A. KAWAŁEK, T. BAJOR, S. SAWICKI, M. KRAKOWIAK, H. JURCZAK

ISSN 0543-5846
METABK 59(1) 43-46 (2020)
UDC – UDK 669.715:539.347.001.4:620.17:513.4/539.374:620.18=111

THE EFFECT OF DEFORMATION CONDITIONS ON THE RHEOLOGICAL PROPERTIES OF THE Al 5754 ALLOY

Received – Primljeno: 2019-06-12
Accepted – Prihvaćeno: 2019-09-05
Original Scientific Paper – Izvorni znanstveni rad

The article presents the results of rheological testing of Al 5754 alloy in series 5xxx, obtained for deformation parameters corresponding to the process of extrusion of large-size sections on presses. The effect of deformation conditions on the variations in yield stress magnitude was determined. Then, using the least squares method., the actual values of the coefficients of the mathematical model describing the rheological properties of the material under investigation were determined, thus obtaining grounds for conducting the model studies of the extrusion process based on numerical methods.

Key words: Al 5754 alloy, plastometric testing, yield stress, strain hardening curve determination, structure

INTRODUCTION

Owing to their properties, and primarily light weight, aluminium alloy find application in various constructional solutions, where the important factor is the mass of the structure, namely in aircraft, motor-cars, rolling stock, the power industry and the construction industry, as well as in the food and chemical industries. Magnesium-containing aluminium alloys in series 5xxx have an average tensile strength, but they are very resistant to corrosion. Alloys of this series are also characterized by very good susceptibility to mechanical treatment and are relatively easy to be joined by the welding method. Moreover, these alloys, similarly to other aluminium alloys, are readily recyclable, and in the case of using aluminium in the production process, it is possible to reuse more than 90 % of the production waste [1].

Products that find wide application in modern, lightweight structures are flats (panels) of a different, often complex design, manufactured by extrusion on presses.

Extrusion is a widely used process in the manufacture of long complex cross-section elements. This technological method enables unique shapes of products to be obtained, which creates exceptional design opportunities for architects and designers.

Prior to implementing the process of manufacturing new products in industrial conditions, it is necessary to understand the rheological properties of the alloy to be processed and to carry out model studies based on numerical methods in order to be able to select the engineering and force parameters of a specific plastic working process.

A basis for the correct simulation and design of technological processes is a good knowledge of the characteristics describing the engineering properties of the material to be deformed. For plastic working processes, a key feature characterizing the susceptibility of a material to plastic forming is the yield stress σ_p [1, 2].

The yield stress σ_p is defined as the value of stress necessary for initiating and continuing the plastic flow of metal under the conditions of the uniaxial stress state occurring during simple tension or compression. Its value depends on the deformation conditions, mainly on the deformation specimen temperature (T), the value of true strain (ε), the mode of this strain increasing in time ε (t), and on the strain rate (ε) [3].

The determination of the engineering plasticity characteristics is especially difficult for hot plastic working conditions, because the considerable plastic deformation preset for this kind of working is accompanied by a significant strain hardening. Under such conditions, recovery and dynamic recrystallization processes proceed intensively in the metal [3 ÷ 5].

The rheological behaviour of deformed materials is sufficiently adequately characterized by the flow curves, σ_p - ε, which are a result of interactions between strain hardening processes, recovery processes and dynamic and meta-dynamic recrystallization processes. By knowing these processes and controlling them, it is possible to optimize the energy–force and engineering parameters of various metal plastic working processes and to significantly influence the mechanical properties and structure of finished products.

PURPOSE OF THE STUDY

The purpose of the study was to determine the properties of the Al5754 aluminium alloy and to present

A. Kawałek (e-mail: kawalek.anna@wip.pcz.pl), T. Bajor, S. Sawicki, M. Krakowiak, Czestochowa University of Technology, Czestochowa, Faculty of Production Engineering and Materials Technology, Poland
H. Jurczak, Albatros LTD, Walcz, Poland

them in the form of stress–strain diagrams, while allowing for the effect of temperature, true strain and strain rate on the yield stress magnitude.

Based on performed tests, the graphs of the variation in stress magnitude as dependent on the preset actual deformation of the Al5754 alloy were determined, the approximation of the obtained curves was made, and the yield stress function coefficients, which could be used in the numerical studies of the extrusion process to be carried out using software programs, such as the finite element method-based FORGE 2011, were selected.

The ranges of strain, strain rate and temperature variation during the experimental tests were taken based on the characteristics of machines used in actual extrusion processes, as well as from the data available in the literature [6, 7].

THE RHEOLOGICAL PROPERTIES OF THE AL5754 ALLOY

The values of yield stress, as dependent on the true strain, temperature and strain rate, occurring in the actual extrusion process, were determined from hot compression tests. The tests were performed on the Gleeble 3800 metallurgical process simulator at the Institute for Plastic Working and Safety Engineering of the Czestochowa University of Technology.

The plastometric tests were conducted for the following parameters:

- specimen temperature: 350 ºC, 400 ºC, 450 ºC, 500 ºC, 550 ºC;
- strain rate: 0,01 s^{-1}, 0,1 s^{-1}, 1 s^{-1}, 10 s^{-1};
- true strain: up to 1,15.

Based on the plastometric tests, the diagrams of the relationship of stress versus true strain diagrams for the Al5754 alloy were developed (Figs. 3 a ÷ e) and the coefficients of the yield stress function were selected (1). Relationship (1) is often used for determining the value of σ_p in computer programs during numerical modelling of extrusion processes. After the approximation of plastometric test results, the coefficients of Equation (1) were determined. The values of the determined coefficients are provided in Table 1. Chemical composition of the alloy is shown in Table 2.

$$\sigma_p = A e^{m_1 T} \varepsilon^{m_2} \dot{\varepsilon}^{m_3} \varepsilon^{\frac{m_4}{\varepsilon}} (1+\varepsilon)^{m_5 T} \varepsilon^{m_7 \varepsilon} \dot{\varepsilon}^{m_8 T} T^{m_9} \quad (1)$$

Table 1 **The values of the parameters *A* and m_1 - m_9 used for determining the values of σ_p for the Al 5754 alloy**

Al alloy	m_1	m_2	m_3	m_4
	-0,007410	0,335976	-0,177727	-0,0002228
A	m_5	m_7	m_8	m_9
0,1900358	-0,0042127	0,4302946	0,0007222	1,6723026

Table 2 **Chemical composition of the Al 5754 alloy / wt. %**

Al alloy	Si	Fe	Cu	Mn
	0,224	0,14	0,007	0,465
Mg	Cr	Zn	Ti	Al
3,44	0,002	0,002	0,018	R

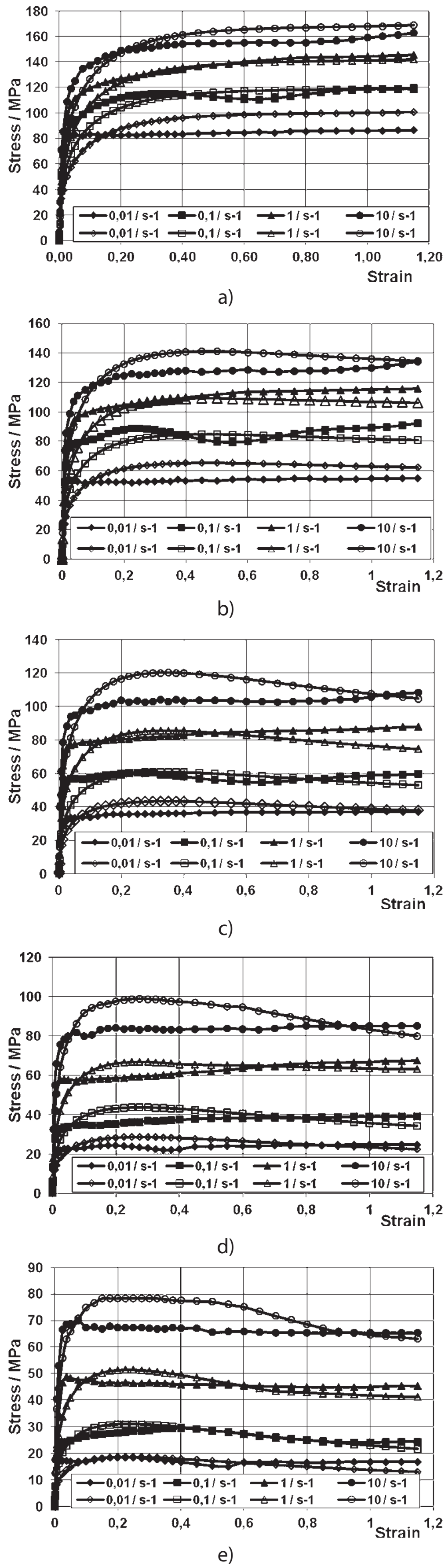
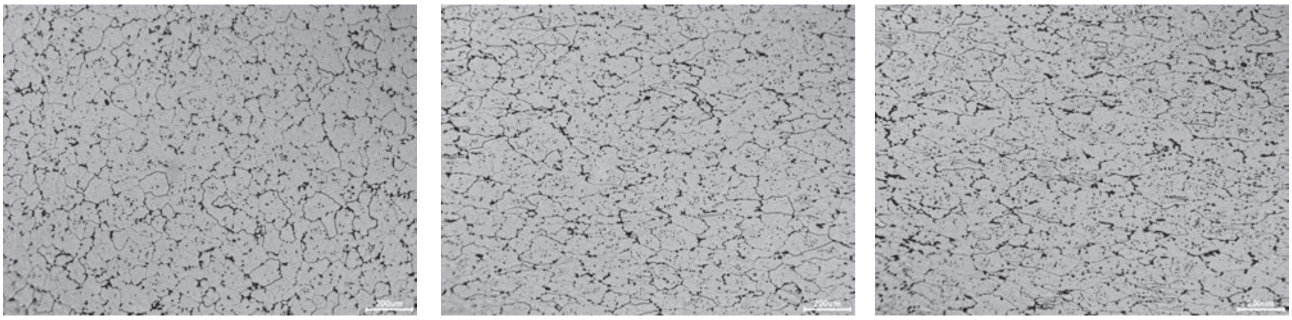


Figure 1 The Al5754 alloy work-hardening curves for the strain rate range of (0,01 s^{-1} – 10 s^{1}): a) at 350 °C, b) at 400 °C, c) at 450 °C; d) at 500 °C; e) and at 550 °C, solid symbols – experimental curves, hollow symbols – approximated curves



a) b) c)

Figure 2 The initial structure of the Al 5754 alloy, 64 x a), and the structure of the alloy deformed at a rate of 0,1 s^{-1} at a temperature of 350 ^{0}C for deformation amounting to b) ε = 0,4 and c) ε = 0,6, respectively

The data presented in Figures 1 a ÷ e shows that during the deformation alloy Al5754 at a low velocity of 0,01 s^{-1} in the entire deformation range tested and in the temperature interval of 350 ÷ 450 °C, the material undergoes strain hardening in the initial phase; however, after attaining a maximum yield stress value, a plateau effect is observed, and on this basis it can be inferred that under such deformation conditions a dynamic recovery process occurs in aluminium, which eliminates the work hardening results. For specimens deformed in the temperature interval of 500 ÷ 550 °C, a slight slope in σ_p yield stress values is visible on the work-hardening curves for true strains of 0,3 ÷ 0,4 at a temperature of 500°C, and 0,4 ÷ 0,6 at a temperature of 550°C.

From the analysis of the work-hardening curves obtained for a strain rate of 0,1 s^{-1} and temperatures from the interval of 350 ÷ 450 °C it can be found that, after attaining a maximum value of σ_p yield stress, its distinct decline is observed in the strain range of 0,4 ÷ 0,8, whereupon the σ_p value increases.

Examples of structure pictures taken after individual deformation stages are shown in Figures 2. The decrease in the value of plasticizing stress is caused by the occurrence of dynamic recrystallization, which is confirmed by the images of structures shown in Figures 2 b and c.

Figure 2 shows a picture of the initial structure of the investigated alloy, where homogeneous grains of a similar size can be seen (a) and alloy structure deformed at 0,1 s^{-1}, at 350 ^{0}C, for real deformations ε = 0,4 (b) and ε = 0,6 (c).

The deformation resulted in the Al alloy grain refining in relation to the initial structure of the alloy and a slight grain elongation in the direction perpendicular to the applied compressive force can be noticed (Figure 2 b and c).

In the strain hardening curve obtained for specimens deformed at a temperature of 500 °C, a slight strain hardening is observed with the increase in deformation, while for the strain hardening curve plotted for a temperature of 550 °C, a slight material weakening is observed, as evidenced by a lower stress value.

The strain hardening curves obtained at strain rates of 1 s^{-1} and 10 s^{-1} within the entire temperature interval tested show a slight strain hardening with increasing true strain magnitude and are monotonically growing.

From the analysis of the approximation error it can be found that at a lower deformed specimen temperature the behaviour of the flow curves is more influenced by strain rate, while at higher temperatures, the influence of strain rate on the shape of the curves decreases. Therefore, at lower temperatures, a larger approximation error occurs for smaller strain rate values, while at higher temperatures – for greater strain rate values.

It is assumed that the coefficients of approximating function (1) are sufficiently adequately selected if the average approximation error does not exceed 8 ÷ 10 % [8]. For the range of thermo-mechanical parameters under examination, the average approximation error is 5,3 %.

Based on the analysis of the shape of the $\sigma - \varepsilon$ curves, for all deformation conditions, the analysis of variations in temperature occurring during the process of deformation in the examined variants was made. For the Al alloy under investigation, the occurrence of a thermal effect was observed for larger strain rate values. The analysis of the data in Figure 1 a shows that for deformations in the range of 0,01 ÷ 0,20, the strain hardening of the materials is greater for higher strain rates. At deformations above 0,20, an increase in material strain hardening is observed for lower strain rates. This behaviour of the material is associated with the thermal effect occurring during plastic deformation. With the increase in test specimen temperature, the in-

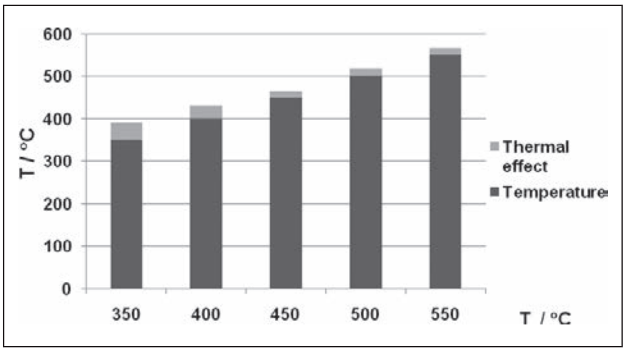


Figure 3 The thermal effect of plastic deformation of the Al5754 alloy, obtained during deformation at a strain rate of 10 s^1 for the temperature interval of 350 °C – 550 °C

fluence of the thermal effect of plastic deformation is smaller. The range of variations in the temperature of specimens deformed at a rate of 10 s^{-1}, allowing for the plastic deformation thermal effect, as related to the preset process temperature, is shown in Figure 3.

SUMMARY

Based on the analysis of the results of investigation into the influence of thermomechanical parameters on the magnitude of the yield stress of the hard deformable Al 5754 alloy, the following conclusions have been drawn:

- the position of the maximum in the flow curves for the Al alloy under examination depends primarily on the temperature and strain rate. The lower the strain rate value and the higher the temperature, the lower the deformation values at which the maximum σ value is attained;
- in the examined range of parameters, a good consistency between the actual yield stress values and the values obtained by approximation was obtained; the average approximation error was 5,3 %, and therefore the results obtained from the approximation of the flow curves can be used in numerical modelling of plastic working processes;
- during plastic deformation of the 5754 grade aluminium alloy, a thermal effect occurred for the largest strain rate values.

Acknowledgement

The project is co-financed by the European Union from the European Regional Development Fund under the Intelligent Development Operational Program 2014-2020.

The project is implemented as part of the National Center for Research and Development competition: Action 4.1 “Research and development works,” Sub-measure 4.1.4 “Application projects,” No POIR.04.01.04-00-0016/17.

REFERENCES

[1] Leśniak D., Rękas A., Libura W., Zasadziński J.: Study of the deformability of 5xxx series aluminum alloys with high Mg content in a semi-industrial extrusion process. Metal Forming 25 (2014) 3, 159 - 167.

[2] Kawałek A., Dyja H., Gałkin A.M, Ozhmegov K.V., Sawicki S.: Physical modelling of the plastic working processes of zirconium alloy bars and tubes in thermomechanical conditions. Archives of Metallurgy and Materials 53 (2014) 3, 935 - 940.

[3] Galkin A.M.: Badania plastometryczne metali i stopów. Seria Monografie nr 15, Wydawnictwo Politechniki Częstochowskiej, Czestochowa, (1990), p.142.

[4] Grosman F., Hadasik E.: Technologiczna plastyczność metali [The engineering plasticity of metals]. Plastometric tests. University Press of the Silesian University of Technology, Gliwice, 2005, p. 198.

[5] Hadasik E.: Badania plastyczności metali [Plasticity testing of metals]. University Press of the Silesian University of Technology, Gliwice 2008, p. 199.

[6] Rękas A., Baścik A., Leśniak D., Bakalarski P., Dokupil K., Libura W.: Wpływ geometrii matrycy na jakość wyciskanych kształtowników z turdmoodkształcalnych stopów aluminium [The effect of die geometry on the quality of extruded sections of hard-deformable aluminium alloys]. Rudy i Metale Nieżelazne 52 (2007) 9, 555-559.

[7] Dyja H., Tussupkaliyeva E., Bajor T., Laber K.: Physical Modeling of Plastic Working Conditions for Rods of 7xxx Series Aluminum Alloys, Archives of Metallurgy and Materials 62 (2017) 2A, 515-521.

[8] Kuvajskova Yu. E., Ekonometrika: uchebnoe posobie, UlGTU, Ul’yanovsk, (2017), p. 166.

Note: The person responsible for the English translation is Czesław Grochowina, Studio Tekst, Czestochowa, Poland.