Л.Н. Гумилев атындағы Еуразия ұлттық университетінің ХАБАРШЫСЫ.
ISSN: 2616-7263. eISSN: 2663-1261
ТЕХНИКАЛЫҚ ҒЫЛЫМДАР ЖӘНЕ ТЕХНОЛОГИЯЛАР СЕРИЯСЫ / TECHNICAL SCIENCES AND TECHNOLOGY SERIES/ СЕРИЯ ТЕХНИЧЕСКИЕ НАУКИ И ТЕХНОЛОГИИ

IRSTI 55.09.81
Article

https://doi.org/10.32523/2616-7263-2024-147-2-231-244

Preparation of AlMgSi1 (6082) aluminum alloy for the study of mechanical and physico-chemical properties in the rolling process

Rail Sovetbayev[1], Yerik Nugman[1], Yerzhan Shayakhmetov*[2], Anna Kawalek[3]

[1]K.I. Satbayev Kazakh National Research Technological University, Almaty, Kazakhstan
[2]Shakarim University of Semey city, Semey, Kazakhstan
[3]Czestochowa University of Technology, Czestochowa, Poland

(E-mail: rsovetbayev@mail.ru)

Abstract. The study is devoted to the preparation of the AlMgSi1 (6082) aluminum alloy for the study of its mechanical and physico-chemical properties under rolling conditions. The purpose of the work is to develop a methodology for preparing an alloy that provides reproducible analysis of its properties. The main directions include the study of rheological and plastic properties of the material, as well as thermal effects during deformation

The scientific significance of the work lies in the analysis of the effect of heat treatment and deformation parameters on the plastic fluidity and corrosion resistance of the alloy. The practical significance lies in improving the quality of materials for various industrial applications. The methodology included experiments with heat treatment and rolling, analysis of the microstructure and mechanical properties of the alloy. The tests were carried out on samples at different temperatures and strain rates using the STD 812 torsion plastomer.

The results showed that the plasticizing stress of the alloy increases with deformation at low temperatures and decreases at high temperatures. The conclusions confirm the significant influence of temperature and strain rate on the properties of the alloy.

Keywords: rolling process, aluminum alloy, tension, deformation, emission capacity, plastic fluidity.

Received 03.06.2024 Revised 21.06.2024 Accepted 22.06.2024 Available online 30.06.2024

* the corresponding author

Introduction

For the correct acceptance of boundary conditions in numerical modeling and the correct development of new or modification of existing technologies for rolling round rods, it is necessary to know the relationship between the value of the plasticizing stress and the deformation and temperature parameters of the alloy under study. The properties of the deformable material have a significant impact, among other things, on its plastic fluidity in the rolling basin, therefore, in order to increase the accuracy of the results of computer modeling of the rolling process, it was necessary to use real curves of plastic fluidity of the material under study. Therefore, the study of the rheological, plastic properties of the material and the determination of the thermal effect during the deformation of the AlMgSi1 aluminum alloy allows us to further increase the reliability of the rolling process simulation [1].

The methodology

Based on the analysis of the technology of rolling bars in a three-roll inclined mill, it was found that this process is characterized by a wide range of changes in deformation parameters and temperature. The average deformation rate under rolling conditions can reach 10 s-1, and the total actual deformation is about 4.

Therefore, it was necessary to develop real plastic yield curves for the material under study for the entire range of changes in temperature and deformation parameters.

This part of the study also includes the conversion of the results obtained in the form of an analytical formula into a form that can be entered into the database of materials in the Rheology program [2].

These tests were carried out at the Institute of Plastic Processing and Safety Engineering (Czestochowa, Poland) during the doctoral student's scientific internship. The hardening curves of the AlMgSi1 aluminum alloy were determined based on torsion tests using the STD 812 – Thermoanalyse GmbH torsion plastomer (Fig. 1), and the main technical parameters of the device are presented in Table 1.

a)

b)

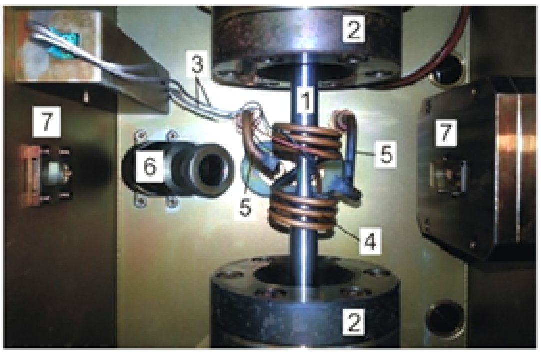


Figure 1. Torsion plastomer STD 812: a) – general view; b) – working chamber with a fixed sample
1 – Sample, 2 – fixing cartridges, 3 – S- type thermocouples, 4-inductor, 5-cooling system nozzles, 6-pyrometer, 7-laser measurement sensors sample diameter

ISSN: 2616-7263. eISSN: 2663-1261

Table 1. The main parameters of the STD 812 torsion plastometer

Heating principle:	Induction
Maximum test temperature:	1500 °C
Heating and cooling speed:	up to 100K / s
Minimum time between successive deformations:	60 ms
Atmosphere:	clearance 10-4 bar, inert gas, air
Torsion	
Rotation speed:	up to 500 rpm
Number of revolutions:	up to 30
Torque:	up to 50 Nm
Deformation speed:	up to 60 s-1
Stretching and compressing	
Changing the length:	about 15 mm
Deformation speed:	up to 30 mm / s
Force during deformation:	up to 25 kN
Deformation speed:	up to 1.0 s-1
Actual deformation:	dependent on sample size
The device allows twisting with simultaneous stretching or compression	

Dependence (1) was used to calculate the amount of actual deformation during twisting in the torsion plastometer control software, whereas the actual deformation rate was determined by dependence (2). The plasticizing stress is determined by the formula (3):

$$\varepsilon = \frac{2\cdot\pi\cdot r\cdot N}{\sqrt{3}\cdot L} \quad (1)$$

$$\acute{\varepsilon} = \frac{2\cdot\pi\cdot r\cdot \acute{N}}{\sqrt{3}\cdot L} \quad (2)$$

$$\sigma_p = \frac{\sqrt{3}\cdot 3M}{2\pi r^3} \quad (3)$$

where:

r – the radius of the sample;

L – the length of the sample;

N – the number of twists (revolutions) of the sample;

Ń – torsion speed (rotation speed);

M – the torque.

For studies related to the determination of the hardening curves of the AlMgSi1 aluminum alloy, samples with a cylindrical working part with a diameter of 6 mm and a length of 10 mm were used (Fig. 2).

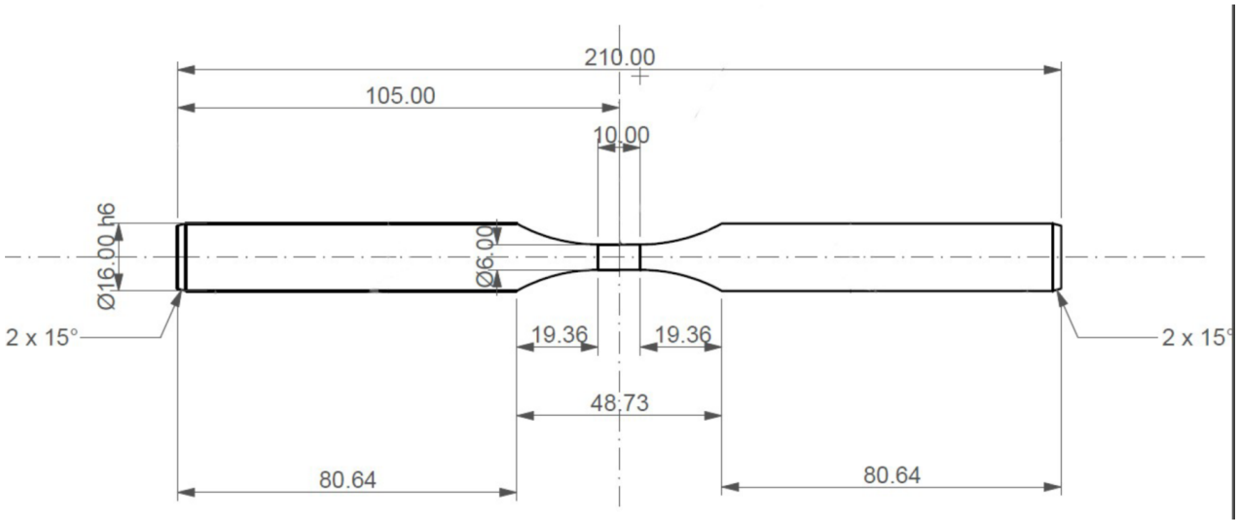


Figure 2. Sample of the plastometric test for the STD 812 torsion Plastomer

The tests were carried out at temperatures of 150, 200, 250, 300 and 350 °C for deformation rates of 0.1; 1.0 and 10.0 s^{-1}. The samples were deformed to failure, whereas approximations were performed for the actual deformation ε=4.

For practical use of plastometric studies and to obtain a mathematical relationship between the value of the plasticizing stress σp [MPa] and the deformation parameters (t, ε, έ), these results were approximated by the Hansel-Spittel equation:

$$\sigma_p = m_1 \cdot \varepsilon^{m_2} \left(\frac{m_3}{\varepsilon}\right) exp\ (m_4 \cdot \varepsilon)(1+\varepsilon)^{m_5 \cdot t} \cdot \acute{\varepsilon}^{m_6} \cdot \acute{\varepsilon}^{m_7 \cdot t} \cdot t^{m_8} exp\ (m_9 \cdot t) \qquad (4)$$

where:
ε – the actual deformation, s^{-1};
έ– the deformation rate, s^{-1};
t – the temperature, °C;
m1÷m9 – coefficients depending on the grade of the studied material.

Rheology software was used for statistical processing of the obtained results, where it is possible to introduce a large number of functions approximating plasticizing stress, depending on strain, strain rate and temperature. This allows you to determine the coefficients of the approximating function specified by the user, or automatically search for the most accurate approximating function in the existing database of functions [3].

Findings/Discussions

The obtained values of the parameters determining the approximating function (Fig.3), which were used during the numerically simulated rolling mill process in a three-roll inclined rolling mill, are shown in Table 2.

Table 2. Parameters of the function (Fig. 3) approximating the results of plastometric tests of AlMgSi1 aluminum alloy

m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m_9	medium pale
1,36610	0,31149	0,00018	0,06608	-0,00270	-0,09845	0,00054	1,32965	-0,00908	0,80430

The results of the approximation of the reinforcement curves (dotted lines) and experimental data (solid lines) for the studied aluminum alloy are shown in Figures 3-7.

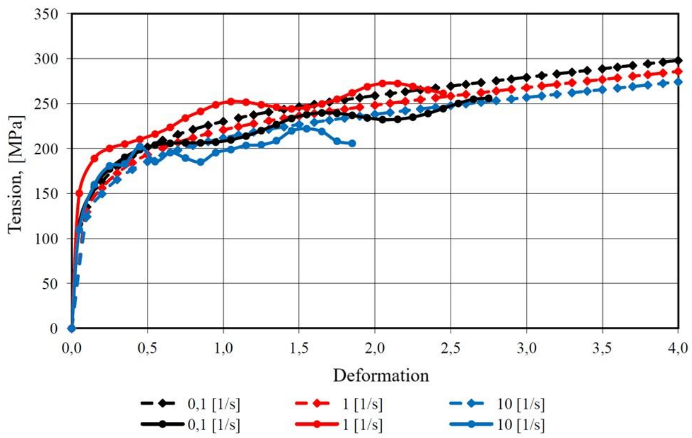


Figure 3. Hardening curves of AlMgSi1 aluminum alloy deformed at a temperature of 150 °C with deformation rates of 0.1; 1.0 and 10.0 s^{-1}

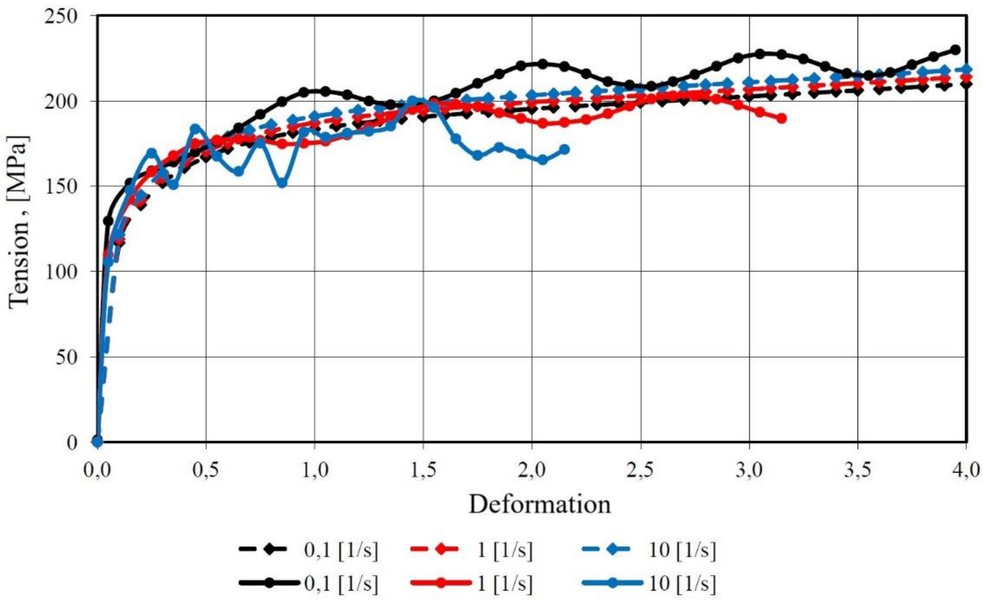


Figure 4. Hardening curves of AlMgSi1 aluminum alloy deformed at a temperature of 200 °C with deformation rates of 0.1; 1.0 and 10.0 s^{-1}

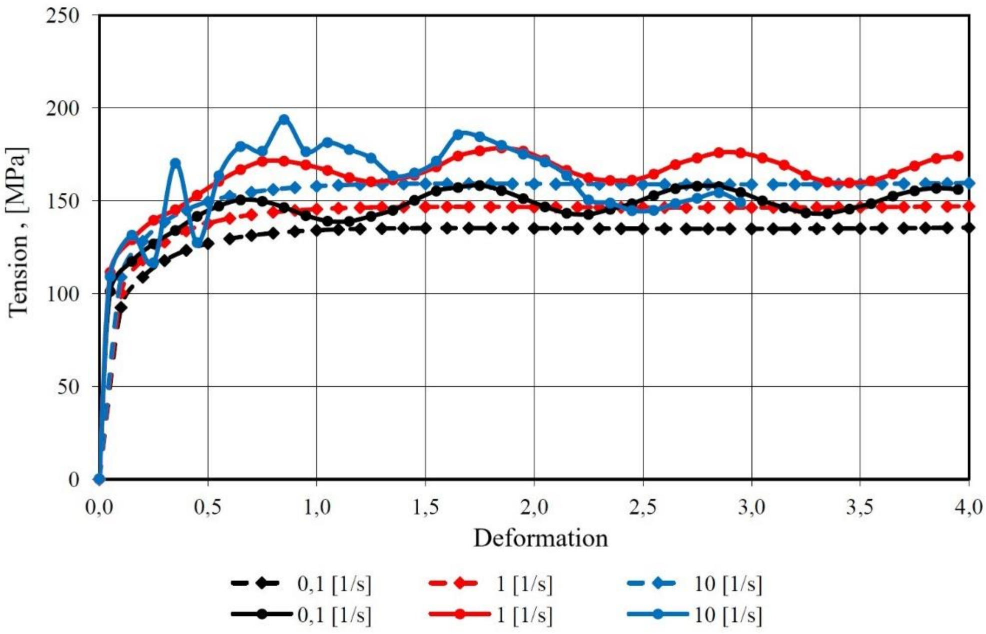


Figure 5. Hardening curves of AlMgSi1 aluminum alloy deformed at a temperature of 250 °C with deformation rates of 0.1; 1.0 and 10.0 s^{-1}

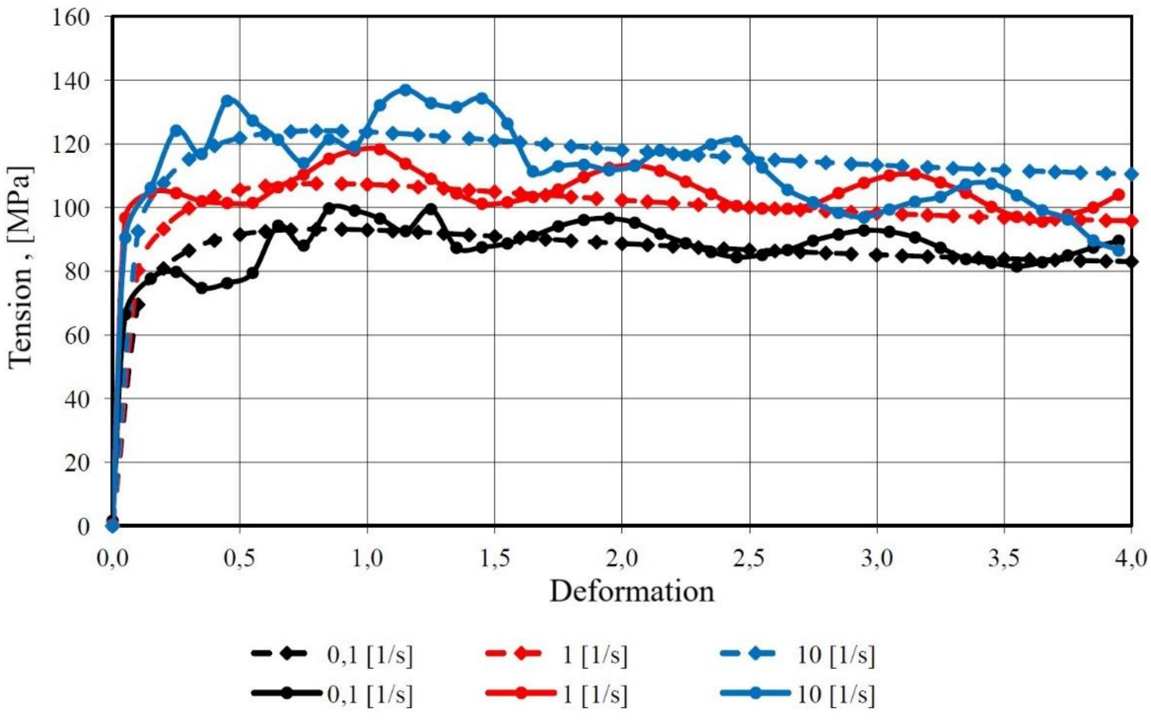


Figure 6. Hardening curves of AlMgSi1 aluminum alloy deformed at a temperature of 300 °C with deformation rates of 0.1; 1.0 and 10.0 s^{-1}

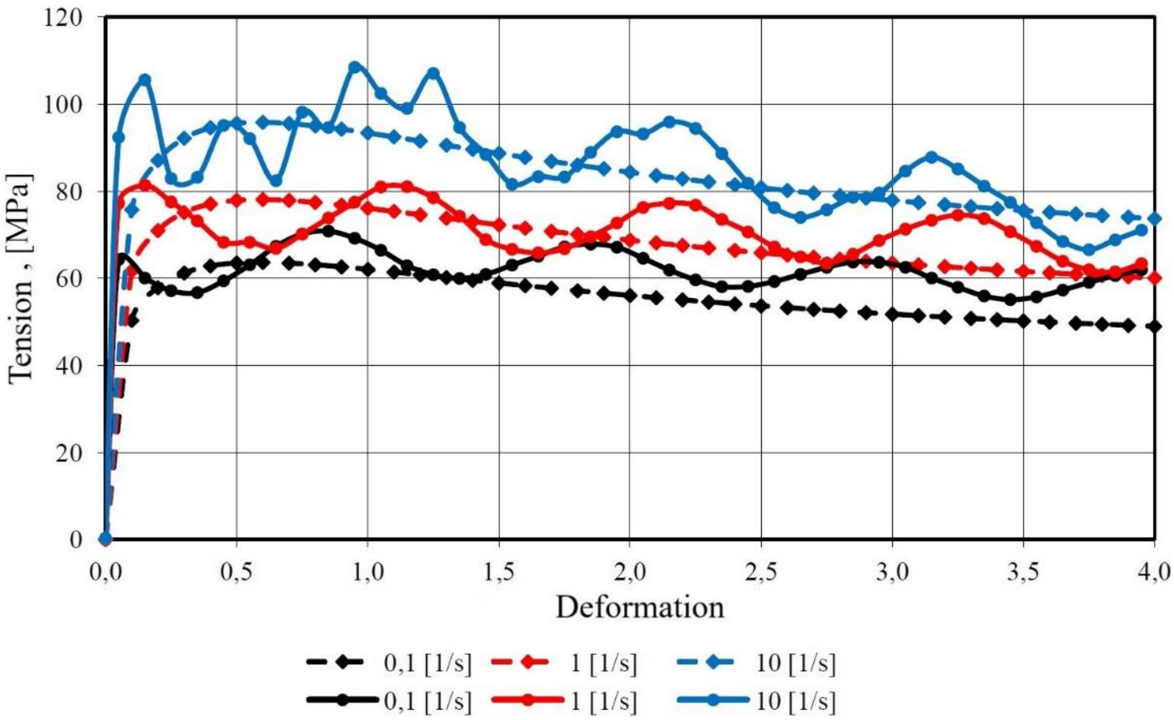


Figure 7. Hardening curves of AlMgSi1 aluminum alloy deformed at a temperature of 350 °C with deformation rates of 0.1; 1.0 and 10.0 s^{-1}

Based on the conducted studies, it can be concluded that there is a great influence of temperature and deformation parameters on the deformation value of the plasticizing aluminum alloy AlMgSi1 [4].

Analyzing the effect of the sample temperature on the value of the plasticizing stress, it can be seen that for the same deformation rates, the plasticizing stress of the alloy under study reaches the highest values at a temperature of 150 ° C, and with an increase in the sample temperature, the value of the plasticizing stress for the same deformation rates decreases. For the corresponding deformation rates, the lowest values of the plasticizing stress of the alloy under study occurred at a temperature of 350 °C [5,6].

From the analysis of the waveform of the real and approximated hardening curves of the studied aluminum alloy, it follows that in the studied range of deformation parameters, a large agreement was obtained between the actual values of the plasticizing stress and the values obtained as a result of approximation.

Figure 8 shows the dependences of the ultimate deformation of the AlMgSi1 alloy as a function of temperature and deformation rate.

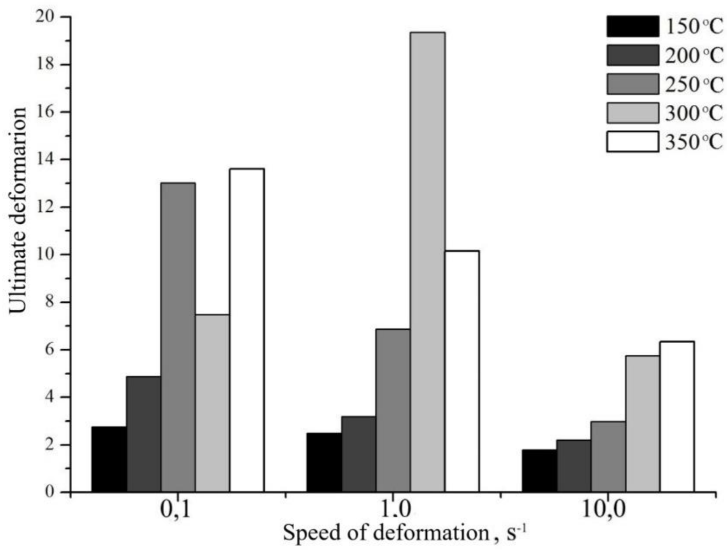


Figure 8. Dependence of the ultimate deformation of the AlMgSi1 aluminum alloy on changes in temperature and deformation rate

From the data shown in Figure 8, it follows that, with the exception of the case of deformation of samples at a temperature of 300° C, with an increase in the deformation rate at the same temperature, the values of the limiting deformation decrease. The highest value of the ultimate deformation occurs at temperatures of 250 and 300°C and at a deformation rate of 0.1s-1.

On the contrary, at a temperature of 300 °C, the maximum limit deformation (~ 20) occurs at a deformation rate of 1 s-1. This behavior of the material at this temperature may be the result of microstructural changes [7]. The results of dilatometric studies show that at temperatures above 279 °C in this structural state, a change in the shape of the curve is observed, reflecting differences in the length of the sample, which indicates the course of dissolution of intermetallic compounds.

Determination of the emission capacity of AlMgSi1 aluminum alloy

One of the key parameters for the correct determination of the measured temperature of the test object using a thermal imaging camera is the precise determination of its emissivity, which was determined experimentally for the AlMgSi1 aluminum alloy.

A description of the methods for determining the emissivity can be found, among other things, in [8].

The method presented in the paper was used to determine the emissivity of the tested aluminum alloy. It consists in determining the emissivity of the object under study based on a contact temperature measurement. According to this method, it is necessary to set such a value of the emissivity in the thermal imaging camera so that the temperature of the material determined by the camera is the same as that determined by the contact method. The value of the emissivity is then equal to the emissivity of the surface of the material under study.

For studies related to the determination of the emission capacity of the AlMgSi1 aluminum alloy, the STD 812 torsion Plastomer from Thermoanalyse GmbH and the ThermaCAM SC640 thermal imaging camera (Fig. 9) from FLIR Systems were used, which provides:

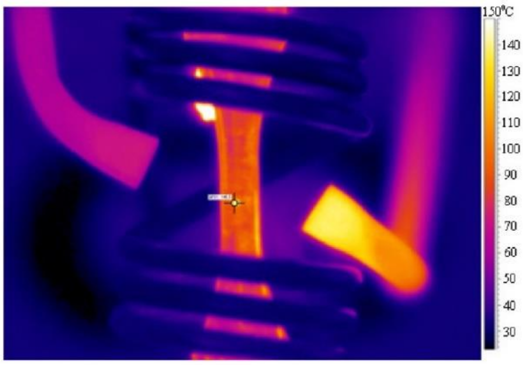
– excellent image quality saved in JPEG format with complete radiometric data;
– accurate non-contact temperature measurement from -40 °C to +2000°C;
– image in visible and infrared light;
– the ability to enter text and voice notes;
– Bluetooth and IRDA wireless communication;
– autofocus;
– fast image transfer to a computer;
– software for creating professional reports on measurements.

Figure 9. Thermal imaging camera ThermaCAM SC640

Samples with a working part diameter of 6 mm and a length of 10 mm were used for testing. Holes were made in the side wall of the samples, into which two K-type thermocouples were placed just below the surface of the samples. The samples were then placed in the chamber of the STD 812 torsion plastomer and heated to the appropriate temperatures from 150 to 350 °C. After reaching the desired temperature in the entire volume of samples, the emission value in the thermal imaging camera was adjusted so that it indicated the same temperature as with thermocouples. Thermacam Researcher Professional software is used to process the results obtained [9,10].

An example of a thermogram with object parameters is shown in Figure 10.

a)



b)

Object parameters	Value
Emissivity	0,40
Distance	0,3 m
Reflected temperature	20,0°C
Air temperature	20,0°C
Relative humidity	50%
Temperature at point Spl	150°C

Figure 10. Temperature distribution in the sample recorded at a temperature of 150 °C:
a) thermogram, b) object parameters

Figure 11 shows a graph of changes in the emission capacity of the tested aluminum alloy for a temperature range of 150÷350°C.

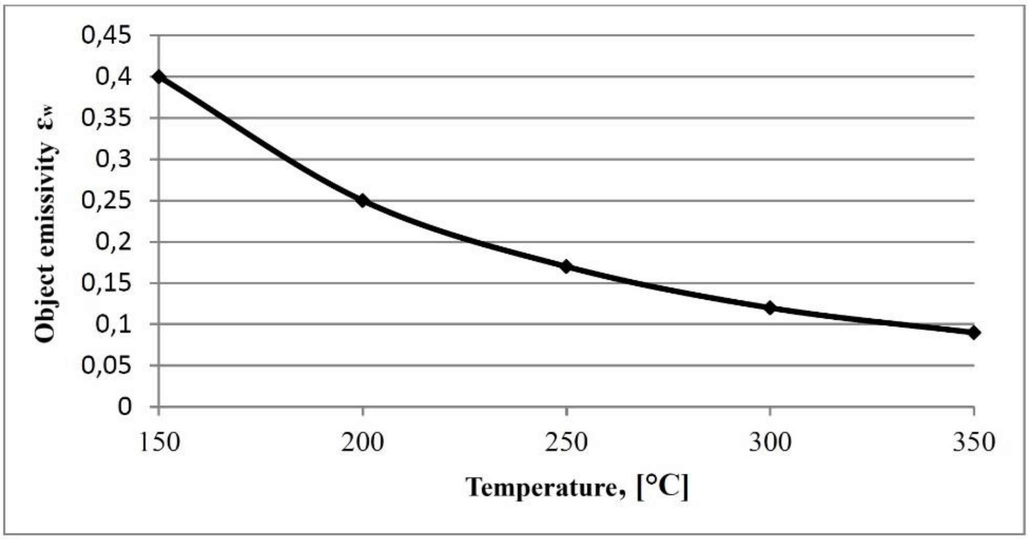


Figure 11. Changes in the emission capacity of AlMgSi1 aluminum alloy in the temperature range 150÷350 °C

Conclusion

Based on the obtained research results, it can be concluded that the nature of the flow curves of the AlMgSi1 plastic alloy is similar for the entire range of studies conducted. From the analysis of the data presented in Figures 3-7, it follows that with increasing deformation, the value of the plasticizing stress of the studied aluminum alloy increases monotonously for temperatures of 150 and 200 °C and takes a constant value for a temperature of 250 °C. At temperatures of 300 and 350 ° C, with strain values up to 0.5, the value of the plasticizing stress increases, and with large deformations it monotonously decreases.

From the conducted plastimetric studies of the AlMgSi1 alloy, it follows that there is a significant influence of deformation, temperature and deformation rate on the value of its plasticizing stress.

With an increase in the deformation rate, a simultaneous increase in the value of the plasticizing stress occurs, while due to an increase in the temperature of the alloy under study, a decrease in this stress is observed.

Based on the conducted studies related to the determination of the emission capacity of the aluminum alloy under study, it was found that in the temperature range of 150-150 °c, its emission capacity varies in the range of 0.40÷0.08. As the temperature increases, the value of the emission capacity decreases (Fig. 11).

The contribution of the authors:

Rail Sovetbayev – consent to be responsible for all aspects of the work, proper study and resolution of issues related to the reliability of data or the integrity of all parts of the article;

Yerik Nugman – approval of the final version of the article for publication;

Yerzhan Shayakhmetov – significant contribution to the concept or design of the work; collection, analysis or interpretation of the results of the work;

Anna Kawalek – writing the text and/or critical revision of its content.

References

1. Zhang, J., Xu, Y., Wang, Z., Zhang, L. & Xu, M. Efect of preheating temperature on microstructure and mechanical properties ofsolid-state recycled AA5083 aluminum alloy. Metals 11(12), 1961 (2021).

2. Zuo, X., Chen, X. & Hu, J. Efect of extrusion temperature on microstructure and mechanical properties of solid-state recycled AA6063 aluminum alloy. Materials 16(16), 5344 (2023).

3. Laber K.: Określenie własności reologicznych wybranych gatunków stali do spęczania na zimno w próbie skręcania. Hutnik – Wiadomości Hutnicze 2015, nr 5, s. 238-242.

4. Sawicki S., Kawałek A., Labek K., Dyja H., Borowski J., Leśniak D., Jurczak H.: Plastometric testing of rheological properties of 5083 and 5754 aluminium Alloy. 2nd International Conference on Non-Ferrous Metals ICNFM'2015, June 22-24.2015, Cracow, Poland, AGH University of Science and Technology, Book of Abstract, P. 129-130.

5. Devanathan, C., Shankar, E., Sivanand, A. & Haribabu, B. Processing and testing of aluminum based hybrid surface composites by friction stir processing. IOP Conf. Ser. Mater. Sci. Eng. 923, 012022 (2020).

6. Koch, M. Bonhage, M. Teschke, L. Luecker, B. Behrens, F. Walther Electrical resistance-based fatigue assessment and capability prediction of extrudates from recycled field-assisted sintered EN AW-6082 aluminium chips Mater Characterization, 169 (2020)

7. Orlov G.A.: Osnovy tieorii prokatki i volotchenia trub. Wyd. Uniwersytetu Uralskiego, Jekaterinburg 2016.

8. Krolo J, Gudic S, Vrsalovic L, Lela B,Dadic Z. Fatigue and corrosion behavior of solid-state recycled aluminum alloy EN AW 6082. J Mater Eng Perform 2020;29(7):4310–21.

9. Effect of grain boundary misorientaton, deformation temperature and AlFeMnSi-phase on fatigue life of 6082 Al alloy Mat Charact, 124 (2017), pp. 229-240

10. Wang, J., Chen, X., Yang, L. & Zhang, G. Efect of preheat & post-weld heat treatment on the microstructure and mechanical properties of 6061–T6 aluminum alloy welded sheets. Mater. Sci. Eng. A 841, 143081 (2022).

Советбаев Р.А.[1], Нугман Е.З.[1], Шаяхметов Е.Я.*[2], Kawalek A.[3]

[1]Қ.И. Сәтбаев атындағы Қазақ Ұлттық Техникалық Зерттеу Университеті, Алматы, Қазақстан

[2]Семей қаласының Шәкәрім атындағы университеті, Семей, Қазақстан

[3]Czestochowa University of Technology, Ченстохова, Польша

AlMgSi1 (6082) алюминий қорытпасын илемдеу жағдайында механикалық және физика-химиялық қасиеттерін зерттеуге дайындау

Аңдатпа. Зерттеу AlMgSi1 (6082) алюминий қорытпасын илемдеу жағдайында оның механикалық және физика-химиялық қасиеттерін зерттеуге дайындауға бағытталған. Жұмыстың мақсаты – оның қасиеттерін қайталанатын талдауды қамтамасыз ететін қорытпаны дайындау әдістемесін әзірлеу. Негізгі бағыттарға материалдың реологиялық және пластикалық қасиеттерін, сондай-ақ деформациядағы жылу әсерлерін зерттеу кіреді.

Жұмыстың ғылыми маңыздылығы термиялық өңдеудің және деформация параметрлерінің қорытпаның пластикалық аққыштығы мен коррозияға төзімділігіне әсерін талдау болып табылады. Практикалық маңыздылығы – әртүрлі өнеркәсіптік қосымшалар үшін материалдардың сапасын арттыруда. Әдістеме термиялық өңдеу және илемдеу эксперименттерін, қорытпаның микроқұрылымы мен механикалық қасиеттерін талдауды қамтыды. Сынақтар STD 812 бұралу пластомерін қолдана отырып, әртүрлі температуралар мен деформация жылдамдықтарындағы үлгілерде жүргізілді.

Нәтижелер қорытпаның пластификация кернеуі төмен температурада деформациямен жоғарылайтынын және жоғары температурада төмендейтінін көрсетті. Нәтижелер температура мен деформация жылдамдығының қорытпа қасиеттеріне айтарлықтай әсерін растайды.

Түйін сөздер: илемдеу процесі, алюминий қорытпасы, созылу, деформация, эмиссия қабілеті, пластикалық аққыштық.

Советбаев Р.А.[1], Нугман [Е.З.1], Шаяхметов Е.Я.*[2], Kawalek A.[3]

[1]Казахский национальный научно-исследовательский технический университет имени К. И. Сатпаева, Алматы, Казахстан

[2]Университет имени Шакарима г. Семей, Семей, Казахстан

[3]Czestochowa University of Technology, Ченстохова, Польша

Подготовка алюминиевого сплава AlMgSi1 (6082) к исследованию механических и физико-химических свойств в условиях прокатки

Аннотация. Исследование посвящено подготовке алюминиевого сплава AlMgSi1 (6082) к исследованию его механических и физико-химических свойств в условиях прокатки. Цель работы – разработка методики подготовки сплава, обеспечивающей воспроизводимый анализ его свойств. Основные направления включают изучение реологических и пластичных свойств материала, а также тепловых эффектов при деформации. Научная значимость работы заключается в анализе влияния термической обработки и параметров деформации на пластическую текучесть и коррозионную стойкость сплава. Практическая значимость – в повышении качества материалов для различных промышленных применений. Методология включала эксперименты с термической обработкой и прокаткой, анализ микроструктуры и механических свойств сплава. Испытания проводились на образцах при разных температурах и скоростях деформации с использованием пластомера кручения STD 812.

Результаты показали, что пластифицирующее напряжение сплава увеличивается с деформацией при низких температурах и уменьшается при высоких температурах. Выводы подтверждают значительное влияние температуры и скорости деформации на свойства сплава.

Ключевые слова: процесс прокатки, алюминиевый сплав, растяжение, деформация, эмиссионная способность, пластическая текучесть.

Information about the authors:

Sovetbayev Rail Ayanovich – a doctoral student at the K. I. Satpayev Kazakh National Research Technical University, specializing in "Digitalization of machine–building production", 22 Satpayev Street, Almaty city, Kazakhstan.

Nugman Erik Zeynelovich – PhD, Head of the Department of Mechanical Engineering of the K. I. Satpayev Kazakh National Research Technical University, Associate Professor of the Department of Mechanical Engineering, 22 Satpayeva Street, Almaty city, Kazakhstan.

Shayakhmetov Yerzhan Yarnarovich – correspondence writer, PhD, senior lecturer at the Department of Technological Equipment and Mechanical Engineering of the Shakarim Semey University, 20A Glinka Street, Semey city, Kazakhstan.

Kawalek Anna – PhD, Professor at Czestochowa University of Technology, Faculty of Industrial Engineering and Materials Technology, 69 Generała Jana Henryka dąbrowskiego Street, Czestochowa city, Poland.

Сведения об авторах:

Советбаев Раил Аянович – докторант Казахского национального исследовательского технического университета имени К. И. Сатпаева по специальности "Цифровизация машиностроительного производства", улица Сатпаева, 22, город Алматы, Казахстан.

Нугман Ерик Зейнелович – PhD, ассоциированный профессор, заведующий кафедрой «Машиностроение» Казахского национального исследовательского технического университета имени К. И. Сатпаева, улица Сатпаева, 22, город Алматы, Казахстан.

Шаяхметов Ержан Ярнарович – автор корреспонденции, PhD, старший преподаватель кафедры технологического оборудования и машиностроения Университета имени Шакарима г. Семей, улица Глинки, 20А, Семей, Казахстан.

Kawalek Anna **–** PhD, профессор Czestochowa University of Technology, факультет производственной инженерии и технологии материалов, улица Generała Jana Henryka dąbrowskiego, 69, Ченстохова, Польша.