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QUALITY OF TUBES OF MAGNESIUM ALLOY AZ31 AT THE DIFFERENT PORTHOLE DIES GEOMETRY AND TEMPERATURE PARAMETERS

Исследовано влияние конструкции прессового инструмента и параметров процесса прессования на показатели качества труб из магниевого сплава системы Mg-Al-Zn-Mn.

Досліджено вплив конструкції пресового інструменту й параметрів процесу пресування на показники якості труб з магнієвого сплаву системи Mg-Al-Zn-Mn.

Influence of extrusion tool and extrusion parameters on tube quality indices made of magnesium alloy of system Mg-Al-Zn-Mn.

Introduction

The advantages of extruded semi-finished products of magnesium alloys are follows: high strength (including fatigue strength) and stiffness, absence of aging effect, high damping properties and practically 100% recycling. If an existing price for primary magnesium is not changed the consumption of tubes and shapes of magnesium alloys will rise, first of all in transport engineering.

Literature analysis. Considered in this work magnesium alloy is widespread enough, however the information about the tool used for its extrusion and relationship of mechanical properties and quality of tubes to process’s temperature -speed conditions is quite limited.

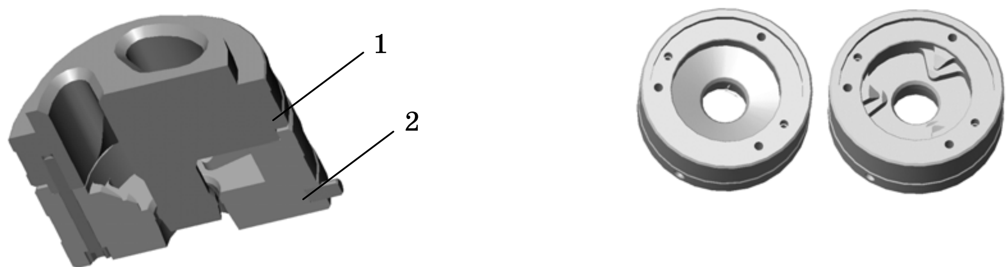
The information about used temperature-speed modes of extrusion and mechanical properties of shapes and tubes of the closest alloys by the chemical composition (system Mg-Al-Zn-Mn) are given in works [1, 2].

Data on the rational temperature-speed modes of extrusion are quite diverse and even inconsistent. Extrusion is carried out normally at the extrusion ratios (ER) about 30. Rods and tubes produced with a long mandrel allow to using the greater ER.

The purpose of the present work is to determine of rational modes of extrusion of tubes $\varnothing 40\times 2$ mm from the magnesium alloy AZ31B with taking into account geometry of the porthole dies.

Experimental methods. The experiments were carried out on 10-MN horizontal hydraulic press of Institute for material science of Lebniz University Hanover. A diameter of the internal core of the container is 125 mm. Process of extrusion is direct without forward tension. Homogenized turned billets with diameter of 120 mm and length 260-300 mm that were casted in a chill mould.

The extrusion was conducted through the porthole dies that are widespread in aluminium shapes production. However, form of a die was differed from traditional one for aluminium. Two dies were used with the same mandrel plate (fig. 1). The first had the double-cone inclined bottom. The second die was designed with the flat bottom on which three pairs of steps are placed. The axes of steps coincide with axes of the mandrel’s ports.



а *б*

Figure 1 – Tool set: *a* – porthole die (1 – mandrel plate; 2 – die plate); *b* – conical die; *c* – flat-stepped plate die

Temperature of the billet T_B and correlation between temperature of the container T_C and temperature of the billet (tab. 1) were also varied. The extrusion tool was heated up to a temperature that was equal to billet temperature. Ram speed was 2 mm/s, extrusion ratio 50, outflow speed 6 m/min.

Table 1

The plan of experiment

Number of experiment	Type of die	T_B, °C	T_C, °C
1	with the double-cone bottom of the welding chamber	360	340
2		400	340
3		400	400
4	with the flat-stepped bottom	360	340
5		400	400

Comparison of results was conducted not only for porthole dies with various types of weld chamber, but also with base variant "0" - extrusion with a long mandrel.

Measurement of surface temperature was being conducted with the help of the manual contact thermocouple; average temperature on a die exit was recalculated taking into consideration distance from the die to the place of measurement and outflow speed of a tube.

Samples for investigation of structure were prepared with using of electrolytic etching in the next solution: 20 ml of acetic acid, 5 g of picric acid, 20 ml of distilled water, 50 ml of ethanol.

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Results and discussion. *The geometrical characteristics of tubes.* The values of a diameter and wall thickness of tubes are given in a fig. 2. Elastic deformation, out-of-contact plastic deformation and temperature expansion are the basic reasons of nonuniformity of tubes geometry and their deviation from nominal values.

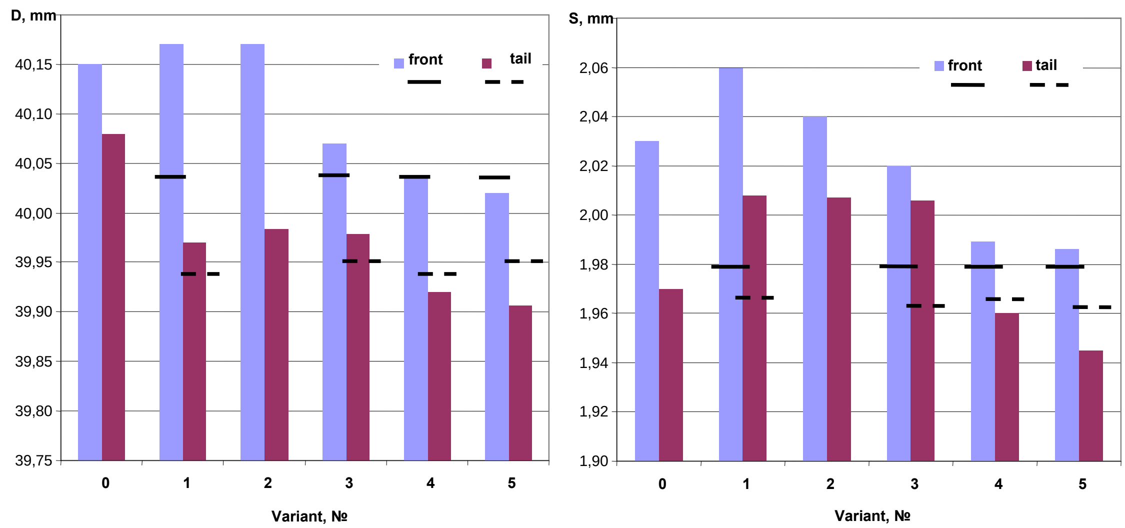


Figure 2 – Tube dimensions: *a* – diameter, *b* – wall thickness

Changing of mandrel and die dimensions due to elastic deformation was defined wit program COSMOSWorks for SolidWorks. Under extrusion pressure radiuses of die orifice and mandrel bearing reduced. Therefore decrease of distance between bearings of mandrel and die in radial direction at the maximal extrusion force was only 0,007 mm for the die set with flat-stepped die and 0,016 mm with conical die.

The analysis of results shows, that the diameter and wall thickness in the tail part is always less than in the front part of tube and to a great extent it caused by thermal expansion. The flat-stepped die allows extruding the tubes of smaller diameter and wall thickness than the conic die. The tubes produced through the flat-stepped die have in the front part of tube much smaller deviation of diameter caused by metal temperature. Wall thickness by using of the conical die is always more than expected value as a result of thermal expansion (on 0,01-0,08 mm), by using of flat-stepped die differs from expected thickness less than 0,01-0,02 mm.

As a whole, deviation of mean diameter and mean wall thickness from nominal value are not great. The allowable deviation for the examined size of tube according to ASTM B 107 for a wall thickness is 0,20 mm, for a diameter is 0,15 mm.

Extrusion force. Extrusion force for the examined tubes usually reached a maximum. The duration of the diagram part with the maximal extrusion force reaches 1/3 of a billet length. For examined extrusion conditions it was not found essential influence of die’s type on the force. The more great influence has billet length, presence of metal in a die and tool temperature.

Temperature of tubes. Magnesium alloys cool fast (in comparison with aluminium) on air. As the tube temperature measurement is difficult at the die bearing, an experiment for definition of cooling rate on air was carried out.

After approximation of the obtained results about temperature change in time (in a range 60 s) the next equation was obtained:

$$T = 0{,}027\ t^2 - 4{,}634\ t + 490, \qquad (1)$$

where T is temperature of tube surface (°C); t is time (s).

Cooling rate can be submitted as:

$$\Delta T/\Delta t = 0{,}3036\ \exp(0{,}0058T), \qquad (2)$$

where ΔT – change of temperature for the time interval Δt = 1 s.

Temperature of tube at the die bearing was determined using the equations (1) and (2) taking into consideration that the difference between temperature of shape's metal and environment in the die is not big (accepted 100°C), but at the outcome from the press (1 m from die bearing) already corresponds to conditions of above described experiment.

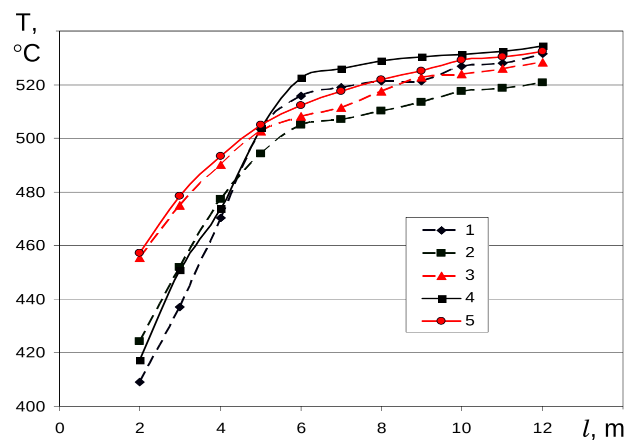


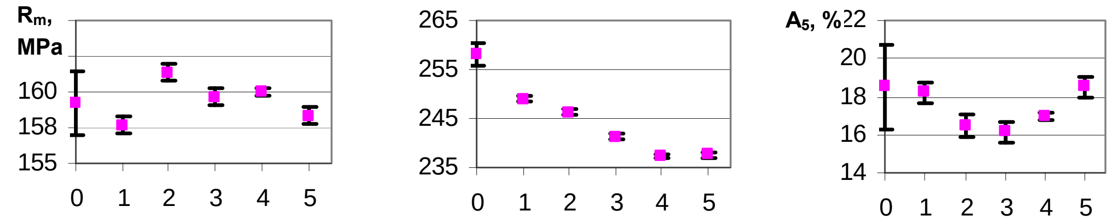
Figure 3 – Temperature changing along tube length

The corrected results of measurement of tube temperature are given on fig. 3. Temperature increase during extrusion with such extrusion ratio (50) is markedly great – 130-160°C (smaller values correspond to bigger billet temperature). Such values correspond with the results of works [1, 2].

The basic change of temperature (about 90 %) falls on a front part of tube that is appropriate to ram stroke that approximately equal to the container diameter.

During the extrusion through flat-stepped die tube temperature is higher, but insignificant (of some degrees).

Mechanical properties of tubes (fig. 4). Yield strength of tubes at the various extrusion conditions differs not considerably - within the limits of 2,5 %. Tensile strength is lower for tubes extruded through the flat-stepped die. At increase of billet’s temperature lead to little decrease the tensile strength of tubes extruded through the conical die (within only 8 N/mm^2) and practically it does not change for the flat-stepped die. Tubes produced with the flat-stepped die have a higher elongation.



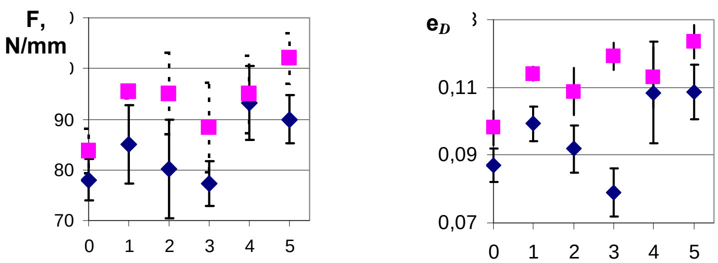


Figure 4 – Mechanical properties: *a* – yield stress; *b* – tensile stress; *c* – elongation; *d* – expanding force related to the tube perimeter at expanding; *e* – relative increase of perimeter; $e_D = \ln(D_1/D_0)$

As a whole the tubes received under above mentioned temperature-speed conditions demonstrate the tensile strength almost on the lower limit of requirements of DIN and ASTM and well higher elongation - on 60-120 %. However, it is necessary to take into account, that these tubes were produced without stretching for straightening, that normally lead to strengthening of tubes and decrease the elongation value.

The expanding tests characterize more objectively the strength of weld seam and a heat-affected zone than extension test. At this test expanding force related to the unit tube perimeter (fig. 4g), and the value of relative increase of perimeter (fig. 4d) are more for tubes extruded through the flat-stepped die. In a whole, these characteristics for welded tubes are not less than for seamless.

Structure of tubes’ metal. The analysis of cross-section of tubes shows that there are layers with finer grain in depth up to 0,3 mm near outside and inside surfaces of tubes. Sometimes at an outside surface on depth about 50 μm lays a layer with larger grains. Such allocation can be explained by the greater work of deformation in in-contact layers and friction on the contact of surface layers with die and mandrel.

The longitudinal weld seam was found only in the sections from front part of tubes extruded by higher billet temperature (400 °C) through the dies of both types. On an axis of a seam the size of a grain is more, than in a heat-affected zone.

In longitudinal section the structure of tubes can be characterized as equiaxed that was obtained from practically completed recrystallization. The grain size is given in table 2.

Table 2

The average grain size in various zones
of tube wall section (longitudinal), μm

Layer	Number of variant					
	0	1	2	3	4	5
outside	5,3	11,9	12,9	14,1	14,6	15,7
middle	9,3	17,9	19,1	25,3	28,7	27,5
inside	6,6	17,4	18,9	21,3	24,9	25,3

In tubes extruded through the flat-stepped dies grain size is greater on 2-4 μm, and at the higher billet temperature the difference is smaller. The extrusion process through the conical die is more sensitive to billet temperature: by increase of T_B from 360 to 400 °C the grain size in the basic body of tube has increased on 30 %, whereas at extrusion through the flat-stepped die it has not changed practically.

Temperature of the container has an essential influence upon structure. So, the extrusion according variant "2" at increased temperature of a billet (400°C), but at the "cold" container (340 °C), provides grain size much closer to variant "1" with the cold billet (360°C), than to variant "3" with a hot billet and the hot container.

Quality of tube surface. Quality of tubes surface was estimated by such criteria as "colour" - darkening as a result of oxidation, as well as presence of weld seen on outside and inside tube surface. In table 3 are given these parameters for different variants and the place of crack’s occurrence during expanding test is characterized.

The analysis of tab. 3 shows the follows:

- tube front is always less oxidized than the tail;
- at lower billet temperatures an inside tube surface is darker than outside, at higher T_B is on the contrary;
- on an outside tube surface the weld seam is not seen as a rule (except for a case of extrusion with the conical die at higher T_B);

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Table 3

The characteristics of tube surface quality

#	Place in tube	Darkening of surface		Type of a seam and a heat-affected zone		Place of a crack during expanding		
		out-side	inside	outside	inside			
0	m	1	3	seamless		b	b	b
1	f	1	1	–	w.s. (2-3 mm)	b	b	b
	t	1	2	–	w.s. (5-8 mm)	es	ms	ms
2	f	1-2	2	–	w.s. (2-3 vv)	es	b	ms
	t	4	3	–	w.g.s.(3-5 / 0,5-2 mm)	b	b	es
3	f	1-2	2	w.s.(0,5-1 mm)	w.g.s.(2-4 / 0,5-1 mm)	ms	b	es
	t	3-4	2-3	–	w.g.s.(3-5 / 0,5-2 mm)	b	es	es
4	f	1	1-2	–	–	–	–	–
	t	1	1-2	–	–	–	–	–
5	f	1	1-2	–	w.s. (0,5-1 mm)	es	es	es
	t	3	1-2	–	–	–	–	–

Remark: "m" – middle; "f" – front; "t" – tail; "b" – body of a pipe; "es" – edge of seam; "ms" – middle of seam; w.s. – white strip, w.g.s. – white-grey strip (edge/centre width of seam), "–" = "not found"

- at extrusion through the flat-stepped die the seam on an inside surface is seldom shown, for a case of lower T_B (360 °C) it was not found out;
- at higher temperature of extruded metal, seam is more wide and gets white-grey colour instead of grey (white colour is a place where fine wrinkles occurred and roughness is much);
- sharp relationship of the place where crack occurred during expanding test was not found.

Conclusion

Dies with the flat-stepped bottom of welding chamber provides higher accuracy of tubes in comparison with conical. Diameter and wall thickness of tubes decreases from front to back part of tube at the use of both die types.

The basic change of temperature (about 90 %) falls on a front part of tube that is appropriate to ram stroke that approximately equal to the container diameter. During the extrusion through flat-stepped die tube temperature is higher, but insignificant (of some degrees).

Extrusion at the considered temperature-speed conditions allow to produce the tubes with relative high elongation value (on 60-120 % higher then required by ASTM B 107).

The mean grain size in the basic body of tube differs from 18 to 28 μm depending on extrusion mode. The longitudinal weld seam was found only in the sections from front part of tubes extruded by higher billet temperature (400 °C) through the dies of both types.

The welded seam on an internal surface is seldom shown also its width less at pressing through a plainly-step matrix. For a pressing case at lower temperature of preparation (360 °C) the welded seam visually is not found out.

On the basis of the received data the rational technological mode and geometry of the tool depending on requirements to mechanical properties, quality of a surface and structure of metal of pipes can be chosen.

Tube front is always less oxidized than the tail. At the extrusion through the flat-stepped die the seam on an inside surface is seldom shown, for a case of lower billet temperature (360 °C) it was not found out.

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