	0.406	0.533	0.433	0.424	0.544	0.494
Rolling from the NHI	surface	0.524	0.494	0.470	0.494	0.497	0.402

work piece, T=450°C, ε_h=75%, h=100 mm	center	0.461	0.479	0.472	0.449	0.407	0.450
Hot rolled strip of metal from the HI work piece, T=550°C, ε_h=94%, h=6 mm		0.510	0.487	0.506	0.471	0.454	0.472
Hot rolled strip of metal from the NHI work piece T=550°C, ε_h=94%, h=6 mm		0.466	0.537	0.471	0.416	0.433	0.474
Cold rolled sheet, ε_h=30%, h=4.2 mm		0.362	0.518	0.359	0.341	0.567	0.417
Cold rolled sheet, ε_h=50%, h=3 mm		0.362	0.522	0.341	0.305	0.541	0.384
Cold rolled sheet, ε_h=90%, h=0.6 mm		0.425	0.493	0.507	0.371	0.463	0.433

Cold rolling with a compression ratio of 30% leads to the appearance of orientations $\{100\}\langle 011\rangle$, $\{139\}\langle 123\rangle$, which contribute to the reduction of μ_{21} and μ_{12} in contrast with μ_1. With cold rolling with a compression ratio of 90%, the weight fractions of the orientations increase $\{100\}\langle 001\rangle$ and $\{123\}\langle 139\rangle$, appears a strong orientation $\{123\}\langle 110\rangle$. As a result, the difference between the anisotropy indices in the sheet plane decreases and the value decreases μ_1.

Verification of the reliability of the obtained models of the relationship of anisotropy parameters with the texture characteristics was carried out by comparing the values of the transverse deformation coefficients calculated by the formulas (12) and determined by mechanical tests of the samples for tension by the formula (8) (Table 2). Differences in calculated and experimental values μ_{ij} do not exceed 10% and are explained by the spread of the values of the pole density, and also reflect the fact that $\mu_{ij}^{\exp}$ the anisotropy of the specimen deformed by stretching rather than the initial one is characterized.

In general, the results of studies indicate a fairly good convergence of the calculated and experimental data, therefore the models (12) reflect the real anisotropy of the deformation characteristics of sheet materials, and the plasticity criterion (1) adequately describes the plastic flow of anisotropic material taking into account its crystal structure orientation.

Conclusion

To obtain the required values of anisotropy in the sheets, it is necessary to increase the weight fractions of the corresponding orientations. So, in the studied hot-rolled sheets of Al-1Mn alloy orientation $\{123\}\langle 139\rangle$, $\{111\}\langle 123\rangle$, $\{110\}\langle 100\rangle$ contribute to the increase in the coefficients of transverse deformation and orientation $\{100\}\langle 110\rangle$, $\{100\}\langle 001\rangle$, $\{139\}\langle 123\rangle$ - their reduction. To create a transversal isotropy, it is necessary to increase the weight fractions of the orientations $\{111\}\langle 123\rangle$, $\{223\}\langle 230\rangle$, $\{233\}\langle 133\rangle$ and reduce the proportion of orientations $\{100\}\langle 001\rangle$, $\{139\}\langle 123\rangle$, $\{110\}\langle 011\rangle$.

In general, the studies of the formation of texture components and anisotropy indicators at the main stages of rolling, comparison of calculated and experimental values of the transverse deformation coefficients confirm the principal possibility of the formation of a given crystallographic orientation of the structure in the sheets, the requirements for which can be formulated on the basis of the analysis of the processes of forming sheet blanks using the plasticity criterion developed by the authors.

Aluminum is used as a material for manufacturing hard drive sections. Deformation of these sections can cause storage system failure. Therefore, this study is of interest to the project devoted to the development of software and hardware complex for predicting failures of data storage systems (DSS). This project has been launched in 2017th and is being implemented with the financial support of the Ministry of Science and Higher Education of Russian Federation. The program complex developing for forecasting of data storage system failures is designing within the project. This complex is developing for the data storage systems running on the platform "YADRO TATLIN" in various configurations [11-14].

The results discussed in this paper can be used to analyze the effect of material properties on hard drive vibration. In the future, it is planned to study the properties of the material on the probability of deformation and violation of the mechanical properties of data storage system components.

Acknowledgements. *This research was financed by Ministry of Education and Science of the Russian Federation within the framework of the Federal Program "Research and development in priority areas for the development of the scientific and technological complex of Russia for 2014-2020", Activity 1.1, Agreement on Grant No. 14.572.21.0008 of 23 October, 2017, unique identifier: RFMEFI57217X0008.*

References

[1] Grechnikov FV. *Deformirovanie anizotropnykh materialov: rezervy intensifikatsii*. Moscow: "Mashinostroenie" Publ. House; 1998.

[2] Barlat F. Crystallographic texture, anisotropic yield surfaces and forming limits of sheet metals. *Materials Science and Engineering.* 1987;91(C): 55-72.

[3] Engler O, Hirsch J. Texture control by thermomechanical processing of AA6xxx Al-Mg-Si sheet alloys for automotive applications - a review. *Materials Science and Engineering A.* 2002;336: 249-262.

[4] Hutchinson WB, Oscarsson A, Karlsson A. Control of microstructure and earing behaviour in aluminium alloy AA 3004 hot bands. *Materials Science and Technology.* 1989;5: 1118-1127.

[5] Pegada V, Chun Y, Santhanam S. An algorithm for determining the optimal blank shape for the deep drawing of aluminum cups. *Journal of Materials Processing Technology*. 2002;125-126: 743-750.

[6] Lo SW, Lee JY. Optimum blank shapes for prismatic cup drawing - Consideration of friction and material anisotropy. *Journal of Manufacturing Science and Engineering, Transactions of the ASME.* 1998;120(2): 306-315.

[7] Park SH, Yoon JW, Yang DY, Kim YH. Optimum blank design in sheet metal forming by the deformation path iteration method. *International Journal of Mechanical Sciences*. 1999;41(10): 1217-1232.

[8] Demyanenko EG, Popov IP, Epifanov AN. Simulation of plastic forming process of shells with minimal thickness fluctuations. *Procedia Engineering.* 2017;201: 489-494.

[9] Erisov YA, Grechnikov FV, Surudin SV. Yield function of the orthotropic material considering the crystallographic texture. *Structural Engineering and Mechanics.* 2016;58(4): 677-687.

[10] Eringen A. *Mechanics of continua*. NY: Robert E. Krieger Publishing Company, Inc.; 1980.

[11] Klochkov Y, Gazizulina A, Golovin N, Glushkova A, Zh S. Information model-based forecasting of technological process state. In: *2017 International Conference on Infocom*

Technologies and Unmanned Systems (ICTUS) (Trends and Future Directions). December 18-20, 2017. IEEE; 2017. p.709-712.

[12] Didenko NI, Skripnuk DF, Kikkas KN, Sevashkin V, Romashkin G, Kulik SV. Innovative and technological potential of the region and its impact on the social sector development. In: *The 32nd International Conference on Information Networking (ICOIN 2018). January 18-20, 2018. Chiang Mai, Thailand.* IEEE; 2018. p.611-615.

[13] Ziniakov VY, Gorodetskiy AE, Tarasova IL. System failure probability modelling. *Studies in Systems, Decision and Control.* 2016;49: 205-215. Available from: doi:10.1007/978-3-319-27547-5_19.

[14] Shevkunov SV. Computer simulation of spin states of electrons in nanoscale cavities in the feynman path integrals representation. *Nanotechnologies in Russia.* 2016;11(7-8): 468-479. Available from: doi:10.1134/S1995078016040169.

[15] Rudskoi AI, Bogatov AA, Nukhov DS, Tolkushkin AO. On the development of the new technology of severe plastic deformation in metal forming. *Materials Physics and Mechanics.* 2018;38(1): 76-81. Available from: doi:10.18720/MPM.3812018_11.

[16] Rudskoi AI, Zolotov AM, Parshikov RA. Severe plastic deformation influence on engineering plasticity of copper. *Materials Physics and Mechanics. 2018;38*(1): 64-68. Available from: doi:10.18720/MPM.3812018_9.

[17] Kitaeva DA, Pazylov ST, Rudaev YI. Temperature–strain rate deformation conditions of aluminum alloys. *Journal of Applied Mechanics and Technical Physics.* 2016;57(2): 352-358. Available from: doi:10.1134/S002189441602019X.

[18] Tsemenko VN, Tolochko OV, Kol'tsova TS, Ganin SV, Mikhailov VG. Fabrication, structure and properties of a composite from aluminum matrix reinforced with carbon nanofibers. *Metal Science and Heat Treatment.* 2018;60(1-2): 24-31. Available from: doi:10.1007/s11041-018-0235-0.

[19] Mikhailov VG, Fritzsche S, Hantelmann C, Ossenbrink R. Aluminum foam sandwiches for lightweight structures. *Metal Science and Heat Treatment.* 2018;60(1-2): 44-49. Available from: doi:10.1007/s11041-018-0238-x.

[20] Ivanov SY, Karkhin VA, Mikhailov VG, Martikainen, J, Hiltunen E. Assessment of the sensitivity of welded joints of al –Mg – si alloys to liquation cracks under laser welding. *Metal Science and Heat Treatment.* 2018;59(11-12): 773-778. Available from: doi:10.1007/s11041-018-0225-2.

[21] Kodzhaspirov GE, Kitaeva DA, Pazylov ST, Rudaev YI. On anisotropy of mechanical properties of aluminum alloys under high temperature deformation. *Materials Physics and Mechanics.* 2018;38(1): 69-75. Available from: doi:10.18720/MPM.3812018_10.

[22] Mikhailov VG. Prediction of the properties of heat-affected zone of welded joints of sheets from aluminum alloys with structured surface. *Metal Science and Heat Treatment.* 2016;58(1): 46-50. Available from: doi:10.1007/s11041-016-9963-1.

[23] Rudskoy AI, Bogatov AA, Nukhov DS, Tolkushkin AO. New method of severe plastic deformation of metals. *Metal Science and Heat Treatment.* 2018;60(1-2): 3-6. Available from: doi:10.1007/s11041-018-0231-4.

[24] Kitaeva DA, Rudaev YI. On macrokinetics under dynamic superplasticity. *Materials Physics and Mechanics.* 2018;36(1): 131-136. Available from: doi:10.18720/MPM.3612018_14.

[25] Zvonov S, Klochkov Y. Computer-aided modelling of a latch die cutting in deform -2D software system. *Key Engineering Materials.* 2016;685: 811-815. Available from: doi:10.4028/www.scientific.net/KEM.685.811.