The research of the cold rolling modes for plates of aluminum alloy sparingly doped with scandium*

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The study of the cold rolling modes of the plates of aluminum alloy sparingly doped with scandium was performed. As a blank for rolling, a 60 mm thick semifinished rolled stock, obtained at one of the Russian metallurgical enterprises by hot rolling of a 1580 alloy ingot was used. At the first stage of the work, an experimental studies of cold rolling of the plates with different degrees of deformation in the laboratory conditions on a rolling mill DUO 330 with a body of roll of 520 mm long has been implemented to determine the critical value of overall reduction, causing the destruction of samples, which have showed that this value during cold rolling of the hot-rolled semifinished material corresponds to 21–22%. At this degree of deformation, the alloy has high strength properties with a sufficiently high plasticity. Further increase in the deformation degree does not lead to a significant growth of strength properties, but can favor to the formation of cracks along the edge of the rolled stock. The hot-rolled semifinished material deformability has been tested in the range of the cold deformation degrees from 10 to 30% using the reduction modes obtained in laboratory conditions at the second stage of the work in order to test the technology of rolling the plates on an industrial mill with a body of roll of 2800 mm long and a billet width of 2000 mm. By the results of mechanical properties testing of the plates rolled with different deformation degrees, it is shown that cold rolling of a hot-rolled billet with deformation degree of 21–22% provides the following mechanical properties of the plates: σ_t = 420 MPa; $\sigma_{0.2}$ = 380 MPa; δ = 8%, and further increase of the cold deformation degree leads to an insignificant growth of strength properties (about 10 MPa).

Key words: aluminum alloys, sparing doping by scandium, hot-rolled semifinished material, plates, cold rolling, mechanical properties, computer simulation.

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Introduction

The use of new structural materials in mechanical engineering, in particular, for the automotive, shipbuilding and aerospace industries requires the development of alloys that have small specific gravity, increased strength properties and corrosion resistance, good weldability and manufacturability in pressure treatment [1]. Alloys of the Al – Mg system doped with rare earth metals have such properties [2–16]. However, the resource of strength characteristics of these alloys, belonging to the class of thermally nonhardenable alloys, has already been exhausted. In this connection, the magnaliums alloyed with scandium were recently developed and are already actively implemented in the products. The domestic 1570 alloy [3–4] is an example of such an alloy, and replacement in the components of an AMg6 alloy by the 1570 one allows to reduce the weight of the product by 49.8–66% [17].

The technologies for producing the deformed semifinished materials already exist for this alloy, and it is used for manufacturing a number of critical industrial products. However, having higher performance attributes compared to the conventional magnaliums, a 1570 alloy is characterized by a high cost due to alloying with expensive scandium, which limits its wide application. In the new 1580 alloy the scandium content is reduced twice in comparison with a 1570 alloy, and in strength properties and performance attributes it is just little inferior to it [18–22]. In this connection, an urgent task for the development of this direction is obtaining the alloys with minimal content of scandium, and working out the technologies for their deformation treatment, which will provide the reduction of production cost of deformed semifinished materials from them and allows to expand

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Table 1.
Chemical composition of a 1580 alloy billet obtained in industrial conditions, wt.%

Content of elements						Impuriments						
Si	Mn	Mg	Cr	Zr	Sc	Fe	Cu	Zn	Ti	Na	Ca	Other / Amount of other
0.12	0.6	5.1	0.15	0.11	0.11	0.18	0.1	0.20	0.15	0.0002	0.0005	0.05/0.15

the market for products containing the components of these alloys.

For a 1580 alloy, sparingly doped with scandium, the promising structural material is flat of different thickness in the form of plates, sheets, strips and even foil.

The technologies for producing hot-rolled and cold-rolled semifinished products from this alloy are still under development and mastering. In particular, the technology for producing plates, which according to GOST 17232–99, is flat rolled products of aluminum and aluminum alloys with a thickness of 10.5 mm and more, is still lacking. Therefore, the aim of the research was to develop the modes of rolling the plates made of the 1580 aluminum alloy.

To achieve this goal, the following tasks have been solved:

–the modes development for rolling the plates a 31.5 mm thick from 1580 alloy and their approbation in laboratory conditions;

–testing the modes of rolling the plates in an industrial environment.

Research procedure

As a blank for rolling, a 60 mm thick roll, obtained by hot rolling of a 1580 alloy ingot at one of the Russian metallurgical enterprises was used [19]. The chemical composition of the alloy is given in Table 1.

The initial thickness of the ingot before hot rolling was 300 mm, so the total degree of deformation during hot rolling in manufacturing conditions was equal to 80%. For experimental studies, samples with dimentions of 150×310 mm (the second size has corresponded to the direction of rolling) were cut from a hot-rolled blank a 60 mm thick. Experimental studies were carried out at the Department of Metal Forming of the School of Non-Ferrous Metals & Materials Science of the Siberian Federal University on a DUO 330 mill with length of a body of roll of 520 mm. Technical parameters of the mill are listed in Table 2.

To assess the influence of deformation degree on mechanical properties of the hot-rolled metal, industrial hot-rolled semifinished rolled stock was cut to three thicknesses: 50, 45 and 40 mm; then they were subjected to cold rolling to a thickness of 31.5 mm. The obtained plates has been used to cut samples for mechanical testing of tensile properties according to GOST 1497–84, which were conducted on a universal Walter+Bai HELL LFM 400 kN testing machine (Walter+Bai AG, Switzerland). Five samples have been used for one experimental point. The test results have been statistically processed.

Table 2.
Technical characteristics of a DUO 330 laboratory flatting-mill

Parameter	Value
Power of electric motor, kW	90
Three-phase supply voltage, V	380
Current frequency, Hz	50
Length of a body of roll, mm	520
Diameter of rolls, mm	330
Maximal rolls setting, mm	70
Rotational speed of rolls, rev/min	10
Maximal rolling force, MN	1.55
Maximal rolling moment, MN·m	0.82

Results and discussion

Before rolling, the mechanical properties of the hot-rolled semifinished product were evaluated in the initial state as well as after annealing in the temperature range of 320–400 °C. The test results has showed that the properties of the alloy after annealing practically have not changed, so further experiments were carried out on the billets in the hot-rolled state.

Cold rolling of billets of all thicknesses was implemented with single reductions from 2 to 8%. Thus, the rolling of the first blank a 40 mm thick to a thickness of 31.5 mm was carried out in 8 passes, and the total degree of cold deformation of the resulting plate was 21%.

When rolling the second workpiece from 45 mm, cracks up to 5 mm have appeared on its edges at the thickness of 33 mm (total degree of deformation ε_{tot} = 27%); they did not increase when rolling to the thickness of 31.5 mm (ε_{tot} = 30).

Rolling of the third sample a 50 mm thick (Fig. 1, *a*) has showed that when a thickness of 39 mm was reached, a crack appeared along the edge of the blank (Fig. 1, *b*), which corresponded to the total degree of cold deformation of 22%. After cleaning the cracks, rolling has been continued and cracks appeared at a thickness of 36.4 mm, which corresponded to the degree of deformation of 27.2%, and the rolling was stopped.

Mechanical properties (temporary tear resistance σ_t, conventional yield strength of metal $\sigma_{0.2}$ and specific elongation (δ) of the 1580 alloy plates are given in Table 3.

Thus, the results of the experiments have showed that the critical deformation degree during cold rolling of the hot-rolled semifinished material of the geometry described above corresponds to 21–22%. At this deformation

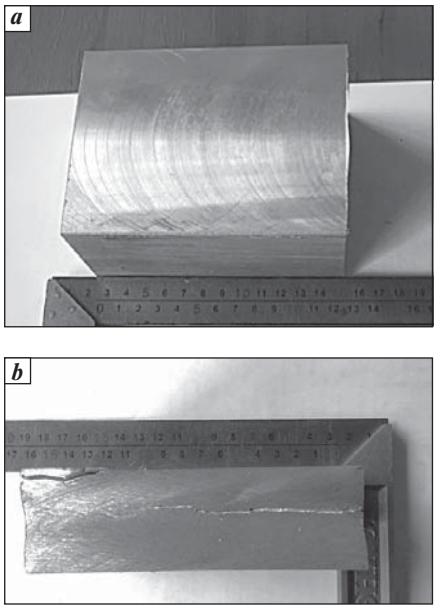

Fig. 1. View of the sample No. 3 before (*a*) and after (*b*) the rolling up to the thickness of 39 mm

Table 3.
Mechanical properties of the 1580 alloy cold-rolled plates, obtained in laboratory conditions

Thickness, mm		ε_{tot}, %	Mechanical properties		
before rolling	after rolling		σ_t, MPa	$\sigma_{0.2}$, MPa	δ, %
40	31.5	21.2	$420^{\pm2}$	$383^{\pm2}$	$8.0^{\pm1}$
45	31.5	30.0	$429^{\pm2}$	$388^{\pm2}$	$8.0^{\pm1}$
50	36.4	27.2	$425^{\pm2}$	$380^{\pm2}$	$9.0^{\pm1}$

degree, the alloy has high strength with a plasticity high enough and comparable to that of plates made of AMg6 alloy (δ = 4–11% according to GOST 17232–99) and a hard-drawn tape made of the same alloy (δ = 6% according to GOST 13726–97). Further increase of deformation degree does not lead to significant growth of the strength properties, but can contribute to the formation of cracks along the edge of the rolled product. However, the authors made the recommendations for the assignment of reduction modes in manufacturing conditions taking into account the differences in the nature of the deformation focus during rolling on the laboratory and industrial broad-strip mills. During industrial rolling on a broad-strip mill, according to [23], more uniform character of deformation of metal is to be expected and above all considerably smaller size of tensile stresses on the blank edges, which are the main cause of the cracks formation. Besides, the deformation divisibility during rolling in laboratory conditions is higher than that in the industrial ones because of restrictions on the force parameters, which leads to a more intense hardening of the metal during its deformation. Taking into account of the above factors allows

Table 4.
Mechanical properties of the 1580 alloy cold-rolled plates, obtained in industrial conditions

Total degree of cold deformation, %	Mechanical properties		
	σ_t, MPa	$\sigma_{0.2}$, MPa	δ, %
12	$405^{\pm2}$	$340^{\pm2}$	$11^{\pm1}$
19	$416^{\pm2}$	$360^{\pm2}$	$10^{\pm1}$
22	$422^{\pm2}$	$363^{\pm2}$	$9^{\pm1}$
26	$427^{\pm2}$	$370^{\pm2}$	$9^{\pm1}$
31	$429^{\pm2}$	$370^{\pm2}$	$9^{\pm1}$

to increase the total deformation degree up to 25–30% on cold rolling the plates in industrial conditions.

Taking into account these features and in order to test the technology of rolling the plates on an industrial mill with a body of roll of 2800 mm long and a blank width of 2000 mm, the second stage of the work has been focused on checking the deformability of the hot-rolled semifinished product in the range of the cold deformation degrees from 10 to 30% using the reduction modes obtained in laboratory conditions. According to the results of testing the mechanical properties of the plates obtained with different deformation degree, the optimal degree of cold deformation was determined taking into account the achieved level of mechanical properties.

A 1580 alloy cast slab, the chemical composition of which has corresponded to the data of the Table 1 has been used as a blank for hot rolling on an industrial mill.

The initial dimensions of the slab were 470×2040×4000 mm. Rolling was carried out on a SGP Quarto 2800 reversible rolling mill, equipped with edger rolls with the following performance attributes:

– diameter of working rolls is 725 mm;
– length of a body of a working roll is 2800 mm;
– diameter of rollers of an edging stand is 1000 mm.

The ingot heating temperature before rolling was 410 °C. The rolling was carried out to a thickness of 46 mm with reductions per pass from 2 to 15%. The metal temperature at the end of rolling was 385 °C. The SP-3 lubricant was used as a cutting emulsion.

After rolling, the semifinished rolled stock was divided into five billets; it has been annealed according to the previously developed mode (heating temperature of 360 °C and holding time of 3 hours) and was subjected to cold rolling with deformation degree of, respectively, 10.5, 18, 21, 25 and 31%.

Cold rolling was carried out on a SHP Quarto 2800 mill with a working rolls diameter of 650 mm and a a body of roll of 2800 mm long. Then the samples were cut from cold-rolled plates to test the mechanical properties, the results of which are presented in Table 4.

Analysis of the test results of mechanical properties of the metal has showed that maximal hardening of the 1580 alloy plates takes place on cold rolling in the range of total degrees of deformation of 20–30%.

Conclusion

Thus, the listed below results were received as a consequence of the conducted studies on determination of modes of cold rolling of plates from the Al – Mg system 1580 alloy, sparingly doped with scandium.

1. The principal possibility of cold rolling of plates a 31.5 mm thick from hot-rolled billets of the 1580 aluminum alloy with degrees of deformation up to 30% is established.

2. The results of strain testing the mechanical properties of a hot-rolled semifinished product showed that the properties of alloy after annealing in the temperature range of 320–400 °C have not practically changed, so cold rolling to obtain the plates may be carried out directly after the hot one.

3. The mode of cold rolling of plates with a 31.5 mm thick from hot-rolled billets a 40–50 mm thick, which was experimentally tested on a DUO 330 laboratory mill, was developed. Found was that rolling without a crack on the edges is possible at total deformation degree of 21–22%, which can be increased to 25–27% subject to side shearing.

4. It is shown that cold rolling of a hot-rolled semifinished material with a degree of deformation of 21–22% in laboratory conditions provides the following mechanical properties of the metal: σ_t = 420 MPa; $\sigma_{0.2}$ = 380 MPa; δ = 8%. Further increase in the degree of cold deformation leads to a slight increase in strength properties (about 10 MPa), but it is possible the appearance of cracks on the edges of the rolled products.

5. When obtaining plates from the 1580 alloy sparingly doped with scandium in industrial conditions, it is recommended the cold rolling mode, which provides the total degree of deformation in the range of 20–30%.

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