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Analysis of Small-Diameter AMg2 Alloy Pipe Extrusion Process

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The analysis of literature data about the technological parameters of AMg2 alloy extruded profile production is carried out. The effect of the porthole die design on extrusion force and effect of heat treatment on the mechanical properties of pipes are determined based on experimental studies of small-diameter pipe extrusion (14×1.5 mm) at the press line of JSC "Dniprovskiy factory "ALYUMASH". Metal forming in the porthole die and temperature distribution in the deformation zone are studied by finite element simulation.

Keywords: EXTRUSION, Al-Mg ALLOY, EXTRUSION FORCE, PORTHOLE DIE, PIPE

Introduction

Al-Mg alloy extruded half-blanks are widely applied in building and engineering industry. It is possible to produce hollow extruded half-blanks from these alloys thanks to high toughness as hot. However, for today data about extrusion regimes and their effect on extrusion force during hollow product manufacture are not enough, especially for alloys AMg1 and AMg2. The present work covers investigation of small-diameter AMg2 alloy pipe extrusion process.

Alloy AMg2 is used for welded understressed constructions which need good technological toughness, high corrosion resistance, especially under conditions of marine atmosphere [1]. AMg2 alloy half blanks are well fusion welded, including by argon-arc method. Sheets and pipes of these alloys can be produced in annealed, semi-cold-worked and cold-worked conditions.

AMg2 alloy is thermally nonhardenable and refers to group of Al-Mg system alloys which corresponds to series 5xxx (proximal analogue EN AW-5251). Chemical composition according to GOST 4784-97 and EN 573-3 is presented in **Table 1**. The basic alloying element in this alloy is magnesium which forms eutectic diagram with aluminum featured by rather high solubility. Magnesium can be present in solid aluminum solution or in the form of proeutectoid constituents β (Al_3Mg_2). There are also manganese and inevitable impurities - iron and silicium in the alloy, they form phases Al (Mn, Fe, Si), Mg_2Si [2]. Titanium, zinc and chromium are used in small amounts.

AMg2 alloy molded articles are used without heat treatment in annealed condition. Requirements to mechanical properties are presented in **Table 2**. Mechanical properties of molded articles depend on manufacturing methods a little. If articles are moldable not enough after extrusion, normalizing annealing is used. The structure of profiles is recrystallized [2].

Al-Mg alloy profile production is covered in many publications, but investigations are usually about the features of AMg6 alloy extrusion while the data on AMg2 alloy extrusion are limited and rather contradictory (**Table 3**), which can be explained by the differences in the production process.

According to traditional production technology, all thermally nonhardenable alloys of

Table 1. Chemical composition of alloy AMg2

Grade	Mass fraction, %										
Alloy (Standard)	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other elemets		Al
									Each	Total	
AMg2 (GOST 4784-97)	0.4	0.5	0.15	0.1-0.6	1.8-2.6	0.05	0.15	0.15	0.05	0.15	Bas.
EN AW-5251 (EN 573-3)	0.4	0.5	0.15	0.1-0.5	1.7-2.4	0.15	0.15	0.15	0.05	0.15	Bas.
Experiment	0.14	0.15	0.002	0.34	2.13	0.03	0.03	0.02	–	–	Bas.

Table 2. Requirements to mechanical properties of alloy EN AW-5251 extruded pipes according to EN 755-2

Condition	$\sigma_в$, MPa		$\sigma_{0,2}$, MPa		δ, %	δ_{50mm},
	min	max	min	max		%
No special treatment	160	-	60	-	16	14
Annealed	160	220	60	-	17	15

Table 3. Temperature-speed regimes of AMg2 alloy extrusion

Articles	T_{in}, °C	T_c, °C	W, m/min	Source
Rods	320-430	350-400	3-15	[3]
Solid and hollow profiles	420-480	400-460	0.6-2	
Wall thickness <5	380-440	350-400		[4]
Wall thickness ≥5	360-460	350-400		
All profiles	400-500			[5]
Pipes, rods, profiles	400-450	350-430	6.5-9.5	[6]

Note: T_{in} – ingot temperature,
T_c - container temperature,
W – extrusion speed

system Al-Mg are extruded with process abruption (temperature-speed regimes are presented in **Table 3**), when after deformation and cooling molded articles are put into annealing furnace [3]. Further molded articles are flattened on separate units. Flattening of molded articles is carried out on a flattener unit located immediately after a cooling machine. After flattening, the articles are annealed in special furnaces.

The task of presented research is analysis of interconnection between the parameters of small-diameter AMg2 alloy pipe multichannel extrusion, in particular, definition of effect of temperature-speed parameters of extrusion and instrument geometry on extrusion force and molded article quality at “Dneprovsky Plant “ALYUMASH” (Dnepropetrovsk).

Results and Discussion

Profile extrusion at “Dneprovsky Plant “ALYUMASH”

A billet Ø 152 mm is produced by semicontinuous casting with the use of proper foundry alloys. Homogenization is carried out at 510 °C during 12 hours after pouring. The chemical composition of metal used in the experiments is shown in **Table 1**.

As the problems of multichannel extrusion of AMg2 alloy articles with diameter of 25 mm are almost not covered in the literature, for investigation we chose a pipe 14×1.5 mm extruded with total elongation ratio 83.5. Two press dies (**Figure 1**), which design differs from that of splitter and welding chamber, are used as the main instrument.

Extrusion is conducted at the rated speed of extrusion stem 4 mm/s. Heating temperature of billet is 500 ºC, heating temperature of container liner and die assembly is 430-450 ºC. The relative strain at stretch flattening is 0.23 %.

Extrusion is carried out with the use of short (150 mm) billets in order to reduce extrusion force due to lowering container friction force. Further, in case the process can be realized, the billet length is increased to required value.

We will analyze extrusion features in press dies of both types. The press die No.1 has smaller volume of splitter feeders and welding chamber as compared to press die No. 2 (**Figure 1**). Distribution of particular elongation ratios defined as a ratio of container cross-section to welding chamber cross-section in given cross-section is illustrated in **Figure 2**.

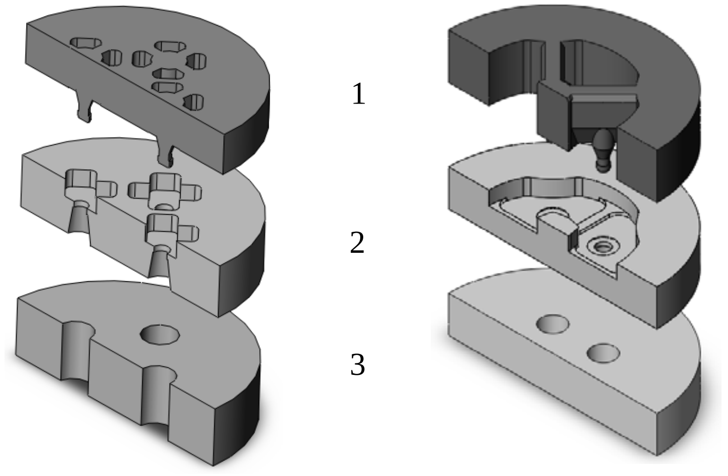

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Figure 1. Overall views of die assemblies used in the experiment: *a* - press die No. 1; *b* - press die No. 2; *1* - splitter; *2* - die ring; *3* - mantle ring

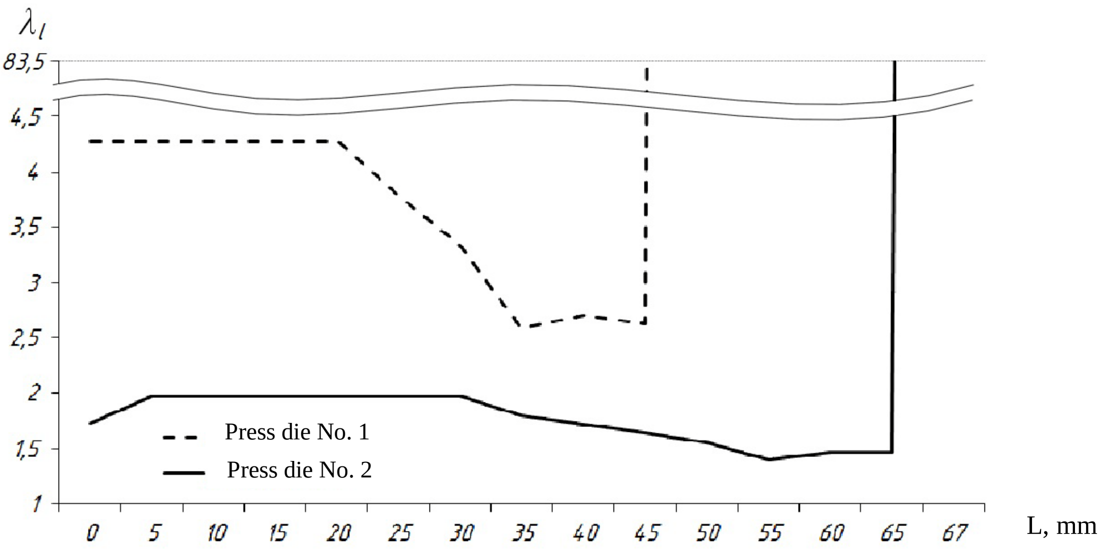


Figure 2. Distribution of specific elongation ratios in mandrel dies in the line of extrusion: *L* - distance from a splitter mirror to the bottom of welding chamber; λ_l - specific elongation ratio

The design of press die No. 1 is characterized by higher stiffness as compared to No. 2, however large friction area on the splitter and small volume of the welding chamber lead to the fact that molded metal in it loses the temperature faster and, as a result, extrusion force is increased.

Pressure diagrams in the basic molder cylinder in the process of extrusion using press dies No.1, 2 are illustrated in **Figure 3**. The maximum pressure in the working cylinder corresponds to the moment of filling-up channels and start of metal flow from the press die channels. At extrusion through both press dies this value is equal to maximum pressure in the working cylinder, but at further extrusion through press die No. 1 the extrusion force is not decreased due to lowering of friction force on the contact between the billet and container, and on the contrary grows a little. This effect can be explained by significant heat removal from welding chambers towards the mantle ring which cannot be compensated by deformation warming up of metal in welding chambers because of low extrusion speed at this stage.

To check this assumption, we carried out extrusion before which the press die already filled with metal was heated up. This led to lowering of extrusion force after pressing-out, however at extrusion of the next billet the force did not lower any more. Also it is necessary to consider the duration of associated operations (27 seconds), at which metal in the press die is cooled more intensively. Force-distance diagrams in case of pressing through press die No. 2 have a form with a dropdown curve which is traditional for direct extrusion. Also after extrusion we investigated the effect of heat-treatment regimes on properties of molded articles by static tension method according to GOST 10006-80. Obtained data are resulted in **Table 4**. Mechanical properties of produced articles meet the requirements of standards (**Table 2**), and heat-treatment regimes have no special effect on molded article properties.

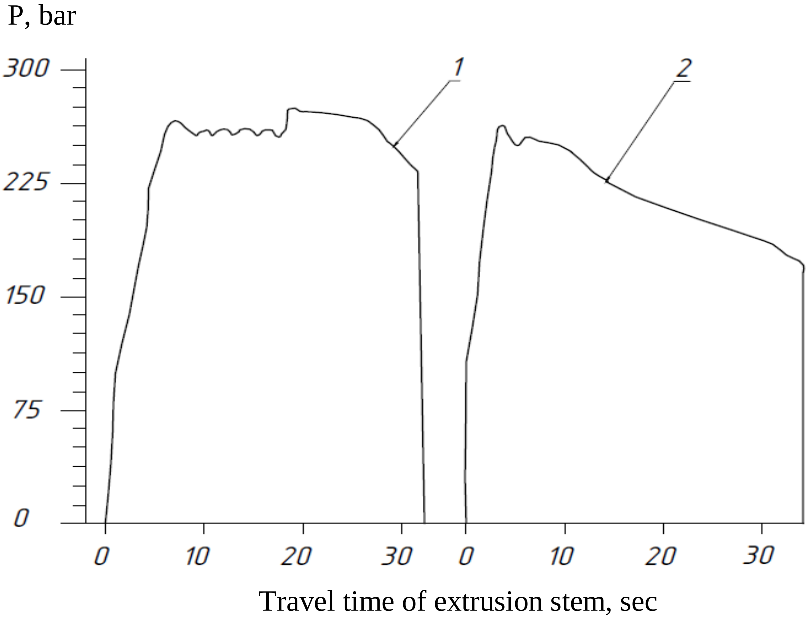


Figure 3. Force-distance pressure diagrams in the basic molder cylinder depending on extrusion stem travel time: *1* - press die No. 1; *2* - press die No. 2

Table 4. Effect of heat-treatment regimes on mechanical properties of molded articles

Heat treatment regime	$\sigma_{\text{в}}$, MPa	$\sigma_{0,2}$, MPa	δ, %
No heat treatment	192	66	27.0
Annealing at 350 °C, soaking 10 minutes	191	68	26.7
Annealing at 400 °C, soaking 10 minutes	190	68	26.8

Computerized modeling of pipe 14×1.5 mm extrusion

To analyze forming and metal temperature at extrusion we used finite-element software Forge 3D® developed by CEMEF, Ecole des Mines de Paris. It is intended for volume thermomechanical simulation of metal flow process.

At simulation of material behavior in Forge 3D® the low of Norton-Hoff is accepted

$$S = \frac{2\cdot K}{\left(\sqrt{3\cdot\dot{\bar{\varepsilon}}_i}\right)^{1-m}}\cdot\dot{\bar{\varepsilon}}, \qquad \text{(Eq. 1)}$$

where S - stress deviator; $\dot{\bar{\varepsilon}}$ - strain rate tensor; $\dot{\varepsilon}_i$, $\dot{\bar{\varepsilon}}_i$ - strain rate intensity; m and K - material invariables [7].

Strain resistance at hot deformation of alloy AMg2 depending on temperature, amount of reduction and strain rate are set using equation of Henzel-Shpitel [8]

$$\sigma_f = Ae^{Ta_1}T^{a_9}\varepsilon^{a_1}e^{a_4/\varepsilon}(1+\varepsilon)^{a_5T}e^{a_7\varepsilon}\dot{\varepsilon}^{a_3}\dot{\varepsilon}^{a_8T} \qquad \text{(Eq. 2)}$$

where σ_f - strain resistance, ε - amount of reduction; $\dot{\bar{\varepsilon}}$ - strain rate, T - temperature and A, a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9 - regression coefficients.

Regression coefficients are defined as a result of processing of mechanical hardening curves (**Figure 4**) of considered alloy. Tests are carried out on the dilatometer with plastometric add-on device by BAHR Thermoanalyse GMBH.

To describe friction on the contact we used Tresk`s model as the most physically grounded one according to many works on extrusion [9, etc.]

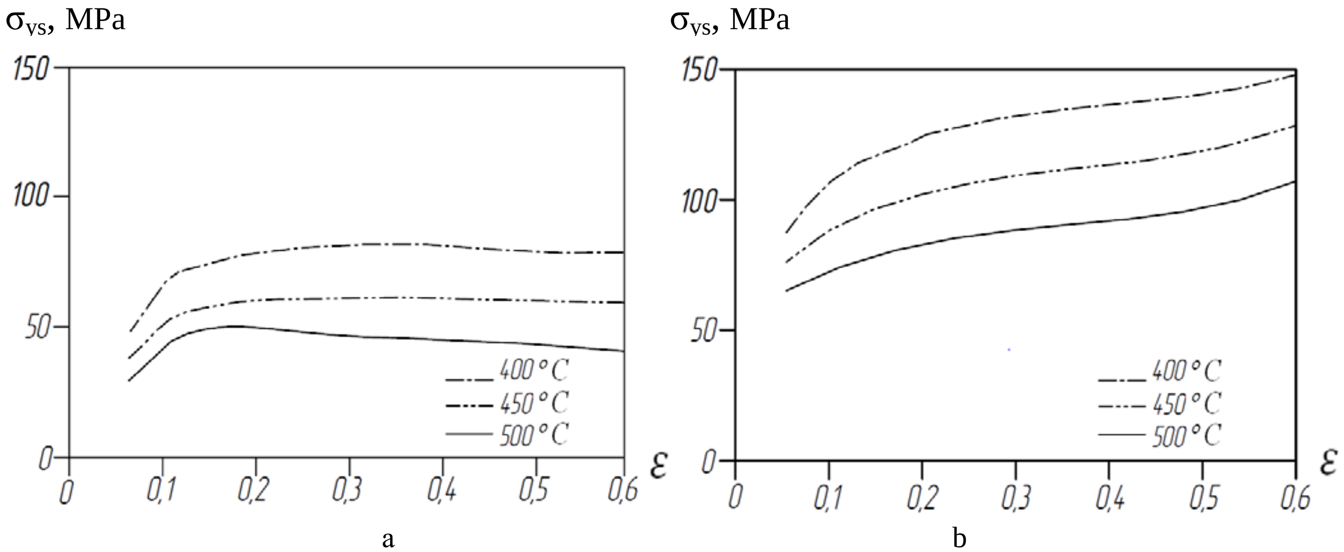
$$\tau = \mu\cdot\frac{\sigma_т}{\sqrt{3}}, \qquad \text{(Eq. 3)}$$

where σ_y - yield strength; μ - friction factor which can vary from 0 to 1. Value μ = 1 corresponds to complete adhesion. According to data [9] for hot-pressing of aluminum without lubrication, it is within the limits from 0.8 to 1.

Value τ_s is experimentally defined in order to specify the friction factor of given extrusion conditions. Further, we can determine value μ. The average arithmetical value of stress on metal and container contact is defined by method mentioned in [10] by means of processing information obtained on 13.5 MN press of JSC “Dneprovsky Plant “ALYUMASH” for alloy AMg2. This value is 19 MPa.

$$\tau_S = \frac{p_1 - p_2}{(l_1 - l_2)\cdot\pi\cdot D_{кр}}, \qquad \text{(Eq. 4)}$$

where p_1 and p_2 - extrusion force at steady process, MN; l_1 and l_2 – billet length at corresponding extrusion forces, m; $D_{кр}$ - container diameter, m.



a b

Figure 4. Curves of AMg2 alloy strain hardening at various strain rates: *a* - $\acute{\varepsilon}$ =1 s^{-1}; *b* - $\acute{\varepsilon}$ = 10 s^{-1}

Yield strength for above-mentioned temperature-speed conditions of extrusion is 38 MPa, then according to formula (3) friction factor μ is 0.86.

Metal extrusion using a mandrel die is featured by many surfaces of contact between the billet and instrument. The press die consists of two parts: upper - splitter and lower - die ring. Metal flow can be conditionally divided on 4 stages:

1) Container filling-up with metal and separation of metal into streams at the entry into splitter (**Figure 5a**);

2) Filling-up of feeding channels of the splitter - windows (**Figure 5b**);

3) Contact of streams and complete filling-up of the welding chamber (**Figure 5c**);

4) Start of pipe flow (**Figure 5d**).

There are so-called dead zones on the splitter mirror and at the bottom of welding chamber during aluminum alloy extrusion. In these zones, metal rate is close to zero. They are shown in **Figure 6a**.

The reason of formation of these zones is a considerable friction stress on the contact between billet and instrument which leads to that metal is in these zones throughout the whole process of extrusion. There are 4 dead zones (DZ) in this cross-section: DZ-1 - on the boundary line between container and press die, DZ-2 - on splitter mirror, DZ-3 - on press die mirror, DZ-4 - on mandrel.

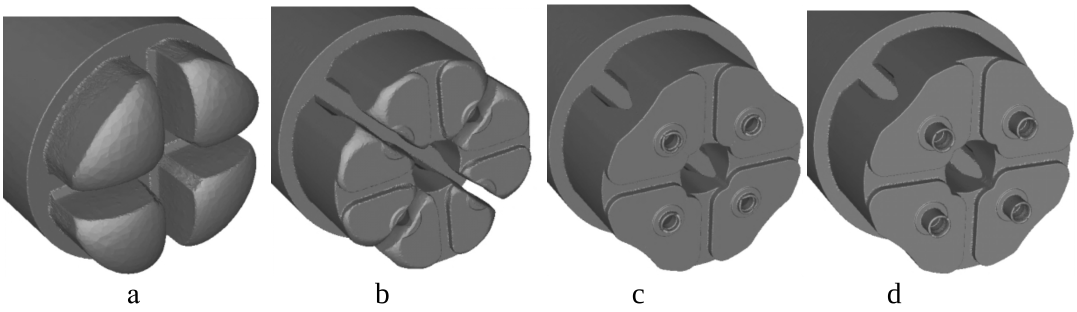


Figure 5. Extrusion process stages

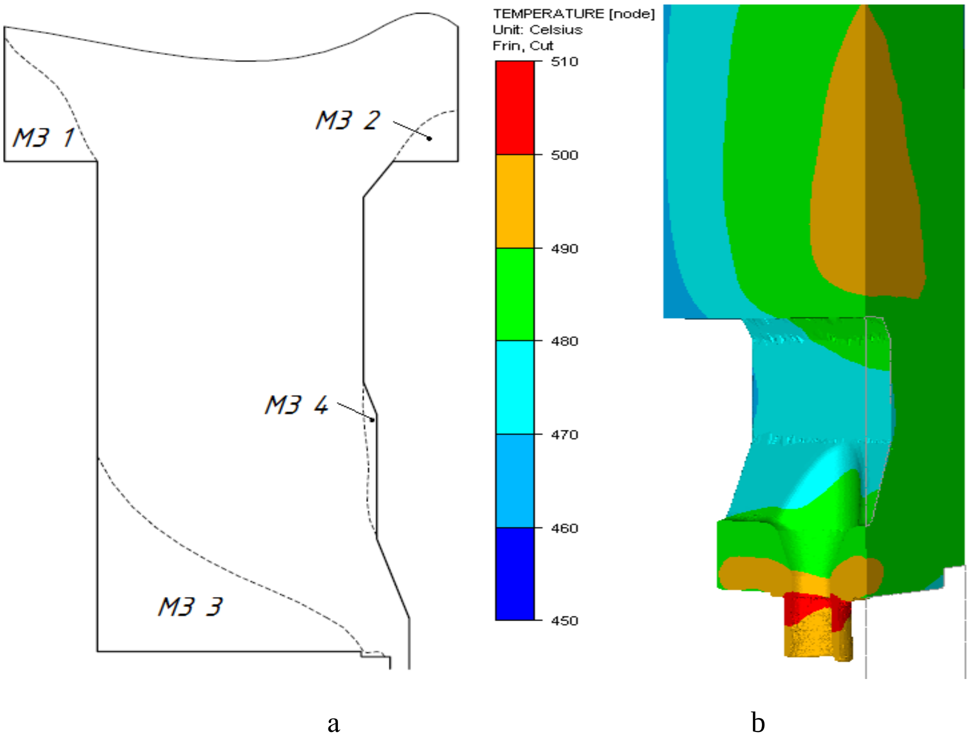


Figure 6. Location of dead zones at steady extrusion process (*a*) and temperature distribution in metal during extrusion (*b*)

The advantage of dead zones is casting defects, and the lack is raise of extrusion force. It is necessary to note that defects concentrate only in DZ-1. To reduce extrusion force it is recommended to produce die assembly so that its construction is similar to dead zones DZ-3 and DZ-4 illustrated in **Figure 6a**.

Change of metal temperature starts from the moment of extrusion start-up. Many factors affect this process: temperature drops due to heat-exchange between billet and instrument, temperature raises due to deformation warming up of metal and instrument friction. Temperature distribution is shown in **Figure 6b**. Temperature in the container drops: the minimum temperature is 464 °C in dead zones on the contact with container, the maximum temperature is 488 °C before splitter where the billet temperature raises because of deformation warming up; further metal temperature drops because of no strain in this zone. The most considerable strain takes place before the entry in the mandrel die channel (**Figure 2** $\lambda_l = 83.5$) that leads to considerable deformation warming up. The maximum temperature exceeds 500 °C.

Conclusions

Experimental research of small-diameter pipe extrusion at JSC “Dneprovsky Plant “ALYUMASH” helped define the effect of mandrel die design on extrusion force and effect of heat treatment on properties of produced molded articles. It is determined that elongation ratio drop on the splitter at invariable total elongation ratio ensures considerable decrease of extrusion force.

Plastometric investigations of AMg2 alloy are carried out, and the effect of amount, speed and temperature on the yield strength of specified alloy is defined.

Friction conditions are analyzed and the friction parameter on the contact with container is experimentally defined for observed alloy.

Metal forming in the mandrel die with flat splitter and temperature distribution in the deformation zone are studied by finite element method simulation.

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References

1. M. B. Altman, Yu. P. Arbuzov, B. I. Babichev, et al. *Aluminievye Splavy*: *Reference Manual*, Moscow, Metallurgiya, 1973, 407 p.*
2. Z. N. Archakova, G. A. Balahontsev, I. G. Basova, et al. *Structura i Svoystva Polufabrikatov iz Aluminievykh Splavov*, Reference Edition, Moscow, Metallurgiya, 1984, 408 p. *
3. V. N. Shcherba. *Pressovanie Aluminievykh Splavov*, Moscow, Interment engineering, 2001, 768 p.*
4. M. Z. Yermanok, V. I. Feygin, N. A. Sukhorukov. *Pressovanie Profiley iz Aluminievykh Splavov*, Moscow, Metallurgiya, 1977, 264 p.*
5. M. S. Gildengorn, V. G. Kerov, G. A. Krivonos. *Pressovanie so Svarkoy Polykh Izdeliy iz Aluminievykh Splavov*, Moscow, Metallurgiya, 1975, 240 p.*
6. L. M. Grabarnik , A. A. Nagaytsev. *Pressovanie Tsvetnykh Metalov i Splavov*, Textbook, second edition, Moscow, Metallurgiya, 1991, 342 p.*
7. S. Berski, G. Banaszek, H. Dyja. *Proceedings of the 10th Jubilee International Scientific Conference AMME 2001*, Leszek, A.Dobrza´nski, (ed.), Gliwice, Cracow, Zakopane, December 9-13, 2001, pp. 43-48.
8. A. Khenzel`, T. Shpitel. *Raschet Energosilovykh Parametrov v Protsesse Obrabotki Metallov Davleniem*, Moscow, Metallurgiya, 1982, 360 p.*
9 I. Flitta, T. Sheppard. *Materials Science and Technology*, Vol. 19, 2003, pp. 837-846.
10. M. Bauser, G. Sauer, K. Siegert. *Aluminium Verlag*, Strangpressen, Düsseldorf, 2001, 908 p.

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Анализ процесса прессования труб малого диаметра из сплава АМг2

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Проведен анализ литературных данных о технологических параметрах производства прессованных профилей из сплава АМг2. На основании экспериментальных исследований по прессованию труб малого диаметра (14×1,5 мм) в условиях прессовой линии ЗАО «Днепровского завода «АЛЮМАШ» определено влияние конструкции комбинированной матрицы на силу прессования, а также термической обработки на свойства труб. С помощью моделирования методом конечных элементов изучено формоизменения металла в комбинированной матрице с плоским рассекателем и распределение температуры в очаге деформации.