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MODERN TECHNOLOGICAL METHODS OF FORMATION AND REDUCTION OF RESIDUAL STRESSES IN ALUMINUM ALLOYS

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Abstract: The article analyzes the formation of residual stresses in the process of producing aluminum alloys and the regularity of their subsequent formation. The parameters affecting the value and sign of residual stresses in aluminum alloys, as well as the basis for selecting optimal modes, are determined. The degree of influence of the main input parameters of the process on the reduction of residual stresses in the rolling process, which is the main one in aluminum production, is determined, in particular, the chemical composition and physical and mechanical properties of the material.

Keywords: *residual stresses, aluminum alloys, flat-rolled products, sheet, physical and mechanical properties.*

Introduction.

The processing of metal parts, from initial technological operations to subsequent temperature and pressure changes, causes plastic deformations. Residual stresses play a very important role among the causes of product quality deterioration. Residual stresses are internal stresses that exist in the structure or its individual elements in the absence of external forces, temperatures, and other influences.

Residual stresses mainly reduce the performance of parts. Many cases of breakdowns caused by large technological stresses are encountered in technology. Despite the fact that many methods and means of combating residual stresses are used in metal technology, residual stresses reduce the performance of the product. Thus, residual stresses can cause negative effects such as bending of the material, the formation of cracks as a result of corrosion, brittle failure, a decrease in the elastic limit, a change in the mechanical fatigue limit, etc. Even when products are stored for a long time without use, their spontaneous bending and twisting can be observed.

One of the methods for obtaining semi-finished products from aluminum alloys is rolling. In relation to other methods of pressure processing, it is characterized by high productivity, which increases the efficiency of metal production in general. At the same time, an increase in the processing speed is reflected in the formation of consumer properties of the metal, which has to be taken into account when creating process flow charts [1, 2, 3]. Therefore, semi-finished products obtained by deformation in low-speed processing processes, such as pressing, often have higher strength properties than those obtained by rolling. In relation to pressing, rolling is a process associated with a greater cyclicity of processing.

Main part. Proper control of residual stresses in metal materials, favorable distribution of their value and sign can increase the resistance of machine parts to vibration and mechanical fatigue caused by resonance. The upper surface of the parts is considered a very sensitive zone in terms of the mechanism of action of residual stresses. In this regard, any type of mechanical processing and thermal processes that cause the formation and development of compressive residual stresses on the upper surface have a positive effect on the operational properties of the product. Thus, the main goal in establishing the production technology of any metal material is not to combat residual stresses, but to optimally manage them according to technological laws [4, 5, 6]. The main goal should be to determine the forms of stress distribution that reliably improve operational properties. Purposeful control of residual stresses is a complex technological problem, since the causes of their formation are diverse, as well as the inhomogeneity of deformation and temperature fields, phase transformations and measurements during structural changes in metals are also quite difficult [7, 8].

The nature of the flow of metal at the source of deformation during rolling is clearly given in the scheme of Selikov. The results of research on the method of high-speed film shooting confirm the correctness of this scheme. According to this scheme, the source of deformation in rolling consists of five zones (Fig. 1). It can be seen from the frames of the film that during the deformation of the billet, a certain volume of it is deformed before it has yet entered the shafts.

Due to the friction on the surface of the billet close to the shafts, the particles begin to move towards the shafts. This sign can be observed by the bending of the ends of the coordinate grid lines drawn on the side faces of the billet.

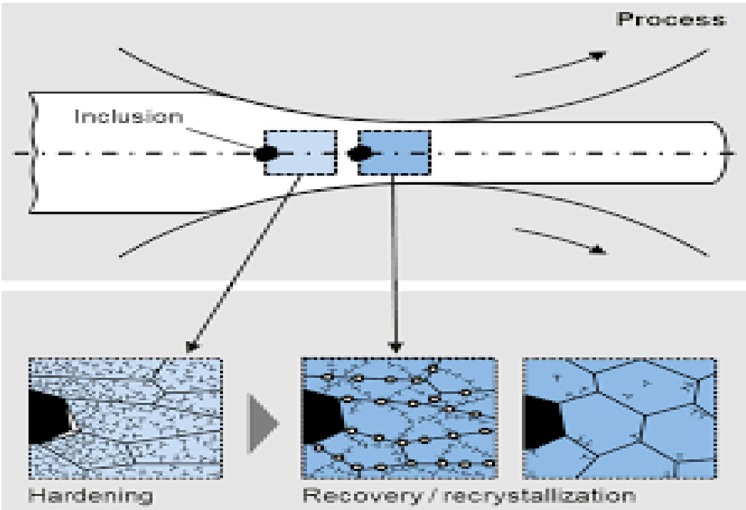

Figure 1. Structural change of the material in the processing of aluminum alloy

According to, during rolling in the area adjacent to the contact zone, at any values of L/H_{av}, compressive stresses act. In the central part of the strip, the sign of the longitudinal stress depends on L/H_{av}. At small L/H_{av} strain hardening practically does not occur, since the degree of deformation is small. With an increase in L/H_{av}, the relative compression usually also increases, strain hardening begins to predominate (at $T<Tr$), and the role of friction forces also increases. The entire route of rolling a plate blank from a thick ingot is reduced to one trend - a gradual increase in the L/H_{av} indicator. Consequently, with the same technology for producing plates (and, consequently, with the same hot rolling route) from the AA7050 alloy, the value of the L/H_{av} indicator in the last pass plays a significant role [9, 10, 11]. Figure 2 shows the dependence of the L/H_{av} indicator on the thickness of the rolled plate made of AA7050 alloy.

The difference in the level of mechanical properties in these samples can be explained as follows. The main indicator of the quality of rolled product processing is the value - the deformation zone shape factor L/H_{av}, where, L- length of the deformation zone, H_{av} average rolling thickness in the pass.

$$L = \sqrt{\Delta HR} \quad (1)$$

$$H_{av} = \frac{H_1 + H_0}{2} \quad (2)$$

According to standard concepts of the deformation zone [12, 13], L/H_{av} is usually divided into the following regions:

- $L/H_{av} < 1,0$;
- $L/H_{av} = 1,0 \div 2,0$;
- $L/H_{av} = 2,0 \div 4,0$;
- $L/H_{av} = 4,0 \div 5,0$.

Figure 2 shows the dependence of the L/H_{av} indicator on the thickness of the rolled plate made of Al-7050 alloy.

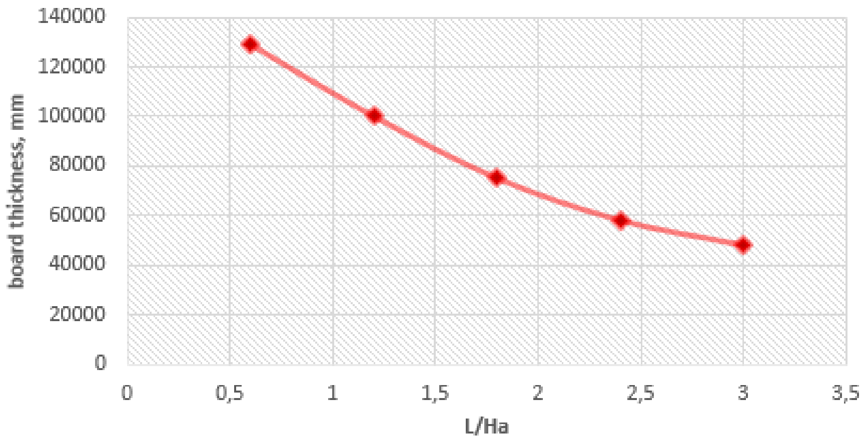

Figure 2. Dependence of L/H_{av} on the thickness of the rolled plate for the AA 7050 alloy formulation of the problem.

The microstructure of AA7050 aluminum alloy during rolling cooling is shown in the following images (Figure 3).

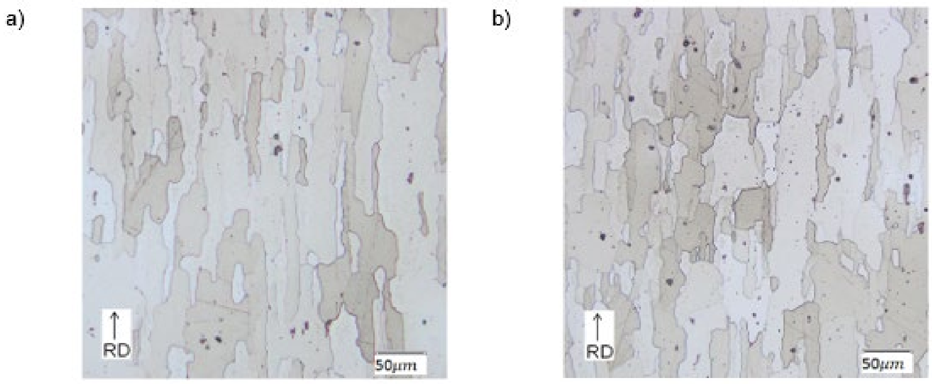

Figure 3. Microstructure of AA7050 aluminum alloy:
a) in the main part of the cooled and rolled block;
b) near the surface of the cooled and rolled block;

PROTO's proprietary position sensitive scintillation detectors (PSSD) provide unsurpassed speed, stability and a wide 2θ range. Unlike other x-ray detectors, they do not deteriorate with exposure to x-rays. Our systems are equipped with two detectors, for accurate sheer stress determination. The detectors can be quickly positioned between Omega or Modified Side Inclination geometry [14, 15, 16]. Available in standard 2θ range, extended 2θ range, and in a miniature package for our specialty miniature goniometers.

Proto's iXRD models are built around a compact and portable 300W self-contained iXRD control unit. With integrated high-voltage supply, x-ray tube cooling, motor control, system electronics and a display panel for kV, mA and interlocks, it provides everything you need to run measurements [17, 18]. Additional safety features include external ports for interfacing to an enclosure or barrier, and beacon lights for 'shutter' and 'x-ray on' (Fig. 4).

Figure 4. iXRD-PORTABLE type Neutron Diffraction device for measuring residual stress

The results also show that there is no advantage in applying 3 % compression to the cold forging for reducing residual stresses in T-section component compared to 1.5 % compression ratio. In Figure 5, residual stress levels for 3 % compression show a slight increase over those for 1.5 % [19, 20].

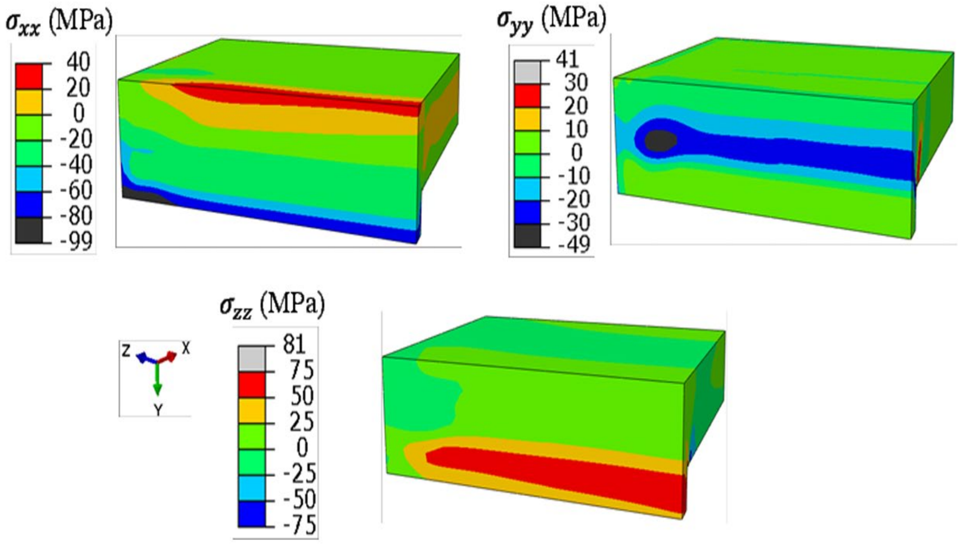

Figure 5. Residual stresses distribution after 3 % compression

Based on the research of Dallas Nigel Nelson, the distribution of residual stress in the y-axis direction in Al-7050 aluminum alloy is as shown in the graph below. Experimental data collected by combination of X-ray diffraction and center hole drilling for Al 7050 samples is shown in Figures 6 and described below [21, 22]. All deep rolling experiments were carried out using a ceramic tool at a deep rolling velocity of 63.5 mm/s with an assumed coefficient of friction of 0.05.

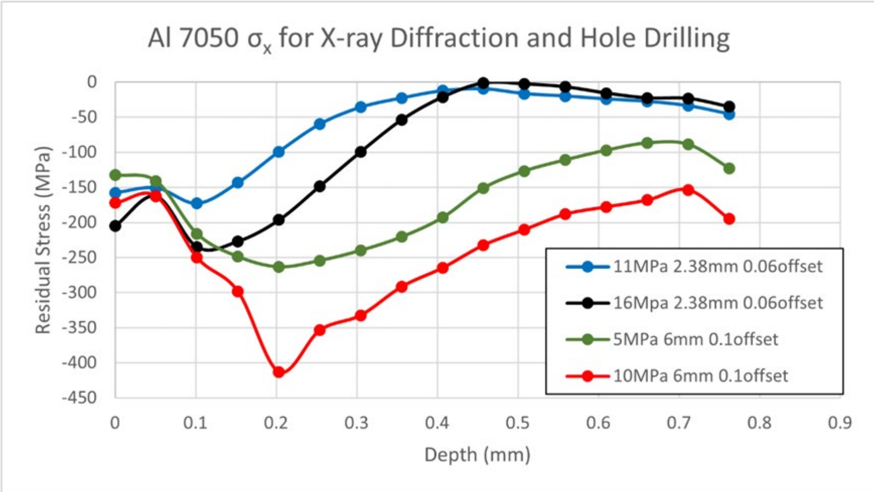

Figure 6. Residual stress parallel to y-axis vs depth for four deep rolled Al 7050 specimens.

Results and Conclusions.

Based on the analysis of theoretical materials, as well as data obtained from experiments, the following generalized conclusions were reached:

1. The main input parameters of the rolling process play the role of the main functional factor in reducing residual stresses;

2. The value and sign of residual stresses are formed primarily depending on the thermal processes and the chemical composition of the material.

In general, we can note that in order to reduce the value of residual stresses, it is necessary to adopt the following technical conditions:

- ➢the material selected for rolling (aluminum alloy) must have a homogeneous metallic structure;
- ➢there must be appropriate and evenly distributed friction conditions in the rolling mill;
- ➢ensuring the maximum uniform distribution of heat during the hot rolling process;
- ➢the geometric shape of the rolling shafts, carrier rollers and aluminum alloy must be correctly selected. The technological conditions of deformation (temperature, deformation rate and speed) must be appropriate.

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