PHYSICAL MODELLING OF THE PROCESS OF ROLLING AlZn5.5MgCu ALUMINUM ALLOY BARS ON THE RSP14/40 THREE-HIGH REELING MILL

Konrad LABER [1], Anna KUŁAKOWSKA [2], Henryk DYJA [3]

[1]*Czestochowa University of Technology, Faculty of Production Engineering and Materials Technology, Institute for Plastic Working and Safety Engineering, Al. Armii Krajowej 19, Czestochowa, Poland, EU*
laber@wip.pcz.pl

[2]*Jan Dlugosz University in Czestochowa, Faculty of Mathematics and Natural Sciences, Institute of Technical Education & Safety Systems, Al. Armii Krajowej 13/15, Czestochowa, Poland, EU*

Abstract

The paper presents the results of physical modelling of the process of rolling AlZn5.5MgCu aluminum alloy bars on a three-high reeling mill. Tests were carried out in a complex strain state (simultaneous torsion with compression) using an STD 812 torsion plastometer. The initial parameters were determined during numerical modelling in the program FORGE 2011®. The purpose of the study was to verify the numerical modelling and to physically represent the process of rolling on the three-high reeling mill. The scope of the investigation encompassed also the determination of the effect of feedstock temperature on the changes in the yield stress of the investigated material, its microstructure and microhardness.

Keywords: Physical modelling, hot torsion test, three-high reeling mill, hard deformable aluminum alloy

1. INTRODUCTION

Physical modelling methods are used with great success both in basic research, as well as application research, the aim of which is to transpose laboratory test results onto the actual industrial facility. Of particular importance are physical modelling methods, which are used in plastic working and in materials science [1]. On the basis of the results of physical modelling of the rolling process it is possible to determine, e.g., the values of yield stress in each pass, thus obtaining the capability to accurately calculate the energy and force parameters needed for carrying it on a commercial scale. It can also be possible to assess the variations in the microstructure of deformed material and its mechanical properties within the entire sequential deformation cycle which occurs in the actual rolling process [2]. The specimen sizes used in physical modelling are sufficiently large to enable the tracking of changes that occur in the structure of material subjected to simulations. Thus, this method allows the optimal parameters of the technological process to be selected for the required structure of product [1].

The analyzed process of rolling bars on the three-high skew mill is characterized by large deformation values (the actual deformation at a level of 3÷4) in individual rolling passes. A method that enables the deformation of material with such a deformation is the torsion test. The main advantage of the torsion method is the capability to obtain large deformations, much larger than in the tensile and compression tests, without the prior loss of the stability of the deformed material. In addition, torsion is a good method for testing hard deformable materials, which include aluminum and its alloys. Moreover, state-of-the-art torsion plastometers enable a complex deformation patters to be generated in material being deformed, which is similar to that occurring in the actual process of rolling on a three-high reeling mill.

2. THE AIM, SCOPE AND METHODOLOGY OF THE INVESTIGATION

The aim of the investigation carried out within this study was to verify the numerical examination results and to physically represent the process of rolling on the three-high reeling mill before rolling in laboratory conditions.

The obtained results were compared with the results of numerical modelling and those obtained from the rolling process. The scope of the investigation encompassed also the determination of the effect of feedstock temperature on the changes in the yield stress of the investigated material, its microstructure and microhardness. Physical modelling of the process under analysis was carried out in a complex strain state (simultaneous torsion and compression) using an STD 812 torsion plastometer in accordance with the numerical examination parameters calculated in FORGE 2011®, while taking into account the testing capabilities of the plastometer. Material used for the tests was an aluminum alloy of series 7XXX, in grade AlZn5.5MgCu.

3. ANALYSIS OF THE INVESTIGATION RESULTS

The chemical composition of the investigated aluminum alloy, complying with the requirements of the PN-EN 573-1:2006 standard is given in **Table 1.**

Table 1 Chemical composition of aluminum alloy AlZn5.5MgCu, in percentage by weight %

Zn	Mg	Cu	Cr	Fe	Ti	Mn	Si	Al
5.72	2.44	1.63	0.2	0.28	0.08	0.13	0.14	rest

The first stage of the investigation was numerical modelling of the process of rolling AlZn5.5MgCu aluminum alloy bars on the three-high reeling mill using the software program Forge2011®, where the mechanical state of deformed material was described with the Norton-Hoff law [3].

$$S_{ij} = 2K_0(\varepsilon + \varepsilon_0)^{n_0} \cdot e^{(-\beta_0 \cdot T)}(\sqrt{3}\dot{\varepsilon})^{m_0 - 1}\dot{\varepsilon}_{ij} \tag{1}$$

where: S_{ij} - stress tensor deviator, $\dot{\varepsilon}$ - strain intensity rate, $\dot{\varepsilon}_{ij}$ - strain rate tensor, ε - strain intensity, ε_0 - initial strain, T- temperature, K_0, m_0, n_0, β_0 - material constants related to the characteristic properties of the material concerned.

The following boundary conditions were adopted for the numerical modelling: roll temperature, 60 °C; ambient temperature, 20 °C; the coefficient of heat exchange between the bars and the rolls, 20000 W / m^{2}K; the coefficient of heat exchange between the bars and the air, 100 W / m^2 K; friction factor, 0.8.

This examination was carried out for two initial feedstock temperature of 200 °C and 250 °C, respectively. Sample results for the distribution of temperature, strain intensity, strain rate intensity and stress intensity in rods being rolled for the first rolling pass are shown in **Figure 1** and **2**.

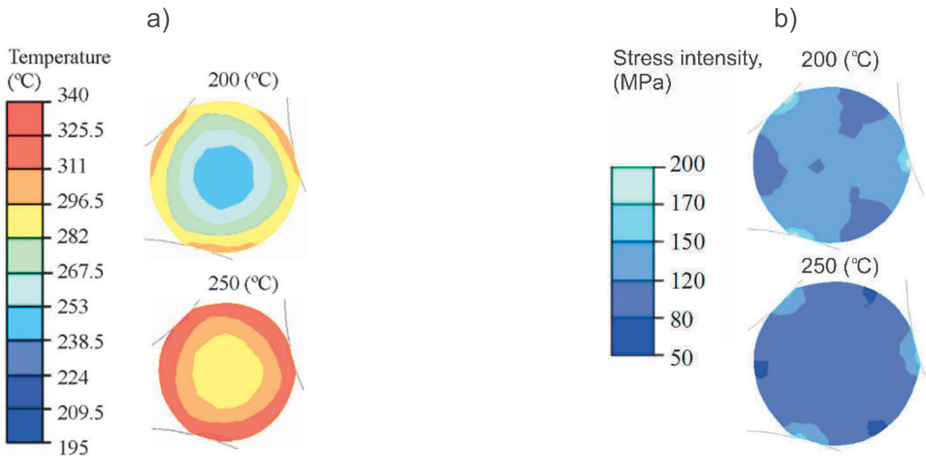

Figure 1 Distributions of temperature and stress intensity on the cross-section of rolled bars in the exit plane - rolling pass no. 1: a) temperature, b) stress intensity

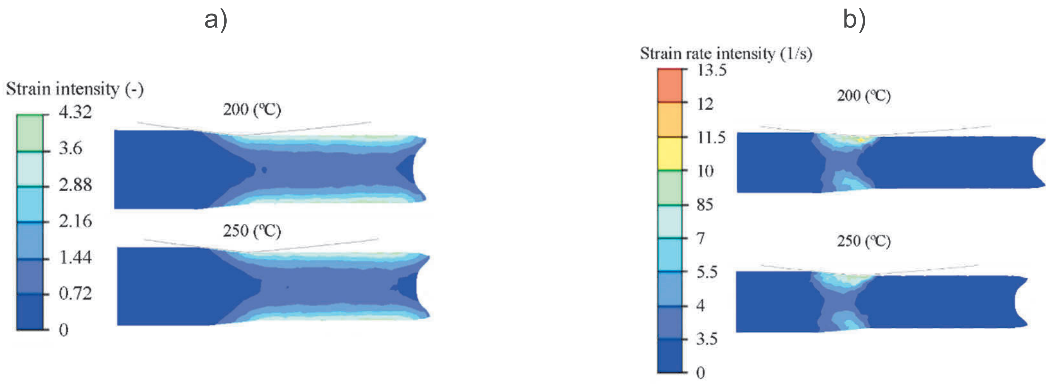

Figure 2 Sample distributions of strain intensity and strain rate intensity in the longitudinal section of rolled bars - rolling pass no. 1: a) strain intensity, b) strain rate intensity

From the data in **Figures 1** and **2** it was found that the examined process was characterized by a big variability of strain parameters over the cross-section of the rolled bars. The temperature, strain intensity, strain rate intensity and stress intensity all attained the largest values at the surfaces in direct contact with the rolls, while the smallest values of the examined parameters were observed in the axis of rolled bars.

For physical modelling of the investigated three-high reeling mill rolling process, alloy specimens with the working portion of a diameter of *d* = 6 mm and a length of *l* = 10 mm were used. The temperature was controlled using a K-type (NiCrNiAl) thermocouple. A general schematic diagram of thermo-mechanical treatment during physical modelling is shown in **Figure 3**, while a general view of working during the investigation is presented in **Figure 4**. Due to difficulties in controlling the temperature of the investigated aluminum alloy using the thermocouple, also a thermovision technique was used in the investigation.

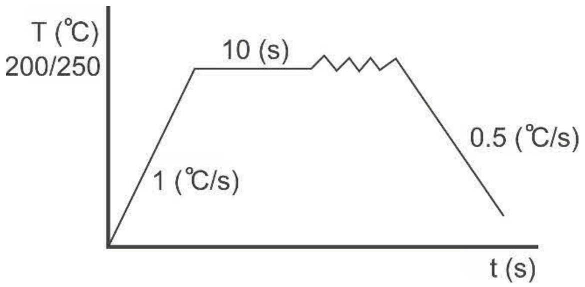

Figure 3 Diagram of thermo-mechanical treatment during physical modelling of the process of rolling 7075 alloy bars in the three-high reeling mill

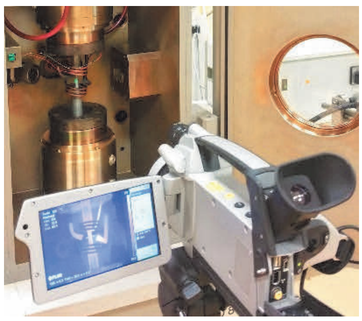

Figure 4 An AlZn5.5MgCu aluminum alloy specimen in the chamber of the STD 812 torsion plastometer

Deformation parameters for physical modelling (**Table 2**) were taken from the analysis of the numerical modelling results, while taking into account the testing capabilities of the STD 812 torsion plastometer. The tests were carried out at constant deformed specimen temperatures which, according to the numerical modelling conditions, were 200 and 250 °C.

Table 2 Deformation parameters in physical modelling using the STD 812 torsion plastometer

	Torsion	**Compression**
Strain	3.12	0.29
Strain rate (1/s)	9.0	0.80

Changes in specimen dimensions in the process of physical modelling of the three-high reeling mill rolling process, corresponding to the total deformation of approx. 3.5, are illustrated in **Figure 5.**

a) b)

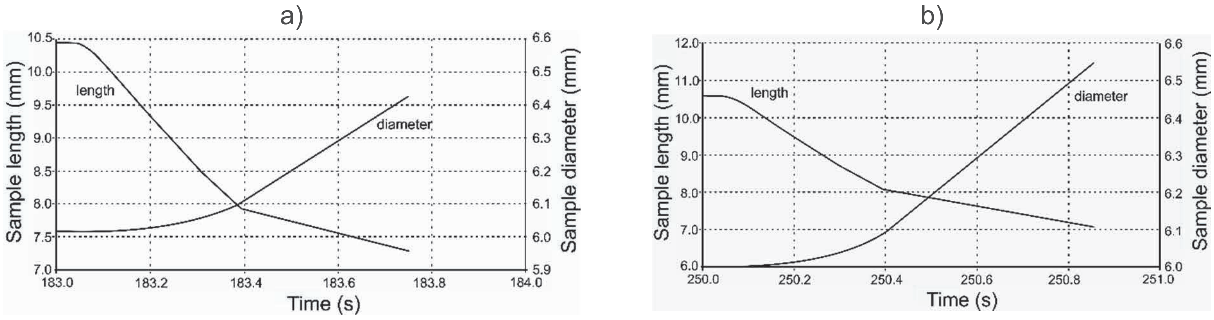

Figure 5 Changes in specimen dimensions during physical modelling of the process of rolling AlZn5.5MgCu alloy bars: a) feedstock temperature, 200 °C; b) feedstock temperature, 250 °C

Figure 6 illustrates the variation in the value of yielding stress (computed numerically and measured during physical modelling of the examined process) as a function of preset deformation. Moreover, **Figure 6** shows also temperature variations, as computed numerically.

a) b)

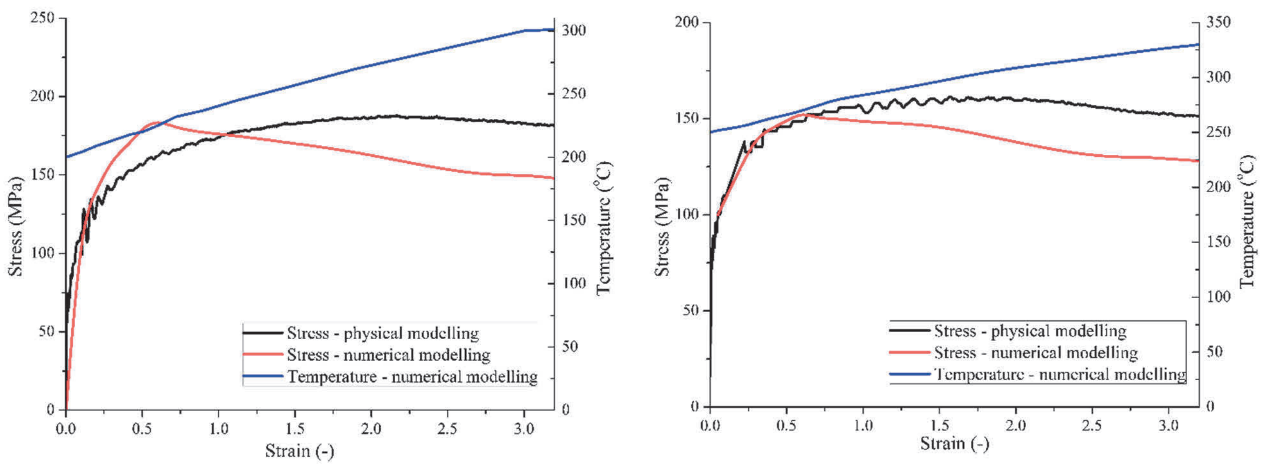

Figure 6 Variation in the yield stress of the AlZn5,5MgCu alloy during physical modelling of the process of rolling bars on the three-high skew mill: a) at the temperature 200 °C, b) at the temperature 250 °C

The analysis of the examination results shown in **Figure 6** has found that the values of the yield stress of the examined alloy obtained from physical modelling are similar to the values obtained from numerical modelling. The greatest consistence in yield stress value occurs at the initial stage of the deformation process (up to the true strain of 0.6). At greater strain values, differences between yield stress values obtained from physical modelling and those obtained from numerical modelling increase. The yield stress values of the examined material obtained from physical modelling are greater than those derived from numerical modelling. This might be caused by the effect of examined alloy temperature on the yield stress magnitude. During numerical modelling of the process of bar rolling on the three-high reeling mill, an increase in the temperature of examined bars was observed with the increase in preset plastic deformation. By contrast, physical modelling of the examined rolling process was conducted at a constant deformed specimen temperature. In the case of physical modelling of the three-high skew mill rolling process at the temperature 200 °C (**Figure 6a**), the maximum yield stress was approx. 180 MPa. In turn, for specimens deformed at the temperature 250 °C (**Figure 6b**), the maximum yield stress value was approx. 160 MPa. From the obtained numerical and physical modelling results it was found that increasing the deformed AlZn5.5MgCu alloy temperature from 200 °C to 250 °C caused a reduction in yield stress value by approx. 18% in either case.

From the material after physical modelling, specimens were made for the examination of the grain size at the sub-surface zone and in the middle of each specimen (**Figure 7**). From the results of the metallographic examination of specimens after physical modelling it was found that the greatest microstructural refinement had been obtained in the sub-surface zone, for both specimens (**Figures 7a** and **7b**). The grain size in those regions was, respectively, 1.85 and 1.44 μm for specimens deformed at 200 °C and 250 °C. In the central zone of the specimens (**Figures 7c** and **7d**), these values were 4.0 and 1.85 μm, respectively. It was found that the microstructure of specimens deformed at 250 °C was characterized by greater grain refinement in the examined zones and a more uniform microstructure, compared with specimens deformed at a lower temperature, which could have resulted from recrystallization phenomena occurring in the investigated alloy.

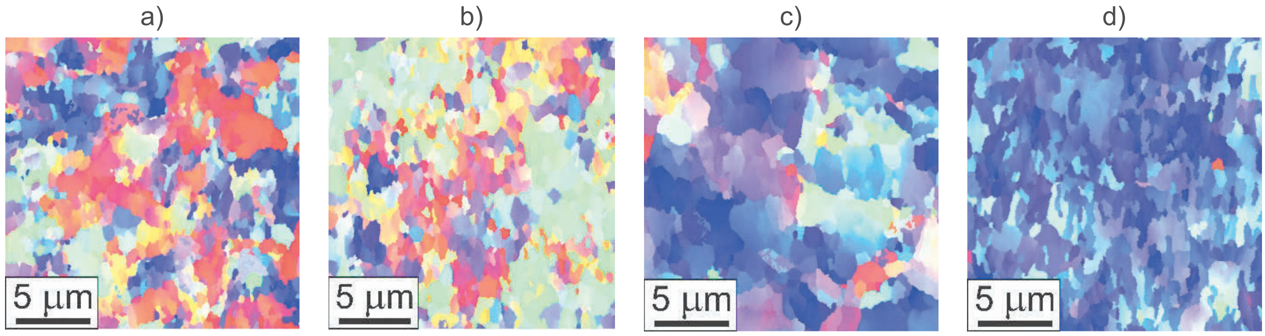

Figure 7 Microstructure of AlZn5.5MgCu aluminum alloy specimens after physical modelling: deformed at 200 °C (a, c) and 250 °C (b, d), in the sub-surface zone (a, b) and in the middle (c, d) of the specimen.

From the material after physical modelling, specimens were also made for the examination of microhardness distributions (**Figure 8**) on the cross-section and the longitudinal section. For microhardness tests, a Future-Tech microhardness tester was employed. The tests were conducted by the Vickers method under a load of 2.94 N with an iteration time of 5 s.

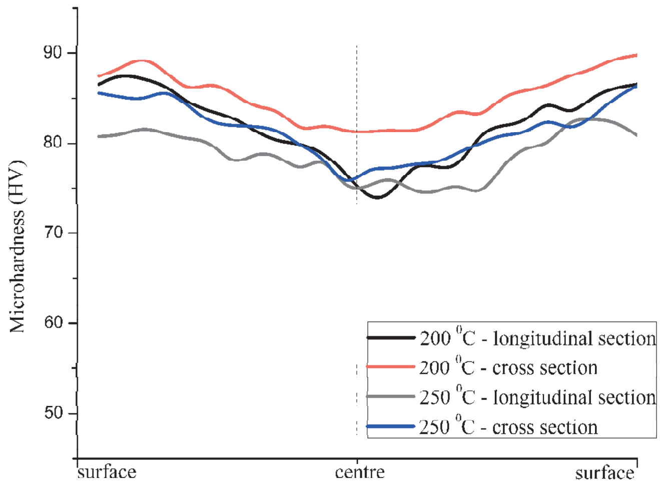

Figure 8 Distributions of microhardness of AlZn5.5MgCu alloy specimens deformed at 200 °C and 250 °C

The analysis of the AlZn5.5MgCu alloy specimen microhardness distributions found that the highest microhardness was exhibited by regions lying at the specimen surface, while the lowest - in the specimen centre. This microhardness distribution was caused by the strain distribution on the deformed material cross-section, being characteristic of the torsion process. A similar strain distribution occurs also in the process of rolling on the three-high reeling mill. In both cases, the largest strains occur in sub-surface regions, while smallest strains, in the deformed material axis. For specimens deformed at 200 °C, the maximum microhardness values were 87 HV on the cross-section and 89 HV on the longitudinal section. The smallest microhardness values of the investigated alloy amounted to 71 HV on the cross-section and 81 HV on the longitudinal section. A similar distribution of AlZn5.5MgCu alloy microhardness was also observed for specimens deformed at 250 °C. In that case, the maximum microhardness values were 82 HV on the cross-section and 86 HV on the longitudinal section. The smallest microhardness values of the investigated alloy were in that case 74 HV on the cross-section and 75 HV on the longitudinal section.

The investigation results reported in this paper correspond with high accuracy to the results obtained for the AlZn5.5MgCu alloy after the three-high skew mill rolling process carried out in laboratory conditions, which are described in detail in paper [4]. On this basis it has been found that the performed physical modelling of the process under examination reproduces with high accuracy the phenomena occurring in the actual rolling process.

4. CONCLUSIONS

By analyzing the results of physical modelling of the process of rolling AlZn5.5MgCu aluminum alloy bars on the three-high reeling mill, the following conclusions have be drawn:

- increasing the testing temperature from 200 °C to 250 °C resulted in a reduction in the value of the yield stress of the investigated material by approx. 18% and a more uniform microhardness distribution on the cross-section and longitudinal section of deformed specimens, compared to the results obtained at the temperature 200 °C;
- lowering the level of the yield stress of the investigated aluminum alloy being deformed at 250 °C has caused a reduction in the energy and force parameters necessary for carrying out the real process of rolling on the three-high skew mill;
- the metallographic analysis of specimens after physical modelling has revealed a more uniform and fine-grained microstructure of specimens deformed at the temperature 250 °C;
- the application of a complex deformation scheme using an STD 812 plastometer enables the verification of numerical modelling results and also allows the examined process to be physically reproduced with high accuracy.

REFERENCES

[1] PADUCH, J., GARBARZ, B. and KUZIAK, R. Kierunki i metody badań naukowych na rzecz przemysłu stalowego [Directions and methods of scientific research for the steel industry]. *Works of the Institute for Ferrous Metallurgy*. Workbook 2, Gliwice. 2005. vol. 57, pp. 29-31, 33-34. ISSN 0137-9941.

[2] KUŹMIŃSKI, Z., NOWAKOWSKI, A. and ŚMIAŁY, P. Fizyczne modelowanie procesu walcowania blach i taśm na gorąco z zastosowaniem plastometru skrętnego [Physical modelling of the hot sheet and strip rolling process using a torsion plastometer]. *Hutnik - Wiadomości Hutnicze* [Metallurgist - Metallurgical News]. Sigma-Not Publishing House, Warsaw, 2006. no. 10, pp. 444-445. ISSN 1230-3534.

[3] MRÓZ, S. *Proces walcowania prętów z wzdłużnym rozdzielaniem pasma.* [The bar rolling process with longitudinal strip separation]. University Press of Czestochowa University of Technology, Czestochowa. Series: Monograph. 2008. no. 138. p. 52. ISBN 978-83-7193-369-1. ISSN 0860-5017.

[4] KUŁAKOWSKA, A. *Kształtowanie własności prętów ze stopu aluminum AlZn5,5MgCu w trójwalcowej walcarce skośnej*. [Forming the properties of AlZn5.5MgCu aluminum alloy bars on a three-high skew mill]. PhD Thesis, Czestochowa 2017.