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RESEARCH ON EXTRUDED PRODUCTS OF MGALZN ALLOYS – MICROSTRUCTURE AND MECHANICAL PROPERTIES

BADANIA WYROBÓW WYCISKANYCH ZE STOPÓW MGALZN – MIKROSTRUKTURA I WŁAŚCIWOŚCI MECHANICZNE

The aim of the study was to test and assess products extruded from the magnesium alloys type MgAlZn: AZ31, AZ61 and AZ80A alloys in the form of Ø35mm round bars and 80x15mm flat bars. The test material was extruded in a direct system with the ram feed speed of 1 mm/s and the extrusion ratio $\lambda = 7 \div 9$. The extruded bars were examined in as-extruded state and after heat treatment to the T5 temper and T6 temper. The strength properties were tested and microstructure was examined with calculation of the average grain size.
Keywords: magnesium alloy, extrusion, mechanical properties, structure

Praca miała na celu zbadanie wyrobów uzyskanych w procesie wyciskania stopów magnezu typu MgAlZn: AZ31, AZ61 oraz AZ80A w postaci prętów Ø35mm oraz płaskowników 80x15mm. Materiał do badań został wyciśnięty w systemie współbieżnym z prędkością posuwu tłoka 1 mm/s, przy współczynniku wydłużenia λ=7÷9. Wyciśnięte pręty analizowano w stanie wyciskanym oraz po obróbce cieplnej do stanu T5 i T6. Zbadano ich właściwości wytrzymałościowe jak również poddano analizie mikrostruktury z określeniem średniej wielkości ziarna.

1. Introduction

Magnesium is now one of the most desirable construction materials. Its growing popularity is associated with the increased demand for lightweight structural parts – the fact which makes magnesium a very attractive material starting from the transport sector, through the electronics industry, and sports and rehabilitation sectors, to bioimplants. This is mainly due to the possibility of reducing the weight of items made of magnesium alloys by plastic forming. Owing to their favourable strength properties, MgAlZn alloys are the most widely used materials in the group of magnesium-based systems [1,2]. Aluminium and zinc have a very beneficial effect on the improvement of tensile strength and hardness. Additionally, the solubility of aluminium in magnesium raising from the eutectic temperature of 437°C up to a maximum content of 12.7% in the solid state allows heat treatment to the T5 and T6 temper, leading to an improvement of the mechanical properties by precipitation hardening [3,4,5,6]. Besides low weight, other advantages of magnesium include satisfactory mechanical properties, good weldability and vibration damping capacity [7].

2. Test material and methodology

Studies of the direct extrusion process were conducted on MgAlZn (AZ31, AZ61, AZ80A) magnesium alloys. The chemical compositions of studied material is presented in the table below (Table.1). Tests of direct extrusion were conducted on horizontal 5MN force press using specially designed and constructed tooling [8].

To obtain a sufficient degree of solutionizing in the extruded parts undergoing a heat treatment to the T5 temper it was necessary to ensure the process temperature high enough to prevent the tested material from cooling down spontaneously before entering the press water wave. In the case of magnesium alloys tested, it was necessary to operate in a range of 390-420°C.

Profiles obtained by the extrusion process were subjected to the subsequent operations of a toughening heat treatment. Magnesium alloys are most often heat treated to the T5 temper (solutionizing from the temperature of plastic forming and artificial aging) and to the T6 temper (solutionizing and artificial aging). The T5 temper yields superior mechanical properties, contrary to the T6 temper which, by involving the heat treatment with additional heating operations, may result in strong recrystallization adversely affecting the properties obtained. As regards the T6 temper, the solutionizing parameters adopted for AZ31 and AZ61 alloys were 420°C/2h. In the case of AZ80A alloy, besides holding at a temperature of 420°C for 1 h, the experiment was designed in such a way as to investigate whether long-term heating of the alloy (for 24 hours) will allow achieving a higher degree of the supersaturation of solid solution, leading ultimately to a more

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TABLE.1

Chemical composition of tested MgAlZn alloys

No	Alloy	Zn	Al	Si	Cu	Zr	Mn	Rest
		[%]	[%]	[%]	[%]	[%]	[%]	[%]
1	MgAlZn (AZ80A)	0,28	8,1	0,02	0,01	------	0,18	< 0,3
2	MgAlZn (AZ61)	0,62	5,97	0,3	0,003	---	0,31	< 0,3
3	MgAlZn (AZ31)	0,72	3,2	0,02	0,001	---	0,37	< 0,3

intensive formation of precipitates during aging. For each of the tested alloys, aging was carried out at 170°C for 20h.

The heat-treated materials were tested in static tensile test (Rm, Rp0.2, A), the distribution of hardness values was measured on the cross-section of the samples (HB), while structure examinations were carried out by light microscopy on macro- and micro-level.

3. Extrusion process

The extrusion process was carried out on a direct-indirect horizontal press of 5MN force, operating at an extrusion ratio of $\lambda = 7 \div 9$ and the ram feed speed of 1 mm/s. Ingots of 100mm diameter were preheated to a temperature of 400°C, while the press recipient and tools were preheated to 390°C. The test material heat treated to the T5 temper was subjected to the on-line solutionizing treatment in a press water wave.

The obtained material was characterized by a uniform outer surface, free from cracks and surface melting (Fig.1).

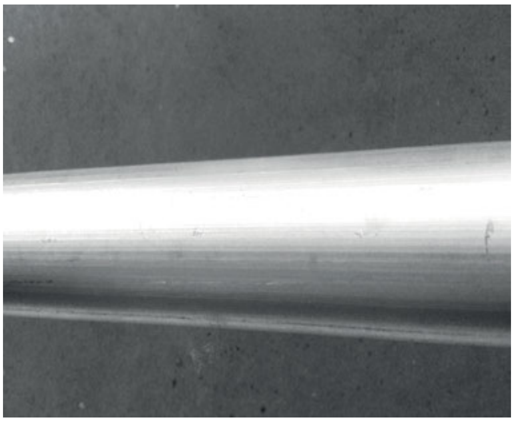

Fig.1. Surface of extruded Ø35mm rods obtained from AZ61 alloy

In the case of a heat treatment to the T5 temper, the surface of the extruded rods was coated with the corrosion products formed during the contact of hot metal with water. The image in Figure 2 shows an example of this effect.

Fig.2. Surface of Mg alloy rod after on-line cooling

4. Structure of investigated alloys

As is widely known, magnesium alloys are considered susceptible to the process of recrystallization and structure recovery at elevated temperatures [2]. To confirm this effect, at each stage of the process of plastic forming and heat treatment, representative samples were collected and macrostructure was examined.

The structural analysis showed some variations in the grain size on the cross-section of the obtained profiles. Particularly evident was the tendency to the formation of a rim of coarse crystals in components with different geometry and sufficiently high degree of processing. Figure 3 gives an example illustrating this effect.

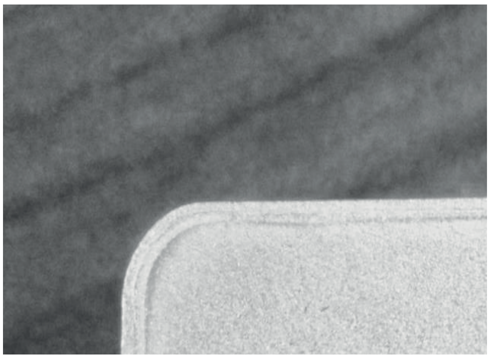

Fig. 3. Rim of coarse crystals formed during extrusion of MgAlZn alloys

Samples taken from the beginning and end of the extruded strip enabled comparing the structure evolution during the extrusion process. Close examination of the sample images (Fig. 4) shows an extremely high degree of structure homogeneity on the entire length of the strip with fluctuations in average grain size not exceeding 20%. The images in Figure 5 illustrate the differences in structure depending on the alloy type.

Detailed analysis of these images shows in samples of the AZ80A alloy a very small average size of grains and distinct effect of recrystallization - the consequence of additional heating process during heat treatment to the T6 temper. Comparing the structure of profiles made from the AZ31 alloy and AZ61 alloy, a slightly more refined and more uniform grain size distribution was observed in the AZ61 alloy. To trace the course of the process of recrystallization in products cooled on the press run out table, the structure of the AZ61 alloy air-cooled and frozen in a “water wave” (“on line” cooling) was examined. The results of this experiment are shown in Figure 6. The examination did not reveal any more significant differences between the two materials. This might be due to a relatively low temperature at which the process was conducted (400°C) and a relatively small heat capacity, which usually results in rapid temperature drop even if no additional cooling in the form of a "water wave" is applied.

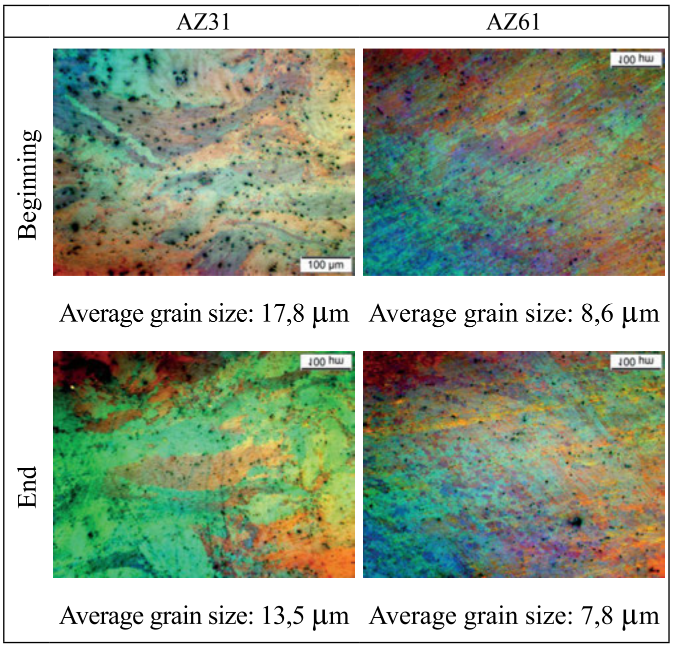

Fig. 4. Microstructure examples of AZ31 i AZ61 alloys; samples taken from beginning and end of rods

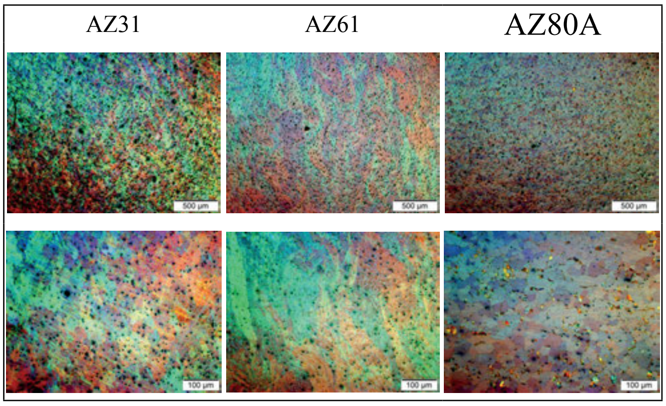

Fig. 5. Microstructure diversity of examined MgAlZn alloys

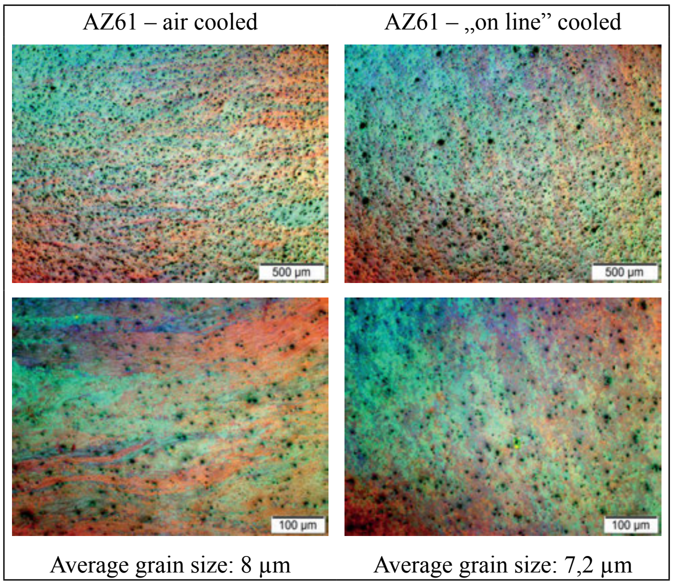

Fig. 6. Comparison of microstructure of air-cooled and on-line cooled extruded AZ61 alloy

5. Mechanical properties

The above mentioned magnesium alloys were also examined for the mechanical properties in a static tensile test (Rm, R0,2, A) combined with hardness (HB) measurements. Table 2 summarizes the results obtained in this respect.

The results of static tensile test and hardness measurements are consistent with the results of structure examinations of the Mg alloys. In the case of AZ31 alloy, because of a low content of the alloying elements, the precipitation hardening (in T5 temper) has not improved the alloy properties. On the other hand, reheating the alloy during heat treatment to the T6 temper has intensified the process of structure recovery, made the grains coarser due to recrystallization and ultimately reduced the mechanical properties. The situation was slightly different in the case of AZ61 alloy. In this alloy, the maximum properties were obtained as a result of heat treatment to the T5 temper, which proves that the alloy is susceptible to precipitation hardening. The attempt to heat treat the alloy to the T6 temper by preheating the samples with the following solutionizing and

TABLE 2

Results of static tensile test and hardness measurement

L.p	Alloy	Temper	Rm	R02	A	HB
			[MPa]	[MPa]	[%]	
1	AZ31	F	306	250	19	71
2	AZ31	T5	307	258	16	70
3	AZ31	T6	255	166	24	65
4	AZ61	F	316	207	19	69
5	AZ61	T5	334	224	21	79
6	AZ61	T6	311	204	20	70
7	AZ80A	F	314	249	8	69
8	AZ80A	T6 short heating	350	247	12,4	74
9	AZ80A	T6 long heating	332	220	17,2	69

aging resulted in a similar effect as in the previously discussed AZ31 alloy. The process of recrystallization and its effect on the grain growth has eliminated the effect of precipitation hardening and reduced the mechanical properties of the alloy.

As regards the AZ80A alloy, from the studies conducted previously it is known that this alloy acquires higher mechanical properties in the T5 temper rather than in the T6 temper [9.10]. Therefore, in this case, both methods of the heat treatment to the T6 temper were compared, i.e. the short (1h) time of holding at 420°C and the long (24h) time of holding at 420°C, followed by artificial aging at 170°C for 20h. The results of this experiment show that, for the tested alloy, shorter time of holding at the temperature of solution heat treatment is sufficient to obtain a strong effect of the precipitation hardening. The sample heat treated for a shorter time exhibited much higher strength properties than the sample treated for a longer time. It is also easy to notice that of all the alloys tested, the effect of precipitation hardening is most eminent in the AZ80A alloy. All tested alloys after the recrystallization process have gained higher values of ductility.

6. Conclusions

- For the examined alloys more preferable has proved to be the heat treatment to the T5 temper, since it provided maximum mechanical properties.
- The heat treatment to the T6 temper caused grain growth and consequently a decrease in mechanical properties with ductility increase in the examined sections.
- The extrusion process should be carried out at a temperature, which will make solutionizing of the material on the press run out table possible. The result will be fine structure and high mechanical properties. At the same time it will allow reducing the extrusion force.
- For the AZ80A alloy, the shorter time of holding at the temperature of solution heat treatment has proved to be sufficient to obtain a strong effect of the precipitation hardening. The sample heat treated for a shorter time has exhibited much higher strength properties than the sample treated for a longer time.
- Of all the tested alloys, the effect of precipitation hardening was most prominent in the AZ80A alloy.

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