Research Article

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Study of strength properties of semi-finished products from economically alloyed high-strength aluminium-scandium alloys for application in automobile transport and shipbuilding

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Abstract: The results of a study on the strength of rolled products from aluminium alloys doped with scandium under various processing conditions of hot and cold rolling are presented. The regularities of metal flow and the level of strength of deformed semi-finished products from aluminum-scandium alloys are established, depending on the total degree of deformation and the various modes of single reduction during rolling. It is shown that when using one heating of a cast billet to obtain high-quality semi-finished products, the temperature during the rolling process should not be lower than 350-370°, and the total degree of deformation does not exceed 50-60%. It was found that the semi-finished products from alloys with a content of scandium in the range 0.11-0.12% in the deformed state had elevated values of ultimate tensile strength and yield strength of the metal, which allows them to be recommended for industrial production of sheet metal products.

Keywords: aluminium alloys, scandium, rolling, deformed semi-finished products, total degree of deformation, temporary tensile strength, yield stress of metal

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1 Introduction

Recently, much attention has been paid to research in the field of creating processing technologies and studying the properties of cast and deformed semi-finished products from aluminium alloys alloyed with rare-earth metals, in particular, by scandium [1–10]. This is because such alloys, along with corrosion resistance and good performance properties, can have high strength characteristics. Alloys of the Al-Mg system that do not contain scandium (for example, alloy 5083) are widely used in industry, and alloys with a high scandium content (up to 0.24%), for example, 01570 alloy, have a high cost due to the use of expensive scandium ligature. Therefore, an urgent task is the development of new alloys, economically alloyed with scandium, having increased strength.

With the purpose of deeper studying the patterns of formation of mechanical and operational characteristics of products made of such high-strength aluminium-scandium alloys, the employees of «RUSAL» together with the scientists of the School of Non-Ferrous Metals and Materials Science of the Siberian Federal University conducted a number of experimental studies to obtain cast and deformed semi-finished products and study their properties. The results of some of these studies are given below.

The article is based on the report presented at the IX International Congress "Non-ferrous metals and minerals-2017".

2 Methods

In the first stage of research, flat ingots of 8 alloys of the Al-Mg system with different scandium content varying in the range of 0.10-0.24% and 1 ingot of the 5083 alloy, which

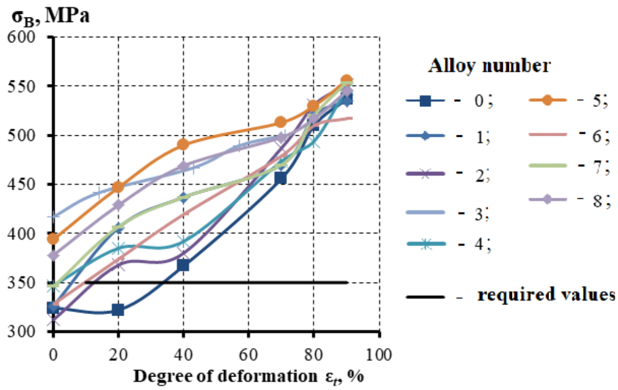


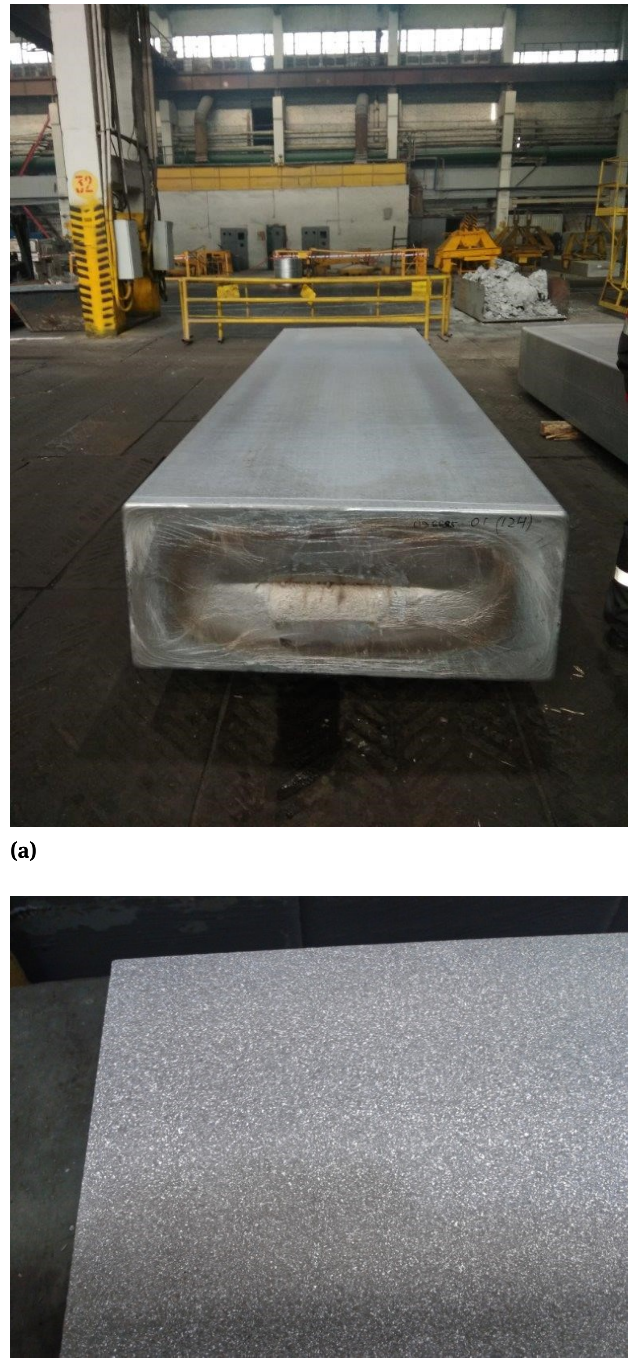
Figure 1: The change in the tensile strength for the investigated alloys

was basic and did not contain scandium, were cast in experimental industrial conditions. They were subjected to homogenization annealing in the following manner: heating with an oven at a rate of 1.16°C per minute to 350°C; holding at this temperature for 11 hours; reheating to temperature T = 425°C at a rate of 1.25°C per minute; holding at this temperature for 8 hours; cooling in air. For the design of the processing route for experimental alloys, a deformation scheme was adopted that included hot rolling of 28 mm thick preforms heated to 450°C to a thickness of 10 mm, and then cold rolling of these strips to a final thickness of 1 mm (Table 1).

When developing the rolling modes of experimental aluminum alloys, the methods and software described in [11, 12] were used to calculate deformation and force parameters and used the dependences characterizing the change in their strength characteristics from the degree of deformation obtained in the course of studying the mechanical properties.

For the study, 8 alloys of the Al-Mg system with Cr 0.15 to 0.20%, Si 0.20%, Zn 0.1%, Cu 0.1%, Fe 0.2% and different scandium content from 0.10 to 0.24% were chosen (Table 2). The DUO 330 mill was used as the equipment for hot rolling, and the MDM ARIETE LS 400×240 mill for cold rolling. As a result of rolling with the use of intermediate heating preheaters, hot-rolled strips were obtained, which were then rolled to specified thicknesses with ϵ_t up to 97%.

In the course of rolling, samples were taken for mechanical testing and tensile strength and yield strength of the metal was determined by means of a universal machine LFM 400. The obtained 3 mm thick strips were annealed at T = 350 °C and a holding time of 3 hours. Data on the mechanical properties of semi-finished products from the experimental alloy in comparison with the alloy-analogue 5083, which does not contain scandium, are



(a)

(b)

Figure 2: The type of ingot (a) obtained under the industrial conditions of the Bratsk aluminium smelter, and its macrostructure (b)

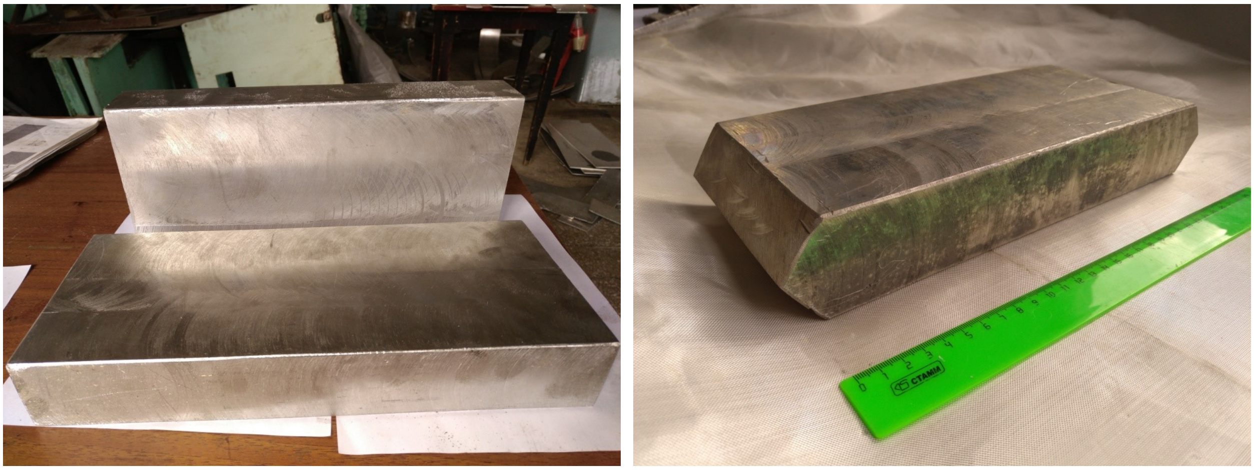
shown in Figure 1 (for the reference point for ϵ = 0, the values of σ_B for the cast preform are taken). Analysis of the dependencies on the graph allows us to conclude that, with an increase in the degree of deformation, the values of the temporary fracture resistance (σ_B) for all investigated alloys increase and at ϵ_t = 96.8% reach values of the order

Table 1: Route of rolling all investigated alloys

Route number	Primary thickness h_0, mm	Final thickness h_i, mm	Draw ratio λ		Degree of deformation ϵ, %	
			Single λ_s	Total λ_t	Single ϵ_s	Total ϵ_t
	28.0	27.5	1.02	1.02	1.96	2.0
	27.5	26.8	1.03	1.05	2.48	4.4
	26.8	25.9	1.03	1.08	3.36	7.6
	25.9	25.0	1.04	1.12	3.48	10.8
	25.0	24.1	1.04	1.16	3.60	14.0
	24.1	23.2	1.04	1.21	3.74	17.3
	23.2	22.3	1.04	1.26	3.88	20.5
	22.3	21.4	1.04	1.31	4.04	23.7
	21.4	20.5	1.04	1.37	4.21	26.9
	20.5	19.6	1.05	1.43	4.40	30.1
	19.6	18.7	1.05	1.50	4.60	33.3
	18.7	17.7	1.05	1.58	5.09	36.7
	17.7	16.8	1.06	1.67	5.36	40.1
	16.8	15.8	1.06	1.77	5.66	43.5
	15.8	14.9	1.06	1.88	6.01	46.9
	14.9	13.9	1.07	2.01	6.39	50.3
	13.9	13.0	1.07	2.16	6.82	53.7
	13.0	12.0	1.08	2.33	7.32	57.1
	12.0	11.0	1.09	2.53	8.07	60.5
	11.0	10.0	1.10	2.78	8.87	64.0
	10.0	9.1	1.11	3.09	9.93	67.6
	9.1	8.0	1.12	3.47	11.03	71.2
	8.0	7.0	1.14	3.96	12.39	74.8
	7.0	6.0	1.16	4.61	14.14	78.3
	6.0	5.0	1.21	5.60	16.50	82.1
	5.0	4.4	1.12	1.12	11.0	84.3
	4.4	3.9	1.14	1.28	11.9	86.0
	3.9	3.4	1.14	1.45	12.2	87.8
	3.4	3.0	1.14	1.66	12.5	89.2
	3.0	2.6	1.14	1.89	12.3	90.7
	2.6	2.3	1.14	2.16	12.1	91.8
	2.3	2.0	1.14	2.45	12.1	92.8
	2.0	1.8	1.14	2.79	12.3	93.6
	1.8	1.6	1.13	3.16	11.7	94.3
	1.3	1.4	1.12	3.55	10.8	95.0
	1.4	1.3	1.10	3.91	9.2	95.4
	1.3	1.2	1.08	4.24	7.8	95.7
	1.2	1.1	1.07	4.55	6.8	96.1
	1.1	1.04	1.06	4.81	5.5	96.2
	1.04	1.00	1.04	5.00	3.8	96.4

of 500-550 MPa. The regularities of the change in the values of the yield strength ($\sigma_{0.2}$) of the metal are of a similar nature, and their values reach 360-478 MPa. It was also found that with the increase in the amount of scandium in the alloy, the strength characteristics of the metal also increase.

At the second stage of the research in the industrial conditions of the Bratsk aluminium smelter on the basis of alloy 5083, flat ingots 560×1360×4520 mm in size (Figure 2)



(a) (b)

Figure 3: View of cast billets from the investigated alloys after milling

Table 2: The chemical composition of ingots from experimental alloys with a reduced content of Mn and Cr of the Al-Mg system

Alloy number	Main elements, %				
	Al	Mg	Mn	Sc	Zr
0		5.0-5.2	0.8	-	-
1		5.0-5.2	0.6	0.24	0.10
2		5.0-5.2	0.6	-	0.20
3		5.0-5.2	0.6	0.10	0.20
4	Basis	5.0-5.2	0.3	0.10	0.20
5		5.0-5.2	0.75	0.10	0.20
6		5.0-5.2	0.6	0.10	-
7		5.0-5.2	0.6	0.10	0.10
8		5.0-5.2	0.6	0.15	0.20

were cast from an aluminium alloy in which the scandium content was in the range of 0.11-0.12%. The templates were cut off from the ingots, from which samples were prepared for testing the mechanical properties of the cast metal and the workpiece with milled faces for rolling with dimensions of 40×120×200 mm (Figure 3).

Further, according to the previously developed regimes, the homogenized preforms were hot rolled in a DUO 330 mill up to a thickness of 10 mm, and the obtained strip was rolled to a thickness of 3 mm in the cold state. In the course of rolling, samples were taken for mechanical testing and a temporary tensile strength, yield strength and elongation were determined. The resulting 3 mm thick strips were annealed at $T = 350^{\circ}$C and a holding time of 3 hours.

Data on the mechanical properties of semi-finished products from the experimental alloy in comparison with the analog alloy 5083, which does not contain scandium, are given in Table 3 and showed that σ_B for deformed semi-finished products increased by an average of 17%, and $\sigma_{0.2}$ of the metal by 29%, for annealed, respectively, by 29 and 49.8%.

In the third stage of the research, the possibility of rolling cast billets from an alloy with scandium content from one without additional metal heating during the rolling process and the strength properties of the obtained deformed semi-finished products were analyzed.

Rolling of the first billet with dimensions of 53×130×330 mm was carried out after homogenization with a single reduction of 2% until cracks appeared on the lateral faces that appeared at a thickness of 30 mm. The total degree of deformation was 43.4%, and the number of passes was 21. The analysis of shortcomings showed that the metal flow for a given compression pattern is uneven: the peripheral layers outstrip the central ones (Figure 4). This caused the appearance of significant tensile stresses and, as a consequence, at a low metal temperature, the appearance of cracks on both sides of the workpiece.

The second billet (Figure 5) was rolled under heating under a similar regime and the maximum reduction at rolling in the scheme 53-48-43-38-35-32-31.2 (6 passes), after which the billet was exposed at its end. The total degree of deformation was 41.1%. It can be noted that during rolling a more uniform flow of metal was observed and there was an absence of cracks on one of the faces (Figure 5b), which indicates that both the peripheral and central layers of the preform are being worked through. However, large values of single compression led to the disclosure of the billet.

Table 3: Strength properties of samples of rolled products from experimental alloys

Sample number	Thickness h_i, mm	Condition	Strength properties, MPa			
			alloy 5083		experimental alloy	
			σ_B	$\sigma_{0.2}$	σ_B	$\sigma_{0.2}$
1	10	hot deformed	297	196	356	232
2	8	hot deformed	305	217	372	280
3	6	hot deformed	318	213	387	312
4	3	cold deformed	394	373	453	429
5	3	annealed	277	139	390	277

(a) (b)

Figure 4: View of the first billet after rolling: a - from above; b - on the side

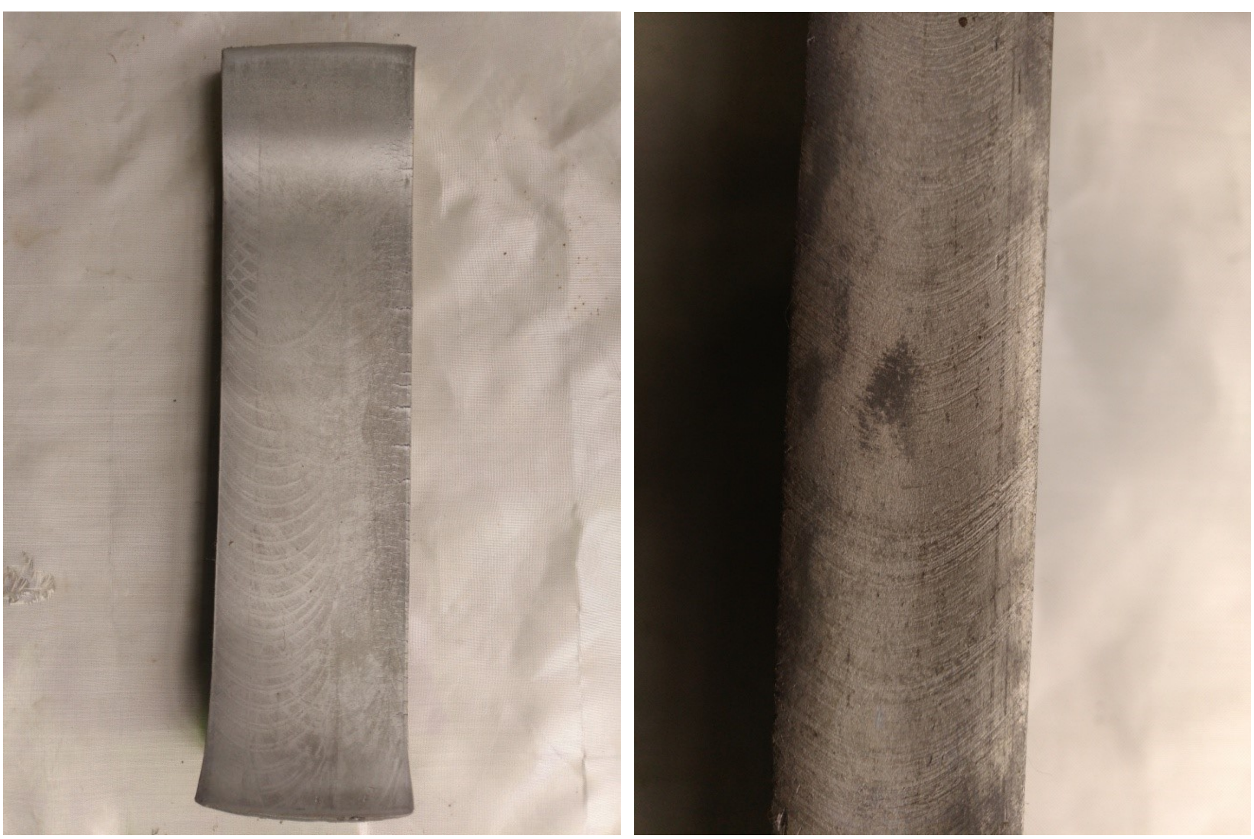
Rolling of the third billet (Figure 6) with a thickness of 40 mm was done with an aluminium cladding of two large facets with a 1 mm thick plate and a length of 0.75 of the sample length at T = 450°C. The modes of reduction and the temperature of the metal are given in Table 4. The total degree of deformation ϵ_t was 75% (final thickness h_i = 11 mm), during the rolling process, 4 intermediate temperatures of the metal had to be used.

The fourth blank with a thickness of 26 mm with a Petrov lock (Figure 7 b) on one side was rolled from one heating at T = 450°C in 45 passes. Rolling was carried out with small crimps (1-2%), the total reduction ϵ_t was 57.6%.

The temporary tensile strength σ_B for the obtained semi-finished products varied within 343-379 MPa, which corresponds to the strength characteristics for hot deformed semi-finished products from the alloy studied earlier (Table 4).

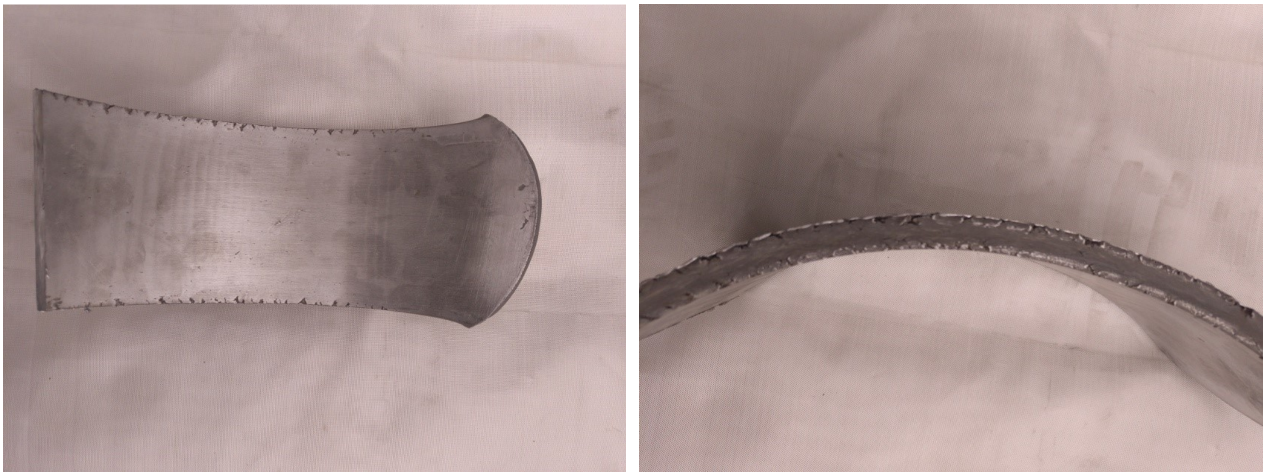
Table 4: Modes of reduction and temperature of metal along the passes during rolling

Pass number	Δh, mm	Reduction, %		Temperature before pass T, °C	Temperature after pass T, °C	Note
		Single ε_s	ε_t			
1	5	12.5	12.5	450		
2	3	8.5	20	445	418	
3	2	6	25	418	395	
4	2	7	30	395	370	
5	2	7	35	370	350	heating
6	3	11.5	42.5	400	386	
7	2	9	47.5	386	357	
8	1	5	50	357	350	
9	1	5	52.5	350		heating
10	3	16	60	440	415	
11	2	12.5	65	415	360	
12	1	7	67.5	360		heating
13	2	15	72.5	430	360	heating
14	2	18	75	415	360	



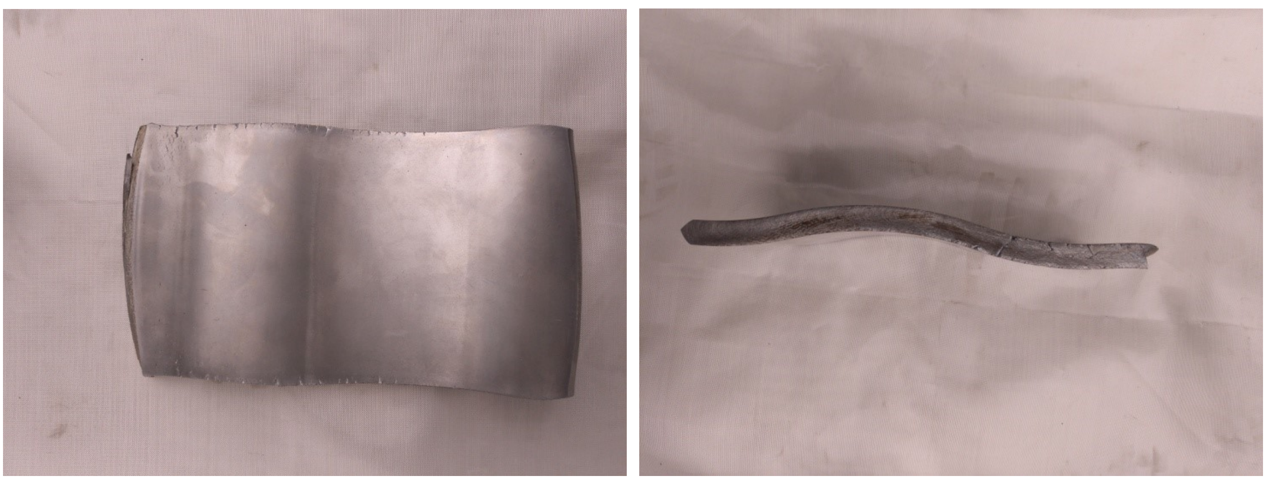
(a) (b)

Figure 5: View of the second billet after rolling: a - from above; b - on the side



(a) (b)

Figure 6: View of the third billet after rolling: a - from above; b - on the side



(a) (b)

Figure 7: View of the fourth billet after rolling: a - from above; b - on the side

3 Conclusions

Thus, the conducted studies made it possible to establish the regularities of the metal flow and the level of strength of the deformed semi-finished products from aluminium-scandium alloys, depending on the total degree of deformation and the various modes of single reduction during rolling. The distribution of the compressions along the passes for the ingots is not important, since even when rolling with single compressions ϵ_s of the order of 10-15% at processing temperatures of 420-450°C, the metal deformation proceeds evenly without defects, and the metal is worked through the entire thickness. The most important technological parameters are the temperature of strip and the total reduction: the temperature is not lower than 350-370°C; the total degree of deformation ϵ_t is not more than 50-60%. Semi-finished products from aluminium alloys with scandium content in the range of 0.11-0.12% in the deformed state have increased values of the tensile strength and yield strength of the metal, which are on average 17-29% higher than the strength parameters for base alloy 5083, in the composition of which there is no scandium. The obtained research results will be used in the development of casting technologies for rolling these alloys in industrial conditions and obtaining products in the form of sheet products for the needs of automobile and shipbuilding.

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Nomenclature

Δh	absolute reduction, [mm]
ϵ_s	single degree of deformation (reduction), [%]
ϵ_t	total degree of deformation (reduction), [%]
λ_s	single draw ratio, [-]
λ_t	total draw ratio, [-]
σ_B	tensile strength, [MPa]
σ_T	yield strength, [MPa]
h_0	primary thickness, [mm]
h_i	final thickness, [mm]
T	temperature [°C]

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