A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 60 2015 Issue 4
DOI: 10.1515/amm-2015-0476

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THE EFFECT OF EXTRUSION PARAMETERS ON POSSIBILITY OF EXTRUSION OF MAGNESIUM ALLOYS IN CONTINUOUS ROTARY EXTRUSION PROCESS

WPŁYW PARAMETRÓW PROCESU WYCISKANIA NA MOŻLIWOŚĆ WYCISKANIA STOPÓW MAGNEZU METODĄ CIĄGŁEGO WYCISKANIA NA KOLE

Continuous rotary extrusion (CRE) is the more and more frequently used variation of the plastic working process. Magnesium alloys, due to its properties are becoming increasingly popular as a substitute for aluminium alloys and steel, particularly in the aerospace and transportation industries. The main aim of this study was to optimize the parameters of the CRE process for selected commercial magnesium alloys such as AZ81 and AZ91. Extruded in CRE process rods were subjected to visual observations, microstructure examination, and testing of mechanical properties. Basing on the CRE test results and studies, parameters enabling successful execution of the process were specified. It was found that the greatest impact on the extrusion process has the die temperature, and it can be controlled mainly by adjustment of other CRE parameters (eg. process speed).
Keywords: CRE, Conform, magnesium alloys, extrusion parameters.

Ciągłe wyciskanie na kole CRE jest coraz częściej stosowanym procesem przeróbki plastycznej przez wyciskanie. Stopy magnezu ze względu na ich właściwości coraz częściej wypierają stopy aluminium oraz stal, szczególnie z przemysłu lotniczego i transportowego. Celem pracy była optymalizacja parametrów procesu CRE, w odniesieniu do wybranych, przemysłowych stopów magnezu AZ81 i AZ91. Pręty wyciśnięte w procesie CRE poddano ocenie wizualnej, obserwacjom mikrostruktury, a także badaniu własności mechanicznych. Na podstawie przeprowadzonych prób wyciskania na kole i wyników badań określono parametry procesu, dla których proces przebiegał pomyślnie. Stwierdzono, że na proces wyciskania największy wpływ ma temperatura matrycy, którą kontrolować można głównie poprzez odpowiednie dobranie pozostałych parametrów (np. prędkości procesu).

1. Introduction

Continuous rotary extrusion (CRE), owing to the possibility of making various products in a stepless way, combined with a specific process of material deformation in the die (changed route of strain), seems to be a promising future solution for plastic working by extrusion. Materials obtained in this process are characterized by fine grain structure and high mechanical properties. The process is, moreover, efficient and fast. [1].

The main role in the CRE process plays friction. It advances the material to the extrusion chamber and further to effectuate its passage through a die. Friction in this process also causes gradual heating of feedstock by its contact with the tools, which produces appropriate temperature and ductility for the rest of the extrusion process [2, 3, 4]. A diagram of the process of continuous rotary extrusion is shown in Figure 1.

The growing demand for products made of magnesium alloys with high mechanical properties manufactured in a commercially reasonable manner requires knowledge of the specific character of various forming processes and their impact on the properties of the obtained products. Wrought products processed by extrusion offer the strength and ductility definitely superior to cast products [6].

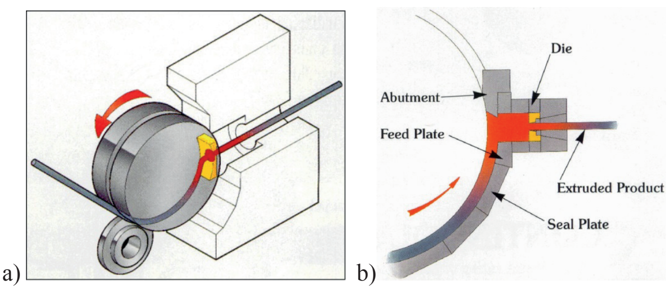

Fig. 1. Schematic diagram of a continuous rotary extrusion process; a) general scheme, b) the die area [5]

Due to the specific crystallographic structure, magnesium alloys have low deformability. Therefore, a very important factor in the process of extrusion is the temperature of

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this process. It is responsible for the engagement of a slip mechanism and its operation in the deformed alloy, affecting the structure (particle size), and consequently also the mechanical properties of the extruded product.

2. Methodology and research results

As a feedstock for the process of continuous rotary extrusion, two commercial magnesium alloys, i.e. AZ81 and AZ91, were selected. Both were direct extruded in the form of 10 mm diameter rods and then examined for the microstructure and grain size, including also testing of the mechanical properties.

Rods with a 10 mm diameter were extruded in the process of continuous rotary extrusion on a Conform-type device (MC-260 made by Meltech-Confex Limited) installed and operating in the IMN-OML Institute of Non-Ferrous Metals – Light Metals Division Skawina (Fig. 2).

Fig. 2. A Conform-type device for the continuous rotary extrusion

During the process of the continuous rotary extrusion, the direct control covered parameters such as the process speed (the rotating wheel speed), the shoe heating temperature (a part of the device which contains the die tools), and the temperature and length of the feedstock material. Additionally, during the process, both wheel and die temperature was recorded. The temperature of the wheel and the die was measured by a thermocouple in the profiled groove of the wheel and in the area of the die bearing land. The feedstock for CRE was used in either cold state or preheated to different temperatures. Rods of different lengths were used. The die was of a circular shape with a diameter of 9 mm.

Rods extruded in the CRE process were assessed visually for the presence of cracks, scratches, delaminations or burrs. As an assessment criterion for the correct run of the process, rods with the surface continuous over a length of at least 1 metre were accepted. Cracks and delaminations were permitted provided they did not result in the process interruption. Rods discontinuous and cracked were evaluated negatively. In the case of AZ81 alloy, positive evaluation gained five rods extruded at different CRE process parameters; in the case of AZ91 alloy, positive evaluation gained ten rods extruded at different CRE process parameters.

Examples of process parameters that have yielded rods with a satisfactory surface in both extruded alloys are shown in Table 1. Examples of process parameters that have yielded rods with an unsatisfactory surface according to the visual assessment criteria are shown in Table 2.

During visual assessment to find the best surface quality in both alloys, the highest rated rods have been extruded at the wheel speed of 3 rpm. and the shoe temperature of 200°C. The temperature of the wheel at which the feedstock was fed to the extrusion device was 200°C for the AZ81 alloy and 210°C for the AZ91 alloy. The die starting temperature was 310°C (AZ81) and 280°C (AZ91). The final die temperature at the time of the CRE process stabilization was in both cases 350°C. For both alloys, the feedstock material was supplied in the form of rods 30-35 cm long preheated up to 250°C (AZ81) and 350°C (AZ91).

TABLE 1

Example of CRE rods extruded from the AZ81 and AZ91 alloys and extrusion parameters

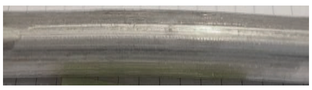
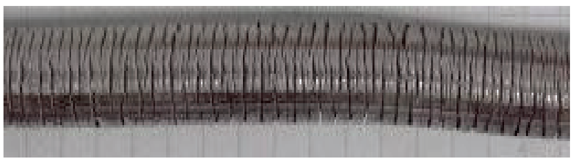
	Alloy	
	AZ81	**AZ91**
Process parameters	Rotating wheel speed: 3 rpm Shoe temperature: 200°C Wheel temperature: 200°C Die temperature: – Start of process: 310°C – End of process: 350°C Feedstock rod temperature: 250°C Feedstock rod length: 30-35 cm	Rotating wheel speed: 3 rpm Shoe temperature: 210°C Wheel temperature: 200°C Die temperature: – Start of process: 280°C – End of process: 350°C Feedstock rod temperature: 350°C Feedstock rod length: 30-35 cm
CRE rod		

TABLE 2

Example of CRE parameters of AZ91 rod with negative visual assessment

	CRE AZ91
Process parameters	Rotating wheel speed: 7.5 rpm Shoe temperature: 200°C Wheel temperature: 180°C Die temperature: – Start of process: 320°C – End of process: – Feedstock rod temperature: 350°C Feedstock rod length: 30-35 cm
CRE rod	

Rods positively ranked during visual evaluation were next examined by light microscopy for the microstructure and grain size. Grains in both alloys were revealed by chemical etching. For both alloys, the grain size was measured in feedstock rods and in rods extruded by CRE. Examples of the microstructure and grains revealed in AZ81 and AZ91 alloys are shown in Table 3, while the results of grain size measurements are shown in Table 4.

TABLE 3
Microstructure and grains as observed in feedstock rods vs CRE rods

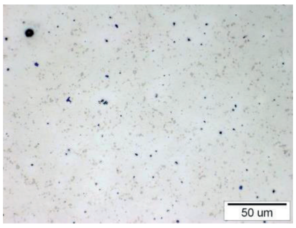
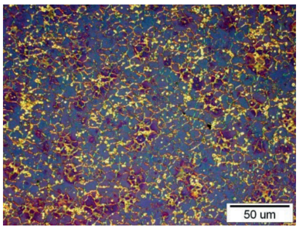
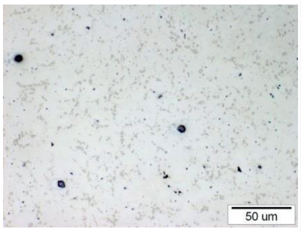
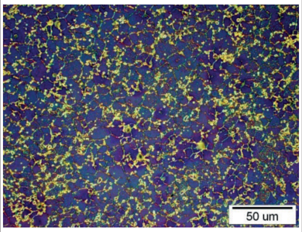
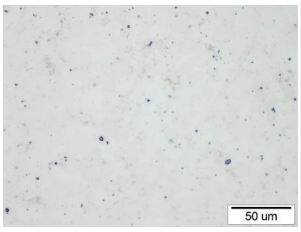
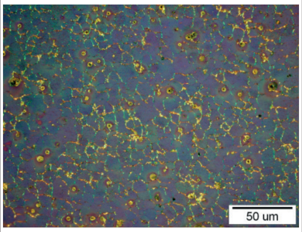
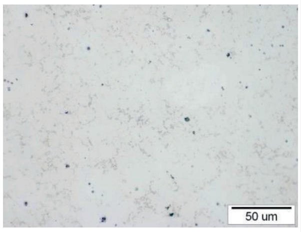
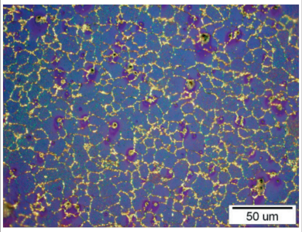
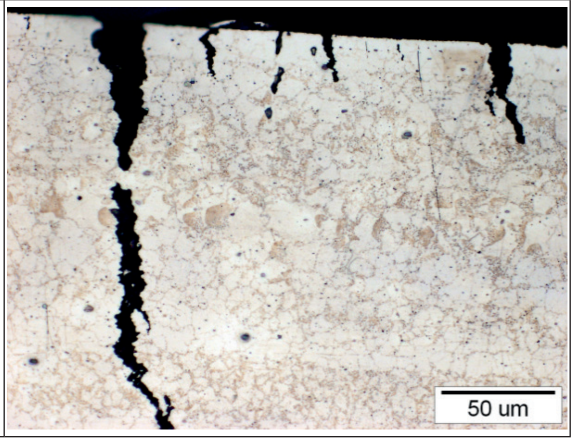
Rod		Microstructure	Grain
Feedstock rods	AZ81		
	AZ91		
CRE rods	AZ81 CRE		
	AZ91		

TABLE 4
The results of measurements of the mean grain diameter [μm] in feedstock rods vs CRE rods

Average grain diameter [μm]			
Feedstock rods		**CRE rods**	
AZ81	**AZ91**	**AZ81**	**AZ91**
8.2	10.6	10.3	7.4
		13.1	8.0
		11.6	8.4
		12.5	7.9
		12.5	8.2
			9.2
			7.3
			8.5
		MAX	**13.4**
		MIN	11.8

Microstructure examinations using light microscopy were also conducted on the CRE (AZ91 alloy) rod which was negatively assessed during visual examination. The microstructure examined on the longitudinal section of the rod negatively ranked for its quality is shown in Table 5.

TABLE 5
Negatively ranked microstructure of the AZ91 rod extruded by CRE

Rod	Microstructure – longitudinal section
CRE AZ91	

Rods of AZ81 and AZ91 magnesium alloys were characterized by a uniform structure before and after CRE. Fine, evenly distributed precipitates and small grains of a uniform size were observed (Table 3). Rods overheated during CRE were characterized by numerous cracks penetrating into the material (Table 5).

Rods extruded by CRE from AZ91 alloy were in most cases characterized by grains more refined than the grains in feedstock rods made of the same alloy. In contrast, grains measured in CRE rods extruded from AZ81 alloy were coarser than in the feedstock rods made of the same alloy (Table 4).

For both alloys, rods extruded by CRE were also subjected to static tensile test and hardness measurement (HBW 2.5/62.5).

Hardness measured on the feedstock material was 71.8 for rods of AZ81 alloy and 74.4 for rods of AZ91 alloy. For rods extruded by CRE from the AZ81 alloy, the highest measured hardness was 73.0, while the lowest was 67.1. For rods extruded by CRE from the AZ91 alloy, the highest measured hardness was 76.2, while the lowest was 68.8. For both CRE-processed alloys, the measured values of hardness were close to the hardness values measured in feedstock rods (Table 6).

In the case of AZ91 alloy, all flat sections extruded by CRE were characterized by the mechanical properties inferior to the properties of rods extruded from the same alloy by conventional technique. In the case of AZ81 alloy, for all rods extruded by CRE, lower yield strength and tensile strength values were reported. The elongation was lower too, with one exception (Table 7).

TABLE 6

The results of hardness measurements taken on feedstock rods and on CRE rods (HBW 2.5/62.5)

Hardness HBW 2,5/62,5			
Feedstock rods		**CRE rods**	
AZ81	**AZ91**	**AZ81**	**AZ91**
71.8	74.4	67.1	72.5
		68.4	75.8
		69.9	**76.2**
		70.5	72.7
		73.0	75.2
			68.8
			74.5
			71.1
		MAX	75.8
		MIN	72.5

TABLE 7

The results of static tensile test made on feedstock rods vs CRE rods

AZ81			**AZ91**			**AZ81**			**AZ91**		
$Rp_{0,2}$ [MPa]	**R_m [MPa]**	**A [%]**	**$Rp_{0,2}$ [MPa]**	**R_m [MPa]**	**A [%]**	**$Rp_{0,2}$ [MPa]**	**R_m [MPa]**	**A [%]**	**$Rp_{0,2}$ [MPa]**	**R_m [MPa]**	**A [%]**
238	340	16,7	255	357	14,5	**175**	**322**	**21,9**	188	310	6,3
						165	295	12,2	**204**	306	6,0
						161	275	10,2	199	294	5,5
						153	289	11,9	178	**319**	**11,0**
						164	305	14,0	150	195	1,5
									155	193	1,8
									178	303	9,8
									186	296	7,2
						MAX			179	209	1,7
						MIN			185	303	8,7

3. Summary and conclusions

During trials of continuous rotary extrusion of magnesium alloys it was noticed that the process of extrusion (its stability and the quality of products obtained) was most influenced by the die temperature, which could be controlled mainly by properly selected rotating wheel speed, proper feedstock material temperature and temperature of the shoe.

Tracing the run of the CRE process, the optimum wheel temperature has been selected at which the feedstock material could be introduced between the rotary wheel and the pressing wheel and moved towards the die chamber. The optimum feedstock temperature was also selected, which did not cause alloy retention in front of the die and did not contribute to excessive heating of the die. The best process speed (the rotating wheel speed) was adjusted to maintain the die temperature at an appropriate level.

The optimum process conditions selected on the basis of extrusion tests and examinations of both feedstock rods and rods extruded by CRE were as follows:

- feedstock material temperature of 200°C for AZ81 alloy and 350°C for AZ91 alloy,
- rotating wheel temperature of approx. 200°C,
- initial die temperature of minimum 280°C,
- rotating wheel speed of 3 rpm,
- die temperature of 350°C (stable process).

REFERENCES

[1] M. Mitka, W. Szymański, Rudy i Metale Nieżelazne **7-8,** 405-411 (2011).

[2] J. Zasadziński, T. Knych, E. Dziedzic, Rudy i Metale Nieżelazne **11**, 757-767, (2007).

[3] Y. Kim, J. Cho, H. Jeong, K. Kim, S. Yoon, J. Mater. Process. Technol. **80-81**, 671-675 (1998).

[4] Y. Kim, J. Cho, H. Jeong, K. Kim, S. Yoon, J. Mater. Process. Technol. **97**, 153-157 (2000).

[5] http://www.meltech.co.uk/

[6] H. Zhang, Q. Yan, L. Li, Mater. Sci. Eng. A **486**, 295-299 (2008).

Received: 10 November 2014.