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EXTRUSION OF ALUMINUM ALLOYS THROUGH A WATER-COOLED DIE

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EXTRUSION OF ALUMINUM ALLOYS THROUGH A WATER-COOLED DIE

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ABSTRACT: A method of extruding aluminum alloy through a water-cooled die has been developed and introduced in industry. Production-scale tests were carried out in a 1500-ton press equipped with a water-cooled die through which D16 and AMg6 aluminum-alloy tubes, 33-53 mm in outside diameter with a wall thickness of 3-10 mm, were extruded from 156 mm x 64 mm x 340 mm ingots. It was established that the use of a water-cooled die made it possible to increase the extrusion rate from 2.56-3.3 m/min to 3.6-5.0 m/min without a significant increase of extrusion force. The water flow should not start until 0.5-1.2 mm of the tube has cleared the die, and then the water should be fed in cycles. The cooling has no negative effect on structure, mechanical properties and corrosion resistance of either extruded or extruded and cold-rolled tubes. The surface quality of tubes extruded through the water-cooled die is somewhat better than that of conventionally extruded tubes because the metal does not stick to the die. Orig. art. has: 6 figures and 1 table. English translation: 13 pages.

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

UDC 621.774.38

EXTRUSION OF ALUMINUM ALLOYS THROUGH A WATER-COOLED DIE

A.I. Baturin

In the extrusion of hard-to-work aluminum alloys (D16, AMg6, and others), the fraction of machine time in the over-all cycle is large (up to 60-90%) as a result of the limited outflow speeds, and raising these speeds will contribute to increasing the productivity of existing presses.

The present paper sets forth the results of studies and industrial implementation of a method of extruding aluminum-alloy articles through a water-cooled die.

Aluminum alloys may be classified as soft and hard. While the soft alloys (AD1, AMts, etc.) are distinguished by high plasticity and low resistance to deformation and extrude at high outflow speeds in a broad temperature range, the hard and high-strength aluminum alloys (D1, D16, AMg6, AMg5 and others) extrude at low outflow speeds (limited to 1-6 m/min), and attempts to increase these speeds in the conventional technology results in the appearance of unacceptable defects on the surfaces of the products. This sharp decrease in the plasticity of these alloys at certain (critical) temperatures (490-500°C) is associated with the presence of low-mounting eutectics. The tensile stresses that arise during extrusion in the outer layers of the product contribute under these conditions to cracking at its surface on emergence from the sizing part of the zone of deformation.

Investigations of the temperature-speed factors in extrusion have shown that practically all of the work of deformation (92-94%) is converted into heat, causing a sharp rise in the temperature of the metal at the focus of deformation. The energy expended on elastic deformation of the billet and structural changes in the crystal lattices of the material is insignificant and need not be taken into account in practice.

In addition to the temperature rise due to the heat of deformation, there is additional heating due to generation of heat at the rubbing surfaces between the metal and the container wall, the "dead zone," and in the sizing port of the die.

The volume of metal in the squeezing part of the deformation zone is small by comparison with the total initial volume of the billet.

After extrusion has begun, heat of deformation is liberated in the zone in front of the die (Fig. 1). The rate of heat liberation depends on the extrusion speed ıd increases with it.

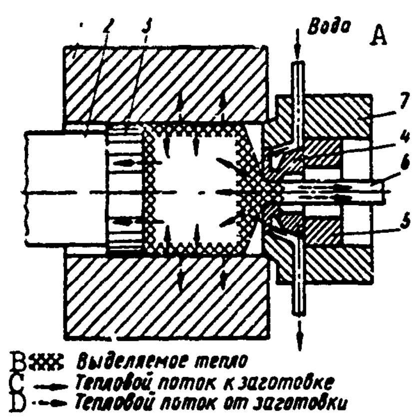

Fig. 1. Generation and dissipation of heat in extrusion. 1) Container; 2) press ram; 3) dummy block; 4) cool die; 5) die ring; 6) extrusion; 7) dieholder. A) Water; B) heat liberated; C) heat flow to billet; D) heat flow from billet.

Part of the heat generated is carried away with the extrusion and conducted off by the tool (container, mandrel, press ram, dieholder). A large part of it propagates through the unextruded volume of the ingot. Here the temperature rises in each successive layer of the ingot as we move toward the beginning of the squeezing segment of the deformation zone. In hard-to-work aluminum alloys, the increase in temperature in the deformation zone and attainment of a certain "critical temperature" contribute to transition of the metal into the region of the brittle state; then the appearance of even small tensile stresses on the surface of the extrusion as the latter leaves the squeezing part of the deformation zone results in gouging and cracking.

In attempting to determine the causes of cracking on the outer surface, many investigators have considered basically only the average temperature of the extruded metal over the volume of the plastic zone, without taking into consideration the role of local contact-friction heating at the lateral boundaries of the plastic zone and in the port of the die.

Displacement of metal relative to the tool surfaces and the "dead zone" involves the expenditure of considerable work and is accompanied by evolution of a large amount of heat in a small boundary volume of the metal; then the local temperature in this region rises and, as a result, we may have fusion of the low-melting eutectics at the boundary of the "dead zone" and the center of deformation at exit from the latter or a sharp decrease in the plasticity of the extrusion's outer layers. This problem has not been studied adequately and additional studies are required in connection with more precise definition of the time at which phase transformations arise for the various alloys and deformation conditions, their influence on cracking in extrusion, and the establishment of qualitative laws describing the variation of temperature through the volume of the plastic zone.

The "critical temperature" is different for different alloys, and depends to a major degree on the extrusion conditions (extrusion speed, draw, etc.).

The critical extrusion speed corresponding to it, i.e., the highest speed at which breakage of the extrusion does not occur, cannot always be used under industrial conditions. For example, the outflow speed in the extrusion of pipes is limited not by cracking, but by the quality of the inside surface, by the presence and size of so-called overstraining cracks.

Limiting the temperature rise in the squeezing section of the deformation zone and holding it at a certain level makes it possible to increase the average speed of outflow over the extrusion cycle.

Temperature can be regulated by two methods:

1. By lowering the extrusion speed and thus lowering the intensity of heat generation and the temperature rise as the press ram moves through its working stroke and the metal accordingly heats up in the deformation zone.

2. By removing the excess heat generated through the tool, using a coolant (for example, by flushing the die with cold water).

Obviously, cooling the die will be more effective than lowering the extrusion speed during the cycle.

In the first method, the process is brought down from the maximum (critical) extrusion speed from the initial moment of extrusion on.

For hard-to-work aluminum alloys, the critical speed is already low for the process parameters commonly encountered in hot extrusion, so that the margin available for increasing productivity in this extrusion method is insignificant.

In the second method, i.e., with cooling of the die (withdrawal of heat from the squeezing segment of the deformation zone), it is possible not only to retain the maximum speed, which corresponds to the critical temperature, over the entire cycle time, but also to increase this speed during the extrusion process by intensifying cooling during the process and holding the metal temperature constant at the exit from the center of deformation.

The manner in which the parameters vary during the steady phase of the extrusion process is indicated in Fig. 2 for the first and second cases.

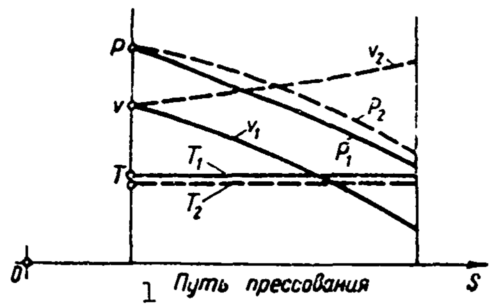

Fig. 2. Manner of parameter variation during steady phase of extrusion process. ________ extrusion with speed lowered during process; - - - - extrusion with variable cooling intensity at center of deformation. 1) Extrusion stroke.

In the former case, the metal temperature at emergence from the center of deformation is held constant by lowering the speed of the press punch by throttling the flow of hydraulic fluid into the working cylinder of the press (here we envisage an accumulator-type drive). At constant metal temperature T_1, the rate of extrusion v_1 and the pressure P_1 diminish as the process advances.

Thus, we are not making full use of press capacity. The second approach embodies the concept of intervening actively in the process by cooling the squeezing section of the deformation center in accordance with the amount of heat being generated, and, if we may disregard possible structure and property changes in the extrusion, we may expect outflow speeds considerably in excess of those obtained in the conventional hot-extrusion technology.

If the constant metal temperature T_2 is provided in this case, the extrusion speed v_2 rises and the time of the extrusion cycle is shortened accordingly. The idea of a water-cooled die is nothing new. It appeared as long ago as 1868 in Kruk's [sic] Patent No. 54121 for a method shaping solder with a melting point of about 150°C. However, forced cooling of dies and mandrels is used relatively seldom, and chiefly for the purpose of increasing their strength or to improve the surface quality of the extrusions.

Although the proposition set forth above concerning withdrawal of heat from the center of deformation is obvious, neither the domestic nor the foreign literature offers any information on research studies or practical use of a process for extruding aluminum alloys through a water-cooled die in order to raise the outflow speed.

Realization of this idea has encountered a number of technical difficulties, such as:

1) the lack of optimum-strength designs for dies weakened by channels for passage of the coolant;

2) the difficulty of changing cooled dies and their high cost;

3) the complex task of sealing the die assembly to prevent water from getting into the container;

4) the sharp increase in extrusion pressure that occurs when water-cooled dies are used;

5) the absence of data on the quality of products produced in extrusion with a water-cooled tool.

As a result of researches conducted by the author and industrial trials of an extrusion process using a water-cooled die, ways have been found to the resolution of the above difficulties and a considerable increase in extrusion speeds has been obtained in the production of pipes from certain aluminum alloys with retention of good quality of the extrusions.

The study described here was carried out under actual production conditions on a 1500-ton horizontal hydraulic press with an independent three-column mandrel system, a moving container and transverse die slide (Fig. 3); this made access to the tool in its working position

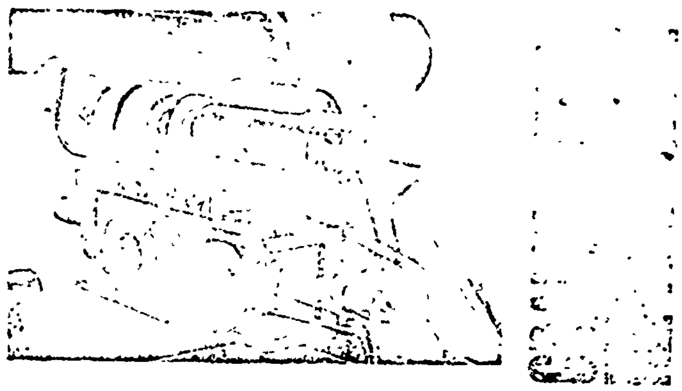

Fig. 3. Die slide of press with dieholder and tubing for coolant (container retracted).

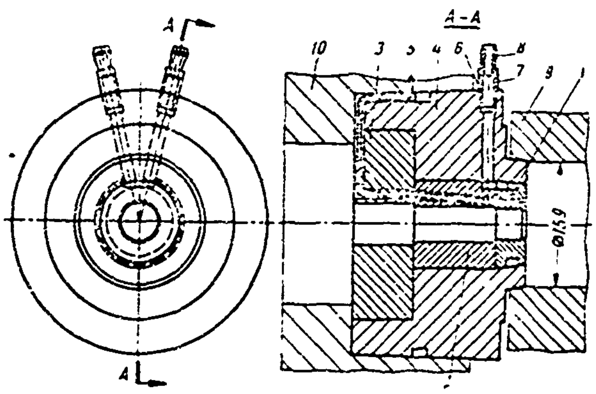

Fig. 4. Pilot-production equipment (die unit) in assembled form. 1) Water-cooled die; 2) die ring; 3) backing ring; 4) dieholder; 5) thermocouple leads; 6) gasket; 7) 1.2" pipe; 8) pipe fitting; 9) press container; 10) die-slide housing.

considerably easier (as compared with mouthpiece-type presses).

Universal pilot-production equipment (Fig. 4) was built on the basis of the existing production tooling for the press, and makes it possible to extrude products either with or without cooling through the same die.

The coolable die was made from an ordinary die by turning an annular channel into it, adding welded-on webbs, and milling out short slots in the face. It is lighter and slightly (5-7%) less expensive, and the time for changing comparable dies in the tooling setup described is practically the same.

Leakage of water into the container is eliminated by the cyclic nature of cooling and the high specific pressure created during extrusion on the planes of parting in the setup which do not permit penetration of water.

The die-cooling system is simple. A centrifugal pump delivers tap water at a pressure of 3-3.5 atmospheres. The system is fitted with devices for regulating and measuring the water flow rate, monitoring the pressure, and measuring the water temperature at entry and exit.

An extremely important characteristic was established during the experimental studies. Uninterrupted cooling prevents making the next extrusion because of inadequate press power due to chilling of the tool while the press is being reloaded and the billet compacted.

Limits for the tool-cooling cycle were established and apply consistently for the alloys studied and products of all standard nomenclatures.

The initial phase of extrusion (compacting) is carried out without cooling the tool. After the metal has filled the entire cavity of the cylinder, outflow through the die port begins; at this point, the pressure in the main cylinder drops (Fig. 5). At this instant, the water-supply system into the cooling cavity of the die is switched on (point a). Beginning cooling at this point prevents chilling of layers of metal in contact with the tool during compacting and makes it possible to lower the extrusion pressure in the initial phase of the cycle. In practice, the water is turned on after 0.5-1.2 m of tubing have emerged from the die port.

Depending on the specific extrusion conditions, the cooling system is switched off (point b) simultaneously with the end of extrusion or slightly earlier, in order to provide a tool working temperature corresponding to press force at the beginning of the next extrusion.

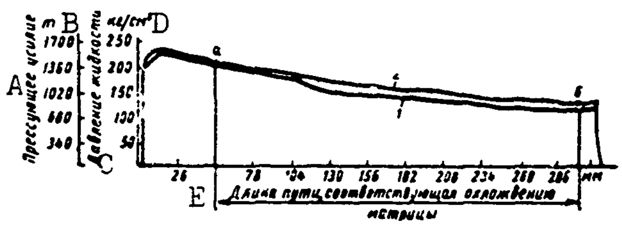

Fig. 5. Force-travel diagram (recorded on tape by SP-1 instrument); alloy AMg6, 49 × 49-mm pipe. 1) Extrusion without cooling; 2) extrusion with die cooled. A) Extrusion pressure; B) tons; C) fluid pressure; D) kg/cm^2; E) length of stroke corresponding to cooling of die.

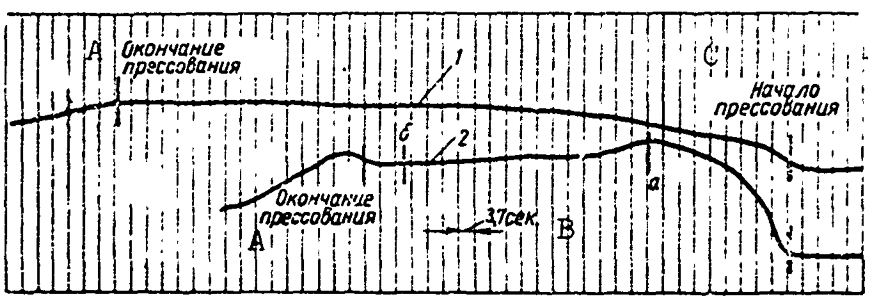

Fig. 6. Variation of die-port temperature during extrusion (alloy AMg6, 49 x 41-mm pipe). Recorded on strip by EPT-09 potentiometer. 1) Without cooling; 2) with cooled die. a) Water turned down; b) water turned off. A) End of extrusion; B) seconds; C) beginning of extrusion.

The flow rate of water through the cooled die is regulated by trial and error at the present stage of refinement. The optimum flow rates established for the setup described were 0.1-0.4 kg/sec for most D16-alloy tubes; 0.08-0.5 kg/sec for most AMg6-alloy tubes.

Figure 6 shows on one diagram curves of die-port temperature variation in extrusion by different methods (recorded on tape with EPP-0.9 potentiometer).

The increase in temperature at the beginning of the cycle is stopped by turning on the water (point a), with the result that the temperature at exit from the squeezing segment of the deformation zone is lower during extrusion than is ordinarily the case; it is also practically constant.

The continuing decrease in temperature after the water has been turned off (point b) and extrusion completed results from retraction of the container and cooling of the tool by the surrounding air. The data presented characterize the variation of temperature at constant cooling intensity. Here the amount of heat given off to the coolant characterizes the effectiveness of intervention in the process and is reckoned from data on the flow rate of the coolant per unit of time as its temperature varies.

Thus, in extrusion of 49 × 41-mm-pipe from AMg6 alloy in the form of a 156 × 64 × 340 mm ingot, the average flow rate of water for cooling of the die was 0.5 kg/sec for 2 min in each extrusion.

The water temperature is 14°C at entrance into the die and 24°C at exit from it. Here the average heat takeoff during extrusion is 600 kcal. Comparing this figure with the amount of work converted into heat (660 kcal for the same extrusion conditions), we can easily satisfy ourselves of the effectiveness of cooling (a 1.4-fold increase in outflow velocities was obtained).

The experimental data and thermal calculations indicate the possibility of considerable heat removal and lowering of the metal temperature at low liquid flow rates. The pressure and work of extrusion are increased insignificantly when cooling is provided (by 5-10%). The results of extrusion are listed in the table.

To complete the comparison, the table lists data for various combinations of process parameters (ingot and container temperatures, etc.) for pipes in several standardized sizes extruded from D16 and AMg6 alloys of average chemical composition. Even at the present stage of improvement of the process, an increase in the average outflow speeds by 30-50% is obtained in extrusion with co nstant cooling rate in all cases.

Results of Comparative Extrusion

A Сплав	B Размер трубы в мм	C Размер слитка в мм	D Технология прессования	E Количество слитков	Температура в °C		I Скорость истечения в м/мин
					F G слитка	H контейнера	
J Д16	33×24	156×64×340	Обычная технология . . . . K	30	410	350	3,3
			Прессование с охлаждением L	300	350	380	4,6
J Д16	36×16	156×65×320	Обычная технология . . . . K	22	400	400	3,2
			Прессование с охлаждением L	22	400	400	5,0
J Д16	41×35	156×64×320	Обычная технология . . . . K	50	400	300	2,8
			Прессование с охлаждением L	700	360	370	4,2
M АМг6	49×41	156×65×340	Обычная технология . . . . K	20	450	370	3,0
			Прессование с охлаждением L	20	450	370	4,1
M АМг6	53×47	156×64×340	Обычная технология . . . . K	25	460	380	2,56
			Прессование с охлаждением L	25	460	380	3,6

Notes: 1. Tubes of each standard size were extruded through the same die, first without cooling and then with cooling, from the same delivery of alloy.

2. In all cases, the outside and inside surfaces of the pipes showed improved quality in extrusion with cooling.

A) Alloy;
B) Pipe size in mm;
C) Ingot dimensions in mm;
D) Extrusion technique;
E) Number of ingots;
F) Temperature in °C;
G) Ingot;
H) Container;
I) Outflow speed in m/min;
J) D16;
K) Conventional technology;
L) Extrusion with cooling;
M) AMg6.

Further improvement of the process and the use of variable cooling rates for the die will make it possible to attain even greater increases in outflow speed.

To compare the quality of pipes in the as-extruded state or after extrusion and rolling (with heat treatment in both cases), a laboratory study of the products was carried out.

The analysis was focused on five characteristic zones along the length of a pipe excluded with cooling of the tool: the front and shrinkage ends, two transitional zones corresponding to the times at which the water was turned on and off, and the central segment of stable cooled extrusion. For an analogy, the corresponding segments of pipes extruded without cooling were investigated.

The macrostructure of various standard pipe sizes, for example, 41 × 43 mm, 36 × 16 mm, made from D16 alloy was satisfactory, with fine grain in the zone of intensive cooling.

Comprehensive studies of the mechanical properties of D16-alloy pipes in the 41 × 33-mm, 25 × 1.5-mm and a number of other sizes (after rolling) indicate the absence of any differences in the properties for products extruded with and without cooling. The results of tests for intergranular corrosion also confirm the identity of properties.

Cooled-die extrusion provides some improvement of the outside and inside surfaces over the entire length of the pipe, resulting from decreased sticking of metal particles to the sizing collar of the die and the mandrel as a result of cooling.

CONCLUSIONS. 1. The possibility and expediency of extruding aluminum-alloy products with cooling of the tool to improve the productivity of existing presses by increasing the outflow speed have been demonstrated and substantiated.

2. An industrial technology has been elaborated and implemented for extrusion of pipes from D16 and AMg6 alloys with a cooled tool, and provides a considerable increase in the outflow speeds.

3. The necessity of cyclical cooling of the die in extrusion was established, and limits were found for the cycle that apply for pipes of all standard sizes and alloys.

4. Industrial production equipment was devel^ped and used for cooled extrusion on a 1500-ton press with a transverse die plate.

5. Comparative studies of the mechanical properties, macrostruc-

ture, corrosion resistance, etc. were carried out and indicated the absence of any differences in the quality of pipes extruded by the conventional technology and with a cooled tool. Here the quality of the outside and inside surfaces of pipes extruded with the cooled tool was somewhat better.

6. The proposal was made, and reasons advanced for it, that the intensity of cooling of the squeezing section of the deformation zone be made variable to ensure maximum utilization of the power characteristics of the press and the plastic properties of the material in order to increase outflow speeds.

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