Study of structure and properties of industrial ingot made of alloy 1580 and determination of its deformability resource during cold rolling

I. L. Konstantinov, Candidate of Technical Sciences, Associate Professor of Metal Forming Department[1], e-mail:ilcon@mail.ru
P. O. Yuryev, Head of the Laboratory of Low-Carbon Metallurgy and Energy[1], e-mail: pashka_urew@mail.ru
Yu. V. Baykovskiy, Assistant, Post-Graduate Student of Metal Forming Department[1], e-mail: baykovskjy98@gmail.com
T. A. Orelkina, Candidate of Technical Sciences, Associate Professor of Metal Science and Heat Treatment of Metals named after V. S. Biront Department[1], e-mail: torelkina@sfu-kras.ru

[1]Siberian Federal University, Krasnoyarsk, Russia.

The structure and properties of an industrial large-size ingot of alloy 1580, obtained by semi-continuous casting, have been studied. Evidence has been presented which indicates that the ingot exhibits a fine crystalline structure and is devoid of primary intermetallides Al3(Sc, Zr). The phase composition of the ingot subsequent to annealing has been ascertained. The present study investigates the modes of hot and cold rolling of the ingot to obtain 1 mm thick sheets. The structure of the resulting sheets, after undergoing the process of annealing, has been shown to represent elongated fibres of grains. These are characterised by the presence of dispersed inclusions of excess phases along their boundaries. It has been established that, upon subjecting sheets to annealing temperatures of 225, 250 and 275 °C, a fibrous structure is observed in the absence of any indications of recrystallisation. However, at an annealing temperature of 300 °C, the presence of single recrystallized grains is detected within the structure. Furthermore, at an annealing temperature of 350 °C, the formation of a recrystallized structure is promoted throughout the volume of the sheet. The graphs presented herein illustrate the dependence of the mechanical properties of annealed cold-rolled sheets on the annealing temperature. The investigation revealed that the plasticity resource of hot-rolled sheets from alloy 1580 is approximately 80% when subjected to cold rolling.

Key words: aluminium alloys, ingot, scandium, rolling, sheet semi-finished product, annealing, mechanical properties, structure.

DOI: 10.17580/nfm.2025.01.08

Introduction

Alloys of the Al – Mg (magnalium) system are utilised in the fabrication of various deformable semi-finished products; however, due to their weldability and corrosion resistance, these alloys are predominantly demanded in the form of flat rolled products of various thicknesses [1]. Al – Mg alloys are distinguished by their high processability in pressure treatment; however, the inability of these alloys to harden during heat treatment represents the primary impediment to their broader dissemination [2].

As demonstrated in numerous studies [3–8], enhancing the strength characteristics of Al – Mg alloys, in addition to cold deformation, can be accomplished through the incorporation of small quantities of transition metals, particularly scandium. It is therefore worthwhile investigating the influence of this element on the structure and properties of Al – Mg alloys. This is due to the similarity between the crystal lattice structure of aluminium solid solution and Al_3Sc particles. These alloys retain an uncrystallised structure after hot deformation and subsequent annealing [9–11]. The augmentation of the strength of Al – Mg alloys, consequent to the incorporation of scandium, has facilitated the creation of numerous industrial aluminium alloys based on the systems Al – Mg (01570, 01571, 1545, 1535, 1523, 1515), Al – Zn – Mg (1970, 1975), Al – Mg – Li (1421, 1424), and Al – Cu – Li (1460, 1464). These alloys have been incorporated into GOST 4784-2019, and their properties are delineated in the following sources [12–19].

The proliferation of alloys comprising scandium is impeded by several factors, the predominant one being the high cost of scandium. It is therefore essential that any augmentation in the production and use of Al – Mg alloys with scandium should be aimed at minimising the content of this element in the alloys, preferably within their standard chemical composition. One potential method of achieving this would be to explore the possibility of replacing it with other transition metals, while maintaining the required level of their properties.

It has been established that the primary factor influencing the enhancement of the strength of Al – Mg alloys is the initial minor addition of scandium. Consequently, the effective alloying of alloys with minimal additions of this element is feasible. In their study, Zakharov et al. proposed a partial replacement of scandium by zirconium in Al – Mg and Al – Zn – Mg alloys [20]. The experimental basis for this proposal is presented in [21], which confirms the favourable effect of zirconium on the processability of Al – Mg alloys in metallurgical production. In [22], the authors established the scientific and metallurgical foundations for the development of aluminium alloys that are sparingly alloyed with scandium. They also provided recommendations on the partial replacement of scandium in the hardening phase Al_3Sc with another metal that facilitates the formation of a hardening phase, such as $Al_3(Sc_{1-x}Me_x)$, which retains the crystal lattice $L1_2$ of the Al_3Sc phase and all its beneficial properties. The paper also demonstrates the expediency of utilising complex alloying with transition and rare-earth metals, which form phases such as $Al_3(Sc_{1-x-y-z}, Me_{1x}, Me_{2y}, Me_{3z})$ with the $L1_2$ lattice and contribute to the formation of a complex supersaturated solid solution. In this instance, the metals that are to be substituted for scandium must satisfy two criteria. Firstly, they must exhibit sufficient solubility in the Al_3Sc phase. Secondly, they must demonstrate at least a minor degree of solubility in aluminium.

In [23–30], the results of the study are presented. These results demonstrate that partial replacement of scandium in Al – Mg alloys by erbium and ytterbium additives provides effective modification of the cast structure of this system of aluminium alloys. Furthermore, the study shows that this replacement reduces the alloys' tendency to unhardening due to the release of dispersed particles $Al_3(Er,Zr)$ during annealing. Furthermore, the fact that the cost of erbium today, according to source [31], is approximately 10 times lower than the cost of scandium and 14 times lower than that of ytterbium, confirms the feasibility of partial replacement of scandium in Al – Mg alloys by these metals.

In order to reduce the scandium content, alloy 1580 was developed. This alloy contains 0.05–0.14% (wt.) of scandium, which is 2-3 times lower than alloy 01570. However, the strength properties of the two alloys are approximately equivalent. Moreover, the reserve for reducing the cost of alloy 1580 is to minimise the content of scandium within the alloy grade. The rheology of alloy 1580 is presented in [32], which also provides experimental and analytical data for predicting the temperature-velocity mode of deformation of this alloy, which is necessary for modelling plastic deformation processes. It is evident that a promising avenue for reducing the production cost of flat-rolled magnalium products with scandium addition is to augment the mass of the produced ingots by increasing their thickness to the greatest extent possible. In accordance with the provisions stipulated in GOST 9498–2019, the thickness of Russian ingots composed of aluminium alloys is subject to a maximum limit of 600 mm [33]. Concurrently, it should be noted that not all Russian enterprises possess the requisite equipment to cast and roll ingots of maximum thickness. For instance, ingots of this nature can be cast at a number of metallurgical enterprises under the ownership of UC RUSAL [34].

The contemporary utilisation of aluminium alloys in the context of rolling technology is predicated on the employment of large-sized ingots, which are produced through the process of semi-continuous casting in an electromagnetic crystallizer tank. This approach ensures optimal productivity, process stability, and the quality of the resulting flat rolled products. Presently, Russian enterprises primarily utilise ingots with a thickness not exceeding 300 mm when manufacturing semi-finished products from aluminium alloys. It is economically advantageous to maximise the thickness of ingots, taking into account the capabilities of the foundry and rolling equipment at a specific enterprise. Scientists of the Siberian Federal University (SFU) and employees of UC RUSAL have developed and proposed regimes for the production and processing of Alloy 1580 large-sized ingots with a thickness of 600 mm. These regimes ensure the production of defect-free rolled semi-finished products [35, 36]. The utilisation of ingots with a maximum thickness renders the fabrication of alloy 1580 semi-finished products a more cost-effective endeavour. However, it should be noted that this undertaking necessitates the possession of the appropriate power characteristics by rolling mills.

In works [36, 37], rolling modes and properties of cold-rolled industrial sheets made of alloy 1580 with a thickness of 3 mm, obtained from large-sized ingots, were studied. Concurrently, the plasticity of the material during the cold rolling process has not been the subject of study in these works. The rationale behind this can be found in the enterprise's mandate to restrict its thickness to this specific dimension. The procurement of a sheet semi-finished product of reduced thickness necessitates comprehensive research, encompassing not only the analysis of rolling modes, but also the entire technological chain. This research initiative must commence with a thorough examination of the ingot structure, culminating in the investigation of the structure and properties of the thin product. Furthermore, it is imperative to assess the influence of annealing modes on the properties of the product. The objective of the present study was to examine the structure and processability of a large-sized industrial ingot composed of alloy 1580 during the rolling process.

In order to achieve the goal, the following tasks were solved in the work:

– study of the structure of a large-size ingot made of alloy 1580;

– determination of alloy 1580 deformability resource during cold rolling;

– study of the structure and properties of thin sheets after annealing.

Materials and methods

A large-sized industrial ingot with a cross-section of 2100×600 mm **(Fig. 1)** was selected for the study. The chemical composition of the ingot under scrutiny is notable for

Fig. 1. Large-sized industrial ingot made of alloy 1580 (*photo by authors*)

Table
Chemical composition of industrial ingot made of alloy 1580

Elements, wt.%										
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Sc	Al
0.11	0.20	0.16	0.50	4.9	0.12	0.08	0.020	0.08	0.06	Rest

its scandium content, which is recorded as 0.06% (wt.). This figure approaches the lower limit of the content of this element in the alloy grade, as indicated in **Table.**

The ingot structure was the subject of detailed investigation in both the cast and annealed states. This investigation utilised a range of analytical techniques, including light and scanning electron microscopy, as well as micro-*X*-ray diffraction analysis (XRD). The microstructure of the samples was examined using an Axio Observer light microscope (model A1m). In order to ascertain the quantitative parameters of the structure by means of the method of random sections (GOST 21073.3–75), the samples were oxidised and observed in polarised light. The following composition was utilised in the oxidation process: The required volumes of H_2O and HF are 1000ml and 15 ml respectively, with a total of 5.5 g of H_3BO_3 also required. The elemental composition of the phases was determined by means of the MRSA method in reflected electron mode, utilising an Energy 250 dispersive spectrometer and an EVO 50 scanning electron microscope.

The deformability of the alloy during the rolling process was investigated within the laboratory conditions of SFU. The initial material was a template that had been cut from an ingot, with the dimensions of all faces determined after milling. These dimensions were as follows: a cross-section measuring 25 by 150 millimetres, and a length of 250 millimetres.

The process of hot rolling was conducted on the mill DUO 330, with the thickness of the material being reduced up to 5 mm, with the crimping degree ranging from 5% to 10% across each pass. The billet heating temperature for rolling was 450 °C. The rolling process was conducted using billet heating for 20 minutes in an electric resistance furnace of the SNO-3,6.2/10I2 type, for every three passes. The process of cold rolling was conducted on an MDM ARIETE LS 400×240 rolling mill, with a compression ratio ranging from 10 to 14% per pass. Tensile mechanical properties of the cut-out samples of cold-rolled strips were tested in accordance with the standard GOST 1497-84. The testing was conducted using a universal testing machine, the Walter+Bai AGLFM 400 kN. Prior to the execution of the experiments, the samples were subjected to annealing procedures at temperatures of 225, 250, 275, 275, 300, 325 and 350 °C for a duration of three hours. In order to ensure the robustness of the findings, a total of seven specimens were collected from each designated point. Subsequent to this, the test results were subjected to statistical analysis, with a confidence level of 0.95.

Results and discussion

Research has demonstrated that the cast structure of alloy 1580 is distinguished by the occurrence of dendritic liquation of alloying elements along the dendritic cell cross-section. Furthermore, the formation of non-equilibrium phases manifests through the presence of light inclusions of irregularly shaped β(Al_8Mg_5) phase and dark inclusions of skeleton-shaped Mg_2Si phase. These phases are located along the grain boundaries and dendritic cells. The alloying of Mn alloy in the presence of Fe impurity has been shown to promote the formation of additional

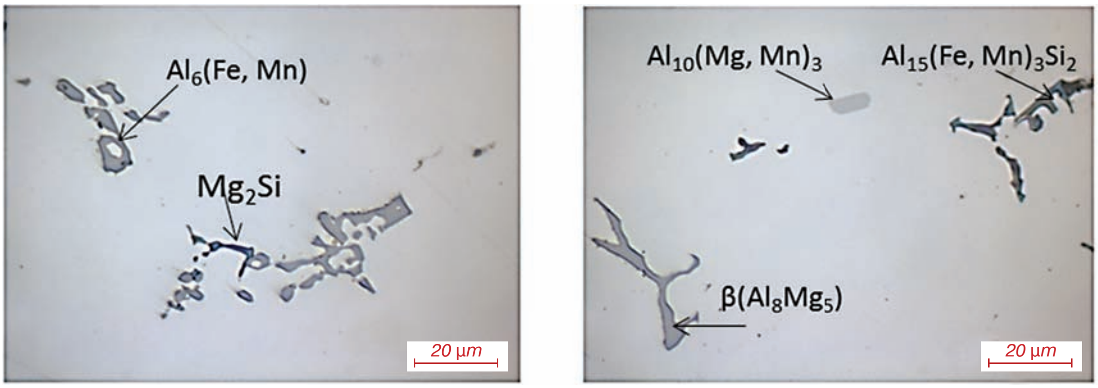
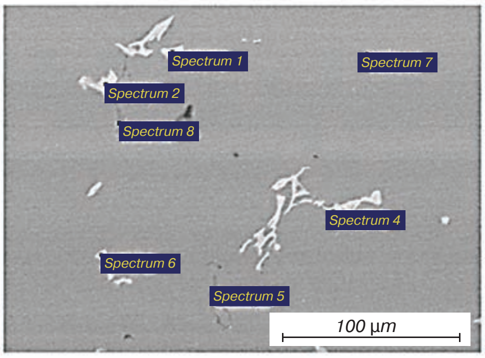


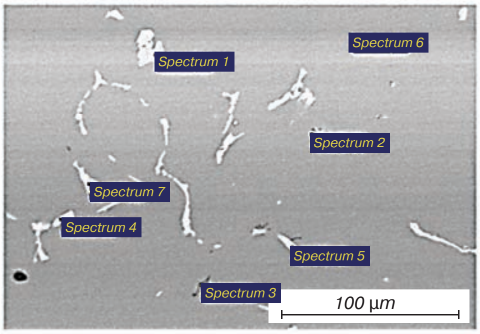
Fig. 2. Microstructure of two sections of 1580 alloy ingot in the cast state



All results, wt.%

Spectrum	Mg	Al	Si	Mn	Fe
Spectrum 1		76.47			23.53
Spectrum 2		69.22		12.25	18.54
Spectrum 4		77.91			22.09
Spectrum 5	41.60	27.54	30.87		
Spectrum 6		73.71			26.29
Spectrum 7	5.97	94.03			
Spectrum 8	35.14	25.29	24.06	0.00	

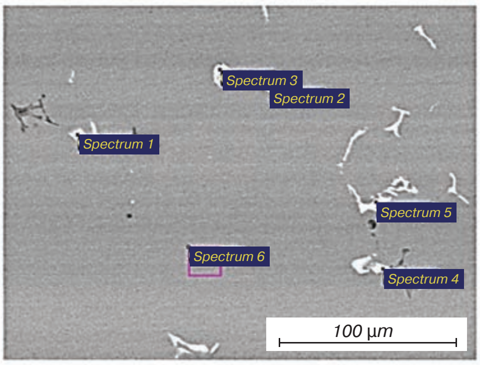
a



All results, wt.%

Spectrum	Mg	Al	Si	Mn	Fe
Spectrum 1	2.87	80.52	0.00	4.42	12.20
Spectrum 2	4.15	64.61	5.83	13.04	12.37
Spectrum 3	24.32	28.95	26.86	0.00	0.00
Spectrum 4	2.19	71.87	0.00	5.89	20.04
Spectrum 5	2.94	65.51	0.00	7.31	24.24
Spectrum 6	4.15	95.85	0.00	0.00	0.00
Spectrum 7	0.00	70.73	0.00	9.28	19.99

b



All results, wt.%

Spectrum	Mg	Al	Si	Mn	Fe
Spectrum 1	0.00	68.05	4.78	11.37	15.81
Spectrum 2	0.00	73.71	0.00	0.00	26.29
Spectrum 3	0.00	72.11	0.00	12.27	15.62
Spectrum 4	0.00	72.32	0.00	8.16	19.52
Spectrum 5	0.00	75.89	0.00	7.39	16.72
Spectrum 6	5.70	94.30	0.00	0.00	0.00

c

Fig. 3. Electronic images of different sections of the 1580 alloy ingot and MRSA results of the alloy in the cast state

phases of crystallization origin, including inclusions of branched form Al(Fe, Mn)$_6$ and a small number of skeleton-shaped phases Al_{15}(Fe, Mn)$_3Si_2$. The presence of the Al_{10}(Mg, Mn) phase within the cast structure was found to be negligible, manifesting as polyhedrons, as illustrated in **Fig. 2**.

The elemental composition of the phases detected by the MRSA method was found to be in accordance with the electronic images of the ingot structure, thereby confirming the microstructure obtained by means of a light microscope. The microstructure in the reflected electron mode is characterised by the presence of aluminium solid solution and primary crystals of excess phases. These phases exhibit a range of contrast and variations in the shape of plates, polyhedrons, and irregularly shaped particles. As demonstrated in **Fig. 3**, an analysis of the cast structure indicates that the plate-shaped phase particles contain aluminium (Al) and iron (Fe). This finding corresponds to spectrum 1, 4, and 6, and the composition of the phase particles is confirmed to be Al_6Fe. As illustrated in **Fig. 3, *b***, the presence of light inclusions of lamellar shape containing Al, Fe, and Mn was observed along the boundaries of dendritic cells. These inclusions are designated as spectrum 1, 4, and 5, and their assumed composition is Al_6(Fe, Mn). Furthermore, dark skeleton-shaped inclusions corresponding to the Mg_2Si phase were also detected in the same region, as illustrated in **Fig. 3, *a*** (spectrum 5) and **3, *b*** (spectrum 3). Along the grain boundaries, there are irregularly shaped inclusions containing Al, Fe, Si, and Mn, with the assumed composition Al_{15}(Fe, Mn)$_3Si_2$, as illustrated in **Fig. 3, *c*** (spectrum 1). Further investigations of the alloy microstructure were conducted following two-stage annealing in accordance with the following regime:

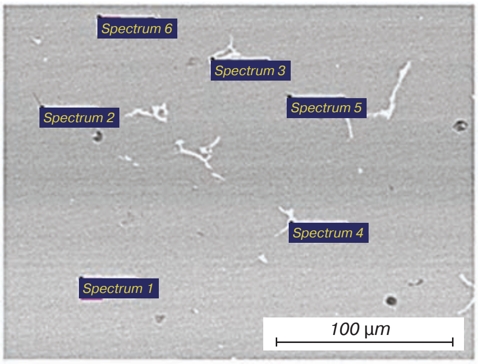
– First stage: heating to 350 °C for 3 hours, then heating to 425 °C for 1 hour

– Second stage: holding at 425 °C for 4 hours.

The microstructure of the alloy after annealing is shown in **Fig. 4**.

It was determined that the non-equilibrium crystallization was eliminated as a consequence of the dissolution of non-equilibrium phases. This comprised the complete dissolution of the β(Al_8Mg_5) phase and the partial dissolution of the Mg_2Si phase. Furthermore, an alignment of the chemical composition was observed along the dendritic cell and grain cross-section. In the structure of annealed alloys, the size and shape of iron-containing phases (Al_{15}(Fe, Mn)$_3Si_2$, Al_6Fe, Al_6(Fe, Mn)) remain unchanged.

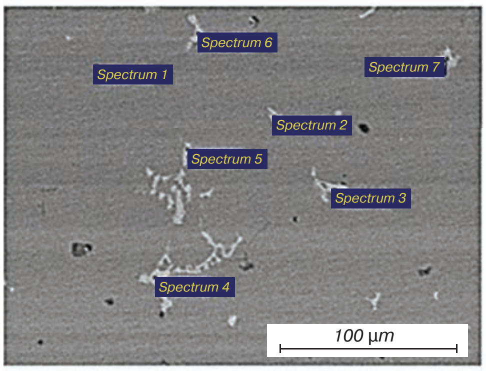
The elemental composition of the phases **(Fig. 4, *a, b*)** was determined by the MRSA method, revealing their assumed stoichiometric composition. The particles of the phase are lamellar in shape and contain Al and Fe, as illustrated in **Fig. 4, *a*** (spectrum 4, 5, 6) and **4, *b*** (spectrum 5, 6). The inferred phase composition corresponds to Al_6Fe. The presence of plate-shaped light inclusions containing Al, Fe, and Mn has been observed along the grain boundaries, **Fig. 4, *a***, (spectrum 4); **Fig. 4, *b*** (spectrum 2, 3, 7); **Fig. 4, *a*** (spectrum 4); **Fig. 4, *b*** (spectrum 2, 3, 6). These inclusions correspond to the composition of the phase Al_6(Fe, Mn).



All results, wt.%

Spectrum	Mg	Al	Si	Mn	Fe
Spectrum 1	4.11	92.37	3.51	0.00	0.00
Spectrum 2	23.40	50.71	25.89	0.00	0.00
Spectrum 3	0.00	69.44	5.01	9.47	16.08
Spectrum 4	0.00	70.21	0.00	11.40	18.39
Spectrum 5	11.68	77.25	11.07	0.00	0.00
Spectrum 6	4.72	95.28	0.00	0.00	0.00

a



All results, wt.%

Spectrum	Mg	Al	Si	Mn	Fe
Spectrum 1	4.99	95.01	0.00	0.00	0.00
Spectrum 2	0.00	69.73	0.00	13.37	16.90
Spectrum 3	0.00	79.29	0.00	9.72	10.99
Spectrum 4	0.00	79.72	0.00	0.00	20.28
Spectrum 5	0.00	85.85	0.00	0.00	14.15
Spectrum 6	0.00	77.20	0.00	0.00	22.80
Spectrum 7	0.00	71.01	0.00	10.50	18.50

b

Fig. 4. Electronic image and MRSA results of 1580 alloy ingot in the annealed state

The results of the plasticity resource determination of alloy 1580 hot-rolled sheet, with a thickness of 5 mm, in the process of cold rolling demonstrated the capacity of the alloy in this state to deform without fracture up to 1 mm, which corresponds to the total compression of 80%.

The microstructure of cold-rolled sheets following annealing is characterised by the presence of grain fibres, the boundaries of which exhibit inclusions of excess phases that are formed during the process of crystallisation. The deformation undergone by 1 mm-thick sheets during the rolling process was instrumental in ensuring the segregation banding of the structural, while the inclusions of excess phases underwent crushing and adopted a predominantly compact, lamellar configuration.

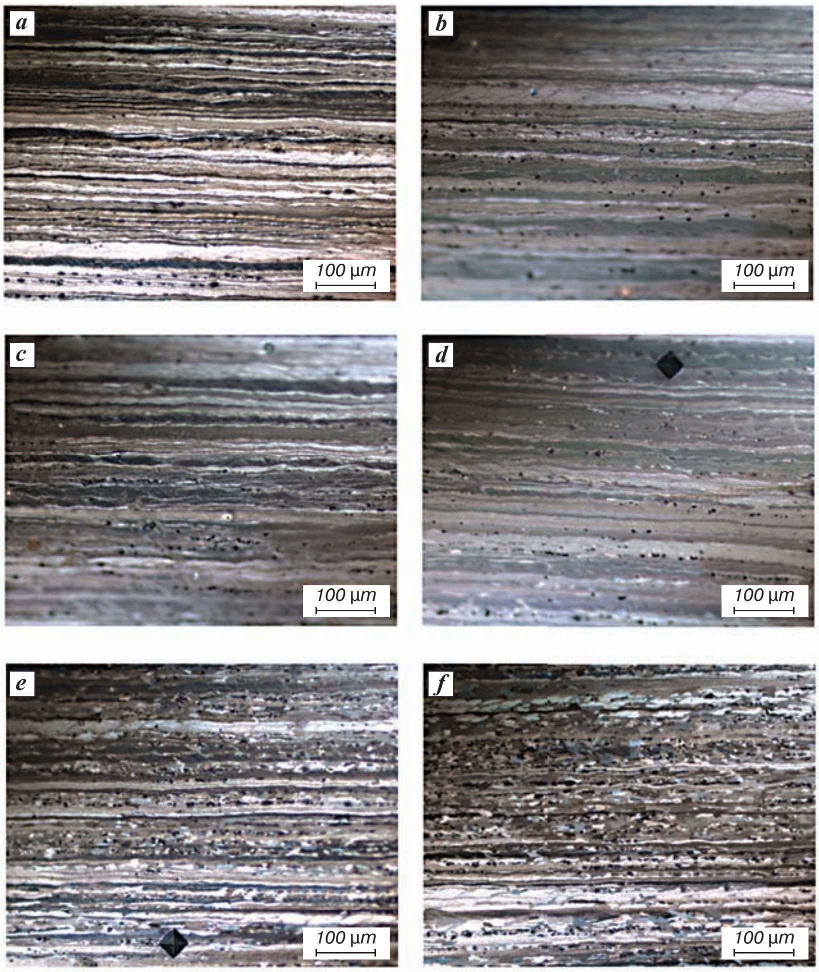


Fig. 5. Microstructure of 1 mm thick cold rolled alloy 1580 sheets in polarised light, annealed at temperatures °C:
a – 225; *b* – 250; *c* – 275; *d* – 300; *e* – 325; *f* – 350

To reveal recrystallisation processes, microstructural analysis of annealed cold-rolled sheets was carried out in polarised light.

The structure of the sheets in polarised light after annealing is shown in **Fig. 5**. The analysis demonstrated that, in the sheets which had been subjected to annealing at temperatures of 225, 250 and 275 °C, a fibrous structure was observed, devoid of any indications of recrystallisation processes. It is evident that recrystallisation processes commence at an annealing temperature of 300 °C, resulting in the presence of single recrystallized grains within the structure of the sheets. Increasing the annealing temperature to 325 °C resulted in the formation of areas of recrystallized grains in individual fibres, and the annealing temperature of 350 °C promoted the formation of recrystallized structure throughout the entire volume of the sheet. The dimensions of the recrystallized grains were constrained by the fibre width, with a size range of 10–20 µm.

The results of the mechanical properties testing of cold-rolled semi-finished products with thicknesses of 1 and 3 mm are presented in **Fig. 6** (for comparison, data for 3 mm thick sheets from alloys 1580 and 5083, as referenced in source [38], are included in the graphs). It is important to acknowledge that alloy 5083 is

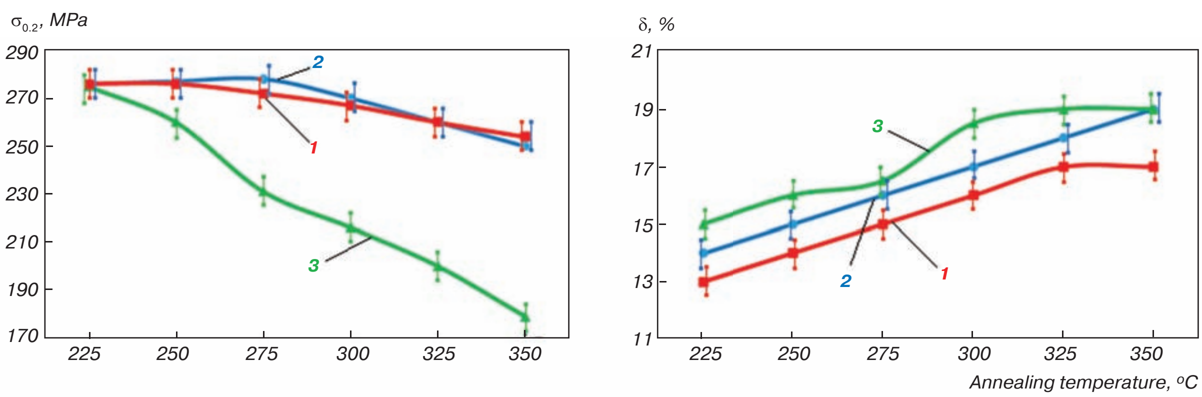


Fig. 6. Graphs of dependence of mechanical properties of cold-rolled sheets on annealing temperature:
1 – alloy 1580 (1 mm); *2* – alloy 1580 (3 mm); *3* – alloy 5083 (3 mm)

analogous to alloy 1580, with the exception of the presence of scandium.

An analysis of the mechanical properties showed that the maximum values of the conditional yield strength of a 3 mm thick sheet correspond to annealing temperatures from 225 to 250 °C. On the contrary, for a 1 mm thick sheet, the maximum of this parameter shifts to a temperature of 275 °C.

Conclusion

Research has demonstrated that the structure of cold-rolled sheets following annealing is characterised by the presence of elongated fibres of grains. These fibres are oriented along the boundaries of dispersed inclusions of excess phases, which are formed as a consequence of eutectic crystallisation. It has been established that in the sheets which have undergone annealing at temperatures of 225, 250 and 275°C, the presence of a fibrous structure is observed, devoid of any indications of recrystallisation. Conversely, at an annealing temperature of 300 °C, single recrystallised grains are present in the structure of the sheets. Furthermore, at an annealing temperature of 350 °C, the formation of a recrystallised structure is promoted, extending throughout the majority of the sheet's volume. The dimensions of the recrystallised grains are constrained by the fibre width, ranging from 10 to 20 microns. The findings demonstrate that the plasticity resource of hot-rolled sheets made of alloy 1580 is approximately 80% at cold rolling.

"The study was supported by the Russian Science Foundation (project № 25-19-20133, https://rscf.ru/project/25-19-20133/), and the Krasnoyarsk Regional Science Foundation".

References

1. Industrial Aluminum Alloys: a Reference Edition. 2nd ed., rev. and exp. Moscow: Metallurgiya, 1984, 528 p.

2. Yakivyuk O. V. Development of Tchnology for the Production of Long-Dimensional Deformed Semi-Finished Products from Alloys of the Al – Mg System Doped with Scandium: Dissertation ... Candidate of Technical Sciences. Krasnoyarsk, 2018. 148 p.

3. Ibrohimov S. Zh., Eshov B. B., Ganiev I. N., Ibrohimov N. F. Influence Scandium on the Physicochemical Properties of the Alloy AMg4. *Izvestia of Samara Scientific Center of the Russian Academy of Sciences*. 2014. Vol. 16, Iss. 4. pp. 256–260.

4. Belov N. A. Phase Composition of Industrial and Promising Aluminum Alloys. Moscow: Izdatelskiy Dom MISiS, 2010. 511 p.

5. Drits M. E., Toropova L. S., Bykov Yu. G., Ber L. B. The Effect of the Dispersion of Al3Sc Phase Precipitates on the Recrystallization of Al – Sc Alloys. *Izvestiya Vuzov. Tsvetnaya Metallurgiya*. 1985. Iss. 4. pp. 80–83.

6. Filatov Yu. A. Various Approaches to Realization of the Strengthening Effect Resulted from Scandium Addition Made to Wrought Al – Mg – Sc System-Based Alloys. *Technology of Light Alloys*. 2009. Iss. 3. pp. 42–45.

7. Marquis E. A., Seidman E. A. Nanoscale Structural Evolution of Al3Sc Precipitates in Al (Sc) alloys. *Acta Materialia*. 2001. Vol. 49, Iss. 11. pp. 1909–1919.

8. Nikitin K. V., Nikitin V. I., Krivopalov D. S., Glushchenkov V. A., Chernikov D. G. Influence of Various Treatment Types on the Structure, Density, and Electrical Conductivity of Al – Mg System Wrought Alloys. *Izvestiya Vuzov. Tsvetnaya Metallurgiya*. 2017. Iss. 4. pp. 46–52.

9. Elagin V. I. Features of Recrystallization of Aluminum Alloys Containing Scandium. *Problems of Metallurgy of Light and Special Alloys*. Moscow: VILS, 1991. pp. 114–129.

10. Elagin V. I., Zakharov V. V., Rostova T. D. Aluminum Alloys Alloyed with Scandium. *Metal Science and Heat Treament*. 1992. Iss. 1. pp. 24–29.

11. Sinyavsky V.S., Valkov V. D., Titkova E. V. The Effect of Scandium and Zirconium Additives on the Corrosion Properties of Al – Mg Alloys. *Technology of Light Alloys*. 1996. Iss. 3, pp. 30–35.

12. Yashin V. V., Rushchits S. V., Aryshensky E. V., Latushkin I. A. Rheological Behavior of 01570 and AA5182 Wrought Aluminum Alloys Under Hot Deformation Conditions. *Tsvetnye Metally*. 2019. No. 3. pp. 64–69.

13. Yashin V. V., Aryshenskiy V. Yu., Latushkin I. A., Tepterev M. S. Substantiation of a Manufacturing Technology of Flat Rolled Products from Al – Mg – Sc Based Alloys for the Aerospace Industry. *Tsvetnye Metally*. 2018. No. 7. pp. 75–82.

14. Shvechkov E. I., Filatov Yu. A., Zakharov V. V. Mechanical And Resource Properties Of Sheets From Alloys Of The Al – Mg – Sc System. *Metal Science and Heat Treament*. 2017. Iss. 7. pp. 57–66.

15. Dobatkin V. I., Eskin G. I. Non-Dendritic Structure in Aluminum Alloy Ingots. *Tsvetnye Metally*. 1991. No. 12. C. 64–67.

16. Elagin V. Ya., Zakharov V. V., Rostova T. D. Structural Features and Properties of Alloy Sheets 1970. *Technology of Light Alloys*. 1991. Iss. 2. pp. 17–20.

17. Zakharov V. V., Rostova T. D. High-Strength Welded Alloy Based on the Al – Zn – Mg 1970 System. *Metal Science and Heat Treament*. 2005. Iss. 4. pp. 10–17.

18. Filatov Yu. A. Deformable Al-Mg-Sc Alloys and Possible Applications. *Perspektivniye Materialy*. 1996. Iss. 5. pp. 45–49.

19. Zhemchuzhnikova D. A., Petrov A. P., Eremeev N. V., Eremeev V. V., Kaibyshev R. O. Effect of Rolling on High-Cycle Fatigue and Fracture of an Al – Mg – Sc Alloy. *Metal Science and Heat Treament*. 2016. Iss. 3. pp. 17–21.

20. Zakharov V. V., Fisenko I. A. Effect of Homogenizing on the Structure and Properties of an Alloy of the Al – Zn – Mg – Sc – Zr System. *Metal Science and Heat Treament*. 2018. Iss. 6. pp. 16–21.

21. Zakharov V. V., Fisenko I. A. On the Problem of Alloying of Aluminum Alloys With Scandium. *Metal Science and Heat Treament*. 2017. Iss. 5. pp. 15–22.

22. Zakharov V. V. Prospects of Creation of Aluminum Alloys Sparingly Alloyed with Scandium. *Metal Science and Heat Treament*. 2018. Iss. 3. pp. 40–44.

23. Zakharov V. V., Fisenko I. A., Kunyavskaya T. M. Principles of Creating Aluminum-Based Alloys Economically Alloyed with Scandium. *Metal Science and Heat Treament*. 2024. Iss. 5. pp. 39–43.

24. Zhang Y., Gao K., Wen S., Huang H., Nie Z., Zhou D. The Study on the Coarsening Process and Precipitation Strengthening of Al3Er Precipitate in Al – Er Binary Alloy. *Journal of Alloys and Compounds*. 2014. Vol. 610. pp. 27–34.

25. Barkov R. Y., Prosviryakov A. S., Khomutov M. G., Pozdniakov A. V. Effect of the Zr and Er Content on the Structure and Properties of the Al – 5Si – 1.3Cu – 0.5Mg Alloy. *Fizika Metallov i Metallovedenie*. 2021. Vol. 122, Iss. 6. pp. 658–664.

26. Mochugovskiy A. G., Barkov R. Y., Mikhaylovskaya A. V., Loginova I. S., Yakovtseva O. A., Pozdniakov A. V. Structure and Properties of Al – 4.5Mg – 0.15Zr Compositions Alloyed with Er, Y, And Yb. *Fizika Metallov i Metallovedenie*. 2022. Vol. 123, Iss. 5. pp. 499–506.

27. Barkov R. Y., Mochugovskiy A. G., Khomutov M. G., Pozdniakov A. V. Effect of Zr and Er Small Additives on the Phase Composition and Mechanical Properties of Al – 5Si – 1.3Cu – 0.5Mg Alloy. *Fizika Metallov i Metallovedenie*. 2021. Vol. 122, Iss. 2. pp. 173–180.

28. Glavatskikh M. V., Barkov R. Yu., Khomutov M. G., Pozdnyakov A.V. Influence of Yttrium and Erbium on the Phase Composition and Aging of Al – Zn – Mg – Cu – Zr Alloy with Increased Copper Content. *Fizika Metallov i Metallovedenie*. 2022. Vol. 123, Iss. 6. pp. 658–664.

29. Amer S. M., Barkov R. Y., Prosviryakov A. S., Pozdniakov A. V. Structure and Properties of New Wrought Al – Cu –Y- and Al – Cu – Er-based Alloys. *Fizika Metallov i Metallovedenie*. 2021. Vol. 122, Iss. 9. pp. 984–992.

30. Konstantinov I. L., Baykovskiy Yu. V., Yuriev P. O., Bezrukikh A. I., Sidelnikov S. B., Saparova A. S., Mansurov Yu. N., Partyko E. G., Bozhko D. N. Study of Deformability During the Rolling of Aluminum Alloy 1580 Doped with Small Additions of Erbium and Ytterbium. *Metallurg*. Iss. 8. pp. 97–101.

31. SIBMETALTORG. Price-list, Sibmetaltorg, Rare-earth metals URL: http://sibmetaltorg.ru/upload/price/SibMetallTorg.ru_Прайс-лист_РЗМ.pdf (Accesed Date: 07.12.2024).

32. GOST R 4784-2019 Aluminum and Aluminum Alloys are Deformable. Stamps. Introduction. 09/01/2019. Moscow: Standartinform, 2019. 31 p.

33. Dovzhenko N. N., Rushchits S. V., Dovzhenko I. N., Yurev P. O. Understanding the Behaviour of Aluminium Alloy P-1580 Sparingly Doped with Scandium Under Hot Deformation. *Tsvetnye Metally*. 2019. No. 9. pp. 80–86.

34. GOST 9498-2019 Flat Ingots Made of Aluminum and Aluminum Deformable Alloys for Rolled Products. Moscow: Standartinform, 2019. 16 p.

35. Flat ingots. Catalogue. URL: https://rusal.ru/clients/catalog/ploskie-slitki/?ysclid=m8iuxcnmdm596885539 / (Accessed Date: 21.03.2025).

36. Bezrukikh A. I., Baranov V. N., Konstantinov I. L. et al. Modeling of Casting Technology of Large-Sized Ingots from Deformable Aluminum Alloys. *The International Journal of Advanced Manufacturing Technology*. 2022. Vol. 120. pp. 761–780.

37. Yuryev P. O., Baranov V. N., Orelkina T. A. et al. Investigation the Structure in Cast and Deformed States of Aluminum Alloy, Economically Alloyed with Scandium and Zirconium. *The International Journal of Advanced Manufacturing Technology*. 2021. Vol. 115. pp. 263–274.

38. Konstantinov I. L., Yuryev P. O., Baranov V. N. et al. Study the Influence of Scandium Content and Annealing Regimes on the Properties of Alloys 1580 and 1581. *International Journal of Lightweight Materials and Manufacture*. 2023. Vol. 6, Iss. 1. pp. 15–24. NFM