Features of cracking during rolling of new aluminum alloys of the Al-Mg-Li system

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Abstract. The authors consider the influence of the new integrated method of thermoanalytical analysis on cracking during rolling of materials of the Al-Mg-Li system, advanced for the aerospace components manufacture. The nature of cracking depended not only on the compression degree of the material, but also on the temperature, holding time of the material in the furnace, and rolling speed. The temperature range has been experimentally revealed, that makes it possible to predict and thereby prevent appearing of cracks network over the area, select the optimal mode when rolling advanced materials in the field of aerospace engineering.

1. Introduction
The most dangerous mark in the aerospace industry today is cracking in the metal (especially in the weld zone, in the weld adjacent zone or in the heat affected zone).

Development of elastic-plastic deformations leads to local fracture and sharp decrease in the ability of the material to stand thermomechanical effects during rolling. However, with adaptability to plastic deformation, it is necessary to take into account the factor of heterogeneity distortion of the crystal lattice to a critical value in various local volumes, i.e. in fragments of the structure.

Obviously, it is necessary to choose the optimal mode, which will provide not only resistance to cracking, but also resistance to cracking during rolling by the selection method. This study is carried out at the junction with the theory of temperature analysis, therefore, structural transformations are expected about temperatures multiple of 343° C. Structural transformations are consistent with a range as in equation (1) [2]:

$$L_\sigma = 343-686-1029-1372-1715-2058 ^\circ C$$ (1)

This thermal range is strictly coherent with temperature periods, reflects process of energy absorption by a crystal lattice. There is a certain similarity between heating a metal and energy absorption of a crystal lattice, in other words, an analogy between the heat content of a metal due to absorption of additional energy by a crystal lattice and distortion of local volume of a crystal lattice to a pseudocrystalline one.

In the structure of any metal, there is a clustering of all hierarchic levels, from the atomic level to the level of the sample, while the severity can be minimal. Therefore, we can say that periodicity is the transition from one level to another, structural transformations of the alloy as a certain result of adaptability to plastic deformation under force. Consequently, the main cause of plasticity failures in the alloy of the Al-Mg-Li system can be called an increase in the elastic modulus around certain
temperatures. This negative effect can be reduced by matching the density of alloy components with a grid of stationary temperatures.

2. Experimental procedure
Since the study is based on the theory of temperature analysis, characteristic effects were primarily associated with formation or divergence of chemical elements, excess phases. Contact between individual components of the alloy and along their boundaries was extremely important [1].

The basis of the study is a comprehensive technique for isothermal discrete scanning and discrete thermal analysis, since internal temperature distributions have common laws of properties, regardless of the structure of material or its composition. Alloy 1420 is lithium- and magnesium-doped, which has an interesting effect on the characteristics of crack resistance, corrosion resistance [3-5] (the main parameters for the space industry). The cold rolling of the alloy was made in the following condition: hot-rolled sheet, 7.3 mm thick. As a control parameter by cracking we can take a change in the workpiece thickness, absolute degree of compression at each pass, which affects the rolling force, in addition, the effect of plastic deformation, a change in heat generation, and a change in temperature at the contacts of structure fragments. The study was carried out in several stages.

In the first stage, eight samples of given size were preheated by the method of isothermal discrete scanning to selected temperature: 180°C, 340°C, 505°C, 525°C, two samples per temperature. Time at temperature was two minutes. Subsequent rolling of the samples at the K220-75 rolling mill was carried out by different speed rates. The first two passes at a low rolling speed: sample 1 – 0.1 m/min and sample 2 – 1.0 m/min, by subsequent passes a high speed was chosen: sample 1 – 10 m/min and sample 2 – 20 m/min.

![Figure 1. Sample 5, heating temperature 525°C.](image1)

After four passes, it was revealed that all samples had fractures, but of a different nature [6], the most optimal heating temperature was 525°C according to a range of stationary temperatures in the equation given above (1), at this temperature, the minimum number of cracks was recorded in the sample after rolling (figure 1). It is very interesting to note that in the remaining samples, cracking was more significant (lateral cracks, local network).

![Figure 2. Sample 4, heating temperature 505°C.](image2)
There is an assumption that this is due to the fact that from the first to the fifth number after switching to a higher rolling speed, there is a monotonic decrease in the force along the passages (figure 2). The second experiment included five samples preheated to an optimal temperature of 525° C using the isothermal discrete scanning method with the following holding time: 1, 2, 3, 4, and 5 minutes. Rolling speed selected 20 m/min.

After the third pass of rolling a monotonic decrease in force is observed for all the samples, with the exception of the first one. Sample 5 retained maximum integrity with a shutter speed of 5 minutes at a heating temperature of 525° C of isothermal discrete scanning. After eight passes, the sample thickness was 1.18 mm with a force of 69.2 kN (figure 3).

The delayed nature of the destruction is apparently explained by the development of transformations in metastable phases and relaxation processes in the zones of action of interfacial stresses at grain boundaries over time.

Experiment number three included four samples preheated to a temperature of 525° C using the isothermal discrete scanning method with the following holding time: 7, 10, 12, and 15 min. Rolling speed selected 20 m/min.

Sample 4 with a holding time of 15 min at a heating temperature of 525° C using the isothermal discrete scanning method has become the most optimal sample with a minimum number of cracks. After 44 passes, the thickness of the sample was 0.855 mm. But not all samples in this experiment were devoid of deformations, so samples 1 and 3 crumbled, not even reaching the middle of the experiment. The nature of the destruction has an analogy (figure 4 and 5) [7-8].

![Figure 3. Sample 5, heating temperature 525° C, holding time 15 min.](image)

![Figure 4. Sample 1, heating temperature 525° C, holding time 7 min.](image)
Figure 5. Sample 3, heating temperature 525° C, holding time 12 min.

In the last experiment, there were five samples preheated to a temperature of 525° C using the isothermal discrete scanning method with the following time delay: 15, 20, and 30 min. Rolling speed selected 20 m/min. Absolutely all samples were successfully rolled to the required thickness of 0.5 mm in a large number of passes, but with a constant degree of compression.

Sample 1 was rolled to a thickness of 0.5 mm without intermediate heating of isothermal discrete scanning, samples 2, 3 and 4 with one intermediate heating of isothermal discrete scanning, sample 5 with two intermediate heating. The moment of intermediate heating appointment of the isothermal discrete scan was determined visually by the state of the rolled sample, and the holding time of temperature retained the value of the initial heating of the isothermal discrete scan. Only the second intermediate heating of sample 5 was carried out with a holding time of 30 minutes.

Figure 6. Photo of rolled samples: sample 1 with intermediate heating of 525° C, holding time 30 min; sample 2 with intermediate heating of 525° C, holding time 20 min; sample 3 with intermediate heating of 525° C, holding time 15 min; sample 4 without intermediate heating; sample 5 with double intermediate heating of 525° C, holding time 15 and 30 min.
Sample 5 completely preserved its integrity with minimal cracks (figure 6) with holding time of 15 min at a heating temperature of 525° C and with two intermediate heating of 525° C according to the method of isothermal discrete scanning with holding time of 15 and 30 min.

Adaptive compatibility is indicated by dynamic relaxation of the material samples and a change in the lattice-cluster structure of the aluminum-lithium alloy of the Al-Mg-Li system. It is impossible not to notice a clear relaxation effect, manifested in periodicity of force variation and in monotonic force decrease to a value of 10-15 kN in the second half of passes after intermediate heating of 525° C using the isothermal discrete scanning method. It was established that additional reheating temporarily prevents the appearance of edge cracks in the sample, and probably makes it possible to get rid of them completely if the specified parameters (holding time, rolling speed, and rolling force) are observed.

3. Conclusions
We can say that cracking in the theory of temperature analysis is closely related to the formation or divergence of chemical elements. The occurrence of cracks can be stopped by creating the optimal mode when rolling new aluminum alloys: adjusting rolling force, holding time of the sample in the furnace, temperature, rolling speed.

After we obtained experimental results, it is safe to say that when a sample passes through structural transformations as a result of heating, a new channel for dissipating elastic energy appears, which demonstrates the principle of cyclic plastic deformation. Or in other words, a sample passing through a stationary temperature from series shown in equation (1) optimizes the structure or adapts it with respect to plastic deformation. The likelihood of cracks’ network in the area of the sample decreases when the sample is heated to 525° C. Cracking is also minimized when the sample is reheated. The optimal sample holding time in a furnace with a programmer is 15 minutes. Further development of new techniques is required.

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