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Investigation of Texture Structure and Mechanical Properties Evolution during Hot Deformation of 1565 Aluminum Alloy

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Abstract. The article is devoted to study mechanical properties and texture evolution during thermal-mechanical treatment of new aluminum 5XXX series alloy (1565 ch in Russian naming system). For the investigation of deformation behavior of 1565ch alloy a Gleeble axial compression mode was used. The expression for steady flow stress as the function of temperature of deformation and strain rate is obtained. For texture evolution investigation industrial mills were used. Texture evaluation is performed using the orientation distribution function (ODF) calculated from the X-ray direct pole figures.

Introduction

One of the promising trends in the development of new aluminum alloys is adding zirconium (Zr) or scandium (Sc) to Al-Mg system (with high content of Mg (≥ 5 % Mg) [1-4]. These additives increase strength, formability, weldability and corrosion resistance. However, mechanical properties of a semi-finished product will be determined not only by the chemical composition, but also by the modes of its thermomechanical treatment. Their incorrect choosing can neutralize all the advantages obtained by using optimal chemical composition.

To design the modes for the technological processing of aluminum semi-finished products it is advisable to have a material model, which will allow to determine the flow stress depending on the parameters of the temperature and strain rate. Currently, just a few studies devoted to establish such relations on aluminum alloys containing Sc and Zr, and none for newly developed 1565 alloy. Also, it should be noted, that for the majority of the alloys of this group hot rolling is a necessary technological process. As a result, there are inevitable problems with the anisotropy due to various texture components which develop during this process. For these alloys, the problem will be complicated because Zr and Sc are practically insoluble in the aluminum matrix. This increases the number of intermetallic particles. The large particles will lead to an increase of the random component during the pauses between rolling passes and heat treatment (such as self-annealing) [5,6]. Small dispersoids will prevent the process of recrystallization [7, 8]. Therefore, for the effective thermomechanical processing of 1565 ch it is also necessary to have some information about texture evolution in this alloy during hot rolling. The purpose of this research is physical simulation the deformation behavior and investigation of texture evolution of the alloy 1565 in the range of temperatures and strain rates typical for hot rolling.

Experimental Procedure

1565 ch alloy ingots containing 5.7 % Mg, 0.75 % Mn, 0.65 % Zn and 0,09 % Zr, cast in industrial conditions, was subjected to homogenization and then hot rolled on a reversing mill to the thickness of 35 mm. The tests for uniaxial compression were carried out on a physical simulator Gleeble 3800 using the cylindrical samples with the diameter of 10 mm and the height of 15 mm. The sample axis was perpendicular to the rolling plane. To reduce the frictional forces upon the dies and the sample surface the emulsive lubricant based on high purity graphite and nickel is applied.

The samples were heated to target temperature of deformation at the rate of 3 °C/s. After reaching the predetermined temperature there was an isothermal exposure for 3 minutes for the temperature to be homogenous over the sample volume. The temperature was monitored with chromel-alumel thermocouple welded to the sample. The temperature gradient along the length of the sample did not exceed 3 °C.

The deformation was performed at temperatures of 350, 400, 450 and 490 °C at the strain rate of 0.1; 1; 10 and 50 s^{-1}. During the experiment the temperature of the sample, the deformation stress and the current value of the height of the sample were recorded. The built-in program was used for calculating the true (logarithmic) strain ε and the average pressure upon the die p automatically, on the assumption that the volume of the sample is constant and its cylindrical shape during the test will remain the same. The recalculation of pressure p in flow stress σ, purified from the influence of friction forces, was carried out by the expression proposes in [9]:

$$\sigma = \frac{p}{1 + \frac{\mu d}{3h}} \quad (1)$$

with μ being the friction coefficient; d being the current diameter and h being the current height of the sample. The expression for the friction coefficient depending on the deformation temperature T (°C) is taken from the work [10]:

$$\mu = 2,86 \cdot 10^{-6} T^2 - 1,33 \cdot 10^{-3} T + 0,2137 \quad (2)$$

In the temperature range of 350 - 490 °C the value of the friction coefficient, calculated by (2), varies from 0.1 to 0.25.

To study the texture evolution in hot rolling in continuous mill, an industrial experiment was carried out.

An ingot of 1565 ch alloy was rolled in the reversing mill at a temperature of 420 °C and then it was rolled in a continuous five-stand group to the thickness of 3 mm (Table. 1).

Table 1. The hot rolling scheme of the experimental ingot in a 5-stand continuous group

№ a mill number	Engineering strain in %	strain rate in 1/s	The time rolling passes in s
1	40.2	3.1	10.9
2	39.2	6.7	6.4
3	31.1	12.1	4.1
4	47.6	30.0	2.433
5	28.9	59.0	

To assess the changes and the metal texture during the process of rolling, the rolled workpiece was stopped and cooled rapidly during rolling in a continuous group. At entry and exit from each mill stand, metal from stopped strip was cut out to prepare the samples for texture study (Fig.2). To investigate the texture after self-annealing one additional sample was cut out from a coil slow cooled down before cold rolling.

The texture in the form of four incomplete pole figures {111}, {200}, {220} and {311} was investigated by "reflection" method using X-ray diffractometer DRON-7 in $Co_{k\alpha}$-radiation. The shooting plane of pole figures was parallel to the rolling plane. The ranges of inclination angles $\alpha = 0$ - 70º and rotation angles $\beta = 0$ - 360º with 5º increments along α and β were used. The orientation distribution function (ODF) was calculated by the measured pole figures, presenting in a form of a superposition a large number (2000) of standard distributions with the same little scattering. For convenience of operation with ODF the three dimensional function can be approximately represented as the sum of several standard functions (texture components, ideal orientations with the scattering). A set of these textural components was selected from the analysis of ODF sections, calculated from the experimental pole figures. The newly created file of orientations, including three Euler angles and preliminary parameters of W_i and ε_i, was processed in the program Texxor [10,11]. The adequacy criterion for the choice of a set of orientations has been selected the minimum value of the root-mean-square deviation between the ODF reconstructed by the pole figures and ODF presented as a sum of individual orientations (1).

Results and Discussion

The experimentally observed dependence of deformation pressure and the true stress upon the temperature and velocity of the uniaxial compression is characteristic for hot deformation processes: stress decreases with an increase of temperature and a decrease of the strain rate (see Fig. 1). At the strain rate of 0.1 s^{-1} stress even at low ε reaches the maximum (peak) value and then remains almost constant up to strain $\varepsilon = 1$ due to a balance between the processes of strain hardening and softening of the alloy provided by the dynamic recovery. A slight drop of stresses with the increasing deformation value, carried out at higher speeds, is caused of two reasons. First is the heating of the samples. At the strain rate of 10 s^{-1} the stress decreases with increase of strain for all represent temperatures. Calculation shows that reason of this behavior is not only adiabatic heating but also same type of softening. Possible reason of this softening is dynamic recovery which often happens in aluminum alloys in such condition [7]. However, this assumption requires verification by structure and substructure analyzes.

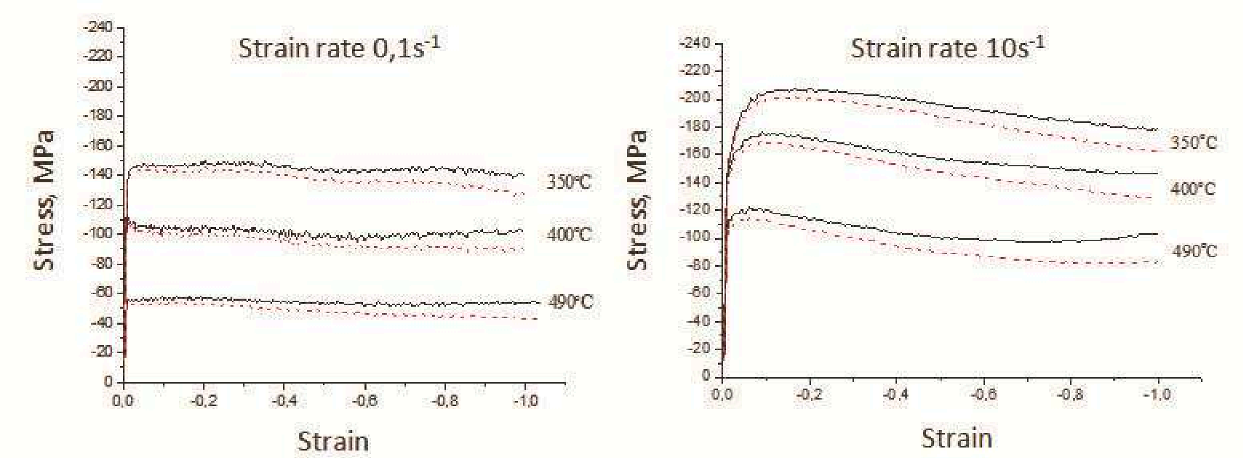

Fig. 1. The curves of the resistance to deformation (solid lines) and true flow stresses (dashed lines) under the conditions of uniaxial compression

The obtained results are in complete conformity with the common views on the combined influence of the temperature T and the strain rate $\dot{\varepsilon}$ on the deformation behavior of metallic materials described by the Zener-Hollomon parameter:

$$Z = \dot{\varepsilon} \exp\left(\frac{Q}{RT}\right) \quad (3)$$

with R being the gas constant, and Q being the activation energy of the process controlling the process of hot deformation.

Under the conditions of the balance between the processes of hardening and softening, Z parameter is expressed by the hyperbolic sine of peak (maximum) stresses σ_m [13]:

$$\sigma_m = \frac{1}{\alpha}\left(\text{arcsh}\left(\frac{Z}{A}\right)^{1/n}\right) \quad (4)$$

With the help of the regression analysis of experimental data, the following parameters of equation (4) for the peak values of flow stress are obtained:

$$A = 6.7196 \cdot 10^{10}\ c^{-1}; \quad \alpha = 0.0184\ \text{MPa}^{-1}; \quad n = 3.51; \quad Q = 1.7645 \cdot 10^{5}\ \text{J/mol} \quad (5)$$

Calculated by equation (4), the peak flow stresses coincide with high accuracy with their experimental values for all the investigated temperatures and speed modes of deformation (Fig. 2).

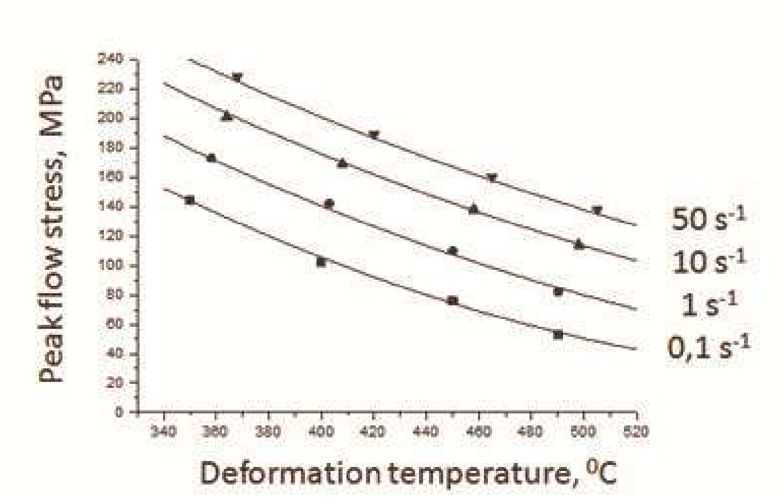

Fig. 2. The experimental (points) and calculated (solid lines) peak values of resistance to deformation of the alloy in 1565 under the conditions of the uniaxial compression

Figure 3 shows the ODF obtained at different stages of hot rolling. The results of the ODF processing are shown in Fig. 4

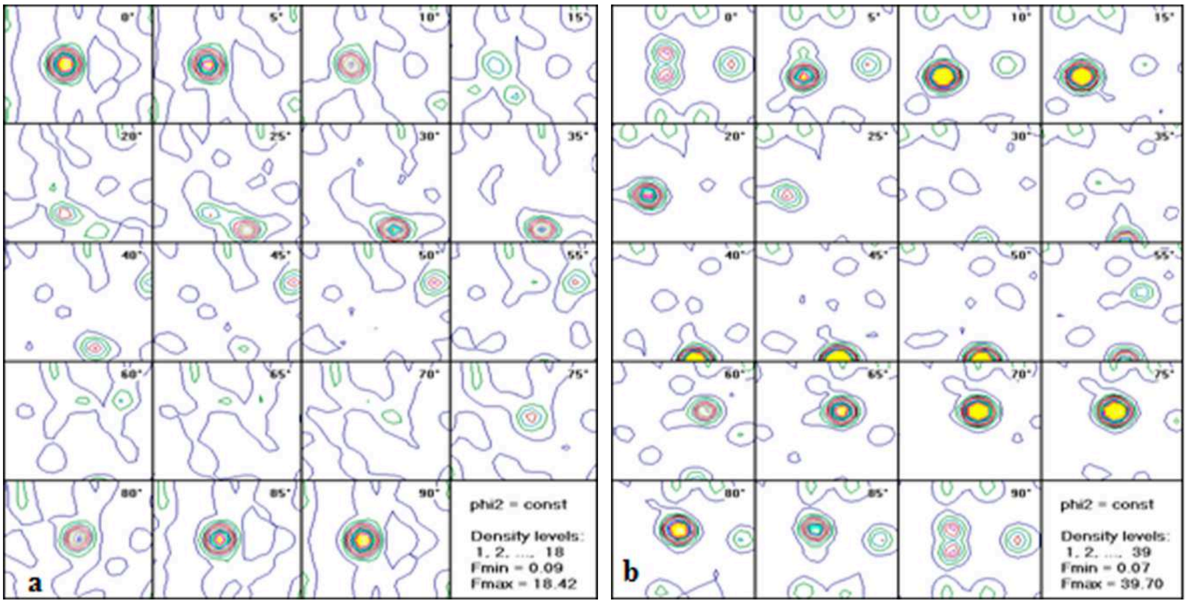

Fig. 3. ODF for the central section into a sheet of 1565ch alloy: a – enter into F1, b – enter into F5

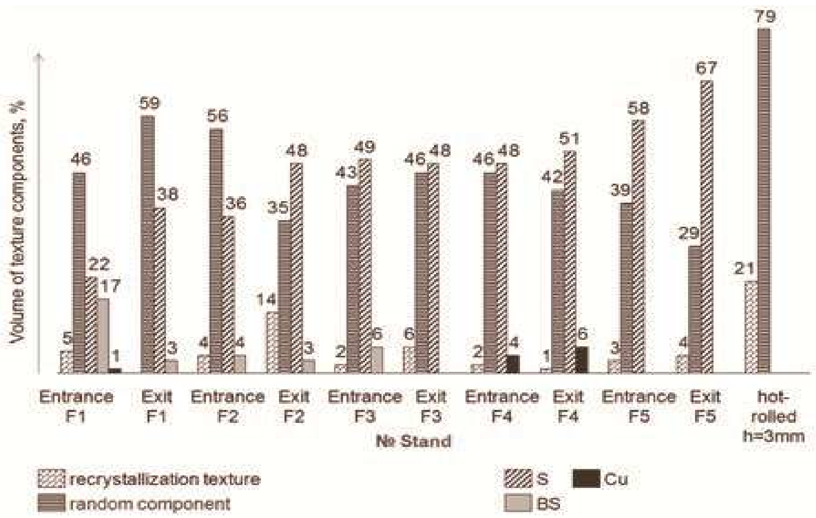

Fig. 4. The results of the X-ray analysis

As it can be seen from the ODF data analysis, as the deformation progresses, a stable rolling texture is formed (β fiber). This texture mainly consists of the classical S components, as well as a small amount of the textures Cu copper and Bs brass. There is practically no transformation of the deformation components into the recrystallization texture during the pauses between rolling passes despite their relatively long duration. The 1565 ch is much different from 5182 alloy in which during the pauses between rolling passes the process of the recrystallization texture formation intensively takes place [14]. This difference can be explained by a large number of dispersoid particles formed due to the presence of zirconium poorly soluble in aluminum. These particles can significantly reduce the growth rate of the new grain boundaries. At the same time during the self-annealing the deformation textures are partially transformed into recrystallization textures, however, the random oriented component is formed most intensively. It can be explained by the presence of intermetallic particles containing zirconium and serving as nuclei for the formation of the random oriented component [7]. Thus, it can be concluded that the alloy is not prone to the formation of recrystallization textures, but the proportion of the random oriented component at all the stages of the rolling is sufficiently large. Consequently, it can be assumed that the hot-rolled sheet will feature weak anisotropy of properties, in case of following of cold rolling, a sharp deformation texture could be developed.

Conclusion

1. The research is carried out on the deformation behavior of 1565 alloy under the uniaxial compression conditions in the temperature range of 350 - 490 ^{o}C and strain rate in the range of 0.1 - 50 s^{-1}.
2. The analytical expression obtained during the research allows to predict the peak values of the stresses in a wide range of temperatures and strain rates, which is important for computer simulation of hot rolling process.
3. The studies of the texture evolution have shown a tendency of 1565 ch alloy to the formation of the random oriented component both during the pauses between rolling passes and self-annealing. The main cause of this can be the presence of zirconium.

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