ISSN 0543-5846
METABK 59(4) 489-492 (2020)
UDC – UDK 669.15.71:621.778/539.417:66.04:620.18:620.17=111

IMPACT OF THE HEAT TREATMENT PARAMETERS ON ULTIMATE TENSILE STRENGTH, MICROSTRUCTURE AND WIRE DRAWING PROCESS OF Zn-Al15

Received – Primljeno: 2020-03-26
Accepted – Prihvaćeno: 2020-06-25
Original Scientific Paper – Izvorni znanstveni rad

Research conducted in the current paper examines the impact of the heat treatment at temperatures from 150 °C to 300 °C with time intervals between 1 and 6 hours on susceptibility to drawing process of Zn-Al15 wire rod manufactured within the industrial continuous casting and rolling line. The mechanical properties studies proved that the heat treatment caused the increase in the ultimate tensile strength values of the alloy whereas the drawing process caused a significant decrease, which suggests that this alloy after the specific heat treatment cannot be subjected to strain hardening.

Keywords: Zn-Al15 alloy, wire drawing, heat treatment, microstructure, mechanical properties

INTRODUCTION

Zinc and aluminum alloys like Zn-Al15 intended for corrosion protection coatings of steel applied via thermal spraying process are ones of the many non-ferrous alloys manufactured in continuous casting and rolling lines (CCR). A wide range of thermal spraying devices like an electric arc or combustion flame equipment combined with many applications of the process require diverse spectrum of mechanical properties and wire diameters to be manufactured. The wire rod produced in the CCR line e.g. using Properzi technology is subjected to wire drawing process in order to obtain the desired geometrical dimensions. The wire drawing process may be proceeded with a specific heat treatment in order to obtain the desired set of properties of the final product. Various heat treatment methods and its influence on phase transformations have been discussed by Zhu et al. in [1], who studied thoroughly the exothermic reactions in Zn-Al based alloys. In [2] Zhu et al. have proved the discontinuous precipitation to occur by means of a cellular reaction in both monotectoid and eutectoid Zn–Al based alloys. He correlated it with an equilibrium phase transformation that took place at about 276 °C. Yan et al. stated that the homogenized Zn–Al solder resulted in little lower microhardness but much higher ductility [3]. In more novel works [4 – 6] scientists have investigated the influence of various alloy additives on the micro and macroscopic properties of the Zn-Al alloys stating that there is very little to no increase at all considering the mechanical properties when elements like Sr, Si, Na, Cu and Mg are added to the alloy. Works have been also conducted on the workability and the final properties of Zn–Al based alloys [7 – 9] which proved that heat treatment increases the hardness and tensile strength of the alloys without affecting their ductility considerably but on the other hand increasing grain size decreased both the maximum elongation under uniaxial deformation and limiting dome height under biaxial deformation. The current paper focuses on the impact of heat treatment parameters on phase transformations in the Zn-Al15 alloy of industrial origin, its impact on the macroscopic properties of semi-finished product and the impact on cold workability of the material in the wire drawing process.

P. Strzępek, P. Osuch (e-mail: piosuch@agh.edu.pl), M. Walkowicz, M. Zasadzińska, A. Mamala,T. Knych, AGH University of Science and Technology, Faculty of Non-Ferrous Metals, Cracow, Poland
T. Napióra, ZM Silesia S.A., Katowice, Poland

EXPERIMENTAL PROCEDURE

Research regarding the impact of the specific heat treatment parameters on the microstructure, mechanical properties and susceptibility to the drawing process have been conducted using Zn-Al15 wire rod manufactured in industrial CCR line with a diameter of 4,25 mm, which acceptable chemical composition in accordance with the European Standard is presented in Table 1.

Table 1 **Chemical composition of the wire rods used during heat treatment and wire drawing process / wt. % [10]**

Main alloy component		Admixtures – together max. 0,17						
Zn	Al	Pb	Cd	Pb + Cd	Sn	Fe	Cu	Si
84-86	14-16	max.						rest
		0,005	0,005	0,006	0,001	0,05	0,01	

Heat treatment

Research concerning heat treatment was divided into two parts, the former being conducted at the temperature range of 150 °C to 300 °C (each 10 °C) at the time intervals of 1, 2, 4 and 6 hours and the latter being conducted after the preferable time of the heat treatment has been determined. The heat treatment carried out at the preferable time was conducted at the same range of temperatures as before, but this time each 30 °C, on the samples later on subjected to wire drawing process. The mechanical properties of the wire rods after the heat treatment process were investigated in the uniaxial tensile test.

Microstructural analysis

Selected samples of the heat-treated wire rods and the reference sample were examined during observations using Scanning electron microscope (SEM), (Hitachi S-3500N) in order to determine the phase transformations occurring after the conducted heat treatment.

Wire drawing process

Zn-Al15 wire rods, with an initial diameter of 4,25 mm, after the heat treatment in preferable conditions were subjected to the wire drawing process in 8 draws to the final diameter of 2 mm. The process was conducted with a constant drawing force measurements. Each used diameter of the die along with the coefficient of deformation and true strain to which the samples were subjected during the process are enlisted in Table 2. After each draw a sample was taken in order to determine its mechanical properties in the uniaxial tensile test.

Table 2 **Parameters of the wire drawing process of ZnAl15 wire rod ϕ 4,25 mm (n – no. of the draw, d – diameter, λ -coefficient of deformation, ε - true strain)**

n	1	2	3	4	5	6	7	8
d / mm	4	3,76	3,34	2,93	2,64	2,31	2,15	2
λ	1,13	1,13	1,27	1,3	1,23	1,31	1,15	1,16
ε	0,12	0,25	0,48	0,74	0,95	1,22	1,36	1,51

RESULTS AND DISCUSSION
Heat treatment

The response to the implemented heat treatment was investigated in the uniaxial tensile test. For each heat treatment variant described in the previous section 5 different samples were tested and the graph in Figure 1 shows the average values of the ultimate tensile strength of the wire rods. The lowest value of the *R*m (128 MPa) occurred when no heat treatment was introduced and a quasi-linear increase in the values may be observed up to 270 °C above which the *R*m values drastically decreased which similarly to Zhu et al. [2] may be correlated with phase transformation that took place at about 276°C. Maximum average value of the *R*m (266 MPa) was measured at 270 °C after 6 hours of heat treatment which was determined to be the most preferable time of

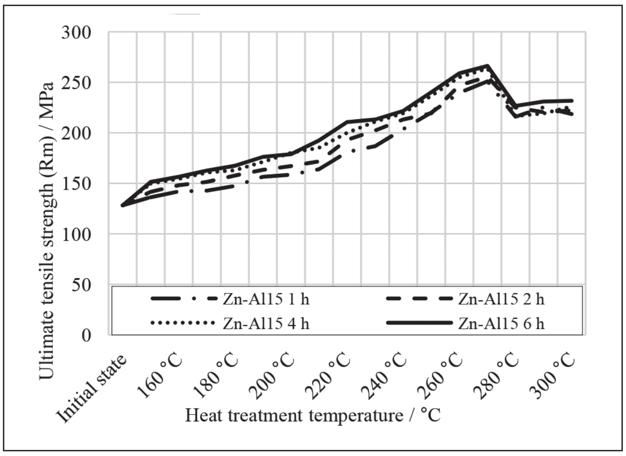

Figure 1 Rm values of Zn-Al15 wire rod after heat treatment at the temperatures from 150 °C to 300 °C with a sample at initial state as a reference material

the heat treatment (out of the tested during this research) as the Rm values after 6 hours were the highest at all tested temperatures.

Microstructural analysis

The analysis of the phase transformations that were responsible for the macroscopic properties identified after heat treatment was conducted on the longitudinal section of the sample in the initial state as well as selected samples after 6 hours of heat treatment at 180 °C, 240 °C and 300 °C using Scanning electron microscope (SEM). Considering the initial samples, which analysis is presented in Figure 2 it can be stated that the second phase particles are situated along the rolling direction resulting from plastic deformation in multi-stand rolling mill. These particles consist of fine lamellae of eutectoid phase (α + η), which result from decomposition of the β phase and are surrounded by eutectic Zn-rich η phase mixed with α particles.

After submitting wire rods to the heat treatment for 6 hours in 180 °C and 240 °C the α + η phase lamellae decomposed completely into coarse Al-rich α particles in the Zn-rich η matrix which is visible at Figures 3 – 4.

Subjecting the Zn-Al15 wire rod to the heat treatment at 300 °C for 6 hours, which was above the temperature of the eutectoid transformation (276 °C) re-

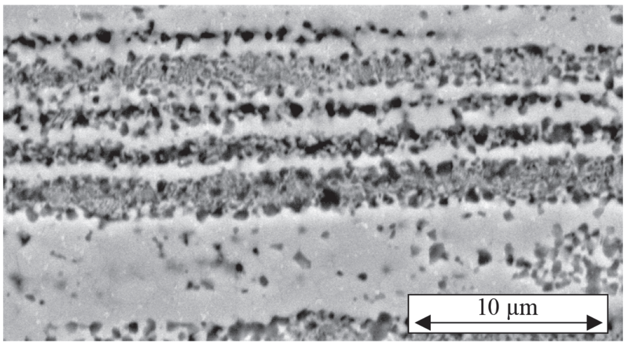

Figure 2 SEM analysis of the longitudinal section of Zn-Al15 wire rod at the initial state

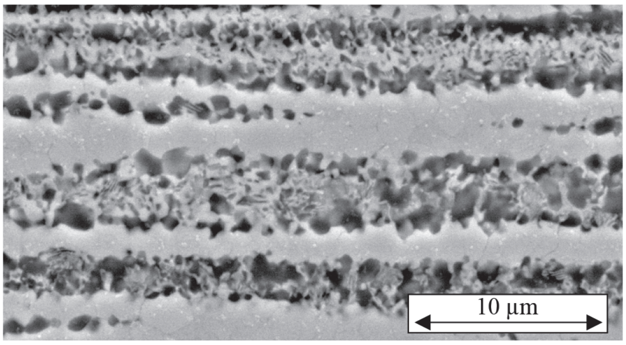

Figure 3 SEM analysis of the longitudinal section of Zn-Al15 wire rod after 6 hours of heat treatment at 180 °C

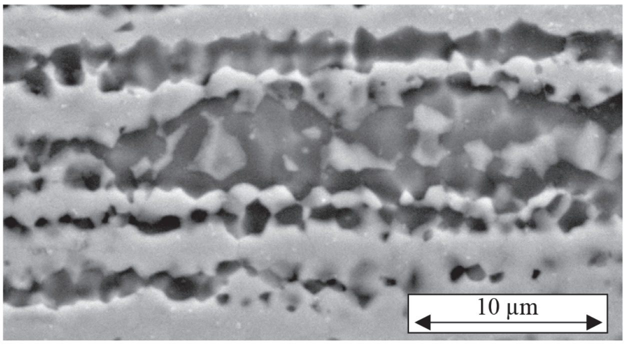

Figure 4 SEM analysis of the longitudinal section of Zn-Al15 wire rod after 6 hours of heat treatment at 240 °C

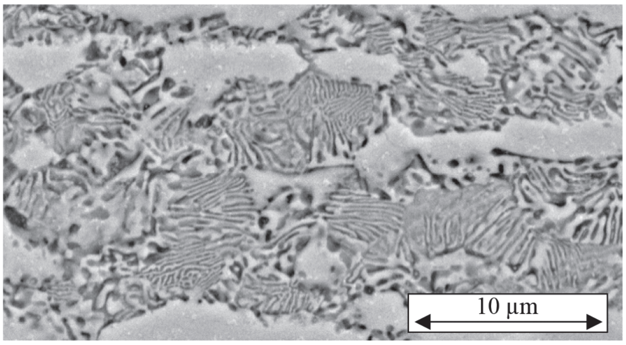

Figure 5 SEM analysis of the longitudinal section of Zn-Al15 wire rod after 6 hours of heat treatment at 300 °C

sulted in formation of α + η lamellae phase zones which is depicted in Figure 5. In comparison to the initial state, where α + η lamellae were also detected, there was no coarse α phase within η matrix present and the proportion of the volume fractions of α + η lamellae were much larger.

Wire drawing process

After the preferable time of the heat treatment of Zn-Al15 alloy was determined to be 6 hours wire rods subjected to the selected temperatures of the heat treatment were dedicated for the wire drawing process. Throughout the entire metal working process the drawing force was measured and was afterwards divided by the cross-section of the wire in order to obtain the values of the drawing stress presented in Figure 6 as a cumulative graph in the function of true strain. It may be easily stated that the drawing stress of the sample in the initial

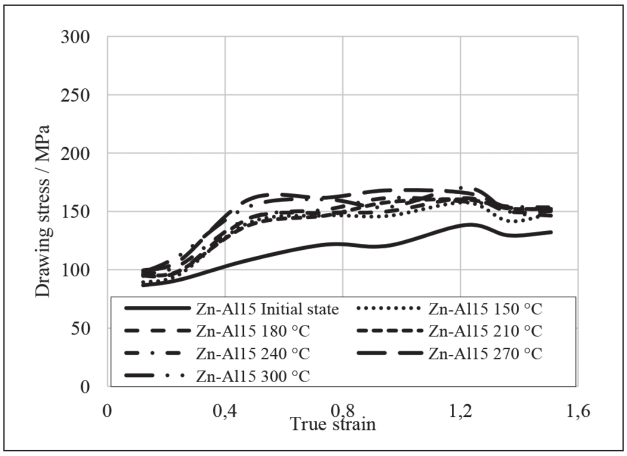

Figure 6 Drawing stress values of Zn-Al15 wires after 6 hours of heat treatment at the selected temperatures from 150 °C to 300 °C with a sample at initial state as a reference material

state was the lowest and as the temperature of the heat treatment increases so is the drawing stress up to 270 °C which is accordance with the mechanical properties of the wire rods presented above.

Each of the samples after the drawing process was subjected to uniaxial tensile test in order to determine the mechanical properties of the wires obtained from wire rods in various states. Correspondingly to the *R*m of wire rods, the *R*m values of the wires were also higher when the temperature of the heat treatment was increasing, again only up to 270 °C above which the phase transformation occurred. The obtained values of the Rm after the heat treatment at 300 °C were significantly lower in comparison to 270 °C (35 MPa lower which was a decrease of over 13 %) and compared to 240 °C were higher only at low values of total strain. The most significant was the fact that the wires did not underwent strain hardening, and to the contrary, the Rm values decreased for the first 2 draws after which they were plateau which was presented in Figure 7. This might be caused by the low temperature of recrystallization which when calculated based on the melting point of the

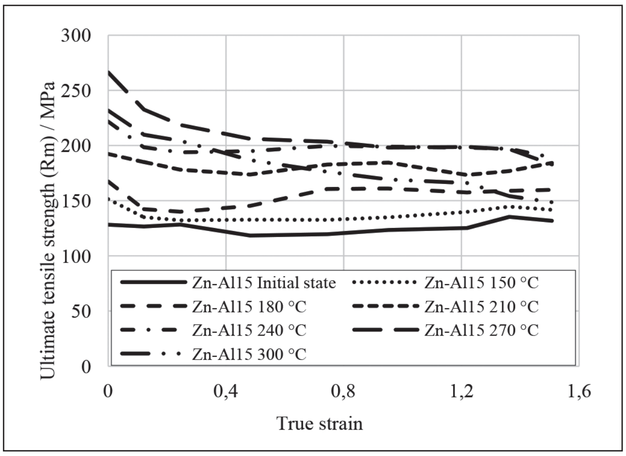

Figure 7 *R*m values of Zn-Al15 wires after 6 hours of heat treatment at the selected temperatures from 150 °C to 300 °C with a sample at initial state as a reference material

material [10] should occur close to the ambient temperature. Taking into consideration that the friction generated during the wire drawing process increased the temperature, the material should be in recrystallized state after the wire drawing process, and thus, its mechanical properties might be lower than the drawing stress measured during the metal working process.

CONCLUSIONS

On the basis of the conducted research the following can be stated:

Heat treatment of the Zn-Al15 wire rods resulted in over twofold increase of the Rm with the increasing temperature of the heat treatment up to 270 °C above which the Rm values decreased, which may be correlated with phase transformation that took place at about 276°C.

Zn-Al15 alloy in the initial state is characterized by relatively fine grain microstructure consisting of eutectoid α + η mixture and coarse Al-rich α particles in the Zn-rich η phase. Submitting the wire rods to the heat treatment of 180 °C and 240 °C caused the complete decomposition of α + η phase lamellae into coarse Al-rich α particles in the Zn-rich η matrix. Increasing the temperature to 300 °C resulted in formation of α + η lamellae phase zones which were much larger in comparison to the wire rod in the initial state.

The Zn-Al15 alloy did not strengthen despite applied deformation during wire drawing process. The *R*m values decreased after the first two draws and further drawing sequences did not affect the mechanical properties.

Acknowledgements

Authors are grateful for the financial support of this research provided by The National Centre for Research and Development – Research Project No. POIR.01.01.01-00-0361/17.

Authors are also grateful for invaluable help of Stanisław Pawlicha and Radosław Sokół from ZM Silesia S.A., Katowice, Poland.

REFERENCES

[1] Y. H. Zhu, H. C. Man, W. B. Lee, Exothermic reaction in eutectoid Zn–Al based alloys, Materials Science and Engineering: A 268 (1999) 1-2, 147-153.

[2] Y. H. Zhu, S. Murphy, C. Yeung, Early stages of phase transformation in quenched zinc–aluminum based alloys, Journal of Materials Processing Technology 94 (1999) 2-3, 78-84.

[3] X. Yan, S. Liu, W. Long, J. Huang, L. Zhang, Y. Chen, The effect of homogenization treatment on microstructure and properties of ZnAl15 solder, Materials & Design 45 (2013) 440-445.

[4] A. Vencl, I. Bobic, F. Vucetic, B. Bobic, J. Ruzic, Structural, mechanical and tribological characterization of Zn25Al alloys with Si and Sr addition, Materials & Design 64 (2014), 381-392.

[5] T. Gancarz, G. Cempura, W. Skuza, Characterization of ZnAl cast alloys with Na addition, Materials Characterization 111 (2016) 147-153.

[6] S. Sandlöbes, Z. Wua, K. G. Pradeep, S. Korte-Kerzel, Precipitation and decomposition phenomena in a Zn-Al-Cu-Mg alloy, Materials Letters 175 (2016), 27-31.

[7] T. Savaşkan, A. P. Hekimoğlu, Microstructure and mechanical properties of Zn–15Al-based ternary and quaternary alloys, Materials Science and Engineering A 603 (2014) 52-57.

[8] T. Prosek, J. Hagström, D. Persson, N. Fuertes, F. Lindberg, O. Chocholaty, C. Taxén, J. Serák, D. Thierry, Effect of the microstructure of Zn-Al and Zn-Al-Mg model alloys on corrosion stability, Corrosion Science 110 (2016) 71-81.

[9] M. E. Cetin, M. Demirtas, H. Sofuoglu, Ö. N. Cora, G. Purcek, Effects of grain size on room temperature deformation behavior of Zn–22Al alloy under uniaxial and biaxial loading conditions, Materials Science and Engineering: A 672 (2016) 78-87.

[10] DIN EN ISO 14919 Wires, rods und cords for flame and arc spraying

Note: The translator responsible for English language: Miłosz Śliwa, Biuro Tłumaczeń Technitra, Kraków, Poland