J. LULKIEWICZ, M. GĄSIORKIEWICZ, A. KAWAŁEK, S. SZKUDELSKI,
T. BAJOR, M. CHRUŚCIŃSKI, M. BĄCZEK, B. PACHUTKO

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EVALUATION OF STRENGTH PARAMETERS AND STRUCTURE ANALYSIS OF AN EN AW - 7075 ALUMINIUM ALLOY RING MADE BY FORGING AND ROLLING AND HEAT-TREATED

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The article presents the results of research on the evaluation of the structure and mechanical properties of a large-size ring made of aluminum alloy EN AW - 7075 according to a new technology, developed under the project “Innovative low-waste technology for forming large-size rings” carried out by Zarmen FPA forge with participation and support of the Lukasiewicz Research Network - Poznan Institute of Technology. Based on the tests, it was found that the produced ring was characterized by a homogeneous structure and the strength properties required by the customers.

Keywords: aluminium 7075, rolled rings, microstructure, hardness, static tensile test

INTRODUCTIONS AND PURPOSE OF THE RESEARCH

The method of forging and rolling rings has been spread all over the world, but the largest production of rings as well as their development can be boasted by countries that are the most technologically developed [1]. This is related to the application of rings, which are used in the offshore, energy or mechanical industries, being responsible structural or installation elements. Currently, the technology of forming steel rings with rectangular cross-section is considered to be known, and no research is being conducted in this direction [2].

Modern developments in the forged-rolled method of ring manufacturing are moving toward the manufacture of rings from lightweight alloys [3], the reduction of technological allowances for machining through the use of shaping tools that allow rings to be made with profiled inner and outer side surfaces [4], and the use of composite materials [5].

In Poland, the ring industry is just developing, and the production range is mainly rectangular steel rings. Within the framework of cooperation between Lukasiewicz – Poznan Institute of Technology and Zarmen FPA forge during the implementation of the project “Innovative low-waste technology for shaping large-size rings”, a complete technology for shaping a ring from EN AW - 7075 aluminum alloy was prepared together with heat treatment to achieve the mechanical parameters required by the customer. The ring was then made on a Hydromec LAR - 325radial-axis rolling mill [6].

The purpose of this study was to evaluate a ring of aluminium alloy EN AW - 7075wrought under industrial conditions and heat-treated at Zarmen FPA forge on the basis of previously developed technology in terms of meeting the customer’s requirements for mechanical parameters (R_m- 500 MPa, $R_{p0.2}$- 450 MPa and A – 10 %), uniform hardness distribution and homogeneity of structure.

Structure analysis, hardness measurements and a static tensile test were carried out for the large-size ring.

RESEARCH MATEIAL AND METHODOLOGY

The tests were conducted for a large-size ring made of aluminum - zinc-magnesium alloy EN AW - 7075, the chemical composition of which is shown in Table 1

A large-size ring of EN AW- 7075 alloy was produced by the forged-rolled method from a 150-kg charge in the form of a cylinder with dimensions ø500 x 271 mm. In order to soften material, it was subjected to annealing at 480 ° C for 14 hours.

Table 1 **Chemical composition of the Al alloy tested / wt. [%]**

EN AW 7075	Si	Fe	Cu	Mn	Mg
	0,08	0,15	1,36	0,06	2,38
	Cr	Zn	Ti	Al	
	0,2	5,68	0,03	R	

B. Pachutko, J. Lulkiewicz (jaroslaw.lulkiewicz@pit.lukasiewicz.gov.pl); M. Gąsiorkiewicz (maria.gasiorkiewicz@pit.lukasiewicz.gov.pl); S. Szkudelski (szymon.szkudelski@pit.lukasiewicz.gov.pl); M. Chruściński (michał.chruscinski@pit.lukasiewicz.gov.pl); M. Bączek (marcin.baczek@pit.lukasiewicz.gov.pl); Łukasiewicz – PIT, Center of Metal Forming, Research Group of Bulk Forming and Automation, Poznań, Poland; A. Kawałek (anna.kawalek@pcz.pl); T. Bajor (teresa.bajor@pcz.pl) Czestochowa University of Technology, Faculty of Production Engineering and Materials Technology, Czestochowa, Poland

To obtain a 180 mm high disc, a swelling operation was carried out on a press with a pressure of 32 MN. Before the swelling operation, the charge was heated in a compact oven to 485°C and then held at this temperature for 2 hours. The disc height of 180 mm versus the expected final height of 154 mm was chosen based on an analysis of model test results and the authors' experience. The next operation was a punching operation, which was also performed on this press, using a ø 230 mm diameter punch with an inclined working surface. After the punching operation, a bottom of about 30 mm thickness remained in the disc. The operation of punching out the bottom was carried out with a ø 230 mm diameter punch.

Final result was a ring-shaped disc with dimensions: ø660/ø230 x 180 mm, which was a semi-finished product for further rolling process to obtain a ring with dimensions (hot): ø1660±9 /ø1532±9 x 154±8 [mm x mm x mm x mm]. Before starting the rolling process, the rolling mill was set up according to the determined parameters obtained from model tests. During the rolling process, the mill operator manually controlled the dynamic parameters of the mill based on measured and calculated rolling process parameters. Figure 1 shows a view of the resulting ring with hot dimensions: ø1660/ø1525x 154 mm.

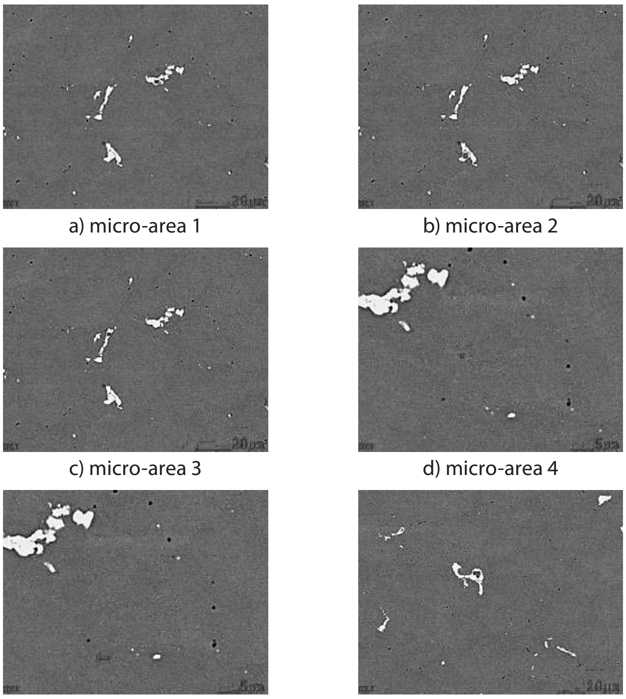
Figure 1 Shaped by rolling a ring of EN AW – 7075

The ring was heat-treated by carrying out a supersaturation and aging process. The selection of the parameters of these processes will not be disclosed, as it remains in the know-how of the Zarmen FPA forge. To evaluate the structure and mechanical parameters, the ring was subjected to the following tests:

- a study of the chemical composition of intermetallic phases using energy-dispersive spectroscopy (EDS),
- microstructure observations on longitudinal sections of the samples using a light microscope (LM),
- scanning electron microscope (SEM),
- hardness measurements on longitudinal and transverse sections of the samples using the Vickers method,
- static tensile test.

Samples were taken from the rolled rings numbered as follows:

- 2-1P OC_W – sample taken longitudinally from the ring after heat treatment from the part with the outer surface,
- 2-2P OC_W – sample taken longitudinally from the ring after heat treatment from the middle part,
- 2-3P OC_W – sample taken longitudinally from the ring after heat treatment from the part with the inner surface.



a) micro-area 1 b) micro-area 2 c) micro-area 3 d) micro-area 4 e) micro-area 5 f) micro-area 6

Element/ spectral line	Element content/ wt.%					
	Micro-area 1	Micro-area 2	Micro-area 3	Micro-area 4	Micro-area 5	Micro-area 6
Mg-K	--	---	---	2,90	2,70	---
Al-K	68,13	68,71	69,91	90,24	91,02	57,39
Fe-K	20,13	20,34	19,37	---	---	14,43
Cu-K	7,75	7,16	6,86	---	---	28,13
Zn-K	3,98	3,79	3,85	6,85	6,28	---

Figure 2 Results of EDS sample No. 2-2P OC_W taken longitudinally from a heat-treated ring

TEST RESULTS

EDS

These tests were performed on specimen no. 2-2P OC_W taken longitudinally from an EN AW-7075 alloy ring and prepared, like a metallographic deposit, according to test instruction No. Z-IB/3-05. The purpose of the study was to determine the chemical composition of the intermetallic phases present in EN AW-7075 aluminum alloy after rolling and heat treatment. The tests used a voltage of 15 kV, a working distance (WD) of 10 mm. The test results are included in Figure 2.

In sample No. 2-2P OC_W, large Al.-Cu-Fe phase separations were noted in micro-areas 1-3 and 6, as well as dispersive MgZn2-type phase separations in micro-areas 4 and 5.

Microstructure observation (LM)

These tests were performed on samples No. 2 1P OC_W, 2-2P OC_W and 2-3P OC_W. Studies of the

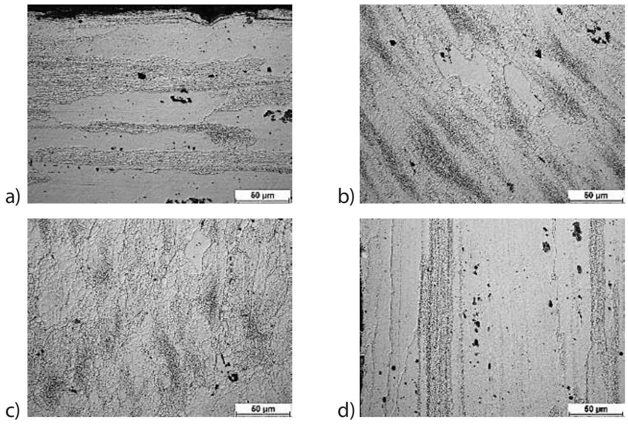


Figure 3 Microstructure on the longitudinal section of specimen No. 2-1P OC_W. LM: a) area 1 at the top surface of the ring, b) area 2 near the centre of the specimen, c) area 3 in the middle zone of the ring, d) area 4 at the outer surface of the ring.

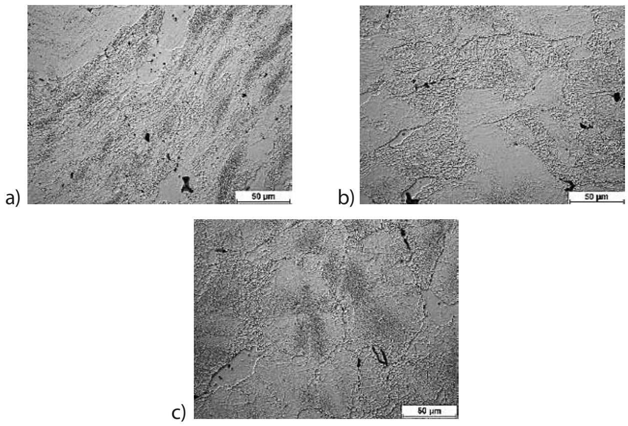


Figure 4 Microstructure on the longitudinal section of the sample No. 2-2P OC_W. LM: a) area 1 near the ring surface, b) area 2 near the centre of the specimen, c) area 3 in the middle zone of the ring

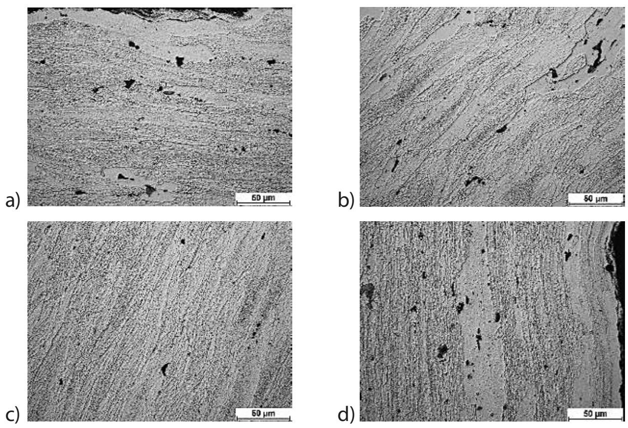


Figure 5 Microstructure on the longitudinal section of specimen no. 2-3P OC_W. LM: a) area 1 near the ring surface, b) area 2 near the centre of the sample, c) area 3 in the middle zone of the ring, d) area 4 near the inner surface of the ring

microstructure of samples taken from the ring subjected to supersaturation and aging in the Zarmen FPA forge were carried out in G. Nomarski's differential interference contrast. Microphotographs of the microstructure were recorded at an image magnification of 310x. Images of the structures are included in Figures 3-5.

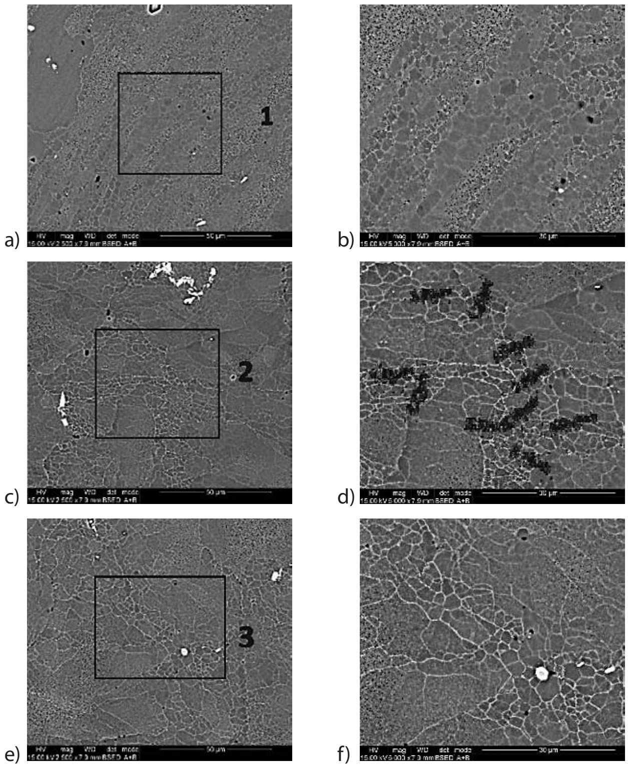


Figure 6 Microstructure on the longitudinal section of sample No. 2-2P OC_W. SEM: a) area 1 in the near-surface zone of the ring, b) enlarged section of area 1, c) area 2 near the centre of the sample, d) enlarged section of area 2 with the size of recrystallized grains marked, e) area 3 near the centre zone of the ring, f) enlarged section of area 3

The microstructure of specimens No. 2-1P OC_W and 2-3P OC_W, at the top, outer and inner ring surfaces shows: plastically deformed grains of α-solid solution (Al) in the rolling direction, bands with recrystallized very fine grains of α-solid solution, and coarse (primary) separations of intermetallic phases (Figure 3b and c, Figure 5b). Near the centre of the two samples, grains of the α solid solution that have not recrystallized are obliquely aligned to the top surface of the ring (Figure 3b and 5c). The microstructure of the subsurface zone of sample No. 2-2P OC_W (more than 0,3 mm from the top surface of the ring)is dominated by areas with recrystallized very fine grains of α-solid solution (Figure 4b). No significant differences in microstructure were observed in the middle zone of this sample and in the middle zone of the ring (Figures 4b and 4c). These areas predominantly show recrystallized very fine grains of α-solid solution and primary separations of intermetallic phases. In order to further observe the recrystallized grains of the α-solid solution, the microstructure of sample 2-2P OC_W was studied by SEM.

SEM

This research was performed on sample No. 2-2P OC_W, which was observed usinglight microscope. The following parameters were used in the study: voltage of 15 kV, backscattered electron detector (BSED), working distance WD=7,9 mm, and image magnifications of 2 500x and 5 000x. The results are shown in Figure 6. Photographs of the microstructure were recorded at magnifications of:660x and 1330x.

Observations of the microstructure of sample No. 2-2P OC_W taken from the centre of the ring after heat treatment by SEM confirmed the presence of large plastically deformed grains of α (Al) solid solution and recrystallized grains of severalmicrometre in size (Figure 6). Also observed in the microstructure of this sample were primary and secondary separations of intermetallic phases, as well as etching "cavities" located in areas of high density of secondary separations of intermetallic phases.

Hardness measurements

Vickers hardness measurements were made at a loading force of 4,903 N on samples subjected to microstructure tests. One HV 0,5-1 hardness distribution was carried out from the top surface of the ring deep into the specimen to the middle zone, and another located perpendicularly HV 0,5-2 in the middle zone of the ring. The results of the average hardness of each hardness distribution for a series of samples taken from the rolled ring after heat treatment are shown in Figure 7.

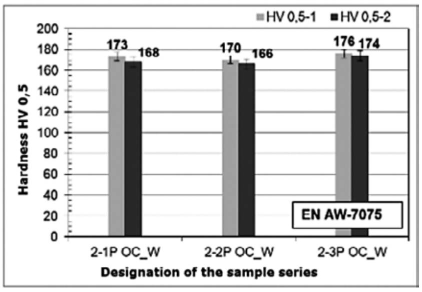


Figure 7 Average hardness of two perpendicularly located hardness distributions of HV 0.5 1 and HV0.5-2 samples No. 2-1P OC_W, 2-2P OC_W and 2-3P OC_W.

The effect of the ring heat treatment was to increase the average hardness to values ranging from 166 HV 0,5 to 176 HV 0,5.

Static tensile test

The static tensile test was performed on samples with a diameter of d_o= 10 mm anda measuring length of L_o =150 mm, which were taken from a heat-treated rolled ring of EN AW-7075 alloy. The results of the static tensile test - the determined indices $R_{p0.2}$, Rm and A are shown in Figure 8.

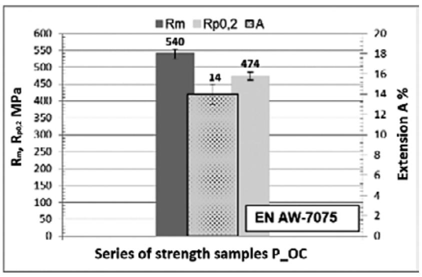


Figure 8 Results of static tensile test of samples taken from rolled and heat-treated EN AW-7075 alloy ring.

Heat treatment of the rolled EN AW-7075 aluminum alloy ring resulted in the following indices of mechanical properties: tensile strength R_m - 540 MPa, conventional yield strength $R_{p0.2}$- 474 MPa and elongation A - 14%. The obtained values of all indicators are satisfactory and exceed the assumed minimum values of: R_m- 500 MPa, $R_{p0.2}$- 450 MPa and A - 10%.

SUMMARY

The proposed technology for shaping the ring using the forged-rolled method made it possible to produce a ring of the given shape with small technological allowances for finishing.

SEM studies conducted confirmed the achievement of a homogeneous ring structure.

Measurements of the hardness distribution in two directions confirm the achievement of a uniform hardness distribution.

The proposed heat treatment parameters of aluminum alloy EN AW - 7075 to the T6 state allowed to obtain a homogeneous structure and the following strength properties of the ring metal: R_m – 540 MPa, $R_{p0,2}$– 474 MPa and A – 14 %and met customer requirements: R_m – 500 MPa, $R_{p0,2}$ – 450 MPa and A – 10 %.

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Note: The responsible translator for English language is Maria Gąsiorkiewicz, Poznań, Poland.