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STUDY ON THE INFLUENCE OF HEAT TREATMENT MODES ON MECHANICAL AND CORROSION PROPERTIES OF ROLLED SHEET PRODUCTS FROM A NEW ALUMINUM ALLOY, ECONOMICALLY ALLOYED WITH SCANDIUM

Baranov V.N.[1], Sidelnikov S.B.[1], Zenkin E.Yu.[2], Konstantinov I.L.[1], Lopatina E.S.[1], Yakivyuk O.V.[1], Voroshilov D.S.[1], Belokonova I.N.[1], Frolov V.A.[1]

[1] Siberian Federal University (SibFU), Krasnoyarsk, Russia
[2] PJSC RUSAL Bratsk, Bratsk, Russia

Abstract. The paper presents the study on mechanical and corrosion properties of rolled sheet products from a new alloy of the Al-Mg-Sc system in a deformed and heat treated state. Its use and development of technologies for the production of relevant parts for automobile and shipbuilding industries are important today due to the tasks of downstream aluminum processing, which are solved by RUSAL, and confirmed by the state support of a comprehensive project aimed at creating a high-technology production division, being currently carried out by the Bratsk Aluminium Smelter and Siberian Federal University. To determine mechanical and corrosion properties, the authors used sheets and coils rolled on industrial reversing hot rolling mill Quarto 2800. The tensile test was used to study deformed samples after rolling and samples produced in five heat treatment modes with varying heating temperatures of 300, 350 and 380°C and a soaking time of 1 and 3 hours. The studies on samples of rolled products with various thicknesses showed that as compared to the initial state, steel strength properties after heat treatment decrease by 12–20% on average, and ductility properties (δ) increase by 50–65%. In this case, heat treatment modes 1–3 give a fairly good ratio of strength and ductility properties. The level of these properties is comparable to the properties of alloy 01570. It is noted that a trend in a decrease in strength properties and a growth of ductile properties with increasing heat treatment temperature is also observed for samples of rolled products produced by various methods of cold rolling (cut-to-length sheets and in coils). If sheet thickness is similar, strength properties are higher, when sheets are cut-to-length rather than in coils. The corrosion tests of sheets with different thicknesses showed that the heat treatment modes under study do not have a significant influence on alloy resistance to intergranular corrosion.

Keywords: aluminum alloys, magnalium, scandium, hot rolling, heat treatment, mechanical properties.

Introduction

At present, there is a need for high-quality aluminum alloys for parts of transport engineering, including for the automotive and shipbuilding industries. The main requirements for these alloys are corrosion resistance, weldability in combination with strength and high processability in pressure treatment, especially during rolling, as the main type of semi-finished products for these industries is sheet metal. This complex of properties is supported by the alloys of the aluminum-magnesium system. However, the resource of the strength characteristics of traditional magnalicides, belonging to the class of thermally unsupported alloys, is limited. In this regard, the urgent task facing the domestic metallurgical industry is the development of compositions of new alloys that would allow them to be used to improve the strength, plastic and corrosion properties of deformed semi-finished products [1, 2]. A promising direction in solving these problems is the creation of alloys based on the Al-Mg system complexly doped with transition metals that combine high mechanical and operational characteristics. An effective modifier of the cast grain structure of aluminum alloys is scandium, which makes it possible to obtain ingots by the method of continuous casting, which have a non-dendrite structure. In this connection, magnanes doped with scandium are considered to be the most promising alloys capable of providing the above complex of properties [3–15]. From the alloys used in industrial production, it is possible to identify alloy 01570, in which the scandium content reaches 0.35% [3, 4]. Complex alloying of alloys with transition metals will reduce the content of expensive scandium without affecting the properties. The production of deformed semi-finished products from such alloys by classical methods of metal processing (rolling, extruding, forging, etc.) will reduce the mass and cost of products without loss of strength and corrosion resistance.

Technology for production of rolled semi-finished products from economically alloyed with scandium aluminum alloys are currently no. This is especially true for the hot rolling process of an ingot, the initial structure of which does not allow heating above the critical temperatures, which can lead to a drop in the strength properties of rolled products. Moreover, the subsequent cold rolling of the hot-rolled billet, accompanied by intermediate annealing, usually presents no difficulties, since it has been worked on conventional magnitudes.

As part of the implementation of a joint integrated project 03.G25.31.0265 «Development of economically alloyed high-strength Al-Sc alloys for use in road transport and navigation» together with the Bratsk Aluminum Smelter, studies were carried out on the rolling regimes as well as on the properties of deformed semi-finished products obtained by hot and cold rolling from a new alloy [16–20]. However, the task of obtaining the required complex of mechanical properties of rolled products from a new alloy after the final heat treatment has not yet been solved.

Therefore, the aim of this work was to search for such heat treatment regimes for deformed semi-finished products that would provide a combination of high strength and plastic characteristics of rolled products from the P-1580 alloy of the Al-Mg system doped with scandium within the range 0.10–0.12%.

Methods of carrying out researches

To achieve this goal, we evaluated the mechanical and corrosion properties of rolled products of various thicknesses and species obtained on an industrial reversible hot rolling mill Quarto 2800.

Studies mechanical properties of metal after rolling and annealing were carried out by tensile testing machines Zwick Z 250 and LFM400. From the obtained strips, flat samples were cut, which were subjected to tensile tests at room temperature and a specified deformation rate.

In determining the strength and plastic properties of the samples, the change in the length of the working part of the sample was recorded each time, and also the value of the tensile force corresponding to this change.

To evaluate the effect of heat treatment on the parameters of mechanical properties, used 5 modes.

1. Temperature 300 °C, holding time 1 h.
2. Temperature 300 °C, holding time 3 h.
3. Temperature 350 °C, holding time 1 h.
4. Temperature 350 °C, holding time 3 h.
5. Temperature 380 °C, holding time 1 h.

The results of the research and analysis

Tables 1 and 2 show the mechanical properties of samples of the P-1580 alloy from 8.8 mm and 6 mm thick sheets obtained by hot rolling and cut in the transverse direction.

Table 1

Mechanical properties of samples of alloy P-1580 from sheet thickness of 8.8 mm in hot-rolled and heat-treated conditions

Condition, heat treatment regime	R_m, MPa	R_p, MPa	A, %	Estimated length, mm
hot-rolled	396	281	19.7	50
1	394	275	20.6	50
3	388	272	19.0	50
5	388	264	18.9	50

Table 2

Mechanical properties of samples of alloy P-1580 from sheet thickness of 6 mm in hot-rolled and heat-treated conditions

Condition, heat treatment regime	R_m, MPa	R_p, MPa	A, %	Estimated length, mm
hot-rolled	453	386	6.1	130
1	396	299	13.4	130
2	394	297	14.6	130
3	390	292	12.3	130
4	390	290	13.6	130
5	389	288	17.2	130

Analysis of mechanical properties shows that, in comparison with the initial state, the strength characteristics (R_m) of samples after heat treatment are reduced by 12–20%, and the plastic (A) increases by 50–65%. In this case, the heat treatment regimes 1–3 give a fairly good ratio of strength and plastic properties, comparable to those of alloy 01570, doped with scandium within the range 0,17–0,35% [3].

According to the test results, it can be seen that the above-mentioned patterns of changes in mechanical properties are also characteristic for sheets of smaller dimensions. At the same time, as the thickness of the hot-rolled sheet decreases, the strength characteristics increase, while the plastic characteristics decrease, which is associated with an increase in the degree of total deformation during rolling.

Similar studies were carried out for the samples of the investigated alloy P-1580, cut from cold-rolled sheets with dimensions 4,5×300×300 mm and 1,5×300×300 mm. The results of the tests are given in **Table 3** and **Table 4**.

Table 3

Mechanical properties of samples of alloy P-1580 from a sheet of dimensions 4.5×300×300 mm in cold-rolled and heat-treated conditions

Condition, heat treatment regime	R_m, MPa	R_p, MPa	A, %	Estimated length, mm
cold-rolled	458	402	5.4	110
1	401	314	15.4	110
2	404	314	15.7	110
3	398	307	14.6	110
4	397	305	14.4	110
5	399	311	13.7	110

Table 4

Mechanical properties of samples of alloy P-1580 from a sheet with dimensions of 1.5×300×300 mm in cold-rolled and heat-treated conditions

Condition, heat treatment regime	R_m, MPa	R_p, MPa	A, %	Estimated length, mm
cold-rolled	432	371	8.4	60
1	386	280	21.1	60
2	389	279	18.3	60
3	378	273	21.8	60
4	381	270	20.0	60
5	380	270	21.8	60

According to the results of the research, it can also be concluded that heat treatment regimes 1-3 provide an optimal combination of strength and plastic properties. The use of regimes 4 and 5 gives relatively low values of the yield strength of the metal **(Tables 1 and 4)**, so their use is not recommended.

To assess the effect of heat treatment regimes on the mechanical properties of cold-rolled samples of alloy P-1580, obtained by card and rolled rolling, the above-mentioned modes of tensile tests. The results of research the mechanical properties of samples of alloy P-1580 from sheets with dimensions of 6×300×300 mm in different states are shown in table 5. The tests were carried out on LFM400 testing machines with a force of 400 kN and Instron 5982 with a force of 100 kN (laboratory tests) and a Zwick Z 250 testing machine with a force of 250 kN (industrial tests).

The results of tests on the LFM400 test machine of the mechanical properties of the samples of the P-1580 alloy from sheets of 6×300×300 mm, produced by roll rolling, in a different state, are given in **Table 6**.

Analysis of the data given in **Table 5 and 6**, shows that the level of mechanical properties of the obtained samples is high enough. The tendency to decrease strength properties and plastic growth with increasing heat treatment temperature is observed for rolled products, regardless of the rolling method. However, the strength parameters at the same thickness of the sheet are slightly higher for card rolling, which, apparently, can be explained by the greater degree of hardening of the metal during card rolling due to the more rigid treatment scheme.

Table 5

Mechanical properties of samples of alloy P-1580 from sheets with dimensions 6×300×300 mm, received by card rolling in the deformed and heat-treated conditions

№ of sample	R_m, MPa		R_p, MPa		A, %		Condition, heat treatment regime
	Lab tests	Industrial tests	Lab tests	Industrial tests	Lab tests	Industrial tests	
1	449	453	398	386	9.1	6.1*	cold-rolled
2	443	-	362	-	8.9	-	cold-rolled
1	391	396	296	299	18.5	13.4	300 °C, 1 h
2	383	-	286	-	19.6	-	310 °C, 1 h
1	388	394	292	297	22.2	14.6	300 °C, 3 h
2	383	-	280	-	22.4	-	310 °C, 3 h
1	-	390	-	292	-	12.3*	350 °C, 1 h
2	370		267		21.0		360 °C, 1 h
1	-	390	-	290	21.8	13.6*	350 °C, 3 h
2	374		262		22.0		360 °C, 3 h
1	-	389	-	288	-	17.2	380 °C, 1 h
2	369	-	257	-	23.3	-	390 °C, 1 h

* - the sample broken by 1/8 of the initial length

Table 6

Mechanical properties of samples of alloy P-1580 from sheets of with dimensions 6×300×300 mm in deformed and heat-treated conditions obtained by roll rolling

№ of sample	R_m, MPa	R_p, MPa	A, %	Condition, heat treatment regime
1	431	309	8.9	cold-rolled
2	428	306	8.2	cold-rolled
3	410	322	8.2	cold-rolled
average	423	312	8.5	cold-rolled
1	388	287	17.5	300 °C, 1 h
2	329	282	18.5	300 °C, 1 h
3	389	299	14.6	300 °C, 1 h
average	389	289	16.9	300 °C, 1 h
1	388	288	18.7	300 °C, 3 h
2	392	270	18.7	300 °C, 3 h
3	389	276	17.3	300 °C, 3 h
average	389	278	18.2	300 °C, 3 h
1	380	270	18.7	350 °C, 1 h
2	380	273	19.1	350 °C, 1 h
3	387	272	21.0	350 °C, 1 h
average	382	272	19.6	350 °C, 1 h
1	384	275	19.8	350 °C, 3 h
2	384	266	19.5	350 °C, 3 h
3	381	250	19.4	350 °C, 3 h
average	382	264	19.6	350 °C, 3 h
1	384	254	21.8	380 °C, 1 h
2	382	264	22.5	380 °C, 1 h
3	385	259	21.2	380 °C, 1 h
average	384	259	21.8	380 °C, 1 h

Table 7

Results of corrosion tests of alloy samples P-1580

Condition, heat treatment regime	Thickness, mm	Testing time, h	Results, mm	Testing time, h	Results, mg/cm^2
		State standard 9.021-74, solution №1		ASTM G 67	
cold-rolled	4.5	24	0.0	24	5.51
1	4,5	24	0.0	24	2.26
2	4.5	24	0.0	24	2.07
3	4.5	24	0.0	24	2,15
4	4.5	24	0.0	24	1.90
5	4.5	24	0.0	24	1.64
cold-rolled	1.5	24	0.0	24	2.75
1	1.5	24	0.0	24	1.90
2	1.5	24	0.1	24	1.82
3	1.5	24	0.0	24	1.92
4	1.5	24	0.0	24	1.95
5	1.5	24	0.0	24	1.97

The results of corrosion tests of sheets tested in accordance with the requirements of State standard 9.021-74 and ASTM G67 **(Table 7)** for samples of different thickness subjected to thermal treatment in the above modes showed that the investigated heat treatment conditions practically do not affect the alloy's resistance to intergranular corrosion.

Conclusion

Thus, the conducted studies allow us to recommend heat treatment regimes 1-3, which are characterized by an optimal combination of mechanical properties and the absence of intergranular corrosion. The choice of a particular regime should be specified by the requirements of the consumer of the product to its mechanical **properties**.

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ РЕЖИМОВ ТЕРМООБРАБОТКИ НА МЕХАНИЧЕСКИЕ И КОРРОЗИОННЫЕ СВОЙСТВА ЛИСТОВОГО ПРОКАТА ИЗ НОВОГО АЛЮМИНИЕВОГО СПЛАВА, ЭКОНОМНО ЛЕГИРОВАННОГО СКАНДИЕМ

Баранов В.Н., Сидельников С.Б., Зенкин Е.Ю., Константинов И.Л., Лопатина Е.С., Якивьюк О.В., Ворошилов Д.С., Белоконова И.Н., Фролов В.А.

Сибирский федеральный университет (СФУ), Красноярск, Россия
ПАО «РУСАЛ Братск», Братск, Россия

Аннотация. Приведены результаты исследований механических и коррозионных свойств листового проката из нового сплава системы Al–Mg–Sc в деформированном и термообработанном состоянии. Актуальность использования и разработки технологий производства из него деталей для автомобиле- и судостроения обоснована задачами глубокой переработки алюминия, решаемыми компанией «РУСАЛ», и подтверждается государственной поддержкой комплексного проекта по созданию высокотехнологичного производства, выполняемого в настоящее время Братским алюминиевым заводом и Сибирским федеральным университетом. В качестве материалов для определения механических и коррозионных свойств использовали листы и рулоны, полученные прокаткой на промышленном реверсивном стане Кварто 2800. Методом испытаний на разрыв исследовали деформированные образцы после прокатки и образцы, полученные по пяти режимам термообработки с варьированием температур нагрева 300, 350 и 380°С и времени выдержки в печи 1 и 3 ч. Результаты исследований на образцах из проката различной толщины показали, что по сравнению с исходным состоянием прочностные характеристики металла после термообработки снижаются в среднем на 12–20%, а пластические (δ) увеличиваются на 50-65%. При этом режимы термообработки 1–3 дают достаточно хорошее соотношение прочностных и пластических свойств. Уровень этих свойств сопоставим со свойствами сплава 01570. Отмечено, что тенденция снижения прочностных свойств и роста пластических с увеличением температуры термообработки наблюдается и для образцов проката, полученного различными способами холодной прокатки (карточным и рулонным). При этом прочностные показатели при одинаковой толщине листа несколько выше при карточной прокатке по сравнению с рулонной. Результаты коррозионных испытаний листов различной толщины показали, что исследованные режимы термообработки практически не влияют на стойкость сплава к межкристаллитной коррозии.

Ключевые слова: алюминиевые сплавы, магналии, скандий, горячая прокатка, термообработка, механические свойства

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