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TRANSLATION

ALUMINUM ALLOYS (COLLECTION OF ARTICLES)

FOREIGN TECHNOLOGY DIVISION

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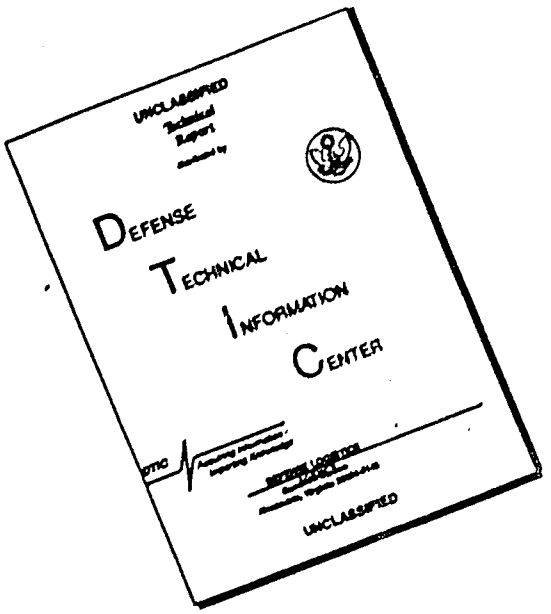

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FTD-MT-64-196

EDITED MACHINE TRANSLATION

ALUMINUM ALLOYS (COLLECTION OF ARTICLES)

English Pages: 205

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Spechennyye Splavy

Gosudarstvennoye
Nauchno-Tekhnicheskoye Izdatel'stvo
Oborongiz

Moskva - 1963

Pages 1-176

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JPRS:

ALUMINUM ALLOYS

- USSR -

/Following is a translation of the Russian-language book Alyuminiyevyye Splavy (English version above), Issue 2, Sintered Alloys, a collection of articles edited by I.N. Fridlyander, Moscow, 1963, pages 2-176. Additional bibliographic information accompanies each article./

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Editors of Second Edition

Candidate of tech. sciences B.I. Matveev

Candidate of tech. sciences M.G. Stepanova

This collection covers questions of the improvement of the technology of obtaining of pressed half-finished products (profiles, pipes, sheets, foil) and stamped details from sintered aluminum powder.

There are described the properties of new deformable materials from sintered aluminum alloys (SAS) with low coefficients of linear expansion.

Collection is intended for engineering-technical and scientific workers of the metallurgic and machine-building industry, and also for teachers and students of technical colleges.

Reviewer, M.F. Bazhenov, Engineer

Editorial assistant, A.S. Zaymovskaya, Engineer

PREFACE (p 3 of source)

At present in different branches of technology there find wide application materials from sintered aluminum powder (SAP) and sintered aluminum alloys (SAS). Mastering SAP has significantly expanded the region of temperatures at which can be applied the aluminum alloys.

In distinction from other aluminum alloys, SAP has comparatively high ultimate strength in the interval of temperatures 300-500C, its prolonged durability in tests during 10,000 and even 100,000 hours is little changed with time and practically can be considered stable.

The 1961 collection of articles "High-Temperature material from sintered aluminum powder (SAP)" was the first attempt to generalize the results of investigations connected with the development of the fundamental technology of obtaining of half-finished products from SAP, and also with the study of its structure, properties and peculiarities.

During the time since the publication of the first collection new forms of half-finished products (profiles, pipe, foil, etc.) have been developed which find wide application in industry, the technology of obtaining of preprepared half-finished products has improved, as well as the technology of preparation of powders and dusts that allow significant reduction of the technological cycle of production of articles.

In the collection there is described a new method of briquetting with preliminary heating of aluminum powders to 500-600C, which gave the possibility of obtaining both round and flat briquettes to weight of one ton; properties of these briquettes differ insignificantly from properties of half-finished products obtained by treatment by pressure. Production from large dimension briquettes of wide strip of dimension 90 x 600 mm for rolling of sheets and rods of diameter 200 mm and more for stamping has been mastered.

High-temperature heating of powder during its briquetting also ensured prolonged operation of half-finished products from SAP temperatures to 550C, where surface of half-finished products after heating remains of high quality (without bubbles).

In published articles there is described also a method of investigation with the help of the electron microscope of the structure of sintered aluminum materials

and results of manifold investigation of properties depending upon conditions of deformation and heating that allowed us to establish several regularities characteristic of the material strengthened by dispersed inclusions of aluminum oxide.

Special attention is allotted in the collection to the problem of formation of welded joints of details from SAP, in particular there are considered the causes determining the not-always-stable results of argon arc fusion welding of SAP and necessary recommendations are given. Results are published of an investigation of the possibility of joining of details from SAP by other methods (resistance and spot electric welding, ultrasonic welding and riveting.

There is great interest in the studies which resolve the problem of obtaining of sheet material directly from aluminum powder. They present the process and technology of rolling of powder, properties and structure of resulting billets and ready half-finished products.

The collection considers the structure and properties of the newly mastered half-finished products; there are given certain regularities of change of their properties and structure depending upon technological factors.

Significant attention is allotted to new materials from sintered aluminum alloys with special properties (for instance, with low coefficient of linear expansion). Obtaining of such alloy, containing to 30% silicon, by the usual method (casting and deformation) is very complicated and only by means of sintering of powder from aluminum alloy have we managed to create a number of alloys with different coefficients of linear expansion, necessary in instrument-making.

Of definite interest are the studies of the structure and properties of standard aluminum alloys (D16, B96), obtained from sintered powders. The quality of half-finished products from SAP is better than from alloys obtained by the usual method, since their structure is uniform, and metallurgic defects inherent in these alloys are absent.

The authors trust that publication of this collection will allow still more expansion of the region of application of high-temp sintered aluminum alloys in industry.

PROPERTIES AND APPLICATION OF HALF-FINISHED PRODUCTS FROM SINTERED ALUMINUM POWDER (SAP) (p 5 of source)

B.L. Matveev, I.N. Fridlyander, G.D. Agarkov,
M.G. Stepanova, P.T. Vlasova

High-temp deformed alloy from sintered aluminum powder at temperatures of 350-500C has significantly higher strength characteristics than standard aluminum deformed alloys which is explained by the presence of a finely-dispersed oxide phase evenly distributed in the aluminum base.

Half-finished products from SAP possess high corrosional stability, practically equal to the corrosional stability of aluminum; they are recommended for prolonged work in interval of temperatures 350-500C and at lower temperatures if there is required a combination of high durability and corrosional stability. For manufacture of half-finished products from SAP use is made of aluminum powder of brands APS-1, APS-2 (aluminum powder for sintering), composition of which is given in Table 1.

Table 1

Composition of Powders for Manufacture SAP (remainder Aluminum) in %

(a) Марка пудры	Al_2O_3	Fe	(b) Жиры	H_2O
		(c) не более		
APS АПС-1	6—9	0,2	0,25	0,1
APS АПС-2	9,1—13	0,2	0,25	0,1

a - Brand of powder; b - Fats; c - not more.

The powder of brand APS consists of oxidized particles of aluminum in form of scales (plates), average dimension of which prior to nodulizing is 10-45 mk with a thickness of less than 1 mk. The powder is prepared by atomizing a melt and grinding the pulverizat in ball mills in a medium of nitrogen with a controlled content of oxygen and

of stearin. In the process of manufacture the powder is subjected to nodulizing (for the purpose of increase of bulk weight), a conglomerate is formed from the elementary particles. Average dimension of conglomerate in the nodulized powder constitutes 50-100 mk. In industry, from powder APS-1 we prepare half-finished products of the brand SAP-1, and from powder APS-2 -- half-finished products SAP-2.

The technology of manufacture from SAP of half-finished products, billets for rolling, forging, stamping includes briquetting of powder, sintering and hot pressing.

GRAPHIC NOT REPRODUCIBLE

Fig 1. Wire from SAP

From SAP-1 we prepare the following half-finished products: rods and pipe of diameter to 200 mm, profiles of section to 100 cm^2 and above, sheets of width 900 mm, length to 3 m and thickness to 0.8 mm, rivet wire (Fig 1), foil of thickness to 0.03 mm (Fig 2), pressed half-finished products (Fig 3).

From SAP-2 we prepare only pressed half-finished products (rods, strip, pipe) of the same dimensions as from SAP-1. Basically the half-finished products from SAP-2, possessing lowered engineering plasticity, are used for the manufacture of details by machining or stamping in closed dies; these operations ensure deformation of material with minimum stretching stresses.

The mechanical properties of pressed, rolled and stamped half-finished products from SAP-1 and SAP-2 are given in Table 2. From SAP-1 it is possible to obtain stamped half-finished products directly from the sintered briquette (billet).

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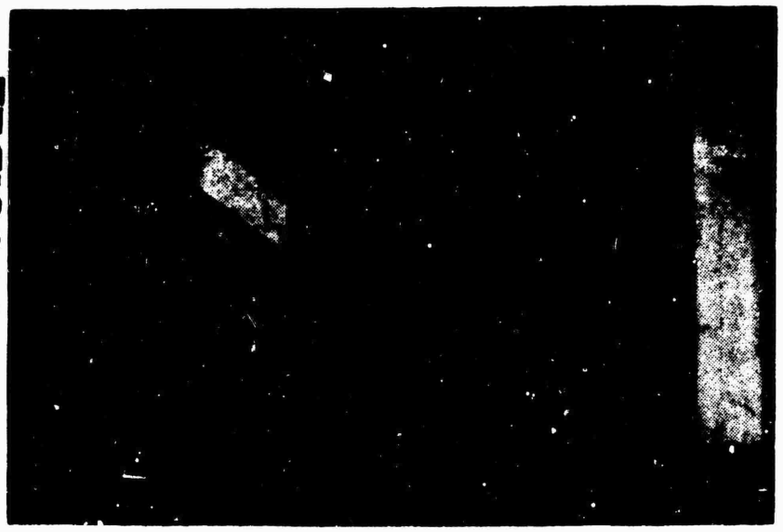

Fig 2. Sheets and foil from SAP

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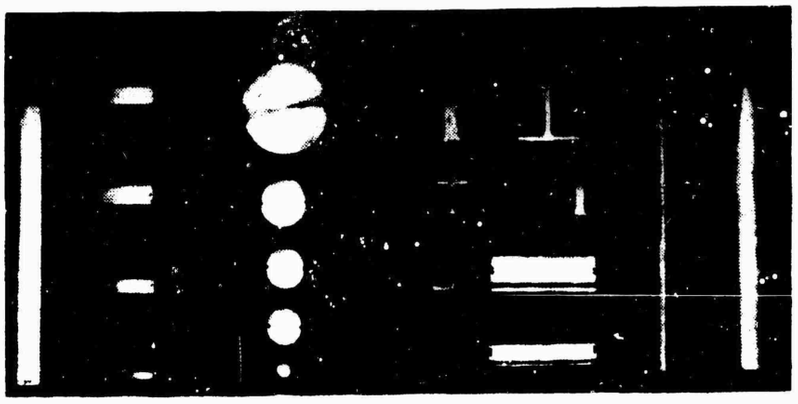

Fig 3. Half-finished products from SAP

Mechanical properties in this case are sufficiently high. With increase of temperature of test to 500C the strength of SAP-1 decreases from 30-35 to 8-10 kg/mm^2, and that of SAP-2 from 40 to 12-13 kg/mm^2.

Table 2

Mechanical Properties of Different Half-Finished Products From SAP-1 and SAP-2

Марка материала и вид полуфабриката (a)		Температура испытания °С (b)	Предел прочности кГ/мм² (c)	Предел текучести кГ/мм² (d)	Относительное удлинение % (e)	НВ кГ/мм² (f)
SAP САП-1	Прессованные (g) прутки диаметром 18—180 мм Прессованные полосы сечением от 20×90 до 410×30 мм (h)	20	33	23	6	95—100
		250	20	16	4	95—100
		300	18	15	3	95—100
		350	15	13	2	95—100
		400	12	—	1	95—100
		500	9—10	8	1	95—100
SAP САП-1	Холоднокатаный лист толщиной (i) 1—3 мм (вдоль направления прокатки)	20	33	—	4	—
		250	16	—	5	—
		350	11	—	4	—
		400	9	—	4	—
		500	7,5	—	1,5	—
SAP САП-1	Холоднокатаный (j) лист толщиной 1—3 мм (поперек направления прокатки)	20	34	—	5	—
		250	16	—	4	—
		350	11	—	4	—
		400	9	—	4	—
		500	7,8	—	2	—
SAP САП-1	Горячекатаный лист (k)	20	30	—	5	—
		500	8	—	2	—
SAP САП-1	Фольга толщиной 0,05 мм после 100 час отжига при температуре испытания (l)	20	33	—	—	—
		200	21,8	—	—	—
		250	19,0	—	—	—
		275	16,3	—	—	—
		300	13,6	—	—	—
		400	8	—	—	—

Table 2 Continuation

Марка материалов и вид полуфабриката (a)		Температура испытания (b) °C	Предел прочности кГ/мм² (c)	Предел текучести кГ/мм² (d)	Относительное удлинение % (e)	НВ кГ/мм² (f)
САП-1 (SAP)	Поковки и штамповки из спеченной заготовки диаметром 160 мм (m)	20	35	—	4	—
		300	15	—	3,5	—
		350	—	—	—	—
		400	10	—	3,0	—
САП-2 (SAP)	Прессованные прутки диаметром 170 мм и полосы сечением 240×30 мм (n)	—196	46	—	0,5	120
		20	40—41	26,0	2—3	—
		250	24—25	23,0	1	—
		350	18—19	15	0,5	—
		500	12—13	9—10	0,5	—
		600	3—4	—	—	—

a - Brand of material and form of half-finished product; b - Temperature of test C; c - Ultimate strength kg/mm^2; d - Yield point kg/mm^2; e - % elongation; f - HB kg/mm^2; g - Pressed rods of diameter 18-180 mm; h - Pressed strip of section from 20 x 90 to 410 x 30 mm; i - Cold-rolled sheet of thickness 1-3 mm (along direction of rolling); j - Cold-rolled sheet of thickness 1-3 mm (across direction of rolling); k - Hot-rolled sheet; l - Foil of thickness 0.05 mm after 100 hour of annealing at temperature of test; m - Forgings and stampings from sintered billet of diameter 160 mm; n - Pressed rods of diameter 170 mm and strip of section 240 x 30 mm.

The prolonged strength of SAP-1 and SAP-2 after 100 hours of test is given in Table 3.

Table 3

Prolonged strength of SAP-1 and SAP-2 after 100 hours, in kg/mm^2

Температура испытания (a) °C	SAP САП-1	SAP САП-2
250	11,0	12,0
350	8,0	9,0
500	4,5	5,5

a - Temperature of test, C

The prolonged strength of SAP-1 and SAP-2 is practically identical and exceeds the strength of all the aluminum deformed alloys. The basic mechanical properties of SAP-1 and SAP-2 are given in Tables 2 and 4.

Table 4

Certain mechanical properties of SAP-1 and SAP-2

(a) Свойства	SAP САП-1				SAP САП-2			
	(b) Температура в °C							
	20	250	350	500	20	250	350	500
(c) Относительное сужение в %	8—11	9—12	8—9	6—7	3—4	3—4	3—4	2—3
(d) Предел ползучести по остаточной деформации $\sigma_{0,2/100}$ в кГ/мм^2	—	—	7	4	—	—	7	4
(e) Предел выносливости в кГ/мм^2 на базе $20 \cdot 10^6$ циклов:								
образец без надреза	9		3	3	11,5	—	3,5	3,5
образец с надрезом	6		2,5	2	7,5	—	—	—
(f) Число циклов до разрушения при повторных статических нагрузках при напряжении $0,7\sigma_в$	4700 (k) при $\sigma_0=23,5$ кГ/мм^2	—	—		4600 (k) при $\sigma_0=28$ кГ/мм^2	—	—	
(g) Динамический модуль упругости в кГ/мм^2	7500	6400	5800	5200	7700	6800	6100	5500

a - Properties; b - Temperature in C; c - Relative reduction in %; d - Limit of creep at permanent deformation $\sigma_{0.2/100}$ in kg/mm^2; e - Limit of fatigue in kg/mm^2 on basis of 20-10^6 cycles; sample without notch, sample w. notch; f - Number of cycles to destruction during repeated static loads at a stress of 0.7σ_B; g - Dynamic elastic modulus in kg/mm^2; h - at

Physical properties of SAP

	SAP-1	SAP-2
Specific gravity in g/cm^3	2.73	2.75
Thermal conductivity in cal/cm sec°C (20-500)	0.4-0.36	0.33-0.34

The coefficient of lineary expansion of SAP varies depending upon temperature (Table 5).

Table 5

Температура °C (a)	$\alpha \cdot 10^6$	
	SAP САП-1	SAP САП-2
20—100	23,0	19,5
100—200	23,0	20,2
200—300	23,0	20,9
300—400	25,9	21,7
400—500	26,3	22,7

a - Temperature C

SAP is characterized by high corrosional stability. During test in conditions of full submersion in 3% solution of NaCl + 0.1% H_2O_2 and in a natural atmosphere during 10 months, the strength and relative elongation (Table 6) of samples did not decrease.

When indispensable, articles from SAP can be anodized. SAP is satisfactorily brazed and can be welded by argon arc welding. Using fusion welding, the welded seam on sheets of thickness 1.5 mm from SAP-1 at normal temperature has a strength of 33 kg/mm^2, and at a temperature of 500C -- 5-6 kg/mm^2.

SAP-1 and SAP-2 are satisfactorily deformed in the hot state at 450-570C. From SAP it is practically possible to obtain any pressed half-finished products which are subjected subsequently to working by pressure or cutting.

Table 6

Mechanical properties of samples from SAP after 10 months of corrosional tests (Corrosion tests conducted by V.S. Komissarova)

Содержание в % (a)		До коррозионных испытаний (b)		После коррозионных испытаний (c)		Уменьшение в % (d)	
Al_2O_3	Fe	$\sigma_в$ кГ/мм² *	$\delta_в$ %	$\sigma_в$ кГ/мм²	$\delta_{в1}$ %	$\sigma_в$	δ
(e) При полном погружении в 3%-ный раствор NaCl+0,1% H_2O_2							
6,0	0,25	32,8	10,5	34,5	10,8	Нет (g)	Нет (g)
9,0	0,11	32,5	5,1	36,2	5,8	Нет (g)	Нет (g)
11,5	0,14	41,5	4,5	39,0	6,0	6	Нет (g)
	—	11,6	34,0	13,6	35,2	Нет (g)	Нет (g)
(f) В естественной атмосфере							
6,0	0,25	30,8	10,5	31,2	9,2	Нет (g)	7,0
11,5	0,14	32,5	4,4	34,8	3,6	Нет (g)	18,0

a - Content in %; b - Prior to corrosional tests; c - After corrosional tests; d - Decrease in %; e - With full submersion in 3% solution of NaCl+ 0.1% H_2O_2; f - In natural atmosphere; g - None

Working of SAP by pressure has certain peculiarities. From hollow billets of SAP using a secured or floating needle it is possible to obtain smooth pipe or with symmetrically located flanges, ribs, but the application of tongue-dies, which are usually used for obtaining complicated hollow or half-open profiles in the deformed alloys, is impossible due to the high resistance to deformation. Pipes obtained by pressing are subjected to drawing for removal of all thickness differences along the length. From SAP-1 it is possible to obtain pipes having wall thickness of 0.4 mm.

Thickness of walls of pressed SAP half-finished product and radii of curvature are lower for a lower content of Al_2O_3 in the initial material.

SAP-1 is satisfactorily deformed in cold and hot states by the methods of impact extrusion and free forging. By impact extrusion it is possible to prepare shaped pipes and pipes closed at one end. By the method of cold rolling

* Throughout this document, the abbreviation кГ stands for kg.

on millsof the type Rokrayt from SAP we can obtain pipe of variable section (with decrease of section by 75%). By rolling on special mills from smooth pipes it is possible to obtain pipe with transverse helical ribs. Furthermore, from SAP-1 we obtain wire of diameter 1-6 mm from which it is possible to head rivets.

Sheets from SAP-1 are prepared from pressed large-dimension plates which are hot rolled to thickness of 3-2.5 mm, and then cold rolled to any given thickness. By rolling from SAP-1 we prepare foil of thickness to 0.03 mm. Sheet material from SAP-1 is subjected to drawing at temperatures of 300-450C, the limiting coefficient of drawing for one operation correspondingly constitutes 1.3-1.8. The minimum radius of bend of sheet material at normal temperature is equal 7-8 times the thickness, at 350C it is 3 times, and at 450C it is 1.5 times the thickness.

SAP-1 and SAP-2 easily are worked by cutting. Here there are not required special conditions for operation of the cutting tool (in distinction from conditions of working of usual aluminum alloys).

The above-mentioned different methods of working of SAP allow us to conclude that the existing idea of the fragility of sintered materials does not apply to SAP. This material is processed by the same methods as the hardening aluminum alloys. Heat treatment for SAP is not required.

The successes attained in the field of working open before SAP more and more new regions of application.

INVESTIGATION OF THE STRUCTURE OF SAP
(p 13 of source)

I.N. Fridlyander, M.G. Stepanova, N.S. Gerchikova
N.I. Kolobnev

High-temp material from sintered aluminum powder (SAP) is characterized by stability of structure and properties at heightened temperatures. Half-finished products from SAP are obtained by consecutive briquetting, sintering and pressing of aluminum powder. Every particle of powder is covered with a thin oxidized film. In the process of the production of the half-finished products there occurs destruction of the oxidized films, splitting of powder particles and distribution aluminum oxide in the form of finely-dispersed inclusions through the entire aluminum matrix.

SAP is a typical representative of the alloys strengthened by dispersed particles and differs from all the other dispersion-hardening alloys in the nature of the hardening phase and the method of dispersion. (N.J. Grant, O. Preston, J. of Metals, 1957, No 3, p 349; F.V. Lenel, A.B. Backensto, M.V. Rese, J. of Metals, 1957, No 1, p 124.)

Strengthening of the dispersion-hardening alloys occurs as a result of singling out of dispersed particles during disintegration of the supersaturated solid solution, therefore at heightened temperatures weakening of the alloy occurs due to coagulation and dissolution of the hardening phase. The usual dispersion-hardening alloys can be hardened only by those elements which dissolve in the base metal. The limit of reasonable alloying is determined by the limit of solubility of the element (or group of elements) in the base metal.

SAP is hardened by particles of aluminum oxide which practically is not dissolved in aluminum; the limit of alloying therefore is not connected with the limit of solubility of the second phase. The dispersiveness of particles of aluminum oxide is the result of splitting of the thin oxidized film and not disintegration of the supersaturated solid solution.

Thus, SAP, which is hardened similarly to the dispersion-hardening alloys by dispersed particles, in principle differs from them in the nature of the particles and the method of obtaining them, this allows us to improve its mechanical properties.

Alloys of the type SAP preserve high strength characteristics at temperatures to 500C. This is explained by the presence of the hardening phase, aluminum oxide, which is characterized by a high temperature of fusing (2050C), low diffusion mobility, insolubility in the matrix and high hardness.

All available theories of hardening of alloys of the SAP type basically lead to dependency of properties on the dimension of the dispersed particles (in this case particles of aluminum oxide) and on the distance between them. In order to better grasp the mechanism of hardening of the aluminum matrix by dispersed particles of the oxide phase, one should start the study of the structure of SAP from a study of the dimensions and character of distribution of particles of aluminum oxide in briquettes, billets, and then in half-finished products.

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Fig 1. Microstructure of rod from SAP with 10.5% Al_2O_3, x 2000

Since particles of aluminum oxide are extremely small the optical microscope does not give a full presentation of the structure of SAP (Fig 1) and it is necessary to resort to electronic microscopy.

There have been only a few studies of the structure of SAP with the help of the electron microscope (E. Gregory, N.J. Grant J. of Metals, 1954, No 2, pp 247-252; F.V. Lenel, G.S. Ansell, E.S. Nelson, J. of Metals, 1957. No 1, pp 117-124; H. Hug, N. Bischsel, Metall, 1961, Nr. 1, SS. 19-22.) and sometimes the authors themselves mark a certain inaccuracy of explanations obtained by them by electron microfotografy of the structure SAP and consider them as suppositional. One of the works contains somewhat contradictory data on the form and character of distribution of particles of the oxide phase in SAP.

Therefore for the carrying out of the electron-microscopic investigation of the structure of SAP we thoroughly developed and made a detailed check of a method of preparation of SAP products. In detail this method is described in an article by N.S. Gerchikova and N.I. Kolobnev (N.S. Gerchikova, N.I. Kolobnev, Factory Laboratory, 1961, No 12).

In the present work with the help of the electron microscope we investigated the structure of briquettes and rods from SAP containing from 9 to 26% Al_2O_3 and sheets containing 7.8% Al_2O_3 (degree of deformation 85%).

The structure of pressed half-finished products from SAP constitutes an aluminum matrix with introduced in it dispersed particles of the oxide phase (Fig 2). The less the distance between particles of aluminum oxide the higher the strength characteristics of the SAP. The distance between particles of aluminum oxide depends on the grinding of the aluminum powder from which are obtained the intermediate products. The finer the grinding and the greater the dispersion of the elementary particles of powder, the less the distance between oxide partices in the SAP. On the grinding of the aluminum powder depends also the quantity of aluminum oxide. In the process of grinding of the powder in a ball mill there also occurs crushing of the particles of aluminum and, consequently an increase of their total surface area.

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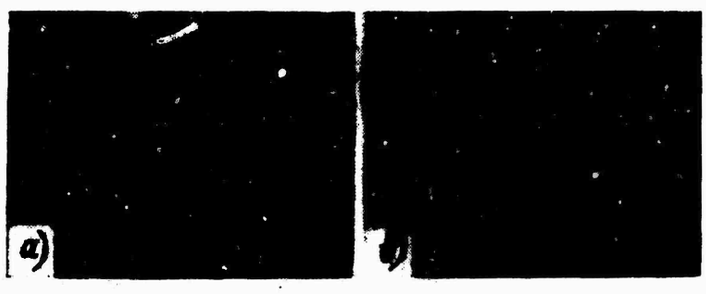

Fig 2. Electron photomicrography of structure of a rod from SAP with 16% Al_2O_3, x 16,000

a - cross section, b - longitudinal section

Every newly formed surface of aluminum oxidizes. Thus, the increase of content of aluminum oxide in powder of the brand APS occurs not by thickening of the oxidized film, but thanks to the fine grinding. Both aluminum powder for SAP and also half-finished products are classified by the content of aluminum oxide; here we consider that the grinding is conducted in strictly determined conditions, ensuring obtaining of powder of each brand with particles covered with an oxidized film of identical thickness.

As our experiments showed, in that case when the content of aluminum oxide in the powder is increased by thickening of the oxidized film on particles of aluminum, the strength of half-finished products from such powder is not increased. The distance between particles of the oxidized phase in this case is not changed with an increase of the content of aluminum oxide, but the oxide particles become significantly larger (Fig 3).

To increase the bulk weight of aluminum powder from SAP after grinding it is subjected to nodulizing, as a result of which will be formed a conglomerate from elementary particles of aluminum. The dimension of the nodulized particles does not affect the strength of half-finished products from SAP (High-temp Material from Sintered Aluminum Powder (SAP), Oborongiz, 1961, p 17-29); the distance between particles of aluminum oxide in SAP, and consequently also the strength, are determined by the dimension of the elementary particles.

In the process of pressing of half-finished products from aluminum powder the oxidized films covering the surface of the elementary particles are destroyed and the distance between particles of the oxidized phase no longer can exactly correspond to the distance between oxidized films (or to the dimension of the particles of powder). However, the relation between the dimensions of the particles of powder and the distances between oxidized particles in SAP nevertheless is maintained.

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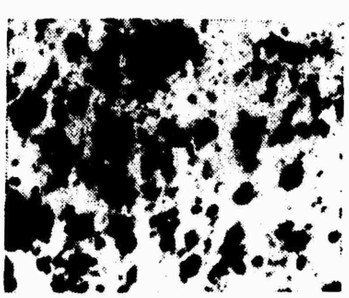

Fig 3. Photomicrograph of structure of rod from SAP with 10.8% Al_2O_3. Content of aluminum oxide in powder was increased by thickening of oxidized film (oxidation in humid atmosphere), x 2000.

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Fig 4. Electron photomicrograph of structure of briquette with 13% Al_2O_3, x 16,000.

This confirms results obtained by us of the determination from electron photomicrographs of the dimension of elementary particles of aluminum powders with 7 to 13% Al_2O_3 and the distance between oxidized particles in rods pressed from these powders (High-temp Material from Sintered Aluminum Powder (SAP) Oborongiz, 1961, p 5-16).

Partial destruction of oxidized films occurs even during cold briquetting of the powder (Fig. 4). Obviously the more plastic particle of aluminum under the action of high specific pressure (50-70 kg/mm^2) is deformed, which leads to cracking of the oxidized film in separate places. It is possible to consider that during hot briquetting (at 450-500C) the difference in plasticity of aluminum (t_m = 660C) and aluminum oxide (t_m = 2050C) significantly increases which leads to greater destruction of the oxidized films.

The sintering (compacting) and hot pressing of half-finished products which follow briquetting completely destroy the oxidized films, forming dispersed particles (of dimension 0.12-0.13 mk) which are comparatively evenly distributed in the aluminum matrix at a distance of 0.3-0.4 mk from each other (see Fig 2).

Electron photomicrographs of longitudinal and cross sections of rods pressed from SAP confirm that the oxidized phase in SAP after pressing of half-finished products has the form of dispersed particles and not partially destroyed films or shells. Analogous structure is shown by sheets from SAP (see below).

The correctness of the method of preparation of specimens for investigation of the structure of SAP and interpretation of the obtained electron microfotographs was checked as follows. After deep etching of a slide from SAP we managed to obtain a replica with black impregnations, which from preliminary analysis should be oxidized particles.

Electronograms taken from such replicas confirmed the initial interpretation -- the black impregnations have the crystalline structure of γ-Al_2O_3.

Furthermore, the obtained electron photomicrographs of the structure of SAP and their interpretation agree with the results of other experiments, (E. Gregory, N.J. Grant, J. of Metals, 1954, No 2, pp 247-252; H. Hug, H. Bischsel, Metall, 1961, Nr 1, SS. 19-22), although the specimens for investigation in these other works were prepared by other methods.

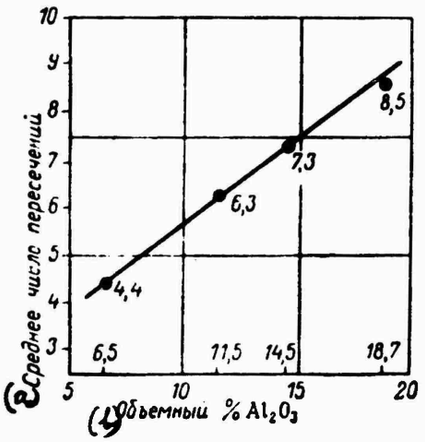

Fig 5. Dependency of average number of intersections on content of Al_2O_3 in rods from SAP.

a - Average No of intersections; b - Volume % of Al_2O_3

Interesting data were obtained after statistical treatment of the electron microfotographs of the structure of rods from SAP with 9, 16, 20, 26% Al_2O_3. On every electron photomicrograph we drew 10 lines and over a length of 2.5 mk we calculated the quantity of particles intersected by the line. Investigations (R. Fullman, J. of Metals, 1953, No 3) have established that the number of crossings per unit of length is proportional to the quantity of particles in a unit of volume (assuming that the magnitude and distribution of all particles in different samples are identical). Fig 5 graphically represents the dependency of the average number of crossings vs the content of aluminum oxide in every SAP rod. The higher the oxide content of aluminum, the bigger the number of crossings.

In the computation of the weight percentage of aluminum oxide the specific weight of SAP was taken as 2.73 g/cm^3, and the specific weight of aluminum oxide as 3.8 g/cm^3.

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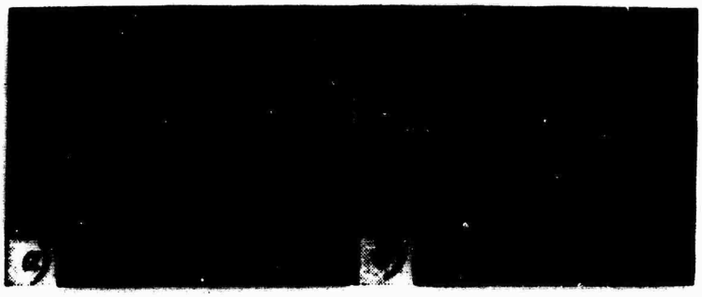

Fig 6. Electron photomicrographs of structure of rods from SAP, x 16,000.

a - with 9% Al_2O_3; b - with 26% Al_2O_3

On Fig 6 are represented the electron photomicrographs of the structure of rods from SAP with 9 and 26% Al_2O_3.

With the help of electron microfotographs of the structure of rods from SAP with content from 9 to 20% Al_2O_3, a check was made of the dependency of the ultimate strength on the distance between particles of the oxidized phase (Fig 7). With an increase of the distance between oxide particles from 0.34 to 0.82 mk the ultimate strength of SAP rods decreases from 45.5 to 33.5 kg/mm^2 at 20C and from 14.5 to 10.0 kg/mm^2 at 500C. Analogous dependencies were obtained earlier in a number of works. (C.G. Goetzel, J. of Metals, 1959, No 3, pp 189-194).

These results once again indicate the fact that the properties of half-finished products from SAP depend on the distance between particles of aluminum oxide, i.e. the strength of SAP is determined by the dispersion of the elementary particles of the aluminum powder.

On Fig 8 are given the electron photomicrographs of the structure of sheets from SAP (7.8% Al_2O_3), obtained at various degrees of deformation. No essential distinction in form of particles of oxidized phase in longitudinal and in cross sections of sheets with various degrees of deformation is observed (Fig 9). Statistical treatment of electron microfotographs of the structure of sheets from SAP showed that the dimension of the particles of aluminum oxide, and also their quantity and the distance between them are identical and do not depend on degree of deformation (Fig 10a, b). Annealing of sheets from SAP for 100 hours at 450C

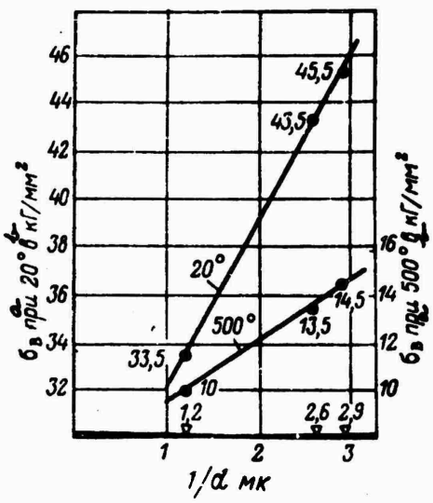

Fig 7. Dependency of ultimate strength of rods from SAP on distance between particles of oxidized phase.

a - At; b - in

and 550C also does not change their structure (Fig 11).

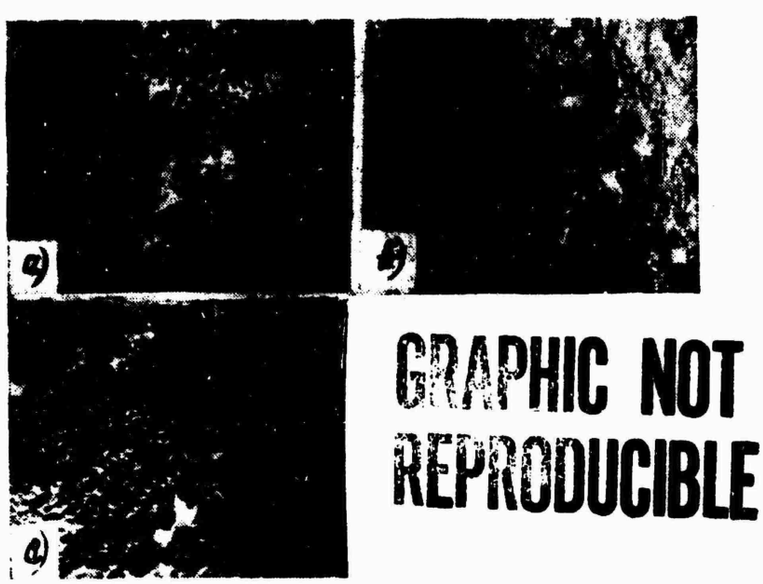

Fig 8. Electron photomicrographs of structure of sheets from SAP (7.8% Al_2O_3), (cross section), x 16,000.

a - hot-rolled sheet, degree of deformation 40%,
b - cold-rolled sheet, degree of deformation 52.5%,
c - cold-rolled sheet, degree of deformation 81%.

The mechanical properaties of sheets from SAP at room temperature depend on the degree of deformation: with an increase of the degree of cold deformation from 0 to 85% the ultimate strength increases from 32 to 41 kg/mm^2. Tests of samples at 500C showed that the strength practically remains without change and is equal 8-9 kg/mm^2 (Fig 12). Annealing at 450C for 100 hours does not affect the ultimate strength of sheets. After annealing at 550C for 100 hours there appeared bubbles and stratification on samples that led to a drop of ultimate strength and relative elongation (see Fig 12).

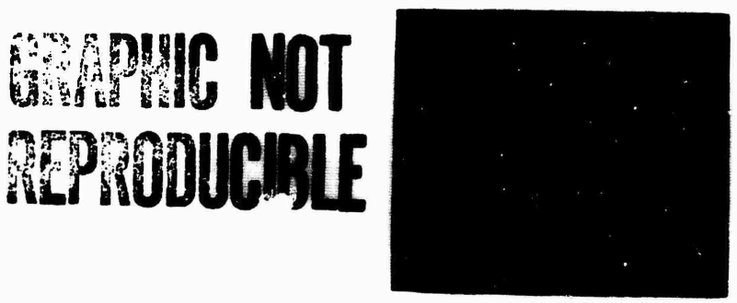

Fig 9. Electron photomicrograph of structure of cold-rolled sheet from SAP with 7.8% Al_2O_3 with a degree of deformation of 52.5% (longitudinal section), x 16,000.

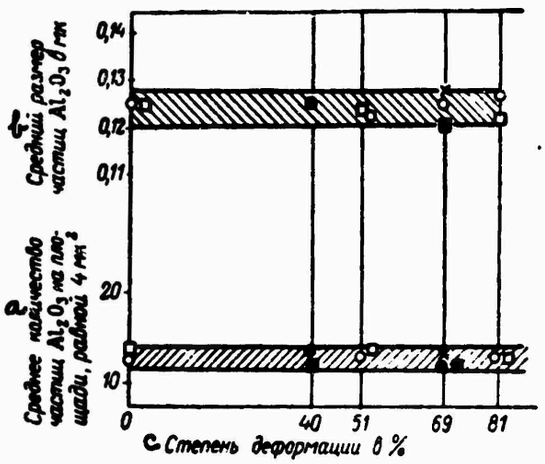

Fig 10. Dependency of dimension and quantity of particles of oxidized phase of sheets from SAP on degree of deformation and annealing.

Cold-rolled sheet: ○ -- without annealing, □ -- annealing at 550C for 100 hours, hot-rolled sheet: ● -- without annealing, ■ -- annealing at 550C for 100 hours.
x -- annealing at 450C for 100 hours.
a - Average quantity of particles of Al_2O_3 on an area equal to 4 mk^2; b - Average dimension of particles of Al_2O_3 in mk; c - Degree of deformation in %.

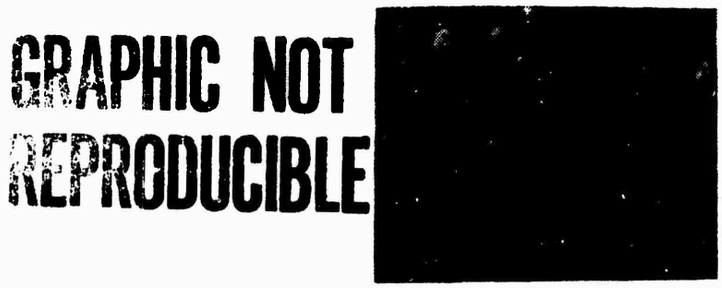

Fig 11. Electron photomicrograph of structure of sheet from SAP (degree of deformation 81%) after annealing for 100 hours at 550C, x 16,000.

These data coincide with the results of an investigation, given in (W.S. Cremens, E.A. Bryan, N.J. Grant, ASTM Preprint 1958, No 84, pp 1-7). The authors observed an increase of the ultimate strength of sheets containing 6-8% Al_2O_3 with an increase of the degree of cold deformation in the investigated limits (to 66%). However the work of B.I. Matveev and I.R. Khanova (High-temp Material from Baked Aluminum Powder (SAP), Oborongiz, 1961, p 59-63) indicates a drop of strength of sheets with 10% Al_2O_3 after increasing the degree of cold deformation to more than 66% (to 76%).

Obviously strengthening of sheets from SAP as a result of cold deformation occurs not from crushing of the particles of the oxide phase, but due to work hardening of the aluminum matrix and formation of texture. The stability of structure and properties at heightened temperatures of sheets from SAP may be explained by the presence of highly-dispersed particles of the oxidized phase embedded in the aluminum matrix. The particles of aluminum oxide serve as sort of barriers, preventing the recrystallizational processes.

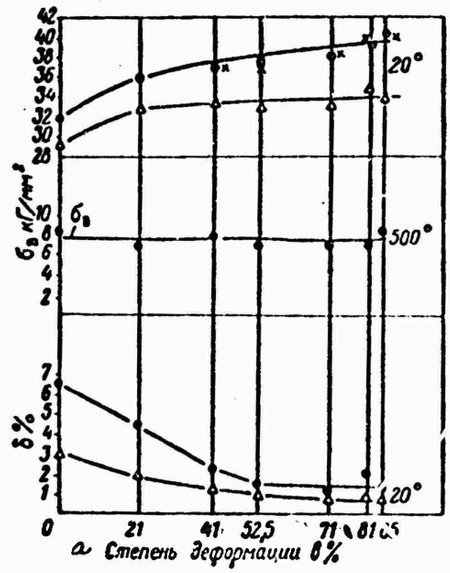

Fig 12. Influence of degree of deformation and annealing on mechanical properties of sheets.
-- sheets without annealing, -- sheets after annealing at 550C for 100 hours, x -- sheets after annealing at 450C for 100 hours.

a - Degree of deformation in %

However the mechanism of hardening of sheets from SAP as a result of cold deformation and the stability of the structure of sheets at heightened temperatures can be more exactly explained only after a study of the block structure of the aluminum matrix of the SAP produced with various degree of deformation, before and after high-temperature annealing (450-650C).

Conclusions

1. The structure of SAP consitutes an aluminum matrix with embedded dispersed particles of the oxide phase.
2. With an increase of content of aluminum oxide the quantity of particles of the oxidized phase increases and the distance between them decreases.

3. Properties of half-finished products from SAP depend on the distance between the particles of aluminum oxide, i.e. on the dispersiveness of elementary particles of the aluminum powder.

4. The dimension, the quantity of particles of oxidized phase and the distance between them in sheets from SAP do not depend on the degree of deformation, but the ultimate strength of sheets at room temperature is increased with an increase of the degree of cold deformation, which is probably explained by work hardening of the aluminum matrix and formation of texture.

FORM AND DIMENSION OF PARTICLES OF ALUMINUM POWDER FOR OBTAINING OF HALF-FINISHED PRODUCTS FROM SAP
(p 23 of source)

M.G. Stepanova, N.I. Kolobnev, L.I. Kibitova

For production of half-finished products from SAP we use aluminum powder of brand APS. The process of its manufacture was described earlier. (High-temp Material From Sintered Aluminum Powder (SAP), Oborongiz, 1961, p 17). An important feature of production of powder one should consider the fact that increase of content in it of aluminum oxide occurs by oxidation of the new surfaces appearing during crushing of particles of aluminum, thanks to which the properties of half-finished products from SAP are increased. According to the majority of theories of hardening the properties of SAP are dependent upon the distance between dispersed particles. And although the distance between particles of aluminum oxide in SAP cannot exactly correspond to the thickness of the particles of powder, this dependency nevertheless is maintained. (F.V. Lenel, A.B. Baskensto, M.V. Rese, J. of Metals, 1957, No 1, pp 124-130). Therefore investigators allot considerable attention to the form and dimension of particles of powder obtained by grinding of aluminum powder.

In a ball mill powder of brand APS is first ground (dimension of elementary particles should be less 75 mk), and then subjected to nodulizing.

During the study of influence of duration of grind on dispersiveness and bulk weight of aluminum powder (dimension of particles was checked by sifting through sieve 0075) it was revealed that enlargement of elementary particles and increase of bulk weight of powder do not start simultaneously (Fig 1).

The bulk weight of powder starts to be increased after grinding for 16 hours while the dimension of particles becomes less 75 mk only after 24 hours. Obviously, in this case there occurs a change of form of the particles which is notrevealed by screen analysis. Therefore the form of particles was studied with the help of an electron microscope with amplification of 5000*. *Study of form of particles on electron microscope was conducted under leadership of N.S. Gerchikova.

In order to trace the change of form of particles of powder, samples were taken every two hours in the process

of manufacture of powder on a ball mill.

Before electron-microscopic investigation the particles of powder were placed on a carbon film sublayer located in an electrostatic field. With the help of a copper grid this film was secured on one plate of a flat capacitor, and on the other we poured a small quantity of powder. With the creation of the electrostatic field the particles of aluminum powder were attracted to the opposite plate of the condenser and fell on the carbon film. This method ensured separation of particles from each other and their uniform distribution on the carbon film without destruction of the nodulized particles of powder.

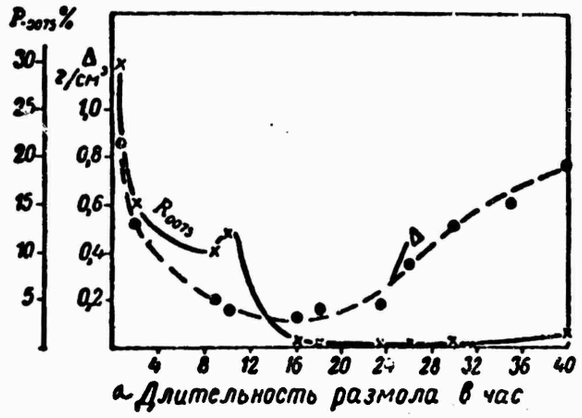

Fig 1. Influence of duration of grind on dispersiveness of particles and bulk weight of powder.

a - Duration of grind in hours

On the electron microscope with amplification of 5000 we studied samples of powders taken 4, 8, 14, 20, 24, 30 and 34 hours after the beginning of operation of the mill. From every sample we obtained 10-15 electron microfotographs from which we calculated the average area (size) of the particle of powder.

Part of the powder of this sample was subjected to chemical analysis for determination of the content of aluminum oxide and oils, furthermcre we made a screen analysis.

On Fig 2 are given curves of dependency of bulk weight of powder, residue on the sieve 0075, content of Al_2O_3 and average area of particles of powder vs duration of grind.

In the process of grinding the bulk weight of powder

at first decreases, after 8010 hours it attains a minimum value of 0.18 g/cm^3, then sharply increases to 0.8-0.9 g/cm^3. Further increase of duration of grind only insignificantly increases bulk weight.

Dispersiveness of powder is changed differently. In the beginning the remainder on the sieve 0075 somewhat drops then a further sharp drop and after 28 hours of grind again there is observed a smooth rise. The average magnitude of area of particles of powder in process of grinding changes analogous to the dispersiveness of particles as determined by screen analysis.

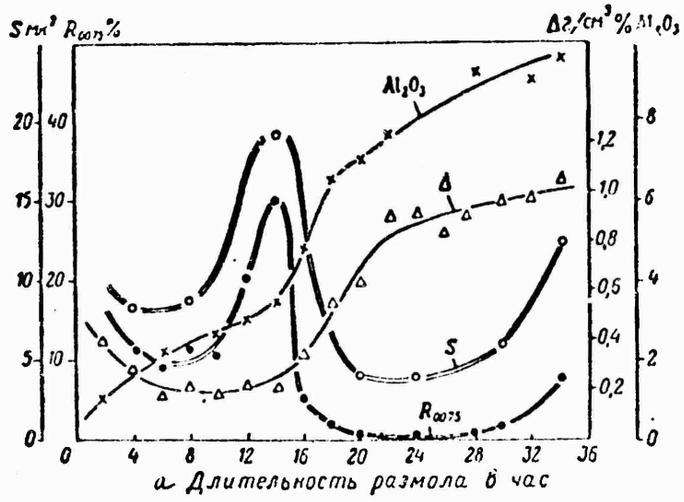

Fig 2. Dependency of average area of particles of powder, bulk weight, screen analysis and content of Al_2O_3 on duration of grind.

a - Duration of grind in hours

On Fig 3-7 there are given electron photomicrographs of particles of powder after 4, 14, 24, 34 hours of grind. On these photographs one may see how the form of aluminum particles changes in the process of grinding powder in a ball mill.

In the production of powder of brand APS the initial product is aluminum pulverizate obtained by atomization of molten aluminum. The dimension of particles of pulverizate is 100-450 mk, their form is close to spherical (see Fig 3). In the process of crushing the particles of

aluminum, possessing high plasticity, are deformed under blows of the balls, being turned into plates of length 40-90 mk and width 12-60 mk (see Fig 4), and then into very fine leaflets of length 30-150 mk, width 20-60 mk with a thickness less than 1 mk (see Fig 5). Flattening of particles leads to increase of their surface (remainder on sieve 0075 sharply increases), which is accompanied by a drop of the bulk weight (see Fig 2). This process continues until the degree of work hardening of aluminum particles attains values at which the plasticity of aluminum sharply decreases. There occurs destruction (splitting) of flat or scale-like particles of aluminum into smaller particles of from 5 to 20 mk (see Fig 6). The remainder on the sieve 0075 sharply decreases while the bulk weight is increased (see Fig 2). Increase of bulk weight in this case occurs by a change of form of the particles. In this stage of the process there is observed the maximum increase of the content of aluminum oxide in the powder. The curve of the change of content of aluminum oxide vs duration of grind rises steeply upwards.

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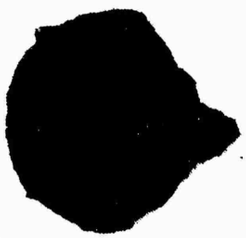

Fig 3. Photomicrograph of particle of aluminum obtained by atomization, x 200.

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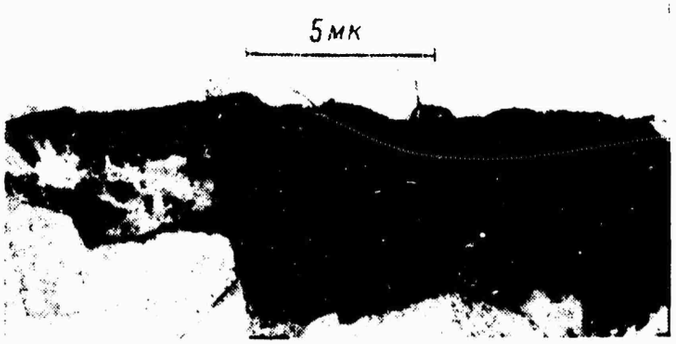

Fig 4. Electron photomicrograph of particle of powder after 4 hours of grind, x 5000.

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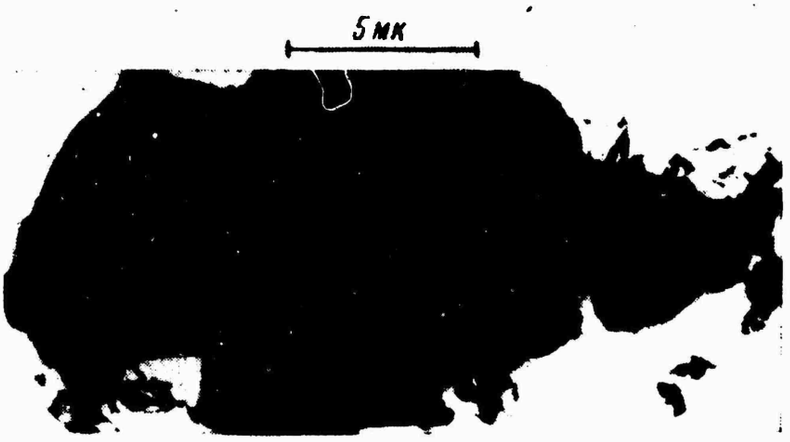

Fig 5. Electron photomicrograph of particle of powder after 14 hours of grind, x 5000.

In the process of grinding the oil is volatilized which makes possible the "joining" of separate elementary particles into bigger particles (conglomerates) (see Fig 7). The enlargement of particles of aluminum powder is accompanied by an increase of bulk weight.

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Fig 6. Electron photomicrograph of particle of powder after 20 hours of grind, x 5000.

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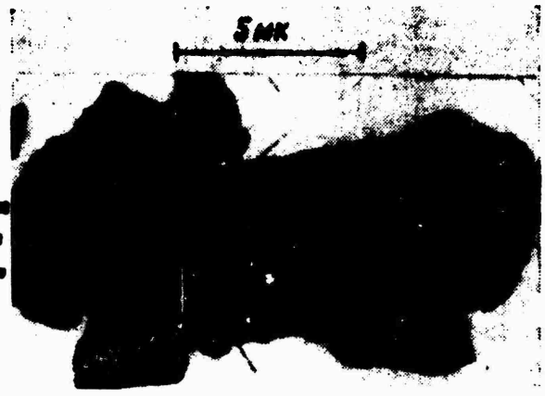

Fig 7. Electron photomicrograph of particle of powder after 34 hours of grind, x 5000.

Thus, obtaining of powder of brand APS in a ball mill goes in three stages:

1. The flattening of aluminum, obtained by atomization, to form particles of petal-like form is accompanied by work hardening.
2. Splitting of petal-like particles of aluminum into smaller particles with dimensions of the same order in length and width. The beginning of this stage is indicated by an increase of the bulk weight of the powder.
3. Joining of the small particles of powder into bigger particles, conglomerates, i.e. nodulizing of the powder.

SAP FROM SECONDARY ALUMINUM (p 28 of source)

E.M. Lekarenko, G.N. Pokrovskaya, G.P. Zenkov,
L.A. Sarul, N.I. Kolobnev

Aluminum powder of brand APS is prepared from primary aluminum of brands A0, A00. Replacement of primary aluminum by secondary will allow us to lower the application of secondary aluminum in production of SAP. It is necessary to investigate the mechanical properties and corrosional stability of half-finished products obtained from secondary aluminum. With this goal, the technology of production of powder of brand APS was used to obtain an experimental lot of powder from secondary aluminum pulverizate of the ATsV grade with bulk weight of 1.15 g/cm (1.1% Al_2O_3; 3.1% Si; 2.88% Cu; 1.56% Zn; 1.11% Fe; 0.01% Mn; 0.03% H_2O, remainder Al).

The duration of grind of the powder constituted 11 hours, and nodulizing took 36.5 hours. As a result of this the content of Al_2O_3 in the obtained powder was increased to 7.2%, and the bulk weight to 1.44 g/cm^3.

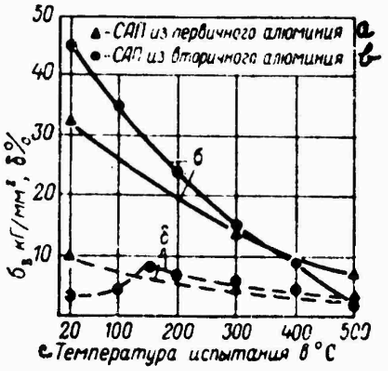

Fig 1. Mechanical properties of SAP from secondary and primary aluminum at heightened temperatures.

a - SAP from primary aluminum;
b - SAP from secondary aluminum;
c - Temperature of test in C.

From the obtained powder we pressed by the usual technology rods of diameter 14mm for investigation of their mechanical properties, corrosion stability and microstructure. (High-temp Material From Sintered Aluminum Powder (SAP), Oborongiz, 1961, p 5).

On Fig 1 are given the mechanical properties of rods of SAP with 7% Al_2O_3 from primary and secondary aluminum at heightened temperatures.

At temperatures to 350C the ultimate strength of SAP from secondary aluminum is higher than SAP from primary aluminum: at 20C by 12 g/mm^2, at 200C by 4 kg/mm^2. Beginning at 350C the ultimate strength of SAP from secondary aluminum is lower than the ultimate strength of primary SAP: at 400C by 1 kg/mm^2, at 500C by 5 kg/mm^2.

The relative elongation with increase of temperature of test from 20 to 150-200C increases from 4 to 7.5-8%. With further increase of temperature of test there is observed a drop of elongation from 8 to 3.5%. The elongation of SAP from secondary aluminum at temperatures to 100-120C is lower, and starting with 120 and to 500C is somewhat higher than SAP from primary aluminum (see Fig 1).

The same, unusual for SAP, character of change of elongation with increase of temperature was revealed in alloyed SAP (5% Cu; 12% Al_2O_3). (High-temp Material From Sintered Aluminum Powder (SAP), Oborongiz, 1961, p 113).

During checks on corrosional stability, samples of SAP from secondary aluminum stood up in a medium of 3% NaCl + 0.1% H_2O_3 for two months. Simultaneously in the corrosive medium there were placed samples of SAP from primary aluminum, pure aluminum, and the alloy D16 for comparison of their corrosional stability (see Table). Corrosional stability was determined by change of ultimate strength and elongation.

As can be seen from the table, corrosional stability of secondary SAP is lower than that of pure aluminum and of primary SAP, which is explained by the presence in SAP from secondary aluminum of silicon, copper, zinc, iron. However secondary SAP possesses higher corrosional stability than the alloy D16.

It is necessary to note that for SAP from secondary aluminum the characteristic (as for primary SAP) of smooth variation of the curve of dependency of ultimate strength with temperature of test is still retained, and the ultimate strength of SAP from secondary aluminum, starting at 300C, exceeds the ultimate strength of the usual aluminum alloys VD17, D16 and others.

TABLE

Mechanical properties of SAP from secondary aluminum, SAP from primary aluminum, pure aluminum, and alloy D16 after corrosion tests

a Материал	b До коррозии		c После коррозии		d Уменьшение в %	
	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$	δ
АОО	11,6	34	12,0	34,2	Нет h	Нет h
e САП из первичного алюминия (7,5% Al_2O_3)	39,8	9,0	39,7	8,8	Нет h	Нет h
f САП из вторичного алюминия (7% Al_2O_3)	43,6	1,3	40,7	1,2	7	Нет h
g Сплав Д16	51,0	16,8	43,5	6,7	15	60

a - Material; b - Before corrosion; c - After corrosion; d - Decrease in %; e - SAP from primary aluminum (7.5% Al_2O_3); f - SAP from secondary aluminum (7% Al_2O_3); g - Alloy D16; h - none.

SAP from secondary aluminum has high ultimate strength thanks to the finely-dispersed structure and the presence of highly-dispersed particles of the oxide phase (Fig 2).

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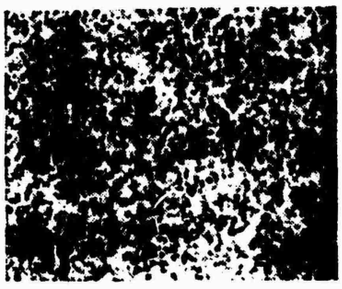

Fig 2. Microstructure of SAP rod from secondary aluminum, x 500.

The high strength characteristics of SAP from secondary aluminum once again confirm the possibility of obtaining by methods of powder metallurgy of standard aluminum alloys with finely-dispersed structure and high properties; this will allow us to avoid certain forms of rejects during casting: liquation, columnar structure, large-crystal inclusions of the intermetallics and others.

Conclusions

1. SAP with 7% Al_2O_3, obtained from secondary aluminum, has at 20C σ_B = 45 kg/mm^2 and δ = 4%; at 300C σ_B = 15 kg/mm^2 and δ = 6% and 500C σ_B = 2.5 kg/mm^2 and δ = 3%.

2. Corrosional stability of SAP from secondary aluminum is lower than for primary SAP, but higher than for the alloy D16.

TECHNOLOGY OF EXTRUSION OF LARGE-DIMENSION HALF-FINISHED PRODUCTS FROM SAP (p 31 of source)

V.G. Kovrizhnykh, Yu.N. Ponagaybo, V.I. Sverlov

(Engineers V.M. Baranchikov, V.A. Tikhomirov, G.F. Bulgakov, O.I. Albert, E.S. Volkov, B.I. Pasynkov, M.V. Kopytova, E.R. Romanova, technician Z.A. Pavlenko participated in this work)

In the manufacture of different half-finished products from SAP we used the very same equipment (presses, furnaces, saws, etc.) and tools (dies) press-plates, etc.), which usually are used during pressing of half-finished products from aluminum and its alloys.

Heating of briquettes for pressing is carried out in electrical resistance furnaces with circulation and without circulation of air. Briquettes were heated to a temperature 520-550C, and in certain cases to higher temperatures. Attempts to press different forms of half-finished products from briquettes heated to a temperature lower than 500C always ended in failure: the briquette would not extrude. Basic data on conditions and parameters of pressing are given in Table 1. Temperature of briquette constituted 520-550C, temperature of container was 430-450C.

The process of pressing of half-finished products from SAP is connected with certain peculiarities, caused by the nature of the material.

The briquette before pressing should be heated to a temperature higher than 500C. At lower temperatures it is impossible to conduct the process since the resistance to deformation of the weakly heated material is too great and specific pressures in the deformation regions are insufficient.

However heating of briquette before pressing to a temperature higher than 500C still is not a sufficient condition to ensure flow of the material. Very frequently, even with heating of briquette before pressing to 520-530C, the process of extrusion does not start if the force on the plunger increases slowly. In the beginning of the process of extruding during slow build-up of load on the plunger, there occurs a slow additional settling of the briquette in container, in the course of which there is a gradual increase of the surface of contact of the briquette with the die and the plunger of the container.

Table 1

Наименование и размер полуфабрикатов мм (a)	Размер брикета мм (b)	Диаметр контейнера мм (c)	Количество очков в матрице (d)	Степень деформации % (e)	Коэффициент вытяжки (f)	Скорость истечения м/мин (g)
Полоса (h)						
12×100×2500	⌀ 135×250	140	1	92	12,8	8—10
25×210×400	⌀ 260×450	285	1	92	12,3	8—10
27×95×4000	⌀ 260×450	285	2	92	12,4	8—10
30×240×3000	⌀ 260×450	285	1	89	8,9	8—10
Пруток (i)						
⌀ 45×5000	⌀ 260×450	285	3	92	12,3	8—10
⌀ 50×4000	⌀ 260×450	285	3	91	10,8	8—10
⌀ 50×5500	⌀ 260×450	285	2	94	16,2	8—10
⌀ 120×6000	⌀ 350×650	370	1	90	10	4—6
⌀ 130×5000	⌀ 350×650	370	1	88	8,5	4—6
⌀ 170×8000	⌀ 500×900	520	1	89	9,3	4—6
Полоса (h)						
30×405×12000	⌀ 500×900	520	1	94	17,4	6—8

a - Designation and dimension of half-finished products mm; b - Dimension of briquette mm; c - Diameter of container mm; d - Quantity of openings in die; e - Degree of deformation %; f - Coefficient of drawing; g - Exit velocity m/min; h - Strip; i - Rod.

Since between the briquette on the one hand and the container plunger and the die on the other there always exists a temperature drop (100-120C) then as the briquette shrinks it is cooled. When the compaction of the briquette is finished, and specific pressures in the material of the briquette attain their maximum values, the temperature of the briquette is strongly lowered and instead of 520-530C becomes lower than 500C. With such a temperature of briquette the process of extruding is not able to start. During fast loading of the plunger the temperature of the briquette does not descend lower than the limit ensuring initiation of flow of the briquette through the die. With beginning of flow the temperature of the briquette starts to increase rapidly due to the very large thermal effect of deformation and flow

of the material continues to termination of extrusion.

Lubrication of the tool facilitates pressing, therefore a high speed of application of load on the plunger in the beginning of pressing is not required.

There exists an upper limit of speed of pressing of half-finished products from standard aluminum alloys. Above this limit the surface of the article starts to crack, and with a further increase of speed of pressing the continuity of the metal over the entire section is destroyed. During pressing of half-finished products from SAP there is observed the inverse: with small exhaust velocities (practically lower than 4-5 m/min) on surface of the half-finished product, as a rule, there appear cracks, with high exhaust velocities (higher than 4-6 m/min) this defect is absent and the pressed article has a smooth and brilliant surface. On Fig 1-2 are given photographs of strip of section 30 x 405 mm and rod of diameter 170 mm, pressed with small exhaust velocities, while on Fig 3-4 are shown the same articles, pressed with higher speeds.

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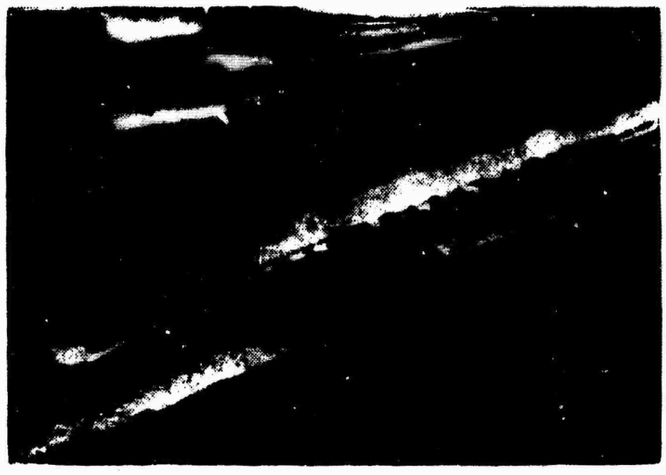

Fig 1. Strip 30 x 405 mm pressed with low exhaust velocity.

Existence of a connection between formation of cracks and small exhaust velocity is confirmed also by the presence of these defects on the leading ends of many articles, pressing of which was conducted with speeds to 10 m/min. No matter how high the rate of increase of pressure on the plunger in the beginning of pressing, the flow of the leading end always starts with speeds < 4 m/min, therefore on the

leading end of half-finished products there are formed cracks. Subsequently, when the speed is increased, extrusion proceeds normally. Pressing with high speeds always is accompanied very large heat emission. The material during pressing is heated so much that a pink glow appears. Comparison of these facts gives a basis to assume that the cause of appearance of cracks is the low plasticity of material, with insufficiently high temperature of the die outlet.

However this question has had little study, therefore exact indication of the mechanism of crack formation is impossible. Obviously between low temperature, low plasticity and ability of the material to bind there exists a definite interconnection.

APHIC NOT REPRODUCIBLE

Fig 2. Rod of diameter 170 mm, pressed with low exhaust velocity.

It is necessary to consider that excessive increase of speed of pressing, especially during manufacture of large-dimension articles, can evoke destruction of another type. On Fig 5 is represented a photograph of a section of rod of diameter 130 mm, on which there is a conspicuous longitudinal crack. This rod was pressed with an exhaust velocity of more than 10 m/minute. Immediately after pressing its surface was clean, smooth, without defects, as a result of the strong heating it had a pink glow.

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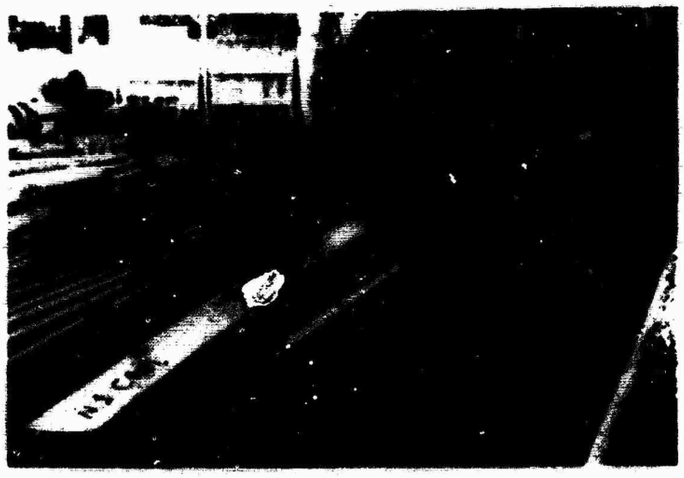

Fig 3. Strip 30 x 405 mm, pressed with high exhaust velocity.

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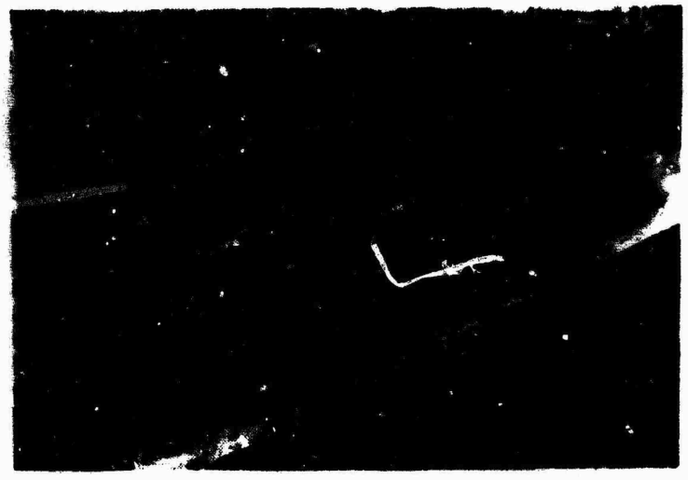

Fig 4. Rod of diameter 170 mm, pressed with high exhaust velocity.

Several minutes after termination of pressing, on the surface of the rod there was formed a longitudinal crack which gradually spread to approximately 3/4 length of the rod. Increase of length of crack was also accompanied by widening. Through the formed crack there were seen the red-hot internal layers of metal. Simultaneously with the formation of the crack the surface of the rod was covered

by bubbles.

Cause of the appearance of bubbles could be the evolving of gases as a result of strong heating while formation of the cracks apparently is connected with the action of stretching stresses which appear in the outer layers of the rod during cooling from the surface.

It is necessary to note that pressing with moderate speeds of rods of large diameter did not evoke the appearance of bubbles or cracks.

One of the peculiarities of pressing of half-finished products from SAP is that the quality of their surface varies along the length: approximately over the last third of the half-finished product approaching the trailing end there is an increased quantity of surface defects. While the outlet end and middle of the half-finished product have a high quality (sometimes even mirror) surface, especially with sufficiently high degress of deformation, on the trailing end there frequently appear quite deep scratches and scaling which are the result of the remaining material adhering to the die near the working region.

GRAPHIC NOT REPRODUCIBLE

Fig 5. Longitudinal crack and bubbles on rod of diameter 120 mm, pressed with exhaust velocity more than 10 m/minute.

During pressing of half-finished products from SAP on the inner surface of the plunger of the container there always is an aluminum "sleeve" remaining from pressing of ingots of aluminum alloys. In the initial moment of pressing, when flow of material occurs from the central volume, the extruded article has an even, smooth surface. With the decrease of volume of briquette, part of the "sleeve" metal is drawn into the region of deformation in the form of a thin layer between the moving volumes of metal and the stationary "dead volume" located at the die. On exiting

from the die opening the layer of aluminum is on the surface of the extruded half-finished product in the form of a thin sleeve (stratification).

By virtue of a number of causes the flow of the aluminum "sleeve" can start unsimultaneously from all sections of the surface of the plunger of the container, can at any time suddenly cease in a particular section, etc. In these cases a nonuniform surface of the articles is obtained. Sometimes aluminum "sleeve" is scaled from the surface of article or is inflated into bubbles. Although this kind of stratification is easily removed and does not influence the quality of the articles themselves the appearance of the half-finished products is poor.

When pressing approaches termination and the press-washer, advancing forward, attains the "dead volume", there starts a flow of material from this volume no longer as a result of a shift of the boundary of the shearing strains (surface of matrix funnel) into the depth of the "dead volume", but due to slip of material along the end surface of the die and there occurs flow of material from the zones directly adjacent to the orifice.

During pressing of half-finished products from the aluminum alloys this phenomenon is also encountered; metal, ensuing from the "dead volume", being separated from the basic volume by the discontinuous oxidized film, is so tightly welded with the basic metal that frequently one can determine the boundary only on a carefully prepared and etched slide. In those cases, when for some reason or other between these volumes of metal there is lubricant, dirt, etc., welding does not occur and the stratification is separated easily and freely.

During pressing of half-finished products from SAP the material of the "dead volume" turns out to be separated from the basic material of the briquette by a comparatively thick layer of aluminum, durable welding between them does not occur and very frequently the surface layer is separated immediately upon getting out of the die. Since the scaling usually is of significant thickness (from 1 to 10 mm depending upon dimensions of half-finished products) the part of the article on which scaling appears is rejected.

Data obtained as a result of investigations conducted (Table 2) show that the technology of pressing of half-finished products from SAP differs from the technology of pressing of standard aluminum alloys.

Pressed half-finished products from SAP at room temperature have comparatively high strength and elongation. With increase of temperature of tests the strength characteristics and elongation are lowered. One may assume that

a Продолжительность отжига час	400°				450°				500°				550°				600°			
	$\sigma_в$	δ	ψ	HB	$\sigma_в$	δ	ψ	HB	$\sigma_в$	δ	ψ	HB	$\sigma_в$	δ	ψ	HB	$\sigma_в$	δ	ψ	HB
	кГ/мм²	%		кГ/мм²	кГ/мм²	%		кГ/мм²	кГ/мм²	%		кГ/мм²	кГ/мм²	%		кГ/мм²	кГ/мм²	%		кГ/мм²
b Испытания при 20°																				
1	30,1	6,3	7,5	—	30,8	7,1	10,3	82	30,9	6,8	9,3	83	30,6	7,1	9,5	82	30,2	8,1	10,7	82
3	30,0	7,1	8,1	—	30,2	7,1	9,8	80	30,1	6,8	9,4	82	30,0	6,7	7,9	80	—	—	—	63
6	30,9	8,3	9,7	—	30,7	7,6	10,2	85	30,4	7,2	8,6	82	30,1	7,2	8,7	80	—	—	—	65
12	31,0	8,3	11,0	—	30,3	6,8	9,2	85	30,8	7,2	8,7	85	29,8	6,8	7,7	80	—	—	—	67
24	30,0	7,1	8,5	—	30,0	7,5	10,9	83	30,0	7,2	8,7	85	29,0	6,5	—	80	—	—	—	62
100	30,9	8,1	9,7	—	30,6	7,7	9,8	85	30,1	6,1	8,4	82	—	—	—	68	—	—	—	63
c Испытания при 500° С																				
1	10,2	2,7	6,5	—	10,1	2,3	7,2	—	10,9	2,5	6,5	—	9,9	2,1	—	—	9,4	3,1	6,7	—
3	9,8	2,5	6,4	—	10,2	3,1	5,8	—	10,4	2,6	6,4	—	10,1	2,9	—	—	—	—	—	—
6	9,9	2,7	6,8	—	10,7	2,8	5,6	—	11,0	3,1	7,7	—	9,9	2,5	—	—	—	—	—	—
12	10,1	2,4	5,6	—	10,4	2,7	7,2	—	11,1	3,2	6,2	—	9,8	2,3	—	—	—	—	—	—
24	9,8	2,9	7,5	—	10,4	2,1	5,9	—	10,5	2,6	5,3	—	9,4	2,4	—	—	—	—	—	—
10	10,2	2,7	6,4	—	10,8	2,5	5,3	—	10,7	2,9	6,3	—	—	—	—	—	—	—	—	—

Table 2

Mechanical properties of 25 x 210 mm strip (8.8% Al_2O_3) after annealing at 400-600C, mean values from tests of 5 samples per point.

a - Duration of annealing in hours; b - Tests at 20C; c - Tests at 500C.

the ultimate strength with increase of temperature in the interval 20-500C decreases linearly, on the average by 1 kg/mm^2 for every 25C. At temperatures higher than 350C the strength properties of pressed articles from SAP are higher than articles from any other aluminum deformed alloy.

The strength properties of a large part of the half-finished products from SAP (especially strip) pressed with a sufficiently high degree of deformation are practically independent of direction of pressing, annealing for 100 hours at a temperature to 500C, holding at temperatures to 500C for 580 hours under a stress equal 50% of the ultimate strength of the material at the temperature of annealing.

The strength properties of half-finished products at room temperature are affected by technological factors and also by the content of aluminum oxide in the material.

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Fig 6. Point inclusion in rod of diameter 50 mm, x 100

The surface of etched macrographs is monotone matte with a large quantity of black point inclusions of dimension to 1 mm (Fig 6). Investigations have established that the point inclusions have microhardness (with a load of 50 kg) of 600-700 kg/mm^2 and react positively to iron in a check by the liquid-drop method. It is possible to assume that these inclusions are particles of ferrous metal, which entered the powder during grinding as a result of destruction of the balls and internal sheathing of the ball mill.

The microstruction of the material does not have any signs of granular structure. On the white matrix of aluminum there are seen evenly distributed particles of the oxide-phase.

On longitudinal microsections one may see the clearly defined filamentary location of particles of the oxide phase (Fig 7).

GRAPHIC NOT REPRODUCIBLE

Fig 7. Microstructure of pressed half-finished products from SAP.

a - longitudingal slide; b - transverse slide, x 130

Conclusions

Large-dimension pressed half-finished products from SAP can be obtained on existing press equipment by the method of hot briquetting.

With correct selection of conditions for pressing (temperatures of heating and speed of pressing) the technology of hot briquetting ensures good quality of the half-finished products, bubbles and internal stratifications in the material are completely absent.

Using the developed technology we produced experimental lots of different pressed half-finished products from SAP: rods of diameter from 45 to 170 mm and strip of section to 30 x 405 mm.

INFLUENCE OF HEATING OF ALUMINUM POWDER BEFORE BRIQUETTING ON MECHANICAL PROPERTIES OF PRESSED HALF-FINISHED PRODUCTS (p 41 of source)

P.V. Kishnev, E.A. Kuznetsov, P.T. Vlasova

As we know, aluminum powder contains a large quantity of sources of gas, which are the oils added during crushing of the powder in ball mills, and moisture. The very large specific surface and high hydroscopicity of aluminum oxide lead to significant saturation of aluminum powder by moisture and formation of the hydrate of aluminum oxide $Al_2O_3 \cdot 3H_2O$. At temperatures of the order of 450-550C there starts decomposition of the hydroxide and interaction of it with the aluminum by the reaction

$$2Al + 3H_2O = Al_2O_3 + 3H_2 + Q,$$

which leads to additional oxidation of the aluminum and evolution of hydrogen. If the decomposition of the hydroxide occurs in a compact material, the evolving hydrogen causes swelling. Consequently, for obtaining from SAP finished articles of good quality it is necessary in the process of manufacture of the material to create favorable conditions for removal of gases. Earlier existing technology, which included the following basic operations: cold briquetting, prepressing of briquettes at 450-500C and pressing at 450-550C, did not ensure a sufficient degree of degassing of the material and therefore in a number of cases during pressing and especially during rolling of half-finished products there appeared internal stratifications and bubbles on the surface.

Heating of the powder before briquetting at definite temperatures should, probably, to a significant degree promote destruction of the sources of gas thanks to burning out of oil and decomposition of the hydroxide. Forming gases can freely depart through numerous pores.

For the purpose of determination of optimum conditions of heating of powder before briquetting, ensuring a sufficient degree of degassing and good mechanical properties, heating of powder was carried out over a wide interval of temperature--from 100 to 600C (every 100C).

For investigation we used aluminum powder of brand APS with content from 7.1 to 16.0% Al_2O_3. The technology of manufacture of pressed half-finished products was the following: heating of powder before briquetting, briquetting in container heated to 420C, prepressing at 450-500C, and pressing at 450-550C.

Briquetting, compacting and pressing were performed on a horizontal hydraulic press with a force of 300 T in a container of diameter 70 mm. Heating of powder was carried out in an electrical resistance furnace without circulation of air.

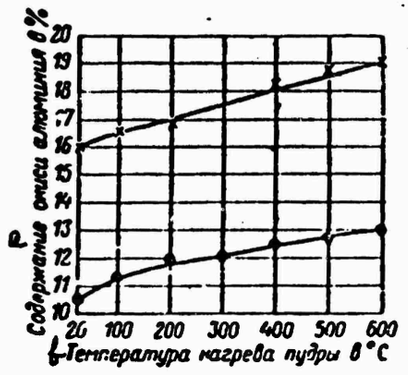

Fig 1. Change of content of aluminum oxide in powder of brand APS depending upon temperature of heating.

a - Content of aluminum oxide in %; b - Temperature of heating of powder in C.

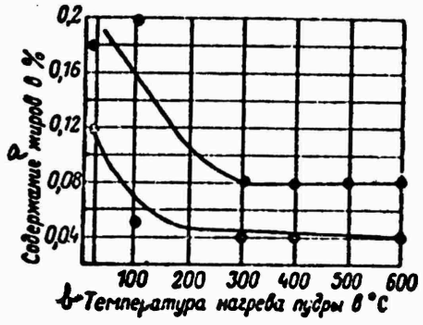

Fig 2. Change of quantity of oil in powder APS depending upon temperatures of heating.

a - Content of oils in %; b - Temperature of heating of powder in C.

During heating to 100, 200, 300 the time constituted 15 min, during heating to 400, 500, 600 it was 15 min, 1 hour, 5 hours. In the process of heating a sample was taken for determination of content of aluminum oxide and oils. On Fig 1 is shown the change of the content of Al_2O_3 depending upon temperature of heating of powder of two lots. Intensity of oxidation in the interval 100-600C with holding for 15 min at every temperature does not depend on the content of aluminum oxide in initial powder. With increase of temperature to 600C the quantity of Al_2O_3 increased by 2.5-3.0% as compared to the initial state. Content of oils with increase of temperature to 300C decreased, further increase of temperature to 600C did not lead to change of content of oils in powder (Fig 2).

For determination of degree of degassing of material in the process of heating of powder, samples were cut from briquettes, billets and pressed half-finished products. Change of quantity of gases depending upon temperature and duration of heating was estimated by content of hydrogen, inasmuch as the latter is the product of disintegration of moisture and oils. Definition of content of hydrogen was carried out with help of heating in vacuum and analysis of gas mixture by the volume method. The analyzed sample was heated to 800C.

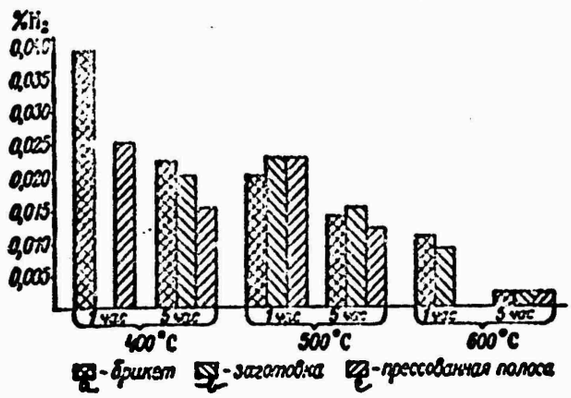

Fig 3. Change of content of hydrogen in briquettes, billets and pressed half-finished products depending upon temperature of heating of powder and time of holding.

a - briquette; b - billet; c - pressed strip;
d - hours

In Table 1 and on Fig 3 are given results of the gas analysis of briquettes, billets and pressed half-finished products.

Table 1

a Виды материала	b Температура нагрева в °С					
	400		500		600	
	c выдержка в час					
	d содержание водорода в %					
e Брикеты	0,039	0,022	0,020	0,014	0,011	0,002
f Заготовки	—	0,020	0,023	0,015	0,090	0,002
g Прессованные полуфабрикаты	0,025	0,015	0,023	0,012	—	0,0018

a - Forms of material; b - Temperature of heating in C; c - holding in hours; d - content of hydrogen in %; e - Briquettes; f - Billets; g - Pressed half-finished products.

With increase of temperature of heating of powder before briquetting from 400 to 600C the content of hydrogen in briquettes, billets and pressed half-finished products decreased to a significant degree. The least quantity of hydrogen was revealed in pressed half-finished products obtained from powder preliminarily heated to 600C and held at this temperature during 5 hours.

It is necessary to note that heating of briquettes before compacting and pressing promoted removal of gases only in the case when the powder was heated to a lower temperature. In the briquette obtained at 400C with holding during 1 hour and 5 hours the content of hydrogen constituted 0.039 and 0.022 % correspondingly, and in the pressed half-finished products -- 0.025 and 0.015%. Heating before compacting and pressing to 500C led to additional degassing of the material.

If briquetting is done at 500 and 600C, i.e. with those same temperatures as compacting and pressing (or above by 100C), additional degassing does not occur. Thus, annealing of powder before briquetting from the point of view of degassing is expediently conducted at 600C. Holding time at this temperature obviously will depend on dimensions of briquettes. The larger the dimension of briquette, the longer the time required for removal of gases.

Content of aluminum oxide in pressed half-finished products is almost independent of temperature and duration of heating in the interval 400-600C (Table 2), while the quantity of aluminum oxide in the powder continuously increases with an increase of temperature from 100 to 600C, as was shown above.

Table 2

Температура нагрева а в °С	400		500		600	
Время выдержки в час b	1	5	1	5	1	5
Содержание Al_2O_3 в прессованных полуфабрикатах в %. c	9,02–9,27	9,02–8,60	8,57–8,55	9,34–9,36	9,46–9,67	10,37–10,78

a - Temperature of heating in C; b - Time of holding in hours; c - Content of Al_2O_3 in pressed half-finished products in %.

The mechanical properties of pressed half-finished products are represented in Table 3. Ultimate strength and elongation were not changed with increase of temperature of heating of powder to 500C with duration of 15 minutes. Further increase of temperature to 600C evoked an insignificant drop of ultimate strength -- by 1-2 kg/mm^2 and increase of elongation by 0.8-1.0%. On Fig 4 is shown the change of mechanical properties of pressed half-finished products depending upon temperature of test (briquetting at 100 and 600C). Character of change of ultimate strength and elongation in each case is identical. However at 100C the ultimate strength is somewhat higher and elongation is lower than at 600C.

An essential influence on mechanical properties was shown by the duration of holding of powder at high temperatures. Holding of briquettes for 5 hours at 600C (Fig 5) brought a drop of ultimate strength at room temperature of 5 kg/mm^2 and increase of elongation of 5.5%.

With increase of temperature of heating of powder from 400 to 600C the ultimate strength of samples tested at 500C is lowered by 2 kg/mm^2 and elongation is increased by 4% (Fig 6). Such change of mechanical properties is impossible to explain only by decrease of content of gases in

Table 3

Температура брикетирования b °С	Содержание Al_2O_3 % c	a Температура испытания в °С: 20		250		350		500	
		$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %
100	10,5	38,5	7,0	22,5	4,0	17,9	1,7	10,4	1,2
	16,0	42,8	2,8	25,3	3,1	20,6	1,5	9,0	0,4
200	10,5	39,2	7,0	22,6	3,3	18,2	3,2	10,5	1,2
	16,0	43,0	3,3	24,2	3,2	19,9	1,7	12,4	0,8
300	10,5	37,5	9,3	22,0	3,8	17,0	4,1	10,4	1,7
	16,0	42,8	3,4	24,0	3,3	21,2	1,7	12,5	0,8
400	10,5	38,0	8,2	22,2	4,3	17,2	3,3	11,2	1,7
	16,0	41,4	3,5	24,1	3,1	20,4	1,5	12,0	0,8
500	10,5	37,6	7,2	22,5	4,0	17,3	2,8	10,4	1,6
	16,0	42,4	3,2	23,6	2,4	20,6	1,5	11,4	0,8
600	10,5	36,4	8,2	21,9	6,3	16,4	4,5	11,3	1,8
	16,0	41,2	3,3	23,7	2,3	20,0	1,3	12,0	0,8

a - Temperature of test in C; b - Temperature of briquetting C; c - Content of Al_2O_3%.

pressed half-finished products and all the more by increase of content of Al_2O_3, since the latter usually leads to lowering of plasticity. Obviously, this is connected either with removal of internal stresses or with the partial recrystallization, occurring in the powder during heating, inasmuch as in the process of crushing of the powder in ball mills there is work hardening. Thus, by correct selection of conditions of heating of powder there can be obtained pressed half-finished products of high quality with good mechanical properties. Hot briquetting allowed us to obtain a briquette of high density (order of 2.5-2.7 g/cm3), while

with cold briquetting the density of briquette constituted 1.7-2.0 g/cm^3. Therefore the operation of precompacting, necessary during cold briquetting, can be excluded from the technological process. The method of briquetting does not have any influence on the mechanical properties of pressed half-finished products (Table 4).

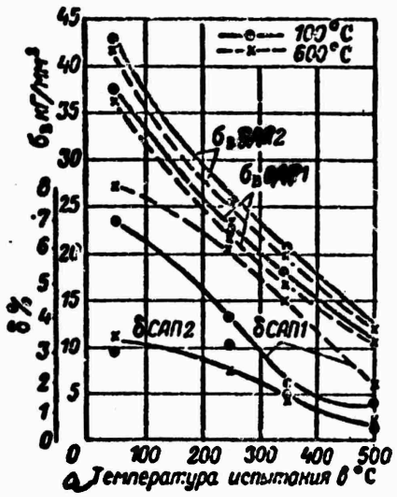

Fig 4. Change of mechanical properties of pressed rods from SAP depending upon temperature of test (temperature of briquetting of powder 100 and 600C).

a - Temperature of test in C.

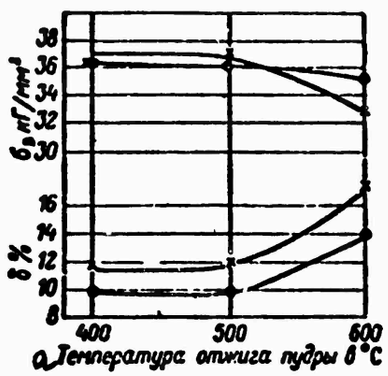

Fig 5. Influence of temperature and duration of heating of powder before briquetting on strength and elongation of pressed strip at a temperature of test of 20C.
x -- holding for 5 hours, -- holding for 1 hour.
a - Temperature of annealing of powder in C.

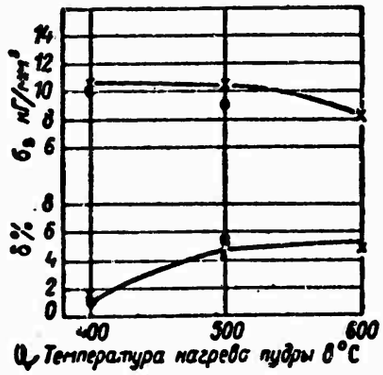

Fig 6. Influence of temperature and duration of heating of powder before briquetting on strength and elongation of pressed strip at a temperature of test of 500C. Time of holding -- 5 hours.

a - Temperature of heating of powder in C

Table 4

a Температура брикетирования	20		500	
b Механические свойства полуфабрикатов	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %
c Холодное брикетирование	29,3	12,7	6,8	1,8
d Брикетирование пудры, нагретой до 480—500°	29,5	12,0	7,6	2,2

a - Temperature of briquetting; b - Mechanical properties of half-finished products; c - Cold briquetting; d - Briquetting of powder heated to 480-500C.

Conclusions

1. Heating of powder before briquetting promotes degassing of the material. Least quantity of gases is revealed in powder held at a temperature of 600C for 5 hours.

2. Mechanical properties of pressed half-finished products do not depend on temperature of heating of powder up to 500C. Increase of temperature to 600C leads to lowering of ultimate strength and increase of elongation.

3. Briquetting of heated powder allows us to obtain monolithic high-quality briquette with a density of 2.5-2.7 kg/cm^3. This gives the possibility of excluding the operation of precompacting which is necessary during cold briquetting, as a result of which there is decreased work of the press equipment.

ROLLING OF SHEETS FROM SAP (p 48 of source)

M.F. Zakharov, F.V. Zhuravlev, S.I. Nomofilov,
V.A. Shelamov

Earlier research works allowed us to determine the basic parameters for rolling of sheets of SAP from pressed strip. However the limited dimensions of the pressed billet (maximum section of strip 30 x 240 mm) in the first stage of the study gave the possibility of rolling from this material sheets of thickness 0.8-2.0 mm, width not more than 600 mm and length to 1500-2500 mm. Hot rolling was conducted on a two-high mill with preheating of rolled stock after every passage.

Such technology of rolling SAP turned out to be extremely complicated and cannot be recommended for serial production. To provide an industrial assortment of sheets from SAP and the possibility of use for hot rolling of more powerful equipment (three-high mill) it was necessary in the first place to resolve the problem of obtaining on existing press equipment wider strip from the SAP. Strip of section 30 x 240 mm was prepared on a horizontal hydraulic press (5000 T) at a specific pressure of 40-60 kg/mm^2. Diameter of operating plunger was 306-360 mm.

For manufacture on this press of wider strip of SAP use of a container with large diameter of plunger (420 mm) is not possible since the maximum operating pressure will not exceed 30 kg/mm^2.

Inasmuch as containers with rectangular plungers (flat containers) allow us to obtain significantly larger working specific pressures with the same power of press, for obtaining wide strip of SAP we designed and prepared two special flat containers: a) for cold briquetting with section of plunger 140 x 535 mm, length of working part of plunger 1240 mm, actual stress in container 59.5 kg/mm^2;

b) for hot compacting of briquettes and pressing of strip with section of plunger 155 x 550 or 170 x 570 mm with length of 1240 mm and actual pressure in container 52.0 kg/mm^2. This container has induction heating of the working plunger.

PRESSING OF WIDE SAP STRIP

The basis of the technology of production of wide strip from SAP is the method of cold briquetting. For this purpose powder of brand APS-1 (with content of 6.5-8.5% Al_2O_3 and volumetric weight 1.1-1.4 g/cm^3) was poured into containers of sheet aluminum (δ = 1.0 mm) of dimension 125 x 52 x 900 mm. The surface of containers is corrugated (Fig 1). Weight of containers filled with powder was approximately 60-90 kilograms. Before briquetting the surface of the containers were covered by lubricant of a mixture of liquid glass and graphite.

GRAPHIC NOT REPRODUCIBLE

Fig 1. Flat container of sheet aluminum of dimension 125 x 520 x 900 mm.

At a specific pressure of 50-60 kg/mm^2 the density of the cold-pressed briquette attained 2.3-2.5 g/cm^3.

On Fig 2. is depicted a flat briquette, obtained by the method of cold briquetting. Dimensions of briquette are 145 x 535 x 450 mm, weight about 80 kilograms.

The following technological operation -- hot compaction of the briquettes -- was performed in a flat container with plunger section 155 x 550 or 170 x 570 mm. Before compacting, the briquettes were heated in an electric resistance furnace at different conditions (sustained 4-6 hours at 430C, 12 hours at 470C and 5 hours at 550C).

We compacted the hot briquettes in a container heated to 410-420C at a specific pressure of 45-52 kg/mm^2. Density of stock after compaction constituted 2.6-2.7 g/cm^3.

To remove the remainders of container metal from the stock they were machined on sides and edges, removing a layer of shaving of thickness to 5 mm.

Inspection of machined stock showed that the best were those from briquettes heated to 550C. On the lateral faces of the majority of the others there were cracks of depth to 30 mm.

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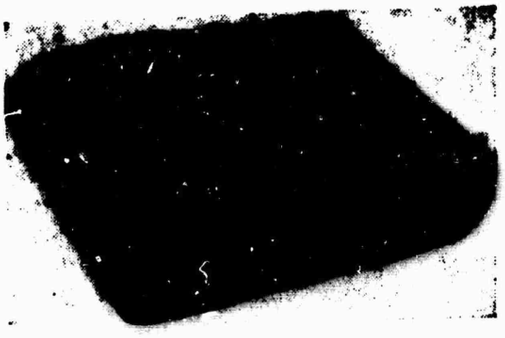

Fig 2. Briquette obtained by method of cold briquetting. Dimensions 140 x 535 x 400 mm, weight 80.0 kilograms.

On Fig 3 are shown two flat billets of SAP prepared for pressing of strip. Thickness of billets is 140-155 mm, width 535-550 mm and height 270-370 mm. Weight of billet after machining is 60-75 kg, percent of removal of metal in shaving (taking into account weight of container metal) is 8-12%.

Pressing of strip SAP of section 30 x 410 mm was performed from the same containers in which briquettes were compacted. In all we made 12 strips.

Conditions of Pressing

Temperature of container	410-450C
Temperature of billet during charge into container	420-450C
Maximum specific pressure during pressing	42-48 kg/mm^2
Exit velocity	1.8-2.6 and 6.0-8.0 m/min
Coefficient of drawing during pressing	7.4

Results of work on cold briquetting, hot compacting and extrusion of wide strip from SAP in flat containers on a horizontal hydraulic press (5000 T) allow us to make the following conclusions.

Cold briquetting of SAP in flat cans in a specially prepared container (without heating) with section of plunger 140 x 535 mm gave the possibility of obtaining flat briquettes of weight to 90 kg without surface defects; density of

briquettes constituted 2.3-2.5 g/cm^3.

Briquettes before compaction have to be heated to 550-600C. In the process of heating, appearance of defects was not observed.

The exit velocity during extruding should be not less than 7.0-8.0 m/minute.

From billets obtained by compaction of briquettes and heated to a temperature below 550C, and also from billets pressed at an exhaust velocity of less than 7.0 m/min, we obtained strip of unsatisfactory quality with breaks along the width and cracks along the edges.

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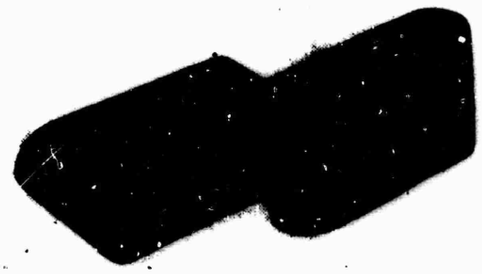

Fig 3. Billets of SAP after machining of hot-pressed briquettes, prepared for pressing of strip. Dimensions 150 x 540 x 320 mm; weight 72.0 kilogram.

On Fig 4 is shown a macrotemplet of pressed strip SAP of section 30 x 410 mm.

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Fig 4. Macrotemplet of strip SAP of section 30 x 410 mm.

ROLLING OF WIDE SHEETS OF SAP

Pressed strips of SAP of section 30 x 410 mm and length to 1700 mm were marked and cut to sheets of length to 650 mm. Before hot rolling the sheets were heated for 6-7 hours to 460-480C in an electric resistance furnace.

Rolling was done on a trio mill with rollers heated to 80-100C. Diameter of rollers was 725 mm, length was 1750 mm, speed of rolling was 1.41 m/sec. As lubricant during rolling we used the usual emulsion applied in rolling of aluminum alloys.

In the first passes the SAP sheets were rolled along the axis of pressing to the required width of stock (900-1300 mm), then the sheet was turned 90° and rolled in the final dimension to thickness of 4-5 mm after 7-9 passes with a degree of reduction per pass of 15-25%. Thickness of stock after hot rolling was 4-5 mm, width was 700 to 1300, length was 1000 to 1500 mm.

The external appearance of sheet rolled on the trio mill was fully satisfactory. However along the cut edges of the sheet, due to low plasticity of the pressed stock, during the first passes there were formed cracks of depth to 20-25 mm. Before subsequent treatment these edges and ends were sheared off.

Before cold rolling the stock was first annealed at 440C to show up bubbles, stratifications and other defects, then etched in a 15% solution of NaOH, brightened in a 10% solution of HNO_3 and washed in water.

After etching the hot-rolled sheets were subjected to inspection of the surface for small defects. On detection of bubbles, scales, delaminations, point inclusions they were cleaned off. Cleaning was done manually -- by scraper or metallic brushes.

Cold rolling of sheets of SAP was conducted on duo mill with rollers of diameter 750 mm and length 2000 mm (profile of barrel 0.05 mm). Speed of rolling V = 1.1 m/sec. As lubricant we used transformer oil.

All finishing operations (straightening and cutting of sheet to final dimension) were executed on existing workshop equipment.

Sheets of experimental lots of SAP had the following dimensions (in mm):

thickness	width	length
1.5÷2.0	1000÷1200	2000÷2500
0.8÷1.0	700÷800	1500÷2000
0.5÷0.6	500÷600	1500÷3000

Cold rolling on existing equipment of experimental lots of sheets of SAP allowed us to make the following conclusions.

Cold rolling should be conducted with reduction not exceeding 3-5% per pass. With in ease of degree of reduction the bearings and neck of rollers are heated rapidly, the profile of the roller changes and due to nonuniform drawing of the metal there are obtained deep lateral or longitudinal fissures on the sheet.

During cold rolling of sheets of thickness 1.5-2-0 mm and width 1000-1200 mm there were observed variations of thickness exceeding the allowable limits. The middle of the sheet is significantly thicker than the edges, on some sheets the difference of thickness attains 15-20%. In the future during serial rolling of wide sheets of SAP it is necessary to select a suitable profile of taper of the rollers.

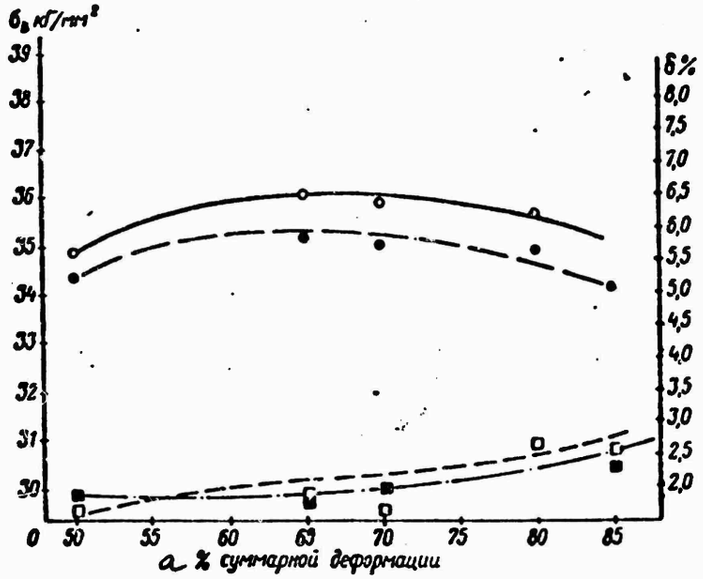

Fig 5. Change of mechanical properties of sheet SAP depending upon total deformation during cold rolling (temperature of test 20C).

—— o —— $\sigma_в$ longitudinal;
– – ● – – $\sigma_в$ transverse;
– – □ – – δ longitudinal;
—·—■—·— δ transverse.

a - % total deformation

Sheets of width 700-1000 mm can be rolled to a thickness of 0.8-1.2 mm, and sheets of width 500-600 mm to thickness of 0.5-0.7 mm. Production of thin sheets of greater width is possible on more advanced equipment existing in industry (four-high rolling mills).

The total degree of reduction during cold rolling should not exceed 60-65%. With larger degrees of reduction the mechanical properties of cold-rolled sheets at a test temperature 500C drop.

Intermediate annealing at 420-450C for 4-5 hours of cold-rolled stock of thickness 1.5-2.0 mm promotes removal of internal stresses and allows during further rolling of sheets of thickness to 0.5-0.8 mm obtaining values of σ_B, $\sigma_{0.2}$ and δ which differ little from the mechanical properties of sheets of SAP of thickness 1.5-2.0 mm. Intermediate annealing also promotes exposure of bubbles and is a control operation.

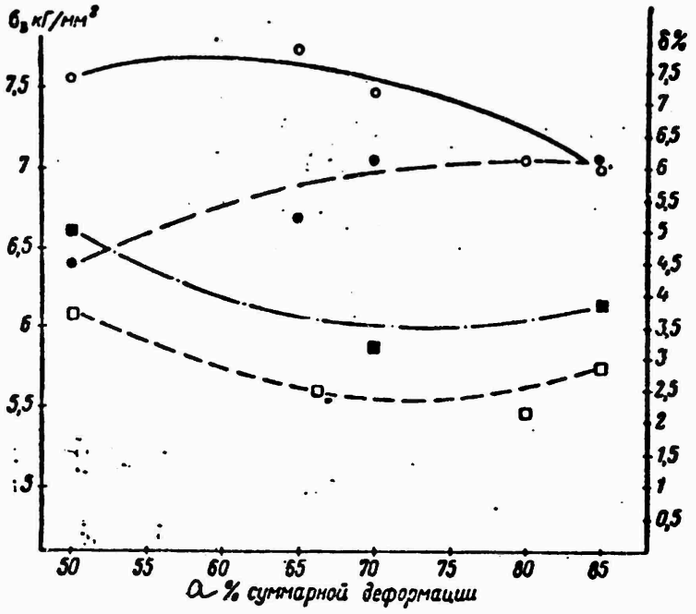

Fig 6. Change of mechanical properties of sheet SAP depending upon total deformation during cold rolling (temperature of test 500C).

Designations the same as on Fig 5.
a - % total deformation

Change of minimum mechanical properties of experimental lots of wide sheets of SAP depending on overall degree of total deformation during cold rolling is shown on Fig 5 (test at 20C) and on Fig 6 (test at 500C).

On Fig 7 is shown the change of mechanical properties of the same lots of sheets of SAP depending upon temperature of tests.

On Fig 8,9,10,11,12 there is shown the microstructure of sheets of SAP rolled with different degree of total deformation (powder with content of 6.6% Al_2O_3).

On the photographs of the microstructures there is seen the filamentary nature of the phase components, where with an increase of degree of reduction there is increased disintegration of oxide particles and a sharper revelation of the directivity of the structure.

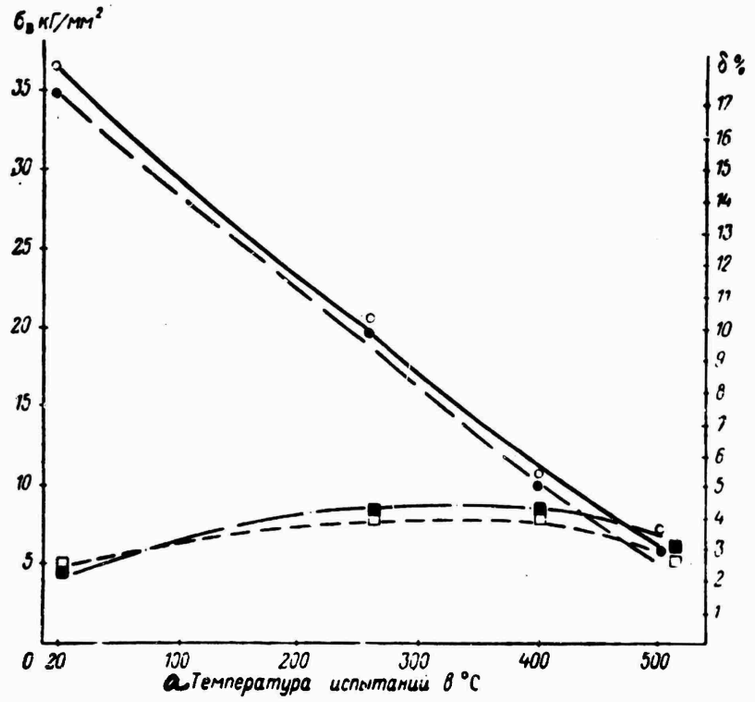

Fig 7. Change of mechanical properties of sheet SAP depending upon temperature.

Designations the same as on Fig 5.

a - Temperature of tests in C

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Fig 8. Microstructure of hot-rolled sheet SAP of thickness 4.0 mm. Across direction of rolling, x 400.

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Fig 9. Microstructure of cold-rolled sheet SAP of thickness 2.0 mm. Direction along rolling. Total degree of deformation during cold rolling 50%, X 400.

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Fig 10. Microstructure of cold-rolled sheet SAP of thickness 2.0 mm. Direction across rolling. Total degree of deformation during cold rolling 50%, X400.

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Fig 11. Microstructure of cold-rolled sheet SAP of thickness 0.8 mm. Direction along rolling. Total degree of deformation during cold rolling 80%, X400.

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Fig 12. Microstructure of cold-rolled sheet SAP of thickness 0.8 mm. Direction across rolling. Total degree of deformation during cold rolling 80%, X400.

Conclusions

1. Application of flat containers allows us to obtain on a horizontal hydraulic press (5000 T) by the method of cold briquetting with subsequent hot compacting of billets of SAP of weight 60-80 kg from which it is possible to extrude strip of section 30 x 410 mm.

2. From a sheet of such strip of length to 650 mm we can roll on a trio mill after 7-9 passes stock of thickness 4-5 mm, width to 900-1300 mm.

3. Cold rolling of such sheet and other technological operations (annealing, etching and stripping, straightening and cutting to finished dimension) in the production of sheet SAP can be executed on existing equipment.

INFLUENCE OF DEGREE OF DEFORMATION, SPEED AND TEMPERATURE OF PRESSING ON MECHANICAL PROPERTIES OF PRESSED HALF-FINISHED PRODUCTS (p 58 of source)

P.V. Fishnev, B.I. Matveev, V.S. Zolotov, L.S. Perevyazkin

(E.A. Kuznetsov, A.A. Gelman, G.M. Bagnenko participated in this study)

For improvement of the technology of manufacture of pressed half-finished products (rods, strips, profiles and so forth) we conducted an investigation of the influence of degree of deformation, speed and temperature of hot pressing on the quality of surface and mechanical properties of pressed half-finished products. The work was executed in factory conditions on existing technological equipment.

INFLUENCE OF DEGREE OF DEFORMATION

For establishment of optimum degrees of deformation during hot pressing of half-finished products aluminum powder of brand APS-1, containing 7.1% of aluminum oxide, was subjected to briquetting in the heated state and compaction with subsequent pressing from it of rods of different diameters on a 1500 T press in a container of diameter 130 mm.

The conditions used for pressing of the rods are given in Table 1. From the obtained rods we prepared samples for mechanical tests, structural analysis and determination of electrical resistance of the material. Dependency of mechanical properties on degree of deformation at temperatures of test of 20 and 500C is shown in Fig 1. Ultimate strength and elongation with an increase of defree of deformation to 80-85% increased just as for the usual aluminum alloys. Further increase of degree of deformation led to an increase of elongation, ultimate strength remained without change.

The increase of mechanical properties with increase of degree of deformation to 85% is connected with crushing of the structure of the material and the more equal distribution of aluminum oxide in the aluminum matrix, and also with the improvement of conditions of sintering in the orifice of the die which is confirmed by macroinvestigations (Fig 2).

Table 1

Conditions of pressing of rods

a Степень деформации в %	b Вытяжка	Диаметр прутков в мм	d Брикетирование		e Подпрессовка		f Прессование	
			температура °C g	время выдержки h мин	температура °C g	время выдержки h мин	температура °C g	скорость прессования i м/мин
62	2,6	80	450	1,5	500	1,5	500	10
81	4,3	63	450	1,5	500	1,5	500	13
85	6,7	50	450	1,5	500	1,5	500	12
94	18	30	450	1,5	500	1,5	500	14
96	27	25	450	1,5	500	1,5	500	15
98	53	18	450	1,5	500	1,5	500	14

a - Degree of deformation in %; b - Drawing;
c - Diameter of rods in mm; d - Briquetting;
e - Compacting; f - Extruding; g - Temperature C;
h - time of holding min; i - speed of pressing, m/minute

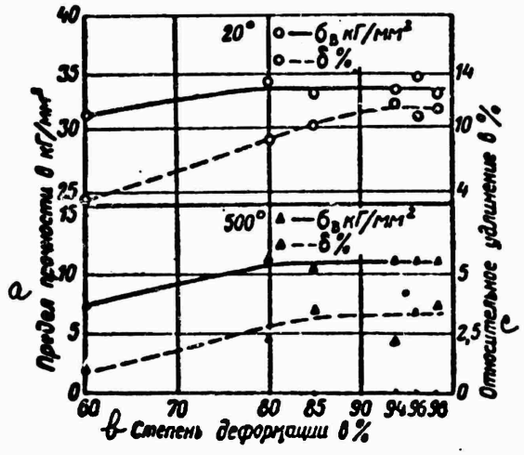

Fig 1. Influence of degree of deformation on ultimate strength and elongation of pressed half-finished products. a - Ultimate strength in kg/mm^2; b - Degree of deformation in %; c - Elongation in %.

In Table 2 are data on the influence of degree of deformation on density and electrical resistance of half-finished products. It had been assumed that at high degrees of deformation the density of the material is increased. Experimental data did not confirm this. There was also no change of electrical resistance. In microanalysis of pressed half-finished products no changes in structure were revealed (Fig 3).

Table 2

a Степень деформации в %	62	81	85	94	96	98
b Плотность в г/см³	2,700	2,702	2,702	2,702	2,700	2,700
c Электросопротивление в ом·мм²/м	0,040	0,039	0,039	0,038	0,039	—

a - Degree of deformation in %; b - Density in g/cm^3; c - Electrical resistance in ohm•mm^2/m

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Fig 2. Macrostructure of rods, pressed with different degrees of deformation.

a - 60%; b - 80%; c - 94%; d - 96%; e - 98%

INFLUENCE OF SPEED OF PRESSING

On the surface of pressed half-finished products there sometimes are noted defects in the form of swellings and transverse cracks. It was assumed that one of causes of the appearance of these defects is connected with incorrect selection of speeds of pressing. Influence of different speeds of pressing (from 0.78 to 16.3 m/min) on the condition of the surface of rods of diameter 50 mm was studied during manufacture of the latter from powder of APS-1 brand containing 7.7% Al_2O_3 under conditions: specific pressure 75 kg/mm^2, temperature of pressing 450-500C.

It was established that at speed of pressing of 0.78 m/min on the surface of the rods there appeared transverse cracks and burrs, with speeds from 8 to 16 m/min defects on the surface were absent.

In inspection of the macro- and microstructure of rods pressed with different speeds no changes were revealed.

The mechanical properties of the rods are presented in Table 3.

The unsatisfactory quality of the surface of rods at low speeds of pressing apparently is connected with welding of the metal to the walls of the container and die which led to the appearance on the surface of burrs and "cracks". Consequently, speed of pressing affects the quality of surface of half-finished products and does not affect their mechanical properties (see Table 3).

Table 3

Mechanical properties of rods of diameter 50 mm pressed with different speeds

Скорость прессования a м/мин	$\sigma_{при\ 20°}$		$\sigma_{при\ 500°}$	
	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %
0,78	35,5	6,4	10,1	3,0
1,06	35,8	6,8	10,7	2,6
1,29	34,7	5,7	10,4	2,8
1,90	36,2	6,9	10,8	3,0
2,97	35,0	5,0	9,9	2,8
16,30	35,6	7,4	11,8	2,7

a - Speed of pressing m/min; b - At

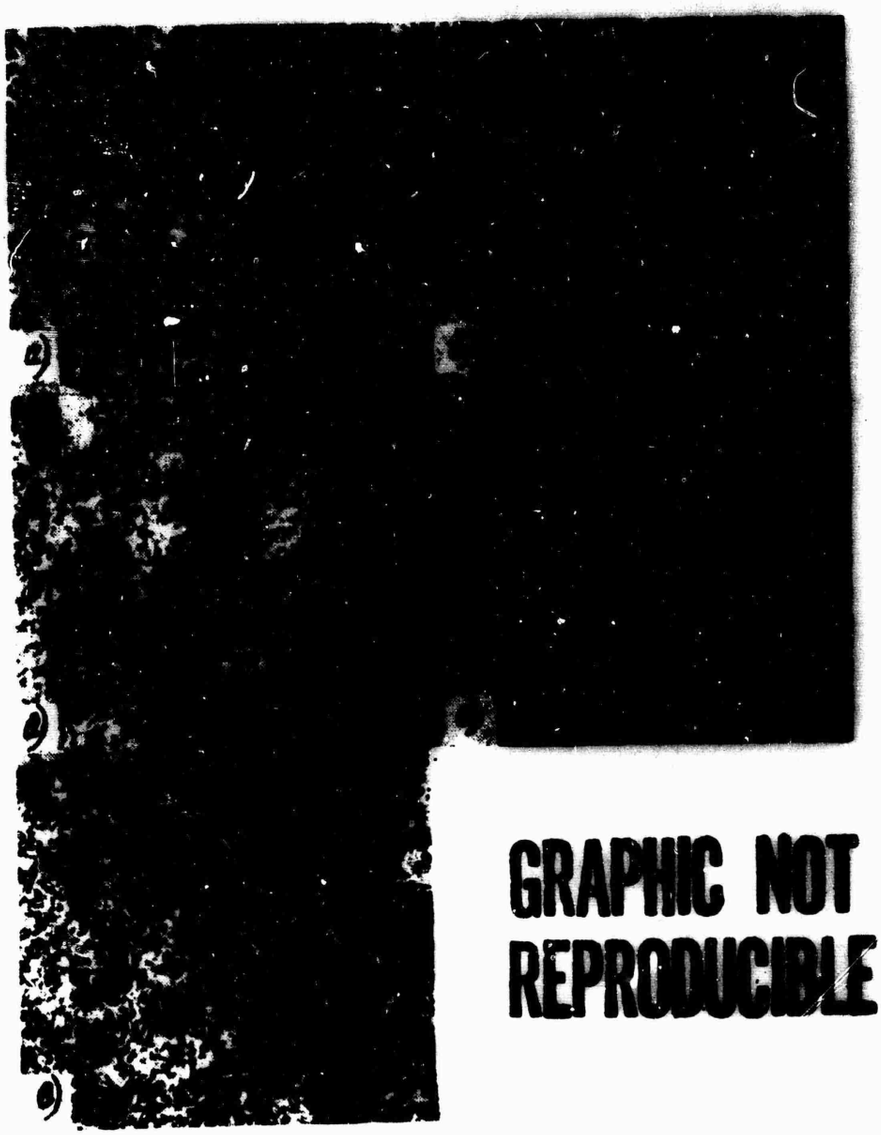

Fig 3. Microstructure of rods pressed with different degrees of deformation.

a - 62%; b - 81%; c - 94%; d - 96%; e - 98%

INFLUENCE OF TEMPERATURE OF HEATING OF STOCK BEFORE PRESSING ON MECHANICAL PROPERTIES OF PRESSED HALF-FINISHED PRODUCTS

For carrying out of this part of the study, the powder containing 7.6% Al_2O_3 was heated to 450C in electric resistance furnaces without protective atmosphere, then briquetted at a temperature of 400-500C and a specific pressure of 75 kg/mm^2. After machining the briquettes were heated to 450, 500 and 550C and pressed into rods on a 1500 T press. The rods passed mechanical tests at 20 and 500C results of which are shown in Fig 4.

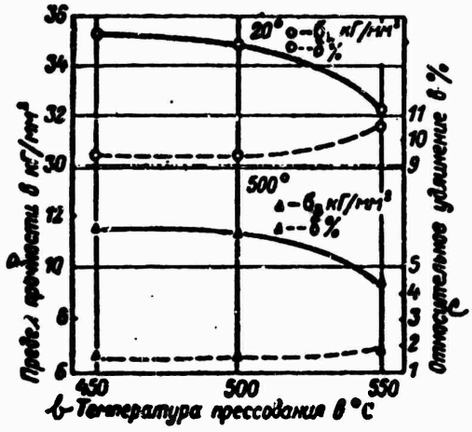

Fig 4. Influence of temperature of heating of stock on ultimate strength and elongation of rods.

a - Ultimate strength in kg/mm^2; b - Temperature of pressing in C; c - Elongation in %.

From the given data it is clear that the ultimate strength with increase of temperature of heating of stock from 450 to 500C was hardly changed, but with a transition from 500 to 550C there was observed a drop of strength.

Elongation with increase of temperature of heating of stock from 450 to 500C remained without change, while during transition to 550C it increased by 1%. Analogous pattern was also observed at temperatures of test of 500C.

The nature of the change of mechanical properties at temperatures of pressing higher than 500C, probably, is connected with partial recrystallization.

Conclusions

1. Increase (during pressing of rods) of degree of deformation to 85% increases the ultimate strength and elongation; at degrees of deformation over 85% the strength is not changed.

2. Speed of pressing does not affect mechanical properties of pressed half-finished products, but does influence the quality of their surface. Low speeds of pressing cause appearance on the surface of half-finished products of scratches, burrs, and cracks. With increase of speeds of pressing to 8 m/min and above, the half-finished products had high-quality surfaces.

3. With increase of temperature of heating of stock from 450 to 500C mechanical properties of half-finished products are not changed. Increase of temperatures of heating of stock over 500C insignificantly lowers ultimate strength and increases elongation.

4. For the purpose of achievement of the best combination of ultimate strength and elongation, and also for obtaining from powder of brand APS-1 pressed half-finished products with high-quality surfaces it is necessary:

a) to ensure that degree of deformation is not below 85%;
b) pressing be conducted with a speed not below 8 m/min;
c) to heat stock to 450-500C;
d) to carry out before briquetting heating of the aluminum powder in the range of temperatures 500-550C with holding at this temperature not less than 2-3 hours.

IMPROVEMENT OF TECHNOLOGY OF PRODUCTION OF STOCK FROM SAP (p 64 of source)

E.A. Kuznetsova, A.A. Gelman

Up to now the technology of manufacture of pressed half-finished products from SAP included the following basic operations: briquetting of powder in cold state, compacting or sintering under pressure at a temperature 450-500C, and pressing of the half-finished products.

The operation of compacting is conducted for the purpose of packing of the material which occurs as a result of increase of plasticity at temperatures of 450-500C. It was assumed also that partial sintering takes place here.

Investigations conducted recently introduced several changes in technology. In particular, cold briquetting in a number of cases was replaced by briquetting of powder heated to 450-500C. Density of briquettes obtained thusly is significantly higher than the density of cold-pressed briquettes. In connection with this the role of the operation of compaction was changed. In order to ensure additional packing of the material, the compacting must be performed at higher temperature than briquetting. Compaction of a sufficiently dense briquette (density 2.6-2.7 g/cm3) at a temperature not exceeding the temperature of briquetting, evokes the appearance of internal cracks which degrade the mechanical properties of half-finished products.

On the other hand, briquettes obtained at a temperature of 450-500C are quite dense and consequently the application of compaction is not advisable, its elimination significantly simplfies the technological process, reduces the work of the press equipment and increases the yield of sound product which naturally leads to lowering of the material cost.

In connection with this, work was conducted in two directions:

-- we investigated the influence of temperature of compaction on structure and properties of billets and pressed half-finished products;

-- we studied the possibility of shortening the technological cycle by eliminating compaction.

INVESTIGATION OF INFLUENCE OF TEMPERATURE OF COMPACTION ON STRUCTURE AND PROPERTIES OF BILLETS AND PRESSED HALF-FINISHED PRODUCTS FROM SAP

The investigations were conducted on powder of brand APS-1 containing 7.4% Al_2O_3.

The powder, poured into tubes of sheet aluminum, was heated in electrical furnaces at a temperature of 450 and 500C for 2-3 hours and then briquetted in a container of diameter 130 mm. Holding under pressure constituted 2 minutes. The resulting briquettes were turned down and then held at a temperature of 450, 500 and 550C for 2-3 hours, then compacted in a container of diameter 130 mm with a two-minute hold under a pressure of 40-50 kg/mm^2. From the briquettes and compacts there were prepared macrographs. From certain of the compacts we extruded rods of diameter 50 mm.

GRAPHIC NOT REPRODUCIBLE

Fig 1. Macrostructure of compact

GRAPHIC NOT REPRODUCIBLE

Fig 2. Macrostructure of briquette

Study of the macrostructure of the compacts showed that temperature of compaction does not influence the structure. Cracks, which, it was assumed, could be formed as a result of compaction at temperatures not exceeding the tem-

perature of briquetting were not found. On Fig 1 is shown the macrostructure of compacts which were compacted at a temperature of 450 C (temperature of preliminary briquetting 500C). There was also not seen any significant difference in macrostructure of briquette before compaction (Fig 2) and after compaction (see Fig 1).

Interesting results were obtained during measurement of hardness and electrical conductivity, whose values should be directly dependent on the quantity of metallic contacts, i.e. on density and degree of sintering of material. Sintering of material, apparently, should occur in a greater degree the higher the temperature of briquetting. Actually, with increase of temperature of heating of powder before briquetting the electrical resistance of the briquettes decreases. Thus, the briquette, pressed at 450C, has a specific electrical resistance of 0.047 ohm•mm^2/m, and at 500C it is 0.040 ohm•mm^2/m, which testifies to stronger destruction of oxide films at the heightened temperatures. However the hardness decreases. Apparently, at high temperatures processes connected with the relief of internal stresses take place in the material.

Compaction of briquettes prepared from powder heated to 450C decreases their electrical resistance from 0.044 to 0.039 ohm•mm^2/m. The hardness here is hardly changed. Temperature of compaction does not affect the hardness and electrical resistance of the compacts (Table 1). Temperature of compaction also does not influence the mechanical properties of pressed rods (Table 2).

Table 1

Influence of temperature of compaction on hardness and specific electrical resistance of compacts

Температура брикетирования a °C	Температура подпрессовки b °C	HB кГ/мм^2	Удельное электросопротивление c ом·мм^2/м
450	20	92	0,044
	450	90	0,039
	500	90	0,039
	550	90	0,039
500	20	82	0,040
	450	86	0,039
	500	86	—
	550	80	0,038

a - Temperature of briquetting C; b - Temperature of compaction C; c - Specific electrical resistance ohm•mm^2/m

Table 2

Influence of temperature of compaction on mechanical properties of pressed rods of diameter 50 mm

Температура брикетирования a °C	Температура подпрессовки b °C	Температура прессования °C c	d Механические свойства			
			20°		500°	
			$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %
450	450	470	33,4	8,9	11,0	2,0
450	500	470	32,7	10,2	10,7	3,0
450	550	470	32,7	9,6	10,3	4,0
500	450	470	31,0	12,2	10,8	3,2
500	500	470	32,5	10,6	10,0	1,8
500	550	470	30,0	11,6	10,5	1,4

a - Temperature of briquetting C; b - Temperature of compaction C; c - Temperature of pressing C; d - Mechanical properties

Thus, on the basis of the first stage of investigations it is established that a change of temperature of compaction in the interval 450-550C does not influence the structure and properties of compacts and pressed half-finished products.

PRESSING OF HALF-FINISHED PRODUCTS BY NEW TECHNOLOGY

Prerequisities for study of the possibility of shortening the technological cycle by eliminating compaction were, first, the assumption that sintering of material basically occurs in the die orifice in the process of pressing of half-finished products, secondly, results of preliminary investigations showing that compaction does not have any essential influence on structure and properties of compacts (in case of briquetting of heated powder).

There were tested two variants of the technology: pressing without compaction and pressing combined with compaction. For comparison we conducted pressing using the earlier technology.

During pressing without compaction (first variant) the turned briquettes were heated to a temperature of 450-550C and from them we pressed half-finished products.

In the second variant the turned briquettes were heated to a temperature of 450-550C, placed in a container between two press-washers, held under a pressure of 65-70 kg/mm^2, then the press-washer was knocked out and the extrusion was performed. Thus, during pressing by the first variant compaction was completely excluded, and the use of intermediate press-washer provided for a combination of the two operations. For the investigation we used aluminum powder of brand APS with different content of Al_2O_3. Chemical composition and basic characteristics of the powder are presented in Table 3.

Table 3

Basic characteristics and chemical composition of powder

a Химический состав в %				Насыпной c вес г/см^3
Al_2O_3	Fe	H_2O	f Жиры	
7,4	0,12	0,063	0,13	1,48
8,9	0,09	0,013	0,22	1,25
13,3	0,09	—	0,29	1,17
14,4	0,10	—	0,29	1,10
8,4	0,10	0,066	0,21	1,19
6,8	0,09	0,06	0,09	1,32

a - Chemical composition in %; b - Oils;
c - Bulk weight in g/cm^3.

Briquetting, compacting and pressing were performed on horizontal presses in containers of diameter 130 and 306 mm. The resulting half-finished products passed mechanical tests at room temperature and at 500C. On Fig 3 is presented the dependency of ultimate strength and elongation on content of Al2O3 in rods of diameter 50 mm, pressed by the different technological variants. In Table 4 are given the mechanical properties of rods of diameter 120 mm at 20 and 500C.

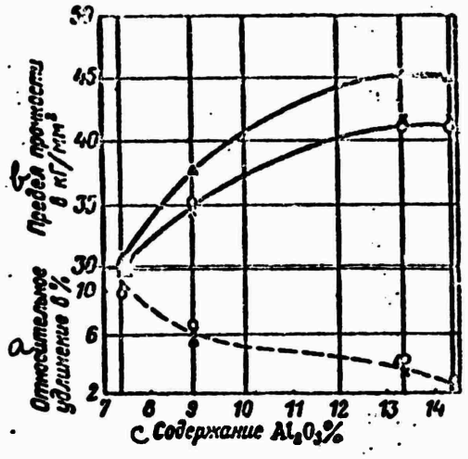

Fig 3. Dependency of ultimate strength and elongation of rods of diameter 50 mm, pressed by the different technological variants, with content in them of aluminum oxide. ○ -- pressing without plug, X -- usual technology, ▲ -- pressing with plug. a - Elongation in %; b - Ultimate strength in kg/mm^2; c - Content of Al_2O_3 %.

As can be seen from Fig 3, with an increase of content of Al_2O_3 in all cases the ultimate strength increases and elongation decreases, here the change of technology (full elimination of compaction) did not affect the mechanical properties of pressed half-finished products. Combination of hot compaction with pressing (second variant) led to unexpected increase of ultimate strength with constant elongation in the case of a content in the powder of more than 8% Al_2O_3.

Table 4

Mechanical properties of rods of diameter 120 mm, pressed by different methods (content of Al_2O_3 7%)

a Технология	20°				500°			
	b продольные		c поперечные		b продольные		c поперечные	
	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %
d Обычная	31,6	8,6	29,0	3,0	9,0	1,8	7,3	2,0
e Прессование с подпрессовкой	33,3	8,0	29,0	2,3	9,3	1,6	7,2	0,4
f Прессование без подпрессовки	33,6	8,2	29,5	3,7	9,5	1,5	6,9	0,6

a - Technology; b - longitudinal; c - transverse; d - Usual; e - Pressing with compaction; f - Pressing without compaction

Apparently, an essential influence on the mechanical properties is shown, on the one hand, by the total time of sintering under pressure, on the other hand by the quantity of cycles of heatings and coolings in the process of the production of pressed half-finished products.

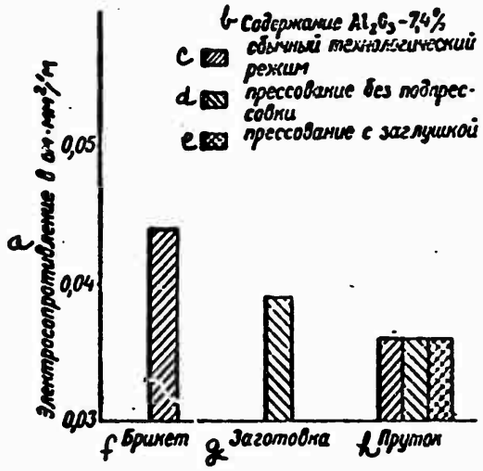

Fig 4. Change of electrical resistance in process of manufacture of pressed half-finished products. a - Electrical resistance in ohm•mm^2/m; b - Content of Al_2O_3 7.4%; c - usual technological conditions; d - pressing without compaction; e - pressing with plug; f - briquette; g - compact; h - Rod.

Increase of duration of sintering led to improvement of interparticle contacts, i.e. to increase of strength of the articles. Increase of quantity of cycles of heatings and coolings may cause additional stresses due to differences of coefficients of linear expansion of Al_2O_3, as a result of which there may be possible formation of micro-cracks and lowering of ultimate strength. During pressing without compaction there decreased both the total time of sintering under pressure and also the quantity of cycles of heatings and coolings (as compared to usual technological conditions). In this case ultimate strength was practically not changed. With use of intermediate press-washers (second technological variant) the total time of sintering under pressure was not changed as compared to the usual technology, but there was a reduction of the quantity of cycles of heatings and coolings that, apparently, led to an increase of ultimate strength.

This increase is the more noticeable the higher the content of Al_2O_3 in the powder.

In the investigation of micro- and macrostructure of rods pressed by different methods no essential difference in structure was found.

Density of the resulting half-finished products does not depend on the method of pressing (Table 5).

Measurement of electrical conductivity of briquette and compact by the method of eddy currents showed that hot compaction somewhat increases the electrical conductivity of the material (Fig 4), while the electrical resistance of the rods was independent of the technological variant used (Fig 4). All this confirms the assumption that the basic sintering of the material occurs during pressing in the die orifice.

Table 5

Density of rods pressed by different methods

a Содержание Al_2O_3 %	b Плотность в г/см³		
	c обычная технология	d прессование без подпрессовки	e прессование с подпрессовкой
7,4	2,702	2,705	2,709
8,9	2,701	2,707	2,706
13,3	2,699	2,698	2,703
14,4	2,709	2,706	2,701

a - Content of Al_2O_3%; b - Density in g/cm³; c - usual technology; d - pressing without compaction; e - pressing with compaction.

Conclusions

In the case of briquetting of heated powder the stock for pressing can be a briquette.

Additional compaction of the hot-pressed briquette over the interval of temperatures 450-550C does not have any essential influence on the structure and properties of half-finished products.

INVESTIGATION OF CERTAIN CONDITIONS OF HOT ROLLING SAP
(p 71 of source)

V.A. Shelamov

Work done under Honored Worker of Science and Technology, Professor Doctor of Tech. Sciences I.L. Perlin and Engineer S.I. Nomofilov.

In the present work we conducted an investigation of certain parameters of the process of hot rolling of pressed compacts from SAP.

For rolling we used strip SAP of the brand APS-1 obtained by method of cold briquetting with compaction and pressing. (High-temp Material From Sintered Aluminum Powder (SAP), Oborongiz, 1961, p 50) Content of Al_2O_3 in initial stock constituted 6-8%.

For determination of the influence of temperature of hot rolling on specific pressure and broadening, from pressed strip SAP of section 25 x 90 (coefficient of drawing 8) we cut longitudinal wedge-shaped samples with smaller height 2 mm, larger height 20 mm, width 30 mm, and length 90 mm.

For the purpose of increasing the plasticity of the stock to show the necessity of preliminary heating before rolling, part of the wedge-shaped samples was subjected to preliminary heating at temperatures of 450, 500 and 550C for 6, 12 and 48 hours. Heating was performed in a laboratory electric resistance furnace with Nichrome heaters. Temperature of heating was controlled by a switching potentiometer using two control thermocouples. The installation ensured accuracy of adjustment of temperature within limits of $\pm$ 10C.

Rolling of samples was done at temperatures of 20, 300, 400, 450, 500 and 550C on a duo mill with rollers of diameter 350 mm, length of barrel 500 mm, speed 18 m/minute. Rollers are prepared of steel ShKh15 (hardness Rockwell 55), surface is ground.

Total pressure of metal on rollers p_{ω} was measured with the help of wire transducers with resistance of 120 ohms and a base of 10 cm, glued on the neutral line of the rolling mill frame. Recording of pressures was carried out on the eight-channel magnetoelectric oscillograph MPO-2. Recordings of oscillograms (Fig 1) were made with a speed of the photographic film of 25 mm/sec.

Broadening $b = B_2/B_1$, absolute broadening ΔB and index of broadening $a = \Delta B/\Delta h$ were determined, proceeding from the law of constancy of volume, from the magnitude of reduction $\eta = H/h$ and drawing $\mu = L_2/L_1$. Use of the wedge-shaped samples gave the possibility of carrying out rolling with reductions from 1 to 90% (wedge-shaped sample was arbitrarily divided into five sections by reduction along the boundaries 18, 36, 54, 72, 90%).

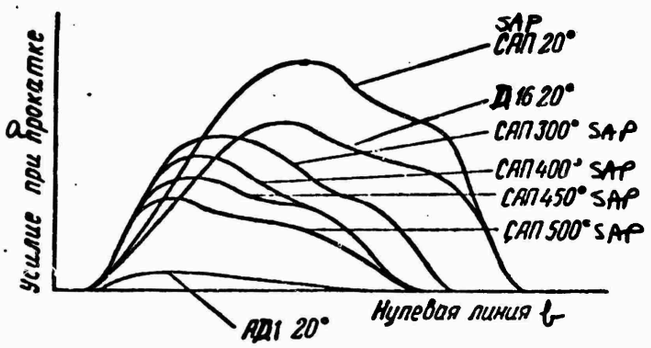

Fig 1. Model oscillograms taken during rolling SAP with different temperatures. For comparison there are shown oscillograms taken during rolling of wedge-shaped samples of the alloys AD1 and D16.

a - Force during rolling; b - Zero line

Broadening during rolling is composed of the following components: broadening due to slip on the contact surface, broadening due to barrel formation, and broadening due to spread of lateral faces of sample on contact surface. (I.M. Pavlov, Basic Positions of Contemporary Theory of Rolling, Transactions of the Sci. & Eng. Div. of Ferrous Metallurgy, Vol 10, Metallurgizdat, 1956)

It has been noticed that during rolling of SAP broadening by barrel formation is predominant. In this respect SAP can be compared with the titanium alloys.

Calculation of broadening ΔB was done by the formula of A. I. Tselikov (Collection of articles under editor Ya.S. Gallay, Materials According to the Theory of Rolling, Chapter 1, Metallurgizdat, 1960, p 526) with the empirical coefficient C determined on the basis of actual experiments:

$$\frac{\Delta B}{\Delta h} = C\left(2\sqrt{\frac{R}{\Delta h}} - \frac{1}{f}\right)\varphi\left(\frac{\Delta h}{H}\right). \qquad (1)$$

where Δh -- absolute reduction in mm;
C -- coefficient, depending on ratio of strip width to length of arc of grip;
R -- radius of rollers in mm;
f -- coefficient of friction; in this case we took f = 0.3;

$$\varphi\left(\frac{\Delta h}{H}\right) = \varphi(u) = \frac{1-u}{u^2}\left[(1-u)\ln\frac{1}{1-u} - \frac{u}{1-u}\left(1-\frac{3}{2}u\right)\right]. \qquad (2)$$

A.I. Tselikov suggests that the quantity $\varphi(u)$ be determined from the graph depending upon the relative reduction $u = \Delta h/H$.

Experiments showed that in rolling SAP it is possible to take the coefficient C = 3.0.

On Fig 2 is given a graph of similarity of magnitudes of broadening on the basis of experimental data and data obtained by calculation by the formula (1) with coefficient C = 3.0.

Dependency of index of broadening on temperature of rolling is given on Fig 3.

Curves for the coefficient of friction f', determined by the broadening formula of S.I. Gubkin (see references on p 79):

$$\Delta B = \frac{\Delta h}{H}\left(1+\frac{\Delta h}{H}\right)\left(f'\sqrt{\Delta h R} - \frac{\Delta h}{2}\right), \qquad (3)$$

are given on Fig 4. On the same figure there is shown the dependency of the specific friction forces calculated by the formula $\tau_s = Pf'$ on temperature of rolling.

For comparison of the magnitudes of pressures during rolling SAP and the usual aluminum alloys we made a recording of oscillograms of rolling of analogous samples from the alloys AD1 and D16.

The specific pressure p during rolling, equated to the resistance to deformation of the material in the given

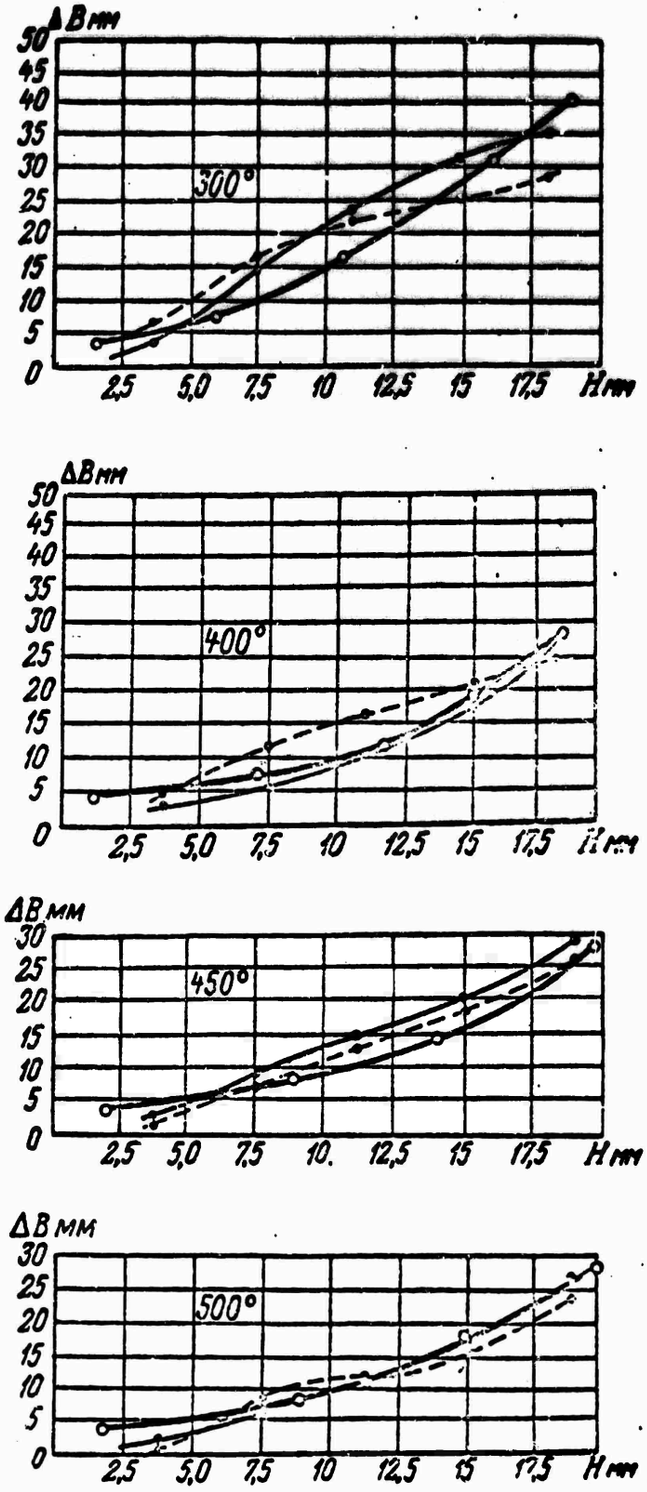

Fig 2. Comparison of magnitudes of actual broadening B with magnitudes calculated by formula.

——●—— after preliminary heating of compacts, ΔB actual;

---●--- without heating of compacts, ΔB actual;

——●—— ΔB calculated

conditions, was determined by the formula

$$p = \frac{P_n}{B_{cp}\sqrt{\Delta h R}}. \qquad (4)$$

Graphs of the dependency of the specific pressure on temperature of rollings are shown on Fig 5, and on relative reduction at the selected temperatures of rolling -- on Fig 6.

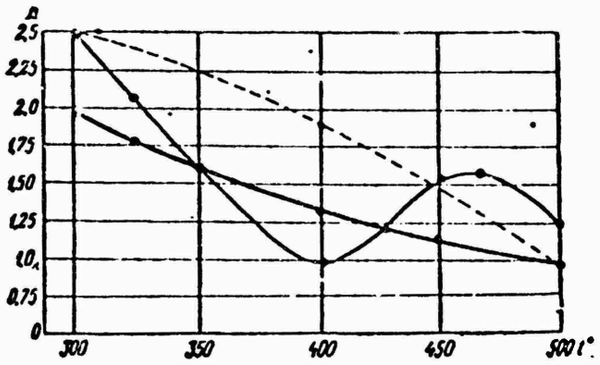

Fig 3. Dependency of index of broadening a on temperature of rolling.

——— after heating of sample, actual measurement;
------ without heating of sample, actual measurement;
▬▬▬ computed curve

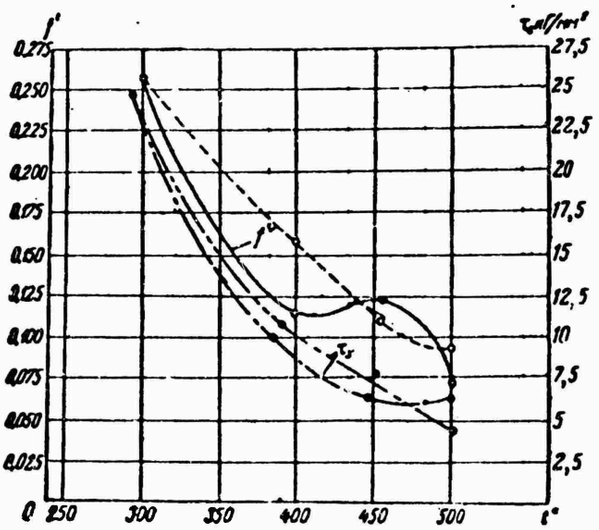

Fig 4. Curves of dependency of coefficient of friction f' and specific friction forces τ_s on temperature of rolling.

———— f' after heating of sample;
- - - - - - - - f' without heating of sample;
— . — . — τ_s after heating of samp` ;
— o — τ_s without heating of sample.

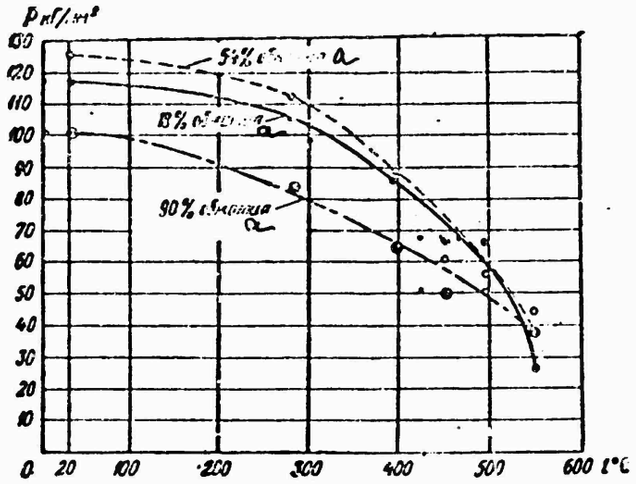

Fig 5. Dependency of specific pressure p on temperature of rolling.

a - reduction

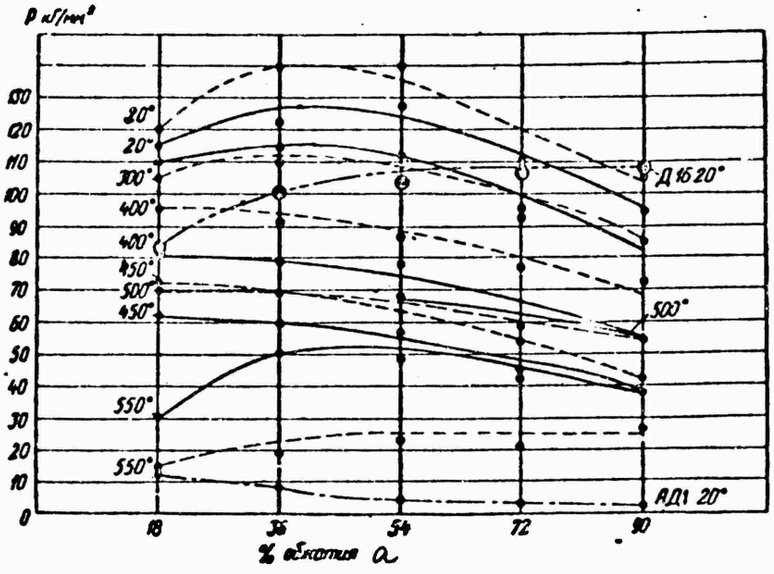

Fig 6. Dependency of specific pressure p during rolling on relative reduction.

———— with heating SAP

---------- without heating SAP;

—•——•— AD1; —.·.— D16

a - reduction

On Fig 7 is given the dependency of the coefficient of friction on relative reduction (rolling at 450C) of a heat treated sample.

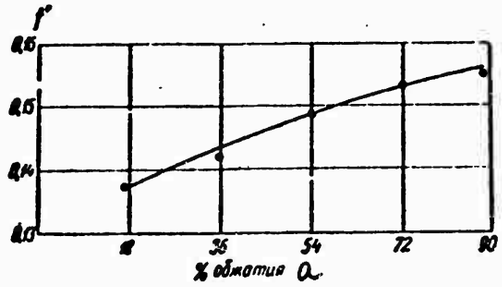

Fig 7. Dependency of coefficient of friction f' on relative reduction (rolling of heat treated sample at 450C).

a - reduction

Conclusions

1. During comparison of magnitudes of absolute broadening ΔB determined from experiment and calculated by the formula, noticeable difference is not revealed. The same may be said of the values of broadening during rolling of a sample after preliminary heating and without heating. A small decrease of the value ΔB is observed with increase of temperature of rolling.

Actual and calculating magnitudes of index of broadening are practically identical.

2. Coefficient of friction f' during rolling SAP has a tendency to a sharp decrease with increase of temperature of rolling.

Analogously are changed specific frictional forces τ_s.

3. During rolling SAP, with increase of reduction to 50% the specific pressure p is increased; with further increase of total reduction (to 90%) it drops.

4. Coefficient of friction f' increases with increase of total reduction.

5. The marked change of magnitudes of specific pressure and of coefficient of friction can be explained by the significant thermal effect appearing during deformation of SAP.

6. With increase of temperature of rolling the specific pressure p decreases.

7. Power parameters of rolling SAP significantly differ from the parameters of rolling of the usual aluminum alloys.

Differences of power parameters in rolling preliminarily heated and nonheated samples of SAP are not noticed.

PROPERTIES AND STRUCTURE OF WIRE FROM SAP
(p 78 of source)

P.V. Kishnev, B.I. Matveev, N.A. Martynova,
S.L. Nomofilov, E.Ya. Bazurina, V.A. Shelamov

(E.A. Kuznetsova, V.V. Martynov, M.V. Kiryushina,
L.S. Perevyazkin participated in this study)

For joining of structures of the high-temp materials (SAP), for instance sheets with profiles, it is necessary to have rivets also made from the high-temp material. With this goal we proposed to develop the technology of manufacture of wire from SAP, to investigate its mechanical properties and structure, and then to prepare a lot of rivets and to test them in the riveting of a connecting seam.

From aluminum powder of brand PP-4 (chemical composition: 4-5% Al_2O_3, 0.06% Fe, 0.26% oil, 0.016% moisture, remainder aluminum) we prepared an experimental lot of wire of diameter 3,4,5 mm.

Briquetting of aluminum powder was done in the cold state on a 750T horizontal hydraulic press in a cold container. The obtained briquettes were subjected to compaction and sintering on the same press at a specific pressure of 90-95 kg/mm^2.

After machining the compacted briquettes (billets) had a diameter of 85-90 mm, height 140-170 mm, weight 2.6-3 kg and density 2.6-2.7 g/cm^3.

Before pressing of wire the billets were heated in electric resistance furnaces with revolving hearth and with circulation of hot air inside the working space.

Pressing of the wire stock was done on 750 T horizontal hydraulic press. Diameter of container was 95 mm, diameter of wire stock 6 mm, length 3.5-4.2 m.

Conditions of pressing of wire were the following:

Temperature of container	400-430C
Temperature of stock	450-480C
Time of pressing	20 sec
Speed of pressing	12 m/min
Specific pressure during pressing	91.5 kg/mm^2
Coefficient of drawing	21

During pressing lubricant was not applied. Temperature of press tool was the usual for hot pressing (250-300C). Pressing of wire was done through sieve die with 12 holes of diameter 6 mm each. Surface of pressed wire obtained was smooth.

On Fig 1 is shown pressed wire stock weighing more than 100 kg was subjected to drawing in cold state on a single drawing mill of brand VSP-1/550 having a maximum force of 2000 kg, speed of drawing 60-100 m/min, and powder of electric motor 40 kilowatt. By further drawing calibrated wire of diameters 3, 4 and 5 mm was obtained using the following scheme.

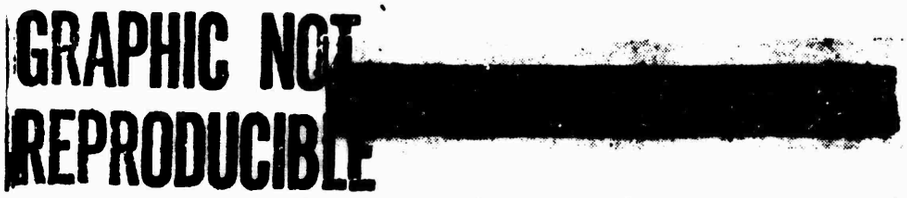

Fig 1. Surface of pressed wire stock of diameter 6 mm.

Transitions from 6.0 to 3.0 mm:

6,0 → 5, 5,5 → 5,20 → 5,0
4,7 → 4,3 → 4,15 → 4,0
3,8 → 3,6 → 3,4 → 3,2 → 3,0

The degree of deformation during drawing constituted 75%.

Drawing of wire from diameter 6 mm to diameters 3, 4 and 5 mm was done without intermediate annealings. During drawing we applied the same lubricant NK-50 as is used in drawing of wire from aluminum or aluminum alloys.

On Fig 2 is shown calibrated wire of diameter 3 and 5 mm. Surface of wire is smooth and brilliant without burrs, form of section is regular without ellipticity.

Mechanical properties of calibrated wire were determined at normal and heightened temperatures. On Fig 3 is given the graph of change of ultimate strength and elongation depending upon temperature of test.

As the curves show, at room temperature the ultimate strength of wire of diameters 3, 4 and 5 mm constitutes from 26 to 29-30 kg/mm^2, and elongation is from 5.5 to 8-9%.

It is characteristic that the smaller the diameter of the wire, the higher its strength. Thus, for instance, wire of diameter 5 mm has at 20C ultimate strength of 26 kg/mm^2, and wire of diameter 3 mm has 28-30 kg/mm^2. This

probably is possible to explain by cold hardening in the process of deformation of wire during drawing. Pressed wire stock of diameter 6 mm at 20C had an ultimate strength of 23 kg/mm^2 and elongation 21.6%, at 500C the corresponding values were 6.8 kg/mm^2 and 6.2%.

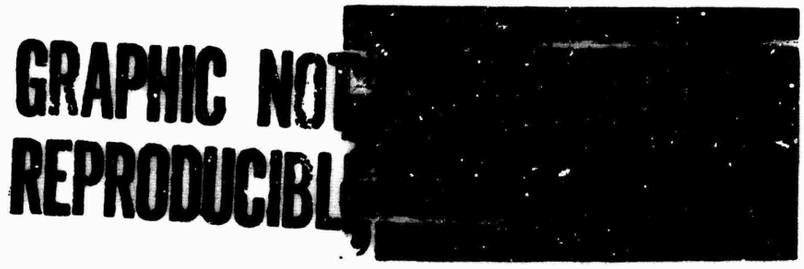

Fig 2. Surface of calibrated wire of diameter 3 mm (a), 4 mm (b), 5 mm (c) after drawing.

With increase of temperature of test the strength of wire of diameter 3,4 and 5 mm dropped and at 500C constituted 4.5-7 kg/mm^2. The ultimate strength of wire of diameter 3 mm with increase of temperature to 250C fell more intensely than wire of diameter 4 and 5 mm, while in the interval of temperatures 250-500C the ultimate strength of wire of all diameters was approximately identical.

Elongation increased with increase of temperatures of test and at 250C attained 12-17%. In the interval of temperatures 250-350C the elongation had a maximum value, which then dropped, attaining at 500C 6.5-10%.

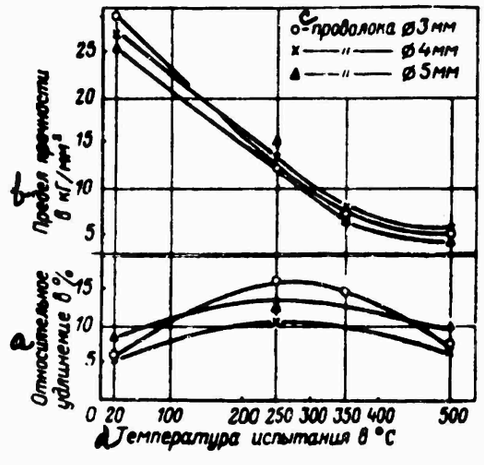

Fig 3. Change of strength and elongation depending upon temperature of test.

a - Elongation in %; b - Strength in kg/mm^2; c - wire; d - temperature of test in C.

Of large practical value is the influence of annealing on mechanical properties of calibrated wire. In connection with this we conducted an investigation of the influence of temperature of annealing (250, 350, 450 and 500C) on ultimate strength, elongation and shearing coefficient of wire. Annealing of wire was done in the usual chamber furnace without protective atmosphere according to the following conditions: heating to temperatures 250, 350, 450 and 500C, holding at these temperatures for 3 hours and cooling in air. With increase of temperature of annealing the ultimate strength decreased, elongation increased, and shearing coefficient was almost not changed (Fig 4).

For wire of all diameter, from the initial state (20C) to temperature of annealing 350C the decrease of ultimate strength and increase of elongation occurs more regularly and smoothly than in the interval of temperatures from 350 to 500C, where there is observed an intense drop of ultimate strength and increase of elongation.

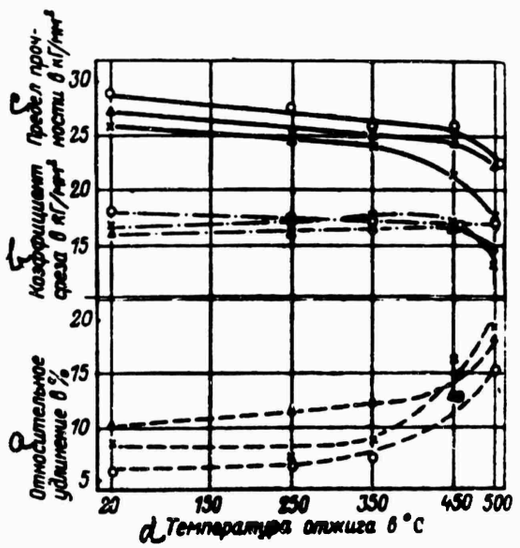

Fig 4. Change of strength, elongation and shearing coefficient depending upon temperature of annealing. Designations the same as on Fig 3.

a - Elongation in %; b - Coefficient of shear in kg/mm^2; c - Strength in kg/mm^2; d - Temperature of annealing in C.

From the given data it follows that annealing decreases ultimate strength and increases elongation, probably by relief of cold hardening and partial recrystallization, which occurs more intensely in the interval of temperatures 350-500C.

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Fig 5. Macrostructure of pressed wire stock of diameter 6 mm (a) and calibrated wire of diameter 3 mm (b).

On Fig 5 is shown the macrostructure of a longitudinal section of pressed wire stock of diameter 6 mm and calibrated wire of diameter 3 mm. No distinctions in macrostructure appear.

On Fig 6 and 7 is shown the microstructure (longitudinal and cross sections) of pressed wire of diameter 6 mm, and calibrated wire of diameter 3 and 5 mm. Pressed wire of diameter 6 mm in longitudinal direction has a banded structure, but in transverse direction banding is absent. Banding appears in the process of pressing of wire when the grains of SAP deformed during sintering, consisting of very finely crushed thin oxidized aluminum films, are extruded along the direction of pressing.

Due to this there is seen the white background of aluminum and the banded black background of aluminum oxide.

Calibrated wire of diameter 3 mm has a clear banded structure in the longitudinal direction, significantly sharper than for wire of diameter 5 mm, although the difference in microstructures of cross sections of these wires is difficult to detect (see Fig 7, a, c).

Wire annealed at higher temperatures has a microstructure with less clearly defined banding (Fig 8).

An important characteristic of wire intended for manufacture of rivets is its rivetability. From pressed wire of diameter 6 mm and calibrated wire of diameter 3, 4 and 5 mm we prepared samples with free heights 1.2d, 1.3d, 1.4d and 1.5d. Heading of samples, or riveting, was

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Fig 6. Microstructure of pressed wire stock of diameter 6 mm, X400.

a - cross section, b - longitudinal section

done on a press to obtain a flat head of height not more than half of the diameter.

On Fig 9 is shown the method of test of samples of wire in press for rivetability. During riveting of the free part of rivets from pressed wire of diameter 6 mm there appeared cracks at an angle of 45° (Fig 10). Samples from calibrated wire of diamter 3,4 and 5 mm did not have defects.

On Fig 11 are shown samples of rivets from calibrated wire of diameter 3 and 5 mm after riveting test. During riveting of samples of rivets from calibrated wire with free part 1.4 and 1.5d there sometimes appeared cracks. In a smaller degree this pertains to wire of diameter 3 mm and in a larger degree to wire of diameter 5 mm.

Annealing of calibrated wire of diameter 3,4 and 5 mm at a temperature of 500C with holding for 3 hours significantly lowers or completely excludes the appearance of cracks on heads of rivets. Consequently the thinner the wire, the better it rivets. Annealing improves riveting of calibrated wire. The pressed wire turned out not to be useful for manufacture of rivets.

On Fig 12 are shown rivets prepared from calibrated wire of diameter 3,4 and 5 mm on special machines in factory conditions, and Fig 13 shows the macrostructure along a cut of a seam joining a profile with sheet by rivets from SAP. On Fig 14 there is shown a riveted seam.

Extruded and drawn wire from aluminum powder of brand APS-1, containing more than 7% Al_2O_3, riveted poorly, therefore in this article we have not expounded the technology of its manufacture, mechanical properties or structure.

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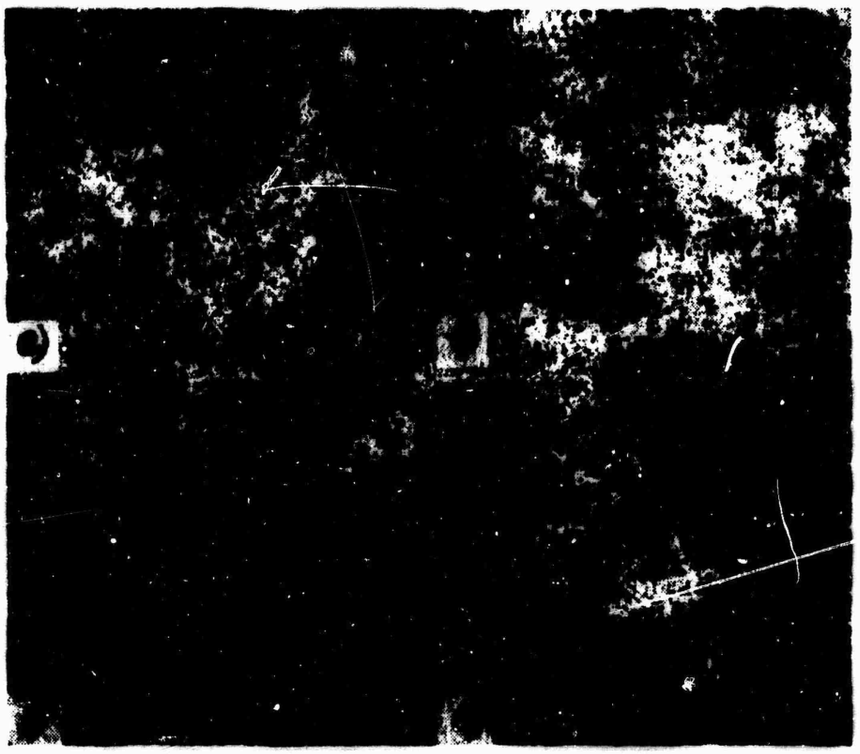

Fig 7. Microstructure of calibrated wire of diameter 3 and 5 mm, X400.

a - cross section of wire of diameter 5 mm, b - longitudinal section of wire of diameter 5 mm, c - cross section of wire of diameter 3 mm, d - longitudinal section of wire of diameter 3 mm.

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Fig. 8. Microstructure of annealed wire of diameter 3 and 5 mm at 500C, X400.
a - longitudinal section of wire of diameter 5 mm,
b - longitudinal section of wire of diameter 3 mm.

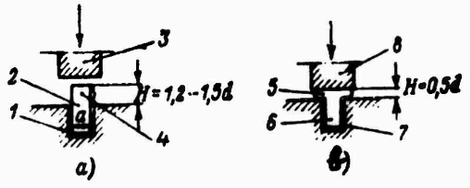

Fig 9. Method of test of samples of wire for riveting.

a - position of sample in nest of press to test for riveting,
b - position of sample after test.
1 - nest in lower plate of press, 2 - sample on test, 3,8 - punch, 4 - freestanding part of sample, 5 - head of rivet, 6 - leg of rivet, 7 - nest in lower plate of press.

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Fig 10. Chipping cracks on heads of rivets from pressed wire stock of diameter 6 mm.

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Fig 11. Samples of rivets from calibrated wire of diameter 5 mm (a) and diameter 3 mm (b) after test.

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Fig 12. Rivets prepared from calibrated wire of diameter 3,4 and 5 mm in factory conditions.

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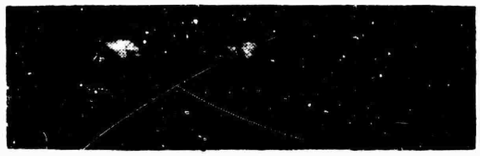

Fig 13. Macrostructure along cut of rivet seam.

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Fig 14. Riveted seam.

Conclusions

The technology of manufacture of high-temp wire from SAP, useful for production of rivets has been developed. In the study of the temperature stability and mechanical properties, structure, results of engineering tests on ability to be riveted, effect of annealing on the mechanical properties of SAP wire suitable for production of rivets, it was found that:

a) after drawing, calibrated wire of diameters 3,4 and 5 mm has at 20C an ultimate strength from 25 to 30 kg/mm^2, and elongation from 5.5 to 8-9%. At 500C ultimate strength is from 4.7 to 7 kg/mm^2 and elongation 6.5-10%.

Wire of smaller diameters has at room temperature higher strength and lower elongation than wire of large diameters;

b) pressed wire stock of diameter 6 mm and calibrated wire of diameters 3,4 and 5 mm from aluminum powder of brand APS-1, containing more than 7% Al_2O_3 is not useful for manufacture of rivets due to cracks on the heads;

c) annealing of wire lowered the ultimate strength and increased its plasticity;

d) a lot of rivets, prepared from wire (obtained from powder PP-4) was high quality, satisfied requirements as to mechanical properties and quality of surface, and riveted well.

TECHNOLOGY OF MANUFACTURE AND PROPERTIES OF FOIL FROM SAP (p 87 of source)

P.T. Vlasova, B.I. Matveev, P.V. Kishnev,
V.A. Stelmashchuk, S.N. Ananin

For obtaining of foil we use the material (SAP) containing a quantity of Al_2O_3 which will ensure high technological plasticity of SAP during cold rolling of foil to thickness 0.05 mm and less; mechanical properties at normal temperatures and temperatures higher than 300C should significantly exceed properties of foil from the other deformable aluminum alloys. Foil from SAP should be elastic and should preserve corrugation in the process of manufacture from it of honeycomb.

We conducted work obtaining of foil from SAP with content of Al_2O_3 within limits 9-10 and 6-7%. It turned out that from SAP with 9-10% Al_2O_3 foil could be produced. However in spite of high strength characteristics at normal and heightened temperatures its subsequent molding is hampered by low plasticity and high elastic spring-back. Foil from SAP containing Al_2O_3 within limits of 6-7% possesses sufficiently high mechanical properties at all temperatures of test.

Temperature of test in C	20	200	250	275	300	400	500
Ultimate strength in kg/mm^2	31,3	21,8	19,8	16,6	13,4	7,0	4,5

Thus, the optimum material for manufacture of foil possessing good formability is SAP containing 6-7% Al_2O_3.

For manufacture of foil we used pressed stock of dimensions 240 x 30 mm, obtained by hot briquetting of powder, sintering and subsequent hot pressing. Strips intended for rolling of foil must not have coarse defects (cracks, deep cavities and so forth). Strips held at 500C for one hour of thickness 30 mm were rolled on a trio or quarto mill to thickness of 5 mm. After stripping of edges the 5 mm strips were again held at 500C for 30 min and rolled to thickness 2.5 mm; then, after trimming of the edges, they were annealed at 350C for removal of internal stresses for two hours.

Further rolling was conducted without heating; to 0.5 mm the strip was rolled on a two-roll mill, but from 0.5 to 0.05 mm -- on a six-roller ribbon mill. After rolling to 0.5 mm we again cut the edges and performed annealing at 350C for two hours. Hot rolling of strips from 30 to 5

mm was done in ten passes, while from 5 to 2.5 mm we used six passes. Cold rolling of strips from 2.5 to 0.5 mm and from 0.5 to 0.05 mm is carried out in ten-twelve passes.

Foil is supplied in rolls of width to 150 mm with cutoff edges (Fig 1).

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Fig 1. Foil of thickness 0.05 mm, prepared from SAP

During both hot and cold rolling foil is prepared with large degrees of deformation. In connection with this there is great interest in the investigation of influence of prolonged annealing on change of mechanical properties. For this purpose from one lot of foil were cut samples which were subjected to prolonged annealing at different temperatures. Then samples underwent mechanical tests at normal and heightened temperatures. Change of ultimate with temperature is shown in the Table. We see from the data that annealing of foil for 100 hours at 400C lowers its ultimate strength very little as compared to unannealed samples, while annealing at 500C for 100-250 hours decreases ultimate strength only by 3-4 kg/mm^2.

The x-ray analysis conducted of foil from SAP showed that during heating to 500C the process of recrystallization is absent. There were not revealed any essential changes in microstructure of the material during investigation on the optical microscope (X500). Consequently, structure of material after prolonged heatings to high temperatures was stable, which is an important property of foil from SAP.

Table

Change of mechanical properties of foil depending upon temperature and duration of annealing

a Режим отжига		Температура испытания °C d	Предел прочности кГ/мм² e
Температура отжига °C b	Выдержка час c		
—	—	20	31,3
		20	31,1
200	25	200	21,8
		20	30,2
250	25	250	19,0
275	25	20	31,4
		275	16,3
300	100	20	30,3
		300	13,6
400	100	20	29,2
		400	7,62
	100	20	27,8
500		500	4,0
	130	20	27,7
	250	20	26,3

a - Conditions of annealing; b - Temperature of annealing C; c - Holding in hours; d - Temperature of test C; e - Ultimate strength kg/mm^2.

Conclusions

1. For obtaining of foil of thickness 0.05 mm and less it is recommended to use SAP with content of aluminum oxide within limits 6-7%.

2. Hot rolling must be conducted in the interval of temperatures 450-500C.

3. Prolonged annealing of foil to a temperature of 400C lowers the ultimate strength very little. Annealing at 500C for 250 hours decreases ultimate strength at room temperature by 4-5 kg/mm^2, and ultimate strength at 500C practically is not changed as compared to unannealed foil.

MANUFACTURE OF PIPES FROM SAP (p 90 of source)

P.V. Kishnev, A.A. Gelman, B.I. Matveev, V.S. Zolotov

(L.S. Perevyazkin, M.D. Levitanskiy, N.D. Narozhnyy, G.M. Bagnenko, B.E. Klemenov, T.P. Prokudina participated in this work)

This work describes the technology of manufacture on factory equipment of round and shaped pipes and results of investigation of their properties and structure.

Initial stock for manufacture of round pipes were:

a) briquettes, obtained by briquetting of heated powder on 1500 T press and then turned to pipe stock;

b) pressed rods of diameter 120 mm cut to standard lengths and turned to pipe stock.

It is significantly more economic and more convenient to use for pipe stock the pressed rods. For obtaining of high-quality pipes it is necessary to do the briquetting with preheating of powder to 500-550C, heating powder for 3-5 hours in order to remove moisture and oils.

For obtaining pipe stock we used powder of brand APS with content of Al_2O_3 within limits 6.5-10%. Pipe stock before pressing was heated in electric resistance furnace to 450-550C (the same temperature as for rods and strips from SAP).

From the heated pipe stock with external diameter 118, internal diameter 67, and height 150-160 mm, on a vertical hydraulic pipe press (600 T) in a container with plunger diameter 120 mm we pressed pipe of dimensions 71 x 3 mm with coefficient of drawing 10.5. Pressing of pipe from stock obtained from powder with content more than 8% Al_2O_3 turned out to be possible only with lubrication of container, while with content in powder of 6.5% Al_2O_3 lubrication of the container was not required.

On Fig 1 is shown the macrostructure of a rod of diameter 120 mm from which pipe was pressed. Pressed pipe of dimension 71 x 3 mm, shown on Fig 2, does not have on the surface any bubbles, scales or other defects.

From the initial rod stock of diameter 120 mm and from the pipes we prepared samples which underwent mechanical test at room temperature for determination of ultimate

strength and elongation. Results of these tests are given in Table 1.

Fig 1. Macrostructure of rod from which was prepared the pipe stock.

From the Table it is clear that ultimate strength of pipe stock is higher by 2-4 kg/mm^2 than pressed pipes. Elongation of pipes is 3% higher than the stock. Consequently, secondary pressing of pipes from stock lowers ultimate strength and increases elongation. Obviously this is connected with the redistribution of aluminum oxide in aluminum matrix which is caused by secondary pressing.

On the basis of investigations conducted it is established that the most successful combination of strength and elongation is shown by pipes prepared from powder containing not more than 6.5-7.5% Al_2O_3. Pipe from such material can be additionally subjected to cold rolling.

Fig 2. Pressed pipe 71 x 3 mm.

One of the problems was the study of the possibility of obtaining pressed pipes of different size with large coefficients of drawing. According to available data on the influence of degree of deformation on mechanical properties and formability of SAP with content in powder of

Table 1

Mechanical properties of pressed pipes and pipe stock

a Наименование промежуточных полуфабрикатов	b Содержание окиси алюминия в пудре %	c Предел прочности кГ/мм²	d Относительное удлинение %
e Заготовка диаметром 120 мм	6,8	33,0	8,2
f Труба 71×3 мм	6,8	30,0	11,0
e Заготовка диаметром 120 мм	8,7	35,1	2,7
f Труба 71×3 мм	8,7	33,7	5,3

a - Designation of intermediate half-finished products; b - Content of aluminum oxide in powder %; c - Ultimate strength kg/mm^2; d - Elongation %; e - Stock of diameter 120 mm; f - Pipe 71 x 3 mm.

7.5% Al_2O_3, pressing is best carried out with a degree of deformation of 92-98%.

We tried pressing of pipe of dimension 22 x 12 mm with coefficient of drawing 37. Stock for these pipes was prepared from powder containing 7.4% Al_2O_3. Pressing of pipes was done on a 600 ton press in a container with diameter of plunger 85 mm, heated to 350-400C. The SAP stock was heated for the first time in induction furnaces. Surface of stock did not have defects.

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Fig 3. Pressed pipe 22 x 2 mm

On Fig 3 is shown pressed pipe 22 x 2 mm with smooth external and internal surfaces (without bubbles, swellings or other defects). Results of mechanical tests showed that these pipes at 20C have a good combination of strength and plasticity. On the average ultimate strength constituted 35 kg/mm^2, and elongation was equal to 10%. During measure-

ment of the wall thickness of the pipes it turned out that average variation is within the allowed limits of ± 0.5 mm.

From the above it follows that on factory equipment it is possible to prepare from SAP pipe of dimensions 71 x 3 and 22 x 2 mm with coefficients of drawing from 10.5 to 37. This process does not evoke additional difficulties and does not require special technological equipment.

Simultaneously with work on the pressing and rolling of round pipes we developed the technology of manufacture of shaped pipes. Conditions of heating and pressing of shaped and round pipes are identical. We prepared shaped pipes:

a) having internal surface shaped, and external round (Fig 4);

b) with smooth internal and external surfaces;

c) with shaped internal and external surfaces.

Pipes of form "a" were obtained by pressing, pipe of form "b" by pressing with subsequent rolling, pipe of form "c" by pressing with subsequent rolling and drawing through a shaped die block.

Results of tests showed that from SAP of any brands able to be deformed by hot pressing, it is possible to obtain pipes of the most diverse configuration. Pipes of form "b" and "c" can be obtained from SAP containing not more than 7-8% Al_2O_3.

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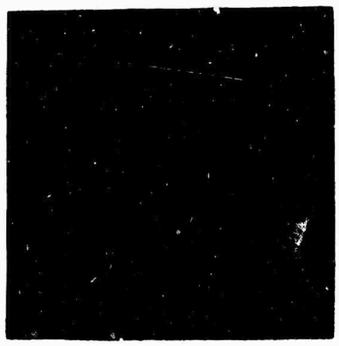

Fig 4. Pressed pipe with shaped internal surface

To establish the necessary rolling conditions on the mill KhPT-75 we selected optimum speeds of supply of the pipes. Conditions of rolling are given in Table 2.

It was established that an increase of speed of supply to 3-4 mm/min does not affect the quality of surface of pipes of dimensions 78.5 x 2.5 and 78.5 x 3 mm. Therefore the optimum speed of supply for these pipes should not

exceed 3-4 mm/minute. After rolling, at a temperature of 450-480C we forged (flattened) the ends of the pipe as necessary for subsequent drawing. Then the pipes were subjected to drawing (on drawing mill) with a speed 15 m/sec with a reduction of 1 mm per side in one pass (from diameter 66 to 64 mm). The round rolled pipes after drawing (to diameter 64 mm) were subjected to drawing through a shaped die on the same mill. During drawing, on the surface of the rolled pipes there appear bubbles, which is explained by insufficient holding time of the powder at 500-550C before briquetting.

Table 2

Conditions of rolling of pressed pipes 78.5 x 2.5 and 78.5 x 3 mm on mill KhPT-75

Содержание в пудре Al_2O_3 % a	Размер прессованной трубы мм b	Размер калибра мм c	Диаметр оправки мм d	Скорость подачи мм/мин e	Число двойных ходов клети f	Размер катаной трубы мм g
6,8—7	78,5×2,5	83×66	62	4—5	60	66×62
6,8—7	78,5×3,0	83×66	62	3—4	60	66×62

Note. As lubricant we applied spindle oil. Surface after rolling was smooth, brilliant.

a - Content in powder of Al_2O_3%; b - Dimension of pressed pipe mm; c - Dimension of die mm; d - Diameter of mounting mm; e - Speed of supply mm/min; f - Number of double movements of stand; g - Dimension of rolled pipe mm.

In Table 3 are given the mechanical properties of pipe stock, pressed and rolled pipes at room temperature.

From the Table it is clear that the ultimate strength of pipe stock is higher and the elongation is lower than for pressed pipes. After rolling and drawing the ultimate strength of pipes is increased by 2.2 kg/mm^2, and elongation decreases by 3.9%. Increase of ultimate strength probably is connected with the work hardening appearing in the process of rolling and drawing of pipes.

Table 3

Mechanical properties of pipes

a Наименование полуфабрикатов	b Предел прочности кГ/мм²	c Относительное удлинение %
d Пруток диаметром 120 мм	33,0	8,0
e Прессованная труба 78,5×2,5 мм	30,3	10,9
f Труба после волочения 68 ×2,0 мм	32,5	7,0

a - Designation of half-finished products; b - Ultimate strength kg/mm^2; c - Elongation %; d - Rod of diameter 120 mm; e - Pressed pipe 78.5 x 2.5 mm; f - Pipe after drawing 68 x 2.0 mm.

After pressing, rolling and drawing we measured the thickness of walls of the pipes. Results of measurements are given in Table 4.

From the Table it is clear that differences in wall thickness of pipes after rolling noticeably decreases and after drawing is kept on the same level.

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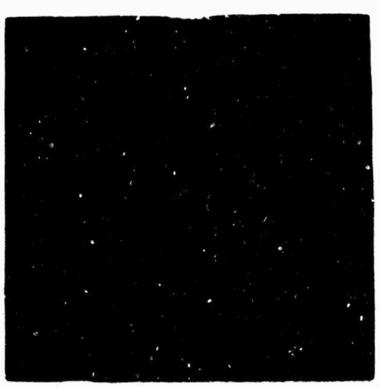

Fig 5. Macrostructure of shaped pipe.

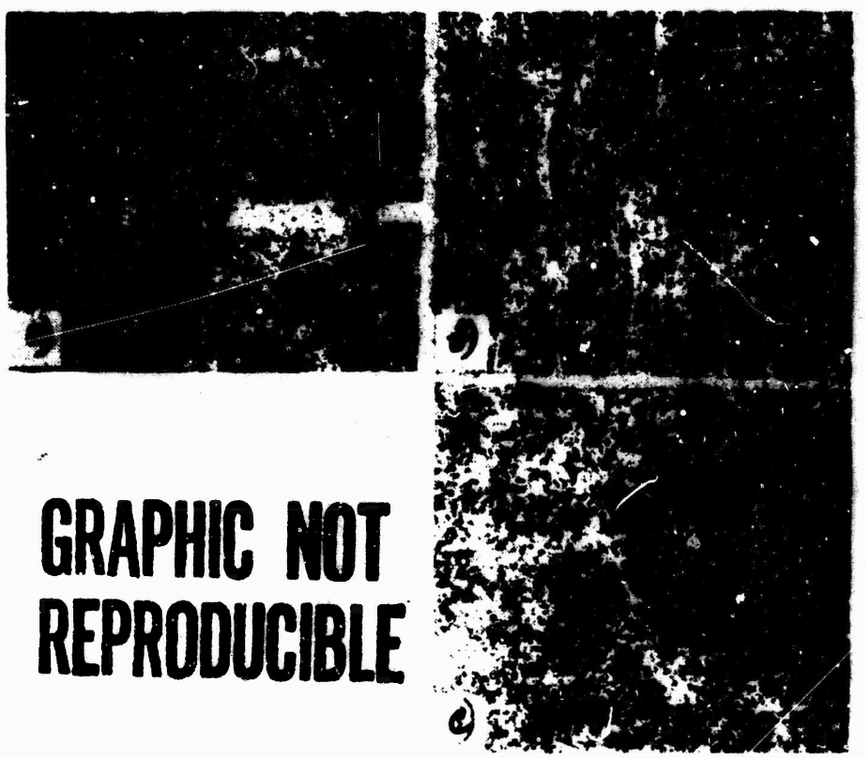

Fig 6. Microstructures of pressed (a), rolled (b) and drawn (c) pipes, X400.

There were no essential changes noted in structure of the material in the process of manufacture of pipes. Macro- and microstructure of pressed, rolled and drawn pipes does not differ from structure of pressed half-finished products from SAP.

On Fig 5 is shown the macrostructure of shaped pipe, and on Fig 6 the microstructure of pressed, rolled and drawn pipes.

Table 4

Differences of wall thickness of pressed, rolled and drawn pipes in mm

a Размеры прессованных труб	b Толщина стенок прессованных труб		e Разностенность труб после прессования	f Толщина стенок труб после прокатки	g Разностенность труб после прокатки	h Толщина стенок труб после волочения	c Разностенность труб после волочения
	c теоретическая	d практическая					
78,5×2,5	2,25	2,40	0,35	1,99	0,07	2,10	0,05
		2,75		2,03		2,07	
				2,01		2,05	
				2,05		2,05	
				2,00		2,07	
				1,98			
78,5×2,5	2,25	2,42	0,23	1,96	0,05	2,08	0,03
		2,65		2,00		2,11	
		2,50		2,01		2,[illegible]	
		2,37		1,96			
		2,59		1,98			
				2,00			
78,5×3,5	3,25	3,36	0,21	1,96	0,15	1,97	0,15
		3,37		1,97		2,01	
		3,42		2,00		2,00	
		3,51		2,03		2,11	
		3,57		2,07		2,07	
				2,10		1,96	
				2,11			

Key: a - Dimensions of pressed pipes; b - Thickness of walls of pressed pipes; c - theoretical; d - actual; e - Differences of wall thickness after pressing; f - Thickness of walls of pipes after rolling; g - Differences of wall thickness of pipes after rolling; h - Thickness of walls of pipes after drawing; i - Differences of wall thickness of pipes after drawing.

Conclusions

1. Round and shaped pipes from SAP can be prepared in factory conditions using existing technological equipment and gear (just as pipe from aluminum and its alloys).

2. For manufacture of round and shaped pipes we recommend:

a) pressing at a temperature of 450-500C on vertical and horizontal hydraulic presses with specific pressure to 90 kg/mm^2 and speed of pressing 1 m/sec;

b) cold rolling of pressed pipes be carried out on cold rolling mills;

c) perform drawing (calibration) of rolled pipes for bringing their dimensions to final values on chain drawing machines.

3. From SAP it is possible to draw pipe of different configurations.

4. The best combination of strength and elongation is shown by pipes produced from aluminum powder containing 6.5-7.5% Al_2O_3.

5. Secondary pressing of pipes from stock leads to lowering of ultimate strength by 2-4 kg/mm^2 and increase of elongation by 3% as compared to initial material. Rolling and drawing increase strength and decrease elongation of pipes depending upon the degree of deformation to which they can be subjected.

6. From SAP it is possible to prepare round and shaped pipes with the same tolerances as for pipes from the aluminum alloys.

7. Heating of pipe stock for hot pressing can be conducted in induction furnaces.

TECHNOLOGY OF STAMPING OF ARTICLES FROM SAP (p 98 of source)

B.I. Matveev, I.R. Khanova, E.I. Shchedrin

(D.M. Likhosherstov, I.I. Shekhtman participated in this work)

SAP as compared to aluminum deformable alloys possesses lowered technological plasticity at room temperature. At high temperatures (450-570C) it can be subjected to any treatment by pressure (pressing, rolling, forging and stamping). Technological plasticity of SAP, as we know from source material, is increased with increase of speed of deformation.

Therefore it was decided to try manufacture details from SAP by the method of stamping on hammers, and also on presses with heating of stock to temperatures of 450-570C.

STAMPING ON HAMMER

For hammer stamping we selected a piston. During its manufacture there occurs upsetting of material (molding of bottom) and flowing (molding of skirt).

The following variants of stamping of pistons were proposed: from briquettes, from sintered billets, from pressed rods.

The initial material -- briquettes, sintered billets and pressed rods -- were prepared from aluminum powder containing 7-10% Al_2O_3. Briquetting and subsequent operations (production of sintered billets and pressed rods) were performed by usual factory technology (without preliminary heating of powder).

Investigations of mechanical properties of initial material showed that briquettes have very low strength and plasticity, whereas properties of sintered billets are near to properties of pressed rods (Table 1).

Stamping was performed by a 2 T hammer in a heated open stamp with lubrication.

Stamping of pistons from briquettes. For stamping of pistons from briquettes we selected a temperature of 570C. Briquettes were held in a furnace with this temperature for 2-3 hours.

Table 1

Property of briquettes, sintered billets and pressed rods

a Вид заготовки	b Содержание Al_2O_3 %	c Свойства при 20°C			
		$\sigma_в$ кГ/мм²	δ %	$a_н$ кГ·м/мм²	HB кГ/мм²
d Брикет	9	9—10	0,1	0,2	76
	10,4	6—12	0,1		
e Спеченная заготовка	7	24	6	0,4	72
	9	36	1,1—2,0		107
	10,4	37—38	1,0—1,5		
f Прессованный пруток	6,6	28—31	5—6	1,8	—

a - Form of stock; b - Content Al_2O_3%; c - Properties at 20C; d - Briquette; e - Sintered billet; f - Pressed rod.

In the process of stamping, due to the low plasticity of briquettes, on the side surface, in the center of the bottom and on the skirt of the pistons there were formed many deep cracks. Strong delaminations appeared on the bosses. Appearance of cracks on the side surface of piston can be explained not only by the low plasticity of material, but also by the fact that in the process of stamping there occurred strong adhesion of the deformed material to the stamp. Therefore for improvement of flow of material we applied an aluminum covering of thickness 0.8 mm, which was placed between briquette and stamp just before stamping. During stamping the shell was tightly connected with the material but no improvement of quality of stamping was observed, since on the shell and on the surface of the detail there were formed cracks (Fig 1).

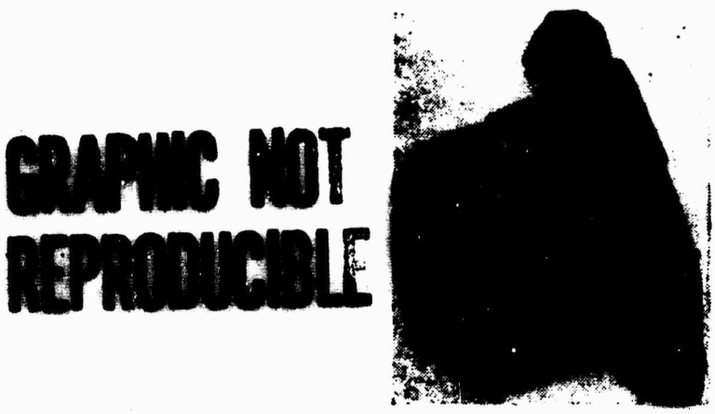

Fig 1. Appearance of piston obtained by stamping from briquette with application of aluminum covering.

Thus, stamping of pistons directly from briquettes in usual conditions did not give positive results.

Stamping of pistons from sintered billets. Most fully was studied stamping during 530-570C of pistons from sintered billets containing 7,9 and 10% Al_2O_3.

On Fig 2 are given the macrostructure of the cross section of pistons with different content Al_2O_3. In the process of impact deformation on the internal surface of pistons from SAP containing 10% Al_2O_3 there was formed a consolidated crust which was partially scaled from the basic mass of material. Least compaction occurred in the zone of the bottom of the piston.

On Fig 2, a is given the macrostructure of a piston with content of 7% Al_2O_3. The internal surface of the forging does not have defects (with the exception of small stratifications on bosses), but on the external surface and especially in the region of transition of skirt there are seen cracks, whose formation can be explained by the low plasticity of SAP.

Forgings containing 9 and 10% Al_2O_3 had a large quantity of deep transverse cracks (Fig 2, b and c).

For improvement of flow of the metal, as in stamping from briquettes, we applied an aluminum covering. It was found that on the forgings (with 7-9% Al_2O_3) there were small cracks in the flashing zone. Basically however the forging was of satisfactory quality (Fig 3).

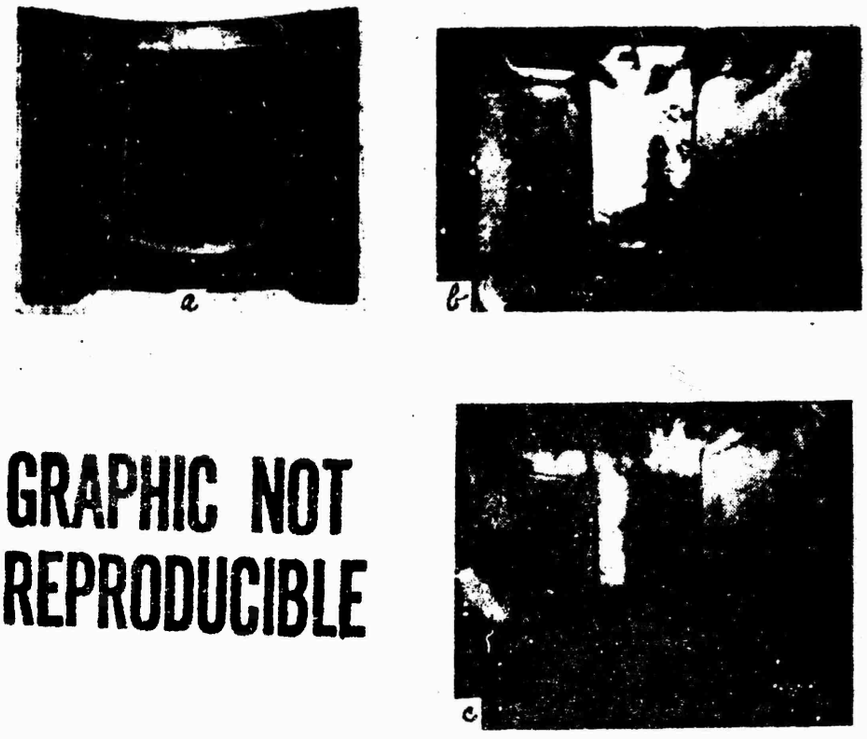

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Fig 2. Macrostructure of cross section of piston, produced from sintered billet.

a - 7% Al_2O_3; b - 9% Al_2O_3; c - 10% Al_2O_3.

Use during stamping of sintered billets, containing 10% Al_2O_3, of the aluminum covering did not improve the quality. In this case it is advisable to produce the stamping in a closed stamp.

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Fig 3. Appearance of piston obtained by method of stamping from sintered billet with application of aluminum covering.

GRAPHIC NOT REPRODUCIBLE

Fig 4. Appearance of piston obtained from pressed rod with application of aluminum covering.

Stamping of pistons from pressed rods. For stamping of pistons from pressed rods we selected a temperature of 570C. Stock was held in furnace at this temperature for 3 hours. Before stamping the rods were subjected to preliminary upsetting.

Since the material of the pressed rods is more plastic, the forging from it do not have transverse cracks and rents characteristic of billets and briquettes. The characteristic for briquettes and sintered billets scaling on internal surface of piston is absent. Macrostructure of piston is fine and uniform.

Good results were also obtained with application of the aluminum covering (Fig 4).

MECHANICAL PROPERTIES OF PISTONS

Samples for determination of mechanical properties of pistons were cut in a definite pattern (Fig 5).

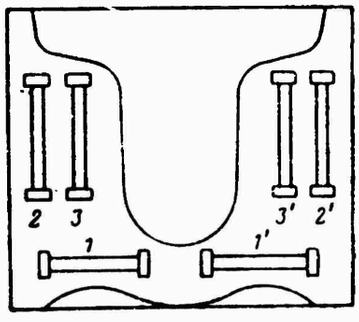

Fig 5. Pattern of cutting of samples from piston

The mechanical properties of these samples at 20C and heightened temperatures are given in Tables 2 and 3, from which it is clear that the best properties are possessed by forging from sintered billets with 9% Al_2O_3. In stamping of sintered billet with 7% Al_2O_3 improvement of mechanical properties was not observed.

Table 2

Mechanical properties of pistons at 20C

a Содержание Al_2O_3 %	b Вид заготовки	№ c образцов по схеме (фиг. 5)	$\sigma_в$ кГ/мм²	δ %	HB кГ/мм²
9,0	d Брикет	1, дно g	35,4	3,3	114
		2, юбка h	25,8	1,7	101
7,0	e Спеченная заготовка	1, дно g	23,6	5,3	68,3
		2, юбка h	25,2	2,0	54
9,0	e Спеченная заготовка	1, дно g	37,1	2,0	107
		1, дно g	37,8	4,3	107
		2, юбка h	35,8	—	107
		2, юбка h	36,0	3,3	107
		3, юбка h	36,4	2,1	107
		3, юбка h	34,0	—	107
6,5	f Прессованный пруток	1, дно g	24,8	6,0	65,5
		1, дно g	25,4	10,0	72,4
		2, юбка h	27,4	13,3	72,4
		2, юбка h	27,1	14,0	65,5
		3, юбка h	26,5	12,0	65,5
		3, юбка h	25,4	9,0	68,0

a - Content Al_2O_3%; b - Form of stock; c - No. of samples on diagram (Fig 5); d - Briquette; e - Sintered billet; f - Pressed rod; g - bottom; h - skirt.

Table 3

Mechanical properties of pistons at heightened temperatures

a Вид заготовки для штамповки	b Содержание окиси алюминия %	c При 300°		c При 350°		c При 400°	
		$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %
d Брикет	9,0	8,6	—	—	—	7,0	—
e Спеченная заготовка	9,0	15,6	—	—	—	11,4	3,5
f Прессованный пруток	6,5	—	—	8—10	6—9	—	—

a - Form stock for stamping; b - Content of aluminum oxide %; c - at; d - Briquette; e - Sintered billet; f - Pressed rod.

STAMPING ON PRESS

(N.N. Aperyanova participated in this work)

The laboratory investigations conducted showed that optimum for stamping on press is a temperature of 450-500C.

As a detail for stamping on press we selected a compressor blade. Initial material -- pressed rods of diameter 30 mm - were obtained from aluminum powder containing 7-8% Al_2O_3. Before pressing of rods there was conducted preliminary heating of the powder. Properties of initial pressed rods are given in Table 4.

Table 4

Properties of initial pressed rods

a Температура испытания °C	b Предел прочности кГ/мм²	c Относительное удлинение %
20	27—30	6
500	8—9	2

a - Temperature of test C; b - Ultimate strength kg/mm²; c - Elongation %.

The blade was produced in two operations: upsetting of head and final stamping. After every operation we investigated the properties and structure of the blade.

GRAPHIC NOT REPRODUCIBLE

Fig 6. Macrostructure of stock after upsetting of head.

On Fig 6 is presented the macrostructure of the stock after upsetting of head on horizontal forging machine at 500C (beating before upsetting for 2-3 hours). Defects in structure of stock are absent.

After final stamping on press at 500C, on the blade there were formed cracks at the transition from basic material to the flashing. These defects were removed by further machining (Fig 7). Thus, stamping at 500C gave satisfactory results.

Samples for determination of prolonged strength were cut from the blade and from the stock after upsetting of heads. As shown by results of tests at 500C for 100 hours, the value of prolonged strength of samples is the same as for the initial material (4.5 kg/mm^2). Samples cut from the stamped blade had a microstructure sharply stretched in the direction of deformation of the material (Fig 8).

GRAPHIC NOT REPRODUCIBLE

Fig 7. Compressor blade prepared by method of stamping on press.

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Fig 8. Microstructure of sample taken from stamped blade, X300.

Conclusions

Pressed rods have the best technological properties for stamping by hammer.

From briquettes, due to their low plasticity it is impossible to obtain high quality details in open stamps even with application of an aluminum covering. Details stamped from sintered billets containing not more than 9% Al_2O_3 had the best mechanical properties.

MECHANICAL PROPERTIES AND STRUCTURE OF FORGED BILLETS FROM SAP (p 105 of source)

P.V. Kishnev, L.S. Perevyazkin,
A.A. Petrova, N.N. Averkina

(G.M. Bagnenko, V.I. Sverlov participated in this work)

In connection with the increased needs of industry for stamped and forged details from SAP there appeared the necessity of a search for the optimum conditions of forging. With this goal we studied forging of billets obtained from pressed rods of SAP.

For the investigation we selected aluminum powder of brand APS-1, containing 7.1% Al_2O_3. For forging we selected rods of square (36 x 36 mm) and round (diameter 110 mm) sections.

FORGING OF BILLETS FROM RODS OF SQUARE SECTION

Rods of square section were prepared from briquettes obtained by pressing of both heated and cold powder in cold containers with subsequent compaction and sintering.

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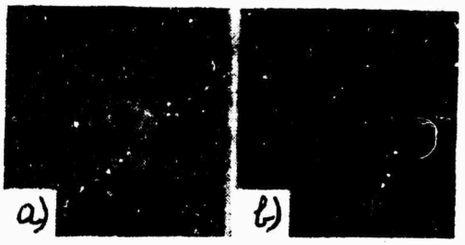

Fig 1. Macrostructure of rod of section 36 x 36 mm, prepared from briquettes obtained by cold (a) and by hot (b) briquetting.

On Fig 1 is shown the macrostructure of rods prepared from briquettes obtained by hot and cold briquetting (samples were cut from the two ends and from middle of rod). On Fig 2 is presented the microstructure of these rods with magnification of 250. Structure of rods from briquettes obtained by both methods is identical. This microstructure is characteristic for the pressed half-finished products from SAP.

Tests of mechanical properties of rods were conducted

at 20 and 500C. Results are given in Table 1.

From Table 1 it is clear that the values of ultimate strength and elongation of rods from briquettes obtained by pressing of powder in heated and cold states are little different.

Forging of procurements from rod was done on a pneumatic hammer of capacity 150 kg. The billets were heated in electric resistance furnaces without protective atmosphere to temperatures of 450, 500, 550, 600 and 650C. Five billets of the eight were obtained from briquettes of heated powder and three from cold pressed briquettes. From the billets we free forged plates of section 10 x 65 mm using the conditions given in Table 2.

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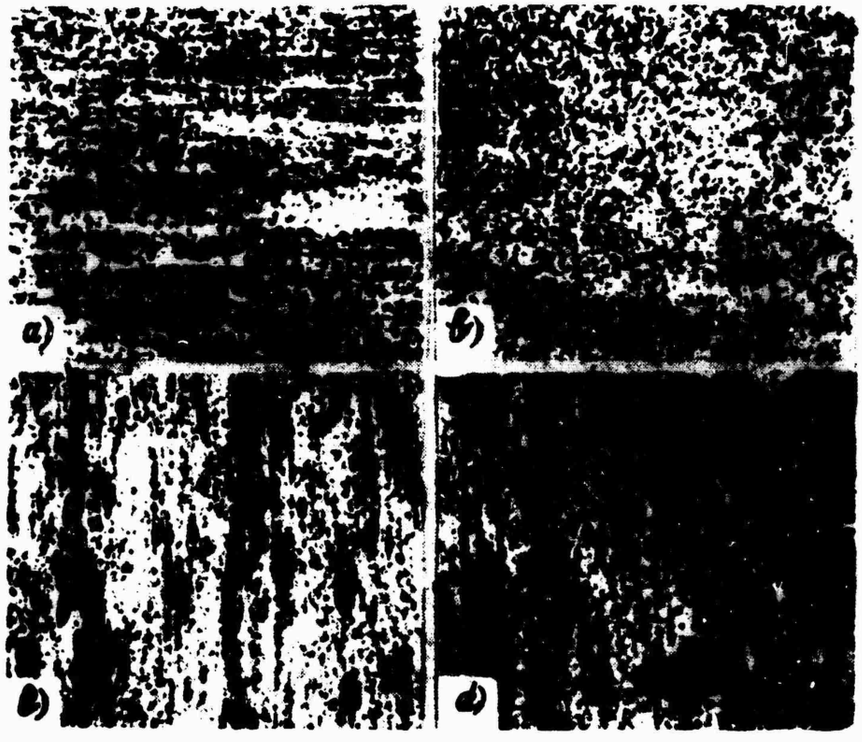

Fig 2. Microstructure of rod 36 x 36 mm, prepared from briquettes obtained by cold (a,b) and by hot (c,d) briquetting, X250.

a,c - longitudinal sections, b,d - cross sections

From every forged plate we cut templets for macrocontrol in longitudinal and transverse directions. On Fig 3 is shown the macrostructure of all eight plates forged in the longitudinal direction. Two plates forged at 600C from rods obtained by briquetting of both cold and heated powder had cracks. All the remaining macrographs were of satisfactory quality.

Table 1

Mechanical Properties of Rods of Square Section (Longitudinal Samples)

a Способ брикетирования пудры	b № образца	c При 20° $\sigma_в$ кГ/мм²	c При 20° δ %	c При 500° $\sigma_в$ кГ/мм²	c При 500° δ %
d Брикетирование нагретой пудры	1	29,3	12,0	6,5	2,4
	2	29,3	12,4	8,0	2,0
	3	29,3	14,0	6,6	2,0
	4	29,0	12,0	5,8	1,2
e Брикетирование холодной пудры	1	29,2	12,0	7,3	2,4
	2	29,0	12,0	7,3	2,4
	3	29,8	12,0	7,8	2,0
	4	29,8	12,0	7,7	2,4

a - Method of briquetting of powder; b - No. of sample; c - At; d - Briquetting of heated powder; e - Briquetting of cold powder

From Table 3 it is clear that the best combination of strength and elongation is observed in plates forged at 550C with both hot and cold briquetting of powder. Thus, for instance, at a temperature of forging of 450C for forged plates prepared from briquettes of heated powder, the ultimate strength at 20C constitutes 27.9 kg/mm^2, and elongation is 11.6%; at a temperature of forging of 550C the strength was increased to 29.1 kg/mm^2, and elongation to 16.4%. Consequently, forging of billets from SAP at 550C increases the strength by 1-2 kg/mm^2, elongation by 3-5%. and also improves the quality of surface as compared to forging 450C. Macrostructure of plates forged at 550C is normal for SAP.

Table 2

Conditions of Forging of Billets

Температура нагрева в печи a °C	Время нахождения в печи b час	Температура начала ковки c °C	Температура конца ковки d °C	Способ брикетирования e	Результаты осмотра поверхности f
470	2,0	450	320	g Горячее	i Поверхность удовлетворительная; трещин нет
510	2,5	500	340	g Горячее	То же j
				h Холодное	"
565	3,0	550	360	g Горячее	"
				h Холодное	"
610	3,5	600	350	g Горячее	k Трещины с боковой стороны по всей длине
				h Холодное	j То же
660	4,0	650	360	g Горячее	i Поверхность удовлетворительная; трещин нет

a - Temperature of heating in furnace C; b - Time in furnace in hours; c - Temperature at beginning of forging C; d - Temperature at end of forging C; e - Method of briquetting; f - Results of inspection of surface; g - Hot; h - Cold; i - Surface satisfactory, no cracks; j - The same; k - Cracks on lateral face over entire length.

Note 1. For equalizing of temperature billets were held in furnace for 30 minutes.

2. Insignificant lowering of temperature of billets occurred during transportation to hammer.

From every forged plate we cut in the longitudinal direction samples for mechanical tests. Results of tests are given in Table 3. (See page 123)

GRAPHIC NOT REPRODUCIBLE

Fig 3. Macrostructure of plates forged at 450 (a), 500 (b), 550 (c,d), 600 (e,f), 650C (g,h).

FORGING OF RODS OF ROUND SECTION

For confirmation of results obtained during forging of rod of section 36 x 36 mm, we also subjected to forging billets from rod of diameter 110 mm, prepared from briquette of heated aluminum powder containing 8.7% Al_2O_3. From the billets we forged on a hammer with weight of impacting parts of 400 kg plates of dimensions 19 x 170 x 780 mm at 550C using the same conditions of forging as for the plates 10 x 65 mm. We then investigated the macrostructure of the plate in longitudinal and transverse directions, and also conducted mechanical tests at 20 and 500C.

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Fig 4. Macrostructure of plates in longitudinal (a) and transverse (b) directions.

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Fig 5. Microstructure of samples in longitudinal (a) and transverse (b) directions.

On Fig 4 is shown the macrostructure of the plate, and on Fig 5 the microstructure of slides cut from middle of the same plate in longitudinal and transverse directions. From figures it is clear that the slides have a banded texture.

Results of mechanical tests of samples cut from middle of plate are given in Table 4.

Table 4

Mechanical Properties of Plates

a Направление вырезки образцов из пластины	b При 20°		b При 500°	
	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %
c Продольные	31,0	10,4	8,8	4,0
	31,2	10,0	8,8	4,8
d Поперечные	29,9	8,0	8,3	3,6
	29,6	8,0	7,7	1,6

a - Direction of cutting of samples from plate;
b - At; c - Longitudinal; d - Transverse.

From Table 4 it is clear that the ultimate strength and elongation for forged plate in the longitudinal direction are higher than in the transverse. Strength of samples cut from strip in the longitudinal direction constituted at 200 -- 31.2 kg/mm^2, and elongation -- 10.4%; ultimate

strength of samples, cut across the strip was equal to 29.6 kg/mm^2 and elongation -- 8.0%.

Conclusions

The investigations conducted showed the possibility of forging of billets from SAP on existing factory equipment. Best combination of strength and elongation is obtained at a temperature of the beginning of forging of 550C and termination -- 360C.

Method of briquetting of aluminum powder has no effect on mechanical properties of pressed rods and forged plates.

Table 3

Mechanical Properties of Plates 10 x 65 mm After Forging

a Режим ковки		c Способ брикетирования пудры	d При 20°		d При 500°	
температура начала ковки b °C	температура конца ковки h °C		$\sigma_в$ кГ/мм^2	δ %	$\sigma_в$ кГ/мм^2	δ %
450	320	e Горячее	27,9	11,6	7,6	3,0
500	340	e Горячее	28,4	13,6	8,2	3,6
		f Холодное	28,8	15,2	8,0	3,6
550	360	e Горячее	29,1	16,4	7,7	4,7
		f Холодное	28,7	16,0	8,3	3,6
600	350	e Горячее	g Образцы не изготовлялись из-за трещин на пластинах			
		f Холодное				
650	360	e Горячее	27,5	10,0	6,5	3,0

(a) Conditions of forging; (b) Temperature at beginning of forging C; (c) Method of briquetting of powder; (d) At; (e) Hot; (f) Cold; (g) Samples were not prepared because of cracks on plates (h) Temperature at end of forging C.

WELDING OF SAP-1 (p 111 of source)

Yu.V. Melnikov, V.V. Zyukin, V.I. Oboturov

(Work was conducted under leadership of K.P. Martishin, with participation of M.V. Korotkova, F.T. Leonov, and O.V. Martishin).

Investigations of welding by fusion and resistance welding of SAP-1 were performed on sheet samples of thickness 1.5 mm, obtained from preliminarily treated briquettes. We used hand argon arc welding with use of a flux, spot and roller electric welding on machines of type MTPT-400 and MShShI-400.

WELDING BY FUSION

During hand argon arc welding of samples from sheet SAP with filler material SAP-1, the alloys AMts, AK, AMg6, B61 could not be satisfactorily welded without flux (Fig 1). A high-quality welded joint was obtained with use of filler wire of brand AK and flux AF-4A (in the form of paste) which was coated in a thin layer on the welded edges from the treated side of seam (Fig 2).

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Fig 1. Macrograph of welded joint, made by argon arc welding; filler AK.

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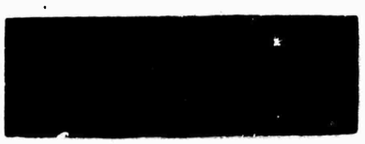

Fig 2. Macrograph of welded joint, made by argon-arc welding with flux, filler AK.

Thickness of material constitued 1.5 mm, diameter of electrode -- 2.0 mm, current intensity -- 60 a, diameter of filler wire -- 3.0 mm, expenditure of argon -- 6-7 liters/minute.

The tests conducted showed (Table 1) that ultimate strength of welded samples is lower than basic material.

Table 1

Results of Tensile Tests of Basic Material and Welded Samples of SAP-1

a № образцов	b Температура испытания °С	c Предел прочности кГ/мм² d основного материала	e сварных образцов	a № образцов	b Температура испытания °С	c Предел прочности кГ/мм² d основного материала	e сварных образцов
1	500	13,3	8,8	7	300	22,3	18,9
2	500	14,7	8,3	8	300	21,0	19,3
3	500	11,2	8,4	9	300	22,6	20,0
21*	500	10,9	5,5	13*	300	—	11,9
22*	500	—	4,6	10	20	34,6	33,7
23*	500	—	7,8	16	20	—	33,7
4	400	19,6	13,7	—	—	—	—
5	400	14,9	12,3	11*	20	—	17,6
6	400	13,1	13,6	12*	20	—	16,5
18*	400	—	10,0	14*	20	—	15,0
19*	400	—	7,4	—	—	—	—

a - No. of samples; b - Temperature of test C;
c - Ultimate strength kg/mm^2; d - basic material;
e - welded samples.

Note 1. Samples with the sign "*" were tested with bead removed.

2. At all temperatures of test failure was in seam.

Metallographic investigations showed that the structure of the basic material consists of an aluminum base and particles of aluminum oxide (Fig 3). On approach to the fused metal the structure changes; there is clearly revealed a grid, at first thin, and then consisting of massive grains, stretched along the sample (Fig 4).

GRAPHIC NOT REPRODUCIBLE

Fig 3. Microstructure of basic SAP-1, X500.

Boundary of transition from basic material to fused is expressed sharply, but a clear boundary between the aluminum base and the fused metal is lacking (Fig 5). In the aluminum-silicon eutectic there are conspicuous inclusions of aluminum oxide, which probably lead to the high temperature strength of the welded joint.

In Table 2 are shown the mean values of strength of the basic material SAP (δ = 1.5 mm) and welded joints.

GRAPHIC NOT REPRODUCIBLE

Fig 4. Microstructure of welded joint, filler AK, X100.

GRAPHIC NOT REPRODUCIBLE

Fig 5. Microstructure of welded joint, filler AK, X500.

Table 2

Температура испытания °C a	b Предел прочности образцов в кг/мм²		
	основного материала c	сварных с усилением d	сварных без усиления e
20	34,6	33,4	17,1
300	22,0	18,5	12,5
400	15,5	12,5	8,0
500	12,0	8,4	5,8

a - Temperature of test C; b - Ultimate strength of samples in kg/mm^2; c - basic material; d - welded with bead; e - welded without bead

CONTACT WELDING

For the investigation of the possibility of roller and spot welding of SAP-1 we prepared samples of dimensions 110 x 220 mm (for roller welding) and 25 x 120 mm (for spot welding), then degreased them, and the place of welding was cleaned with a clean steel brush. We conducted several experiments for the purpose of determination of optimum conditions of welding. Welded samples were subjected to mechanical and metallographic investigations.

ROLLER WELDING

Roller welding was performed on the machine MShShI-400 using conditions shown in Table 3.

Table 3

a Номер режима	b Продолжительность сварки сек	c Давление атм	d Ступень трансформатора	e Шаг ролика мм	f Скорость сварки в делениях шкалы	g Цвет шва
1	0,10	2,0	4	2,9	20	h Серебристый
2	0,14	2,2–2,3	4	2,9	21	i Серый оттенок
3	0,12	1,8	3	2,9	20	j Грязно-серый

a - No. of conditions; b - Duration of welding, sec; c - Pressure in atm; d - Stage of transformer; e - Step of roller, mm; f - Speed of welding in scale divisions; g - Color of seam; h - Silvery; i - Gray cast; j - Dirty-gray

Samples welded by conditions shown in Table 4, were subjected to mechanical and metallographic investigations.

Results of mechanical tests of samples of thickness 1.5 mm are presented in Table 4.

Metallographic investigations showed that the microstructure of the welded core constitutes an aluminum base with impregnations of particles of aluminum oxide. In separate places there is no solid fusion, there are conspicuous stratifications and scale. This probably occurs due to nonuniform preparation of surface for welding.

Table 4

№ режима сварки a	Разрушающее усилие кГ b	Характер разрушения c
1	520	dСрез по шву
	440	eТо же
	510	"
	500	"
	490	"
	500	"
	570	"
2	640	fРазрыв по зоне термического влияния
	620	eТо же
	670	"
	620	dСрез по шву
	590	eТо же
	620	gРазрыв по зоне термического влияния со срезом
	610	fРазрыв по зоне термического влияния
3	500	dСрез по шву
	490	eТо же
	460	"
	480	"
	570	"
	480	"
	385	"

a - No. of condition of welding; b - Rupture force, kg; c - Character of failure; d - Shear along seam; e - the same; f - Tensile in zone of thermal influence; g - Tensile in zone of thermal influence with shearing.

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Fig 6. Macrograph of welded sample made by roller electric welding.

Fig 7. Microstructure of welded sample made by roller electric welding, X100.

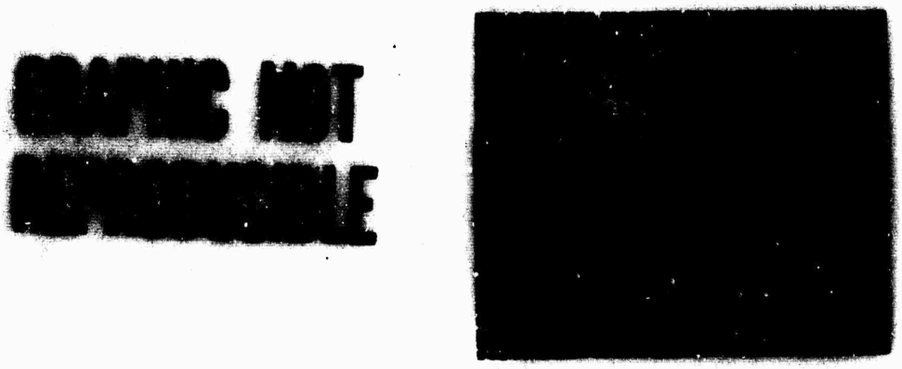

Fig 8. Microstructure of welded sample made by roller electric welding, X500.

Results of metallographic investigations are shown on Fig 6,7,8 and in Table 5.

Table 5

a № режима сварки	b Ширина ядра мм	c Глубина проплавления %
1	11,0	66,0
2	8,5	60,0
3	13,0	66,0

a - No. of condition of welding; b - Width of core, mm; c - Depth of melting %.

Samples welded under optimum conditions (conditions 2) were subjected to mechanical tests at temperatures of 300, 400 and 500C (Table 6).

Table 6

Температура испытания a °C	Предел прочности b кГ/мм²	Характер разрушения c
20	22,6	d Разрыв по зоне термического влияния
	24,2	e То же
	19,8	f Срез по точке
	20,7	d Разрыв по зоне термического влияния
300	14,9	d Разрыв по зоне термического влияния
	17,3	e То же
	12,3	"
	18,2	"
400	14,9	d Разрыв по зоне термического влияния
	10,0	e То же
	13,7	"
	14,8	"
500	9,3	d Разрыв по зоне термического влияния
	9,8	e То же
	15,2	"
	9,7	"
	16,5	"

a - Temperature of test C; b - Ultimate strength kg/mm^2; c - Character of failure; d - Tensile along zone of thermal influence; e - The same; f - Shear along spot

SPOT WELDING

Spot welding of sample was performed on the machine MTPT-400 using conditions shown in Table 7.

Table 7

a № режима сварки	b Продолжительность сварки сек	c Время включения дополнительного импульса сек	d Время запаздывания ковки в делениях шкалы	e Давление в *am*			f Ступень трансформатора
				P_0	P_1	P_2	
1	0,16	0,06	—	0,8	1,1	1,0	4
2	0,16	0,08	7	0,8	0,8	0,8	14
3	0,16	0,08	7	0,8	0,8	0,7	10

a - No. of condition of welding; b - Duration of welding sec; c - Time of additional impulse, sec; d - Time lag of forging in scale divisions; e - Pressure in atm; f - Step of transformer.

Note: Table 7 is in abbreviated form and presents only the basic parameters of the conditions of welding.

The welded samples were subjected to mechanical and metallographic tests. Results of mechanical tests of samples of thickness 1.5 mm at 20C are presented in Table 8.

Table 8

a Режим сварки	b Разрушающее усилие *кГ*	c Характер разрушения
1	475	d Срез по точке
	580	e То же
	575	f Разрыв по зоне термического влияния
2	430	d Срез по точке
	470	e То же
	505	f Разрыв по зоне термического влияния
3	425	d Срез по точке
	465	e То же
	430	

a - Condition of welding; b - Rupture force kg; c - Character of failure; d - Shear in spot; e - The same; f - Tensile along zone of thermal influence.

Metallographic investigations showed that the microstructure of the welded spot consists of an aluminum base and particles of aluminum oxide. Along the edge of the spot there are conspicuous weakly etching fields, constituting the aluminum base with a smaller content of aluminum oxide than in the basic material. On some sections of seam (spots) there are regions of nonfusion of the material.

GRAPHIC NOT REPRODUCIBLE

Fig 9. Macrograph of welded spots

GRAPHIC NOT REPRODUCIBLE

Fig 10. Microstructure of welded spot, X500

Results of metallographic investigations are shown on Fig 9,10 and are given in Table 9.

Table 9

№ a режима сварки	Диаметр точки b мм	Глубина проникновения c %
1	12—13	60
2	12	60
3	9	70

a - No. of condition of welding; b - Diameter of spot, mm; c - Depth of penetration %.

Conclusions

1. It was determined that argon arc welding of SAP-1 with application of flux AF-4A is possible with the use of high-temperature annealing of briquettes.
2. Strength of welded joints constitutes 95% of the strength of basic material at room temperature and 70% at a temperature of 500C.
3. Roller and spot welding of SAP-1 is possible also.
4. Strength of welded joints made by spot welding is fully satisfactory and is not less than the strength of welded joints of the high-strength aluminum alloys of type D19A-T, D20A-T, D16A-T.

ROLLING OF SHEET MATERIAL DIRECTLY FROM ALUMINUM POWDER

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(p 119 of source)

In Soviet and foreign literature there have been published several articles on questions pertaining to rolling of powders of the ferrous and nonferrous metals. Regarding, however, the technology of manufacture of sheet material by direct rolling of aluminum powder (with content to 9-10% of aluminum oxide), neither in foreign or Soviet literature is there information.

The object of our study was the investigation of conditions of manufacture of sheet material from SAP by rolling of powder of brand APS and clarification of the fundamental possibility and expediency of obtaining it by this method.

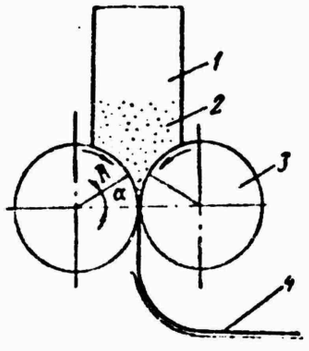

Fig 1. Diagram of vertical rolling of powder.
1) bunker, 2) powder, 3) rollers, 4) tape.

Rolling of the powder constitutes the process of continuous pressing by two rollers of a rolling mill revolving in opposite directions. Rolling of powder can be performed with horizontal (Fig 1), or other positions of rollers. For creation above the rollers of a column of powder of comparatively constant section and height we use a bunker

(see Fig 1). Forced supply of powder to the rollers promotes improvement of quality of tape rolled from powder. Rollers have to have a smooth working surface and flanges (Fig 2). Rolling of powder occurs on the deformation section determined by the angle of capture α (see Fig 1), and is finished with exit of tape or sheet from gap between the two rollers.

To decrease or increase the angle of capture we use a baffle (Fig 3) that allows a corresponding change of thickness of the rolled tapes.

Aluminum powder used for manufacture of sheet material (tape, sheet), should have good rollability, which depends on bulk weight, looseness, form of particles, dispersiveness and other factors. Bulk weight of powder determines thickness and desnity of the rolled tape or sheet. Other things being equal the thickness of tape is directly proportional to bulk weight. Looseness of powder gives the possibility of judging about the permissible speed of rolling. Powder with particles of spherical form cannot be rolled fully satisfactorily. Powder with particles of flake form is rolled well.

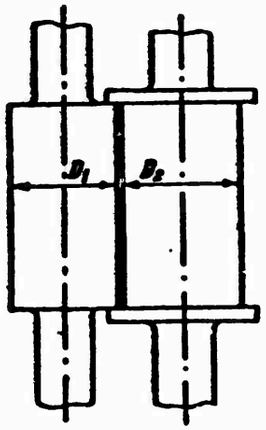

Fig 2. Diagram of rollers with flanges, D_1 and D_2 are diameters of rollers.

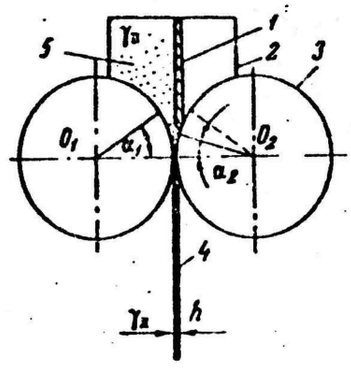

Fig 3. Diagram of rollers with baffle.
1) baffle, 2) bunker, 3) rollers, 4) tape, 5) powder

During our work we used aluminum powder of brand APS with various content of aluminum oxide H-- unannealed powder; O--annealed powder: lot No 13--H (9.6-9.7%); 13-O (9.9-10.1%); 14-H (7%); 14-O (9.3%); 21-O(10.5%) and pulverizate (1.5-2.5%).

On Fig 4 are shown particles of powder: original nonseparated (a) and separated by fractions (b), while Table 1 gives chemical analysis, bulk weight and screen composition by fractions.

On Fig 5 are shown particles of nonseparated powder (a) (the same fractions as on [illegible]) in the field of view of a microscope. Large difference in magnitude of particles of powder can lead to a condition in which on the surface of tape rolled from such powder there are formed cracks due to heterogeneity of deformation of particles of powder of large and small dimensions.

For determination of influence of oils contained in the powder on rollability we used unannealed powder and powder annealed in a vacuum (10 mm mercury column) at 500C for 3 hours.

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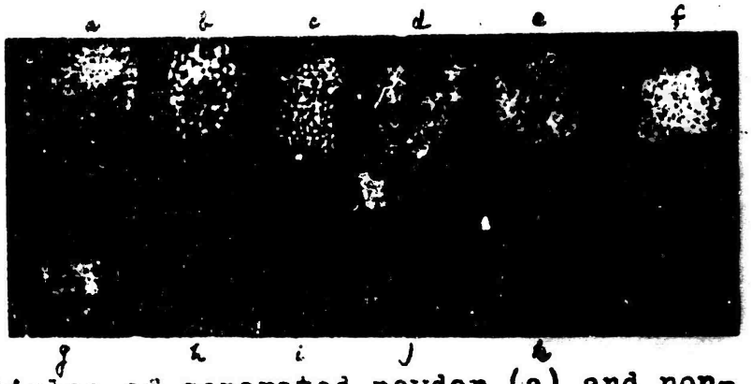

Fig 4. Particles of separated powder (a) and nonseparated (b,c,d,e,f,g,h,i,j,k).

The process of rolling is in its physical nature considered close to pressing, therefore for an indirect appraisal of rollability of powder and its compacting we studied the dependency of density of pressing of samples on the specific pressure of pressing.

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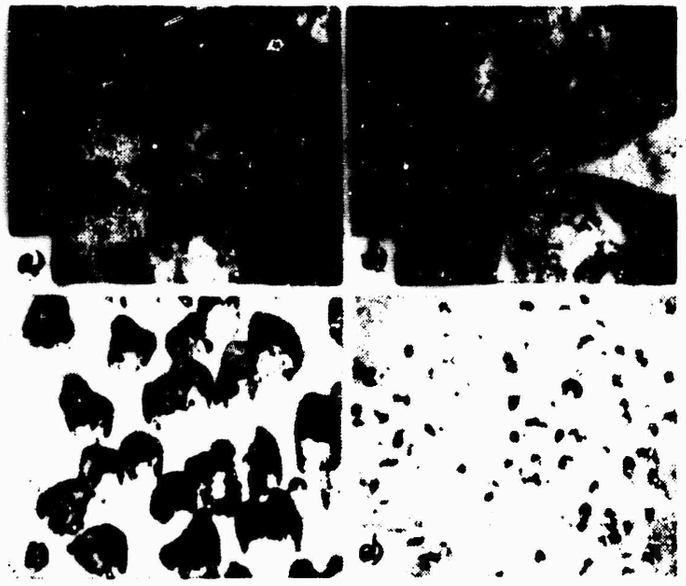

Fig 5. Particles of powder of various dispersiveness, X40.
a - nonseparated powder, b - fraction +1.0,
c - fraction +0.2, d - fraction — 0.05.

Pressing from powder of brand APS (annealed and unannealed) of cylindrical samples of diameter 16 mm was performed in a press-form at specific pressure 2,4,6,8 T/cm^2, then we measured the density and hardness of samples (Fig 6,7).

It was established that with a decrease of dimension of particles of powder the density is increased; with increase of pressure the density and hardness are increased, vacuum annealing of powder in this case does not affect density and hardness of pressed samples. These results made it possible to draw a preliminary conclusion concerning fitness of such powder for rolling of tape. Rolling of tape from powder was done on three rolling mills having the following characteristics (Table 1).

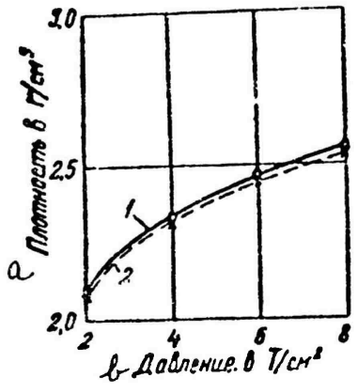

Fig 6. Influence of pressure on density of unannealed (1) and annealed (2) powder.

a - Density in g/cm^3; b - Pressure in T/cm^2.

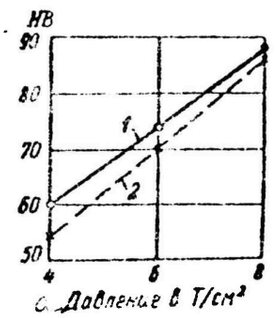

Fig 7. Influence of pressure on hardness of unannealed (1) and annealed (2) powder.

a - Pressure in T/cm^2.

Table 1

№ стана a	Диаметр дисков мм b	Длина бочки мм c	Число об/мин d	Мощность квт e	Направление прокатки f
1	70	90	2—30	2	g Вертикальное
2	180	150—330	1—8	10	"
3	300	350	22	35	h Горизонтальное

a - No. of mill; b - Diameter of disks mm; c - Length of barrel mm; d - Number rev/mm; e - Power in kilowatt; f - Direction of rolling; g - Vertical; h - Horizontal.

ROLLING FROM SAP OF TAPE STOCK

After preliminary experimental rolling of aluminum powder on mill No 1 the basic experiments were conducted on mill No 2. On rollers without flanges we managed to roll into tape only the initial powder and powders of fraction from 1 to 0.63 mm, from 0.63 to 0.4 mm. In rolling of powder of the remaining fractions there occurred strong spilling. However, on the obtained tapes there was a large quantity of transverse cracks (through and along edges of tapes).

In connection with this, further rolling of powders was conducted on rollers with flanges, where we managed to obtain tape from all forms of powder. Theoretical analysis of the influence of flanges on rolling of powder into tape is given in the works of G.I. Aksenov and A.M. Nikolaev (G.I. Aksenov, Rolling of Metallic Powders into Tape, Collection, "Powder Metallurgy", Metallurgy Publishing House, 1954. A.N. Nikolaev, Rolling of Metallic Powders. Izvestia of Higher School. Ferrous Metallurgy, 1958, No 2). Near the movable flanges the angle of capture becomes larger than in the middle of rollers. Entering of powder into the region of deformation also is facilitated thanks to the presence of the moving metallic surfaces (flanges). In connection with this the edge of the tape becomes more dense.

During rolling of tapes with dense edges significant difficulties appear in extraction of tapes from flanges. During cold rolling of such tapes (from powder of various fractions) the tape was wedged in the flanges -- it wound itself around the roller.

Rolling of powder heated to 300-350C significantly strengthens the tapes obtained. Heating of powder higher than 350C leads to sintering of its particles, therefore tapes are obtained with sharply expressed nonuniform density and cracks.

On tapes rolled from nonseparated unheated powder (in state of delivery), there were conspicuous longitudinal and transverse cracks, since the powder consists of particles of various dimension.

While the average bulk weight of nonseparated powder is equal to 1.39 g/cm^3, the bulk weight of components of its fractions changes from 1.19 (big fractions) to 0.77 g/cm^3 small fractions). Therefore we subsequently used only powder separated fractions. On tapes prepared from powder of big fractions (remainder on sieves + 1; + 0.63; + 0.4) there appeared cracks -- longitudinal and

transverse. From powder of the remaining fractions we obtained tape without cracks with uniform density and satisfactory strength. We obtained tapes of different density -- from 2.0 to 2.4 g/cm^3. Attempts to roll tape of high density ended in failure. On these tapes there were formed longitudinal and transverse cracks. To avoid the appearance of surface cracks on tapes rolled from powder of the large fractions, one should decrease the thickness of tapes, decreasing by the baffle the angle of capture of the powder.

We conducted experiments on rolling of nonseparated and separated powders with various positions of baffle into tapes of thickness 1.2, 1.5, 1.7, 2.0, 2.4, 2.8 mm and width 150 and 300 mm. Tapes of satisfactory quality were obtained from powders of following fractions: - 0.4, + 0.314, + 0.2, + 0.16. The external appearance of good tapes is shown on Fig 8.

On the basis of data obtained during rolling of powder of lots 14 — H, 14 — O and pulverizate we plotted the dependency of thickness of tape on bulk weight of powder (Fig 9). Since the density of rolled tapes varied we took a thickness, reduced to the same density — 2.4 g/cm^3.

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Fig 8. Raw tape stock rolled from SAP.

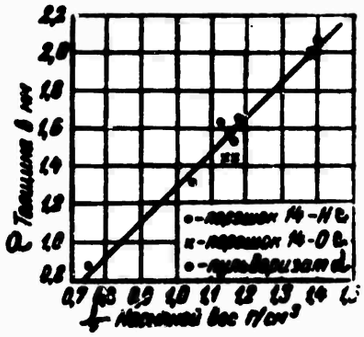

Fig 9. Influence of bulk weight of powder on thickness of tape. a - Thickness in mm; b - Bulk weight in g/cm^3; c - powder; d - pulverizate.

HOT ROLLING OF RAW TAPES

Preliminarily conducted experiments of test rolling of raw tapes both in the cold, and in the hot state, and also in the cold state with preliminary annealing showed the expediency of application (in our conditions of work) of hot rolling. The number of passes per hot rolling and magnitude of reduction per pass were different.

Hot rolling of raw tapes of thickness 1.2, 1.5, 1.7, 2.0, 2.4 mm to thicknesses of 1.0-0.50 mm and less was conducted for the purpose of determination of strength characteristics of compacted tapes prepared in this way. We rolled raw tapes on a two-roll rolling mill with diameter of rollers 300 mm and length of barrel 350 mm with rotation of rollers with a speed of 22 rpm.

For hot rolling of raw tapes of above-mentioned thicknesses we cut the stock -- sheet of length from 200 to 500 mm, width 150 and 300 mm, thickness 1.5-1.7 mm. Such stock with cutoff lateral edges (on the average 10-15 mm to the side) were heated in an electric resistance furnace in air atmosphere and rolled to small dimensions. Lubricant of rollers was not used.

On the working surface of the rollers there remained particles of powder that led to the formation on the rolled tapes of defects in the form of dents, through holes or tears.

Nonetheless the experiments conducted on hot rolling of raw tape stock obtained directly from aluminum powder showed the possibility of forming of comparatively compact sheet material.

COLD ROLLING

From part of the tapes, rolled in the hot state, we cut samples for determination of mechanical properties, density and porosity. The remaining part of the tapes was rolled to thicknesses of 0.15, 0.11, 0.06 mm. Cold rolling was done on a four-high mill, surface of mill was lubricated by machine oil.

Some of the tapes (foil) rolled in the cold state without defects (with satisfactory surface and edges) are shown on Fig 10.

Following is a typical scheme of the experimental technology of manufacture (in laboratory conditions) of tapes (foil) from aluminum powder:

I. Heating of powder 300-320C for 30 min in electric resistance furnace (in air atmosphere).

Fig 10. Samples of tapes (foil) after cold rolling.

II. Hot rolling from aluminum powder heated to 300-320C of tape-stock of thickness 2 mm on rolling mill with horizontal location of rollers of diameter 180 mm with length of barrel 330 mm with speed of rotation of rollers 3 rpm.

III. Cutting of edges of tape-stock by 10 mm to the side.

IV. Heating of tape-stock at 480-500C for 40 min in electric resistance furnace (air atmosphere).

V. Hot rolling of heated tape-stock from thickness 2 mm to thickness 0.5 mm with relative reduction per pass equal to 10-12%. After every three passes heating to 480-500C.

VI. Cutting of edges of tapes.

VII. Cold rolling of tapes from thickness 0.5 mm to thickness 0.05 mm with relative reduction 10-16% per pass.

VIII. Cutting of edges of foil.

For introduction into production of the method of manufacture of tape and foil by rolling of aluminum powder, it is necessary to apply the more economic (as compared to sheet) ribbon method of coil rolling.

For the transition to coil rolling, in connection with the difficulty of coiling of tape-stock of thickness near 2 mm, we should roll from aluminum powder tape-stock of thickness 1 mm. This will facilitate the process of coiling and will reduce the number of operations (eliminates the necessity of heating and hot rolling of tapes from thickness of 2 mm to thickness of 1 mm).

Besides we should consider that with coil rolling in factory conditions, the number of operations (heatings and passes) will be less than during the sheet method of rolling in laboratory conditions.

In order to clarify the influence of preliminary heating of the powder on properties, we rolled several tapes, and the stock obtained from them was rolled in hot and cold state into foil. In properties of tapes prepared from heated and cold powder there is not observed any great difference.

Heating of the powder in an atmosphere of nitrogen, apparently worsens the properties of the tapes. For these tapes, obtained both in hot, and in cold state, large fragility is characteristic.

Mechanical properties of tapes prepared from powder heated in an atmosphere of nitrogen are significantly worse than tapes obtained from powders preliminarily heated in an air atmosphere and rolled in the cold state. Strength of tapes obtained by hot rolling of aluminum powder is higher than tapes rolled from unheated powder and this is important during transportation.

MECHANICAL PROPERTIES OF TAPES

Ultimate strengths of tapes of thickness 0.5-0.1 mm (on the average) are equal to 34-40 kg/mm^2. Ultimate strength of rolled foil of thickness 0.06 mm at 20C constituted 36-42 kg/mm^2, and at 480C was 7-9 kg/mm^2.

INFLUENCE OF DEGREE OF DEFORMATION ON MECHANICAL PROPERTIES OF SHEET MATERIAL OBTAINED BY ROLLING UNHEATED POWDER

To establish the influence of initial size of particles on properties for the same degrees of reduction we investigated tapes obtained by rolling of powder of lot 14-H of fractions + 0.16 and + 0.315.

Tapes of thickness 1 mm were annealed at 480-500C for 30 min, after which they had a density of 2.7 g/cm^3. From thickness 1 mm the tapes were rolled in the cold state to thicknesses 0.9, 0.8, 0.7, 0.6, 0.5, 0.4 mm, i.e. degress of deformation were 10, 20, 30, 40, 50, 60%. Samples of tapes rolled with various degree of deformation were tested in tension. Results of tests are presented on Fig 11.

From Fig 11 and Table 2 it is clear that the density of cold-rolled tapes obtained with degree of reduction of 10, 20, 30, 40, 50% in this case is not changed; hardness and ultimate strength are increased with increase of percent of reduction; with decrease of dispersiveness of initial powder the ultimate strength is increased.

Table 2

a Степень деформации %		10	20	30	40	50	60
Фракция b +0,16	плотность c	2,71	2,71	2,70	2,70	2,71	2,65
	твердость d	127	133	135	135	134	125
Фракция b +0,315	плотность c	2,7	2,7	2,7	2,70	2,71	2,66
	твердость d	126	134,5	134,5	136	137,5	129

a - Degree of deformation %; b - Fraction; c - density; d - hardness.

The decrease of ultimate strength, hardness and density during deformation of tapes by 60% occurs, apparently, from the surface micro-cracks.

INFLUENCE OF ANNEALING ON MECHANICAL PROPERTIES

Samples of tape rolled in the cold state with a degree of deformation of 50% were annealed at temperatures of 300, 400, 500, 600C for 3 hours in a vacuum of 10 mm mercury column. Results of determination of ultimate strength and hardness of annealed samples are shown in Fig 12,13.

Strength of tape noticeably decreases at a temperature of annealing higher than 500C (at 500 σ_B = 36.5 kg/mm^2, at 600 σ_B = 33.5 kg/mm^2) which, apparently, is connected with recrystallization; this is confirmed by Fig 14.

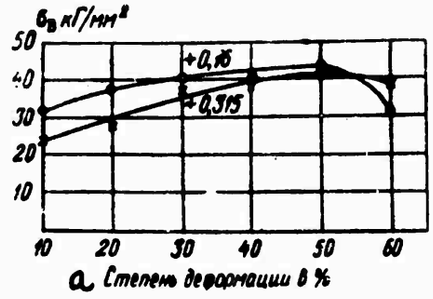

Fig 11. Influence of degree of deformation and dimension of particles of powder on ultimate strength of tape. a - Degree of deformation in %.

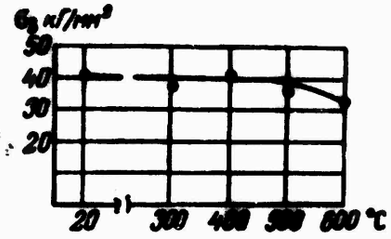

Fig 12. Influence of temperature of annealing on ultimate strength of tape.

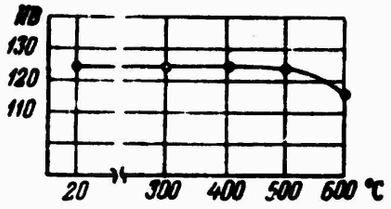

Fig 13. Influence of temperature of annealing on hardness of tape.

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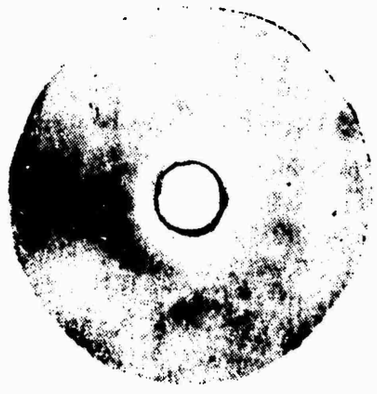

Fig 14. X-ray photograph of tape annealed at 500C.

Conclusions

1. This work experimetally proves the possibility of manufacture of sheet material of tapes-foil from SAP by the method of rolling of powder.

2. In the given conditions of rolling for obtaining of high-quality sheet material it is necessary to use definite fractions of separated powder of brand APS — 0.4; + 0.315; — 0.315; + 0.2; — 0.2; + 0.16. This is more

efficient as compared to rolling of unseparated powder.

3. Rolling can be conducted both in cold and hot states (at 300-320C). Tapes rolled from heated powder have higher strength than from nonheated, therefore it is expedient to conduct rolling of powder in the heated state.

4. We developed the fundamental scheme of the technology of manufacture from SAP sheet material of tapes and foil by the method of rolling.

5. We prepared development samples of sheet material of thickness from 1 to 0.05 mm.

6. We determined the influence of degree of deformation on ultimate strength, and also density and hardness; at a degree of deformation higher than 50% we observed lowering of these properties.

7. Ultimate strength of sheet material after hot and cold rolling at 20C constituted 42 kg/mm^2 and at 480C was 7-9 kg/mm^2.

ANISOTROPY OF PROPERTIES OF SAP DURING HOT ROLLING
(p 130 of source)

V.A. Shelamov, F.V. Zhuravlev

(This work was conducted in the Dept. of Pressure Working of Metals of Moscow Aviation Technology Institute. Scientific leader was Honored Worker of Science and Technology Professor Doctor of Tech. Sciences I.L. Perlin).

This work was conducted for the purpose of study of influence of annealing of stock and direction of rolling on uniformity of distribution of mechanical properties in hot-rolled SAP. We investigated the technological process of obtaining of sheets from pressed stock of SAP of section 12 x 5 100 mm with content of 7.5-8.0% Al_2O_3. Rolling (A.I. Murzov, S.I. Nomofilov, V.A. Shelamov, Coll. "High-temp Material from Sintered Aluminum Powder (SAP)", Oborongiz, 1961. B.L. Matveev, S.I. Nomofilov, V.A. Shelamov, Coll. "High-temp Material From Sintered Aluminum Powder (SAP)", Oborongiz, 1961). (Ya.B. Fridman, Mechanical Properties of Metals, Oborongiz, 1962)) was conducted to dimension of 3 x 100 mm on a duo mill with rollers of diameter 350 mm and length of barrel 500 mm. Speed of rolling constituted 0.3 m/sec, temperature 450-470°, total degree of deformation 75%, reduction per passage was 12-25%.

Billets were rolled lengthwise and across axis of pressing. Part of billets before rolling were annealed at 450° for 48 hours.

Investigation of properties was conducted at room temperature according to method of Roytman--Fridman on micro-samples of diameter 1.2 mm with gage length 5.8 mm.

Samples were out from the rolled sheets after every pass. Diagram of cutting is shown in Fig 1. At every point we tested four samples.

As a result of the work conducted we obtained a series of indicator stress-strain diagrams p — Δl). The character of curves obtained does not depend on degree of deformation during rolling or direction of rolling. On the curves, areas of plasticity almost completely absent. On Fig 2 are shown characteristic indicator diagrams p — Δl, obtained during tension of samples cut from stock and sheet during the technological process.

During the analysis of mechanical properties of hot-rolled SAP it is revealed that the anistropy of properties in longitudinal and transverse directions is identical for the periphery and the center of the sheet and does not depend on initial direction of rolling.

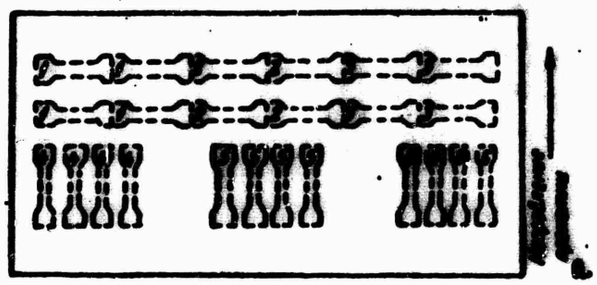

Fig 1. Diagram of cutting of samples from hot-rolled sheets.

a - Direction of rolling

With increase of total reduction the ultimate strength changes insignificantly. On Fig 3 are shown curves of dependency on degree of deformation during rolling of ultimate strength of transverse and longitudinal samples of sheets without preliminary annealing of the pressed billet (Fig 3,a) and with preliminary annealing (Fig 3,b).

Ultimate strength drops with increase of degree of deformation to 45-50%, and then with further increase, increases. This may be explained by the thermal effect during deformation of SAP. During deformation to 50% the influence of the thermal effect is most noticeable, with further increase of degree of deformation it ceases to show up.

Ultimate strength of transverse samples is 10-12% higher than longitudinal. For the majority of metals and alloys, conversely the properties of longitudinal samples are higher than transverse. SAP in distinction from the usual deformable aluminum alloys is characterized by the fact that during deformation, along with the strengthening, there occurs splitting of the particles of aluminum oxide, present in large quantities in the microvolume of aluminum, and subsequent formation of texture.

Splitting of particles, occurring chiefly along the rolling direction, decreases the effect of hardening in this direction, therefore properties of transverse samples are higher than longitudinal.

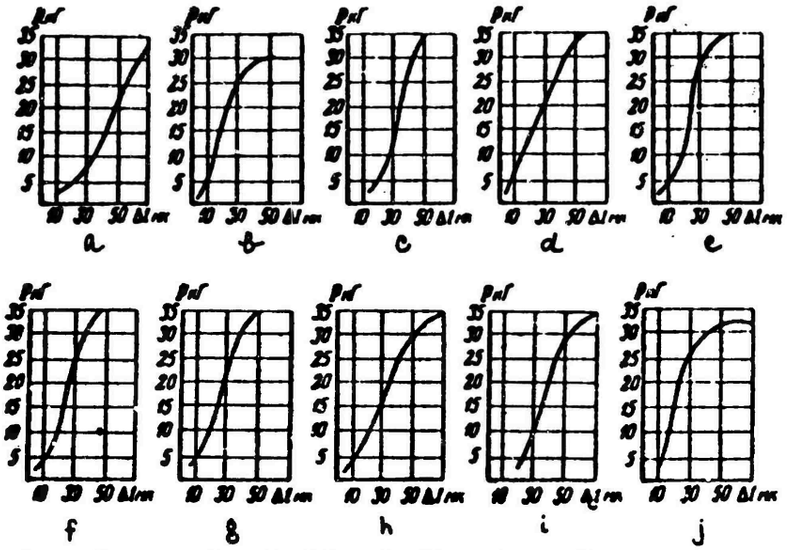

Fig 2. Characteristic indicator diagrams p — Δl, obtained during tension of samples.
a - pressed billet, b - rolling lengthwise with degree of deformation per pass 25%, after 50% total deformation, c - the same, after 75% total deformation, d - rolling lengthwise with degree of deformation per pass 15%, after 50% total deformation, e - the same, after 75% total deformation, f - the same, rolling across, g - rolling lengthwise with degree of deformation per pass 12%, after 25% total deformation, h - the same, rolling across, i - the same, rolling lengthwise after 75% total deformation, j - the same, rolling across.

Furthermore there is a noticeable influence of annealing on the value σ_B. For unannealed material (Fig 3,a) properties follow a broken line, in second case (Fig 3,b) diffusion processes occurring as a result of annealing somewhat stabilize the properties and they follow a smooth curve.

Yield point $\sigma_{0.2}$ is changed depending upon degree of deformation during hot rolling just as σ_B. Besides there is a marked equalizing action of annealing on the change of $\sigma_{0.2}$ with increase of total deformation (Fig 4,a).

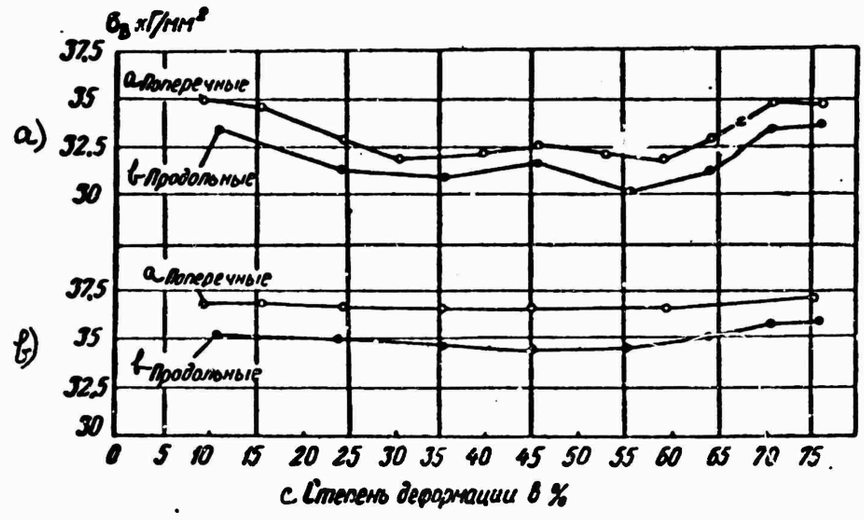

Fig 3. Change of $\sigma_в$ depending upon degree of deformation during rolling of pressed stock without annealing (a) and after annealing (b).

a - Transverse; b - Longitudinal; c - Degree of deformation in %.

Elongation (Fig 4,b) and narrowing (Fig 4,c) for transverse samples on the average is higher than for longitudinal (for annealed and unannealed stock).

In the remaining cases the values of δ and ψ with a change of degree of deformation give significant scattering and it is difficult to note any regularity.

Analysis of the microstructure of the material during the progress of rolling showed that the structure becomes stable with increase of total reduction. Besides there is a noticeable tendency to regrouping of phase particles along with the formation of texture.

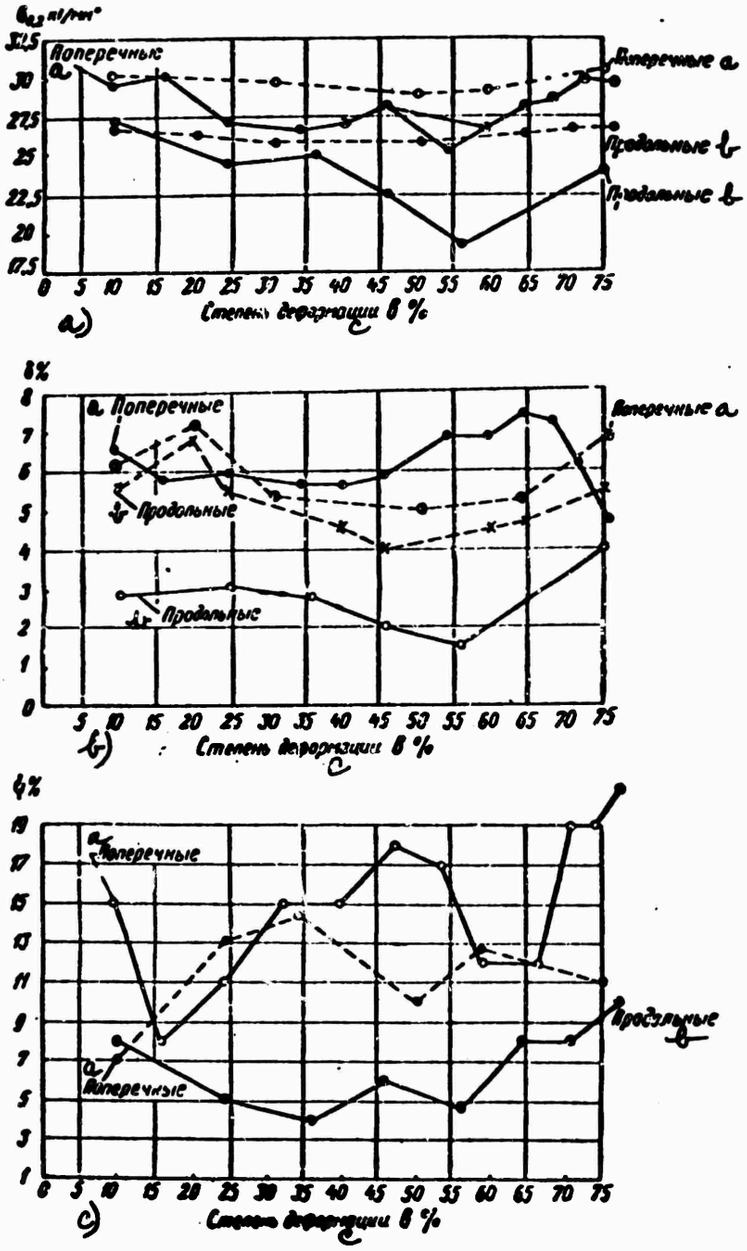

Fig 4. Change of yield point $\sigma_{0,2}$ (a) relative elongation δ (b) and narrowing ψ (c) depending upon degree of total deformation.

——— without annealing;
- - - - - after annealing.

a - Transverse; b - Longitudinal; c - Degree of deformation in %.

Conclusions

1. Ultimate strength and yield, elongation and narrowing of transverse samples of hot-rolled SAP are higher than for longitudinal. This is explained by the peculiarity of the hardening processes occurring in SAP during rolling.

2. Direction of rolling does not affect change of properties of material with increase of degree of deformation. There is noted only an insignificant decrease of σ_b with a degree of deformation of 40-50% with subsequent increase to the initial value.

3. For preliminarily annealed material, with an increase of total deformation the properties were changed more evenly than for unannealed.

4. On indicator diagrams obtained during tensile tests of micro-samples of SAP yield areas are almost completely absent.

5. Structure of material is uniform and is stable, but there is observed a tendency to formation of texture with increase of total reduction.

FUSION WELDING OF SAP (p 135 of source)

G.D. Nikiforov, S.N. Zhiznyakov,
E.Ya. Bazurina, B.I. Matveev

At present industries need heat-resistant materials possessing low specific gravity. One of such materials is SAP. The essential deficiency delaying wide application of SAP is the difficulty of its welding. From foreign data fusion of welding SAP is considered, in general, impossible.

Fig 1. Appearance of seam obtained during automatic argon arc welding SAP-1 using layer of flux.

Experiments performed by us on argon arc welding of sheets of SAP-1 with flux and without flux allowed us to make the conclusion that fusion welding of SAP-1 by the usual process is impossible due to poor stability of the direct action arc and difficulty of formation of the welding pool in connection with ejection of the liquid base and filler metals in the form of porous drops and accumulations on the edges of the welded plates. Introduction of flux in the bath does not improve the process of welding. On Fig 1 is shown the appearance of a section of a seam obtained during argon arc welding of SAP-1 with addition of flux.

In a number of cases it was revealed that on separate small sections there are formed welded joints as a result of partial dissolution of SAP in the bath of liquid filler metal. In connection with this we decided to search for a method of artificial creation of a liquid bath of significant volume and as a result of contact of the bath with the edges of the welded material to achieve its dissolution and to thus obtain a welded joint. With this goal we tested the following process methods:

welding by independent arc along a layer of flux with application of filler wire;

arc welding along a layer of flux on an aluminum substrate using a non-consumable tungsten electrode with argon protection. During application of these process variants we obtained the joinings shown on Fig 2 and 3.

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Fig 2. Macrostructure of joining obtained during automatic welding of SAP-1 along layer of flux by independent arc in atmosphere of argon, X3.

The presence of a very large quantity of pores, frequent unsatisfactory fusion of base material with filler, and also the complexity of the proposed process forced us to terminate further work in this direction.

As a result of the study of causes of unsatisfactory behavior of SAP-1 during arc welding we found ways of avoiding them and propose a technology of obtaining of heat-resistant SAP, possessing the ability to be fusion welded.

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Fig 3. Macrostructure of joining obtained during automatic argon arc welding of SAP-1 along layer of flux with use of aluminum substrate, X8.

Sheets of such SAP possess the following properties:

1) are not distended during heating to 900C with holding for 30 minutes (as is known, sheets of nonwelding SAP are distended during brief heating higher than 520C);

2) have heightened plasticity and high strength at room and heightened temperatures: with a content of 6.9% Al_2O_3 the ultimate strength at room temperature constitues 30-36 kg/mm^2, at 500C it is 5-7 kg/mm^2; with a content of 10.6% Al_2O_3 the ultimate strength at room temperature is equal to 36-40 kg/mm^2.

This material can be welded by arc welding with application of fluxes and in a medium of argon. The latter method is more desirable in production, inasmuch as in this case we eliminate the necessity of subsequent washing of

welded joints for removal of remainders of flux.

Investigations conducted showed that for full melting of sheets of weldable SAP during butt welding it is necessary to apply a welding current of greater intensity than for sheets of the same thickness from aluminum and its alloys. For instance, during welding of sheets of SAP of thickness 1.5 mm full melting occurs only with a welding current of 280-300 a.

Subsequently it turned out that during use of currents of very great intensity the strength of welded joints, due to stratification of basic material near seam, does not exceed 18-24 kg/mm^2, where failure of samples during test occurs, as a rule, in the basic material at a distance of several millimeters from the seam. Lowering of welding current from 280-300 a to 150-200 a during welding of sheets of thickness 1.5 mm essentially improves the quality of joining, however during assembly it is necessary to leave a gap of 1-1.5 mm between edges of sheets for full melting of joint.

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Fig 4. Appearance of seam obtained during automatic argon arc welding of weldable SAP.

a - facing side of seam, b - reverse of seam.

A large influence on quality of welded joints is shown by the speed of supply of the filler wire, since with insufficient speed there are observed burns, and sometimes cracks along the center of seam.

Rational selection of composition of filler wire for welding of SAP is an important but unfortunately still unsolved problem. In our experiments as filler material we used wire of the alloy AMg6.

The conditions of automatic argon arc welding by tungsten electrode of sheets of SAP of thickness 1 and 1.5 mm

with filler wire of the alloy AMg6 are given in Table 1, and appearance of obtained seam on Fig 4.

During investigation of the properties of welded joints obtained by this method we established the following:

1. In the process of welding there occurs mutual dissolution of the basic and filler materials;

2. In the zone of mutual crystallization a clear-cut line between basic and filler materials is absent which indicates fusion of the surface of the basic material with formation of a common bath (Fig 5,6);

3. In the seam metal there are pieces of undissolved SAP forming zones with sharply distinguished etchability (Fig 7) and higher hardness;

4. The basic material in zones near seam possesses heightened hardness which testifies to possible diffusion in it of magnesium and formation of a solid solution of magnesium in aluminum.

Table 1

Conditions of welding

a Толщина свариваемых листов *мм*	b Сила тока *а*	c Скорость сварки *м/час*	d Скорость подачи присадочной проволоки *м/час*	e Диаметр проволоки *мм*	f Расход аргона *л/мин*
1	100—140	10—15	20—35	2	7—8
1.5	150—170	10—15	20—35	3	8—9

a - Thickness of weld sheets, mm; b - Current intensity a; c - Speed of welding, m/hour; d - Speed of supply of filler wire, m/hour; e - Diameter of wire, mm; f - Expenditure of argon liters/minute.

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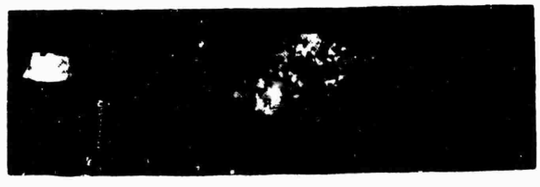

Fig 5. Macrostructure of joining obtained during automatic argon arc welding of weldable SAP, X5.

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Fig 6. Zone of mutual crystallization of joining obtained during automatic argon arc welding of weldable SAP, X200.

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Fig 7. Microstructure of metal of seam in region of separated pieces of SAP, X70.

Results of tensile tests of welded joints are given in Table 2.

Table 2

Температура испытания a °C	Предел прочности кГ/м.м² b	Характер разрушения c	Примечание d
20	24,1—28,5 / 26,2	e По околошовной зоне	Сварка поперек прокатки g
	20,6—26,1 / 23,2		Сварка вдоль прокатки h
	25,5—28,0 / 26,8		Выдержка после сварки при 400° С в течение 1 часа i
	22,9—28,0 / 25,5		Выдержка после сварки при 500° С в течение 1 часа i
	31,2—35,3 / 33,3	f По основному материалу	Материал изготовлен по более совершенной технологии j
	22,3—26,4 / 24,4	e По околошовной зоне	Сварка на увеличенном токе k
500	5,7—6,4 / 6,1		

a - Temperature of test C; b - Ultimate strength kg/mm^2; c - Character of fracture; d - Note; e - In heat-affected zone; f - In basic material; g - Welding across rolling; h - Welding along rolling; i - Soak after welding at__ C for 1 hour; j - Material is prepared by more advanced technology; k - Welding with increased current.

Judging by results obtained during welding of SAP we can obtain joining with ultimate strength of 24-28 kg/mm^2 at room temperature and 5.506.5 kg/mm^2 at 500C. The heightened thermal resistance of metal of seam obtained with use of filler wire of the alloy AMg6 may be explained by the action of inclusions of oxides of aluminum, which migrate

into the seam from the basic material.

Some lowering of strength of welded joints at room temperature as compared to basic material can be explained by the slight overheating of basic material in the heat-affected zone in the process of welding. Difference ir properties of welded joints made lengthwise and across direction of rolling corresponds to the scattering of the values of properties of the usual nonweldable material.

Conclusions

1. SAP prepared by the usual technology is not useful for welding by fusion. As a result of our investigation we developed a technology of obtaining SAP possessing the ability to be fusion welded.

2. Such material can be welded by either argon arc welding (melted and unmelted electrodes) or by the methods of arc welding with use of fluxes.

3. Ultimate strength of welded joints obtained with application as filler material of wire from the alloy AMg6 constitutes 24-28 kg/mm^2 at room temperature and 5-6 kg/mm^2 at 500C. These properties can be improved by improvement of the technology of manufacture of the material and the process of welding. For instance, during welding of material obtained by a more advanced technology the strength of welded joints at room temperature constitues 30-35 kg/mm^2.

4. Prolonged soak of welded joints at 400 and 500C does not change the ultimate strength at room temperature.

5. SAP is easily welded with other aluminum alloys, for instance with the alloy AMg6, which expands the possibility of application for manufacture of different structures.

BUTT RESISTANCE WELDING OF WIRE FROM SAP
(p 141 of source)

V.K. Ivanov, P.V. Kishnev, E.Ya. Bazurina

During selection of equipment for butt welding it is necessary to consider the properties of aluminum or aluminum alloys. The high heat-conductivity and low electrical resistance of aluminum require application for butt welding of welding machines of great power. The narrow temperature interval of transition from solid state to liquid leads to necessity of automated feed during fusion and upsetting and a high regulated pressure, sufficient for displacing from the joint of oxidized metal.

A necessary condition of obtaining a high-quality welded joint is simultaneity of turning off of current and initiation of upsetting. According to A.S. Gelman (A.S. Gelman, Electric Resistance Welding, Mashgiz, 1949) even with a slight lead of turning off of current before upsetting the metal in the joint intensely oxidizes, which leads to lowering of quality of the joint. In the American literature (W.F. Haessly, Welding Journal, 1954, No 12) there is also confirmed the necessity of timely turning off of current during welding of nonferrous metals. Investigations of butt welding of aluminum and its alloys conducted by VNIIESO showed that initiation of upsetting should be simultaneous or lead the turning off of current by 2-3 cycles.

A still more complicated problem is the welding of SAP, consisting of particles of pure aluminum with melting temperature of 657C and the refractory oxide of aluminum having temperature of fusion of 2050C.

Check of possibility of butt welding of wire from SAP on the machines ASIF-5 and MSR-25, having spring drive upsetting and mechanical turning off of current, did not give positive results. The welded joint, containing a large quantity oxide, was fragile and was easily broken by hand (force approximately 15-25 kg).

A high quality welded joint may be obtained only by simultaneous melting of both components of SAP with preservation in the joint of the structure of the basic material or close to it.

Welded joints of satisfactory quality were obtained during welding of wire from SAP on a machine of the type MSKN-150 (Fig 1) developed by VNIIESO.

GRAPHIC NOT REPRODUCIBLE

Fig 1. Machine for butt welding of nonferrous metals of type MSKN-150.

Short Technical Characteristic of Machine MSKN-150

Line voltage	380 volts
Electrical power during short circuit	200 kilovolt ampere
On time, PV	10%
Maximum upsetting force (with pressure in line 5 kg/cm^2)	3000 kg
Maximum speed of fusion	50 mm/sec
Maximum speed of upsetting	200 mm/sec
Maximum travel of plate	40 mm
Number of stages	16
Limits of adjustment of secondary no-load voltage	4-8.1 volts
Welding current during short circuit	0.37 ohm
Power factor of machine during short circuit	0.54

The characteristic feature of this machine, distinguishing it from earlier machines with hand feed or with mechanical drive of shift of plate, is the pneumatic drive with hydraulic brake. Use of the hydraulic brake allows in wide limits to regulate and to exactly hold the magnitude and character of build-up of speed of fusion and to obtain instantaneous and powerful upsetting. The electrical circuit of the machine, thanks to the presence of an electronic timer relay, allows switching off of the current at any given moment.

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Fig 2. Welded samples of SAP-1

a - welded joint, b - with removed burr, c - after stretch to appearance of permanent deformation.

The investigation of weldability of SAP was conducted on wire of diameter 4,5 and 6 mm obtained from powder PP-4 (with 4% Al_2O_3) and from powder APS-1 (with 6-10% Al_2O_3). We welded the wire under condition given in Table 1, and under conditions shown in Table 2. Comparative results of tests of strength of basic material and welded samples (Fig 2) are given in Table 3.

Table 1

a Установочные данные	ПП-4		АПС-1
	Ø 6 *мм*	Ø 5 *мм*	Ø 4 *мм*
b Первичное напряжение в *в*	380	225	225
c Суммарная установочная длина в *мм*	12—13	12—13	12—13
d Давление осадки по манометру в *ат*	3	3	3,5
e Ступень трансформатора	1	5	5
f Положение движков на шкале (деление шкалы):			
g дросселя	22	20	10
h рычага	0	0	3
i осадки	13	13	13

a - Initial data; b - Primary voltage; c - Total initial length in mm; d - Upsetting by manometer in atm; e - Stage of transformer; f - Position of cursors on scale (scale division); g - coil; h - lever; i - upset.

Table 2

a Параметры режима	ПП-4		АПС-1
	Ø6 мм	Ø5 мм	Ø4 мм
b Скорость оплавления в мм/сек	9—10	9—10	12
c Скорость осадки в мм/сек	200	200	200
d Усилие осадки в кГ	2000	1800	1800
e Вторичное напряжение холостого хода в в	4	3	3
f Ток короткого замыкания в а	24	13	13

a - Parameters of conditions; b - Speed of fusion in mm/sec; c - Upsetting speed in mm/sec; d - Upsetting force in kg; e - No-load secondary voltage; f - Short circuit current in amps.

Table 3

Results of Tensile Test of Wire

a Марка пудры для проволоки	b Диаметр проволоки мм	c Предел прочности кГ/мм²	d Отношение прочности сварного соединения и основного материала %	e Место разрушения
ПП-4, основной материал f	6	21,6	91	—
ПП-4, сварной образец g	6	19,7		По сварному стыку h
ПП-4, основной материал f	5	22,0		—
ПП-4, сварной образец g	5	20,3	92	По сварному стыку h
САП-1, основной материал f	4	25,6	100	—
САП-1, сварной образец g	4	25,6		По основному материалу i

Key: a - Brand of powder for wire; b - Diameter of wire mm; c - Ultimate strength kg/mm^2; d - Ratio of strength of welded joint and basic material %; e - Place of failure; f - basic material; g - welded sample; h - In welded joint; i - In basic material.

The joint of welded wire of diameter 5 mm sustains a bend of 180° and twisting on posts of diameter 10 mm as shown on Fig 3.

Bending tests of welded joints with rebending per All Union Standard--1688 and in impact bend using a pendular hammer type MK-5 showed that the welded joint is more fragile than the basic material. This is explained by the change of structure of material in the joint in the process of welding, as confirmed by metallographic investigations.

The microstructure of a longitudinal sample of wire of diameter 4 mm from powder APS-1 has rectilinear directivity (Fig 4). In the microstructure of the welded joint (Fig 5) there are boundaries of the two welded wires. The joint has a structure oriented perpendicularly to the longitudinal axis of wire which transitions smoothly to the structure of the basic material.

GRAPHIC NOT REPRODUCIBLE

Fig 3. Joint of welded wire of diameter 5 mm.

The macrostructure of a welded joint of wire of diameter 4 mm is shown on Fig 6. With insufficiently thoroughly selected conditions of welding, on the macrograph (Fig 7) there is revealed a line of separation of the wires. During microanalysis of this slide (Fig 8) there is revealed a line of dark inclusions.

During determination of microhardness of wire of diameter 6 mm from powder PP-4 it turned out that the hardness in the center of the welded joint is somewhat less than the hardness of the basic material.

As is known, wire (rods of length 4-5 mm, section 6-8 mm) is obtained from SAP by hot extrusion of billets. The possibility of obtaining wire of smaller sections depends on the quality of welded joints, able to sustain the plastic flow of the process of drawing.

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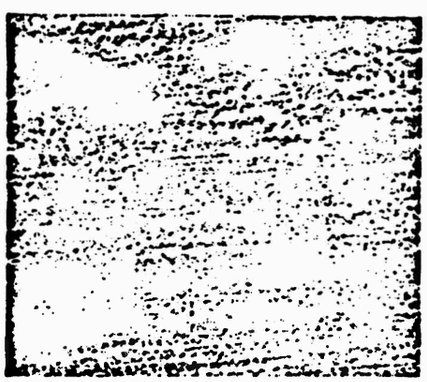

Fig 4. Micro-structure of basic metal, X200.

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Fig 5. Microstructure of welded metal in area of joint, X200.

We tried drawing of wire consisting of six sections of length 200 mm, united by fusion welding on a machine MSKN-150. Speed of drawing constituted 2.7 m/minute. Results are given in Table 4.

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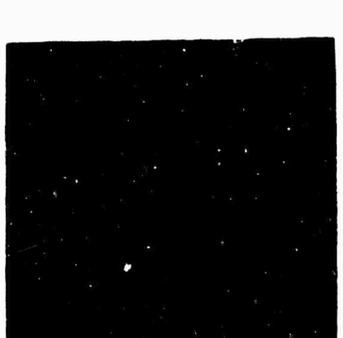

Fig 6. Macrostructure of welded sample of diameter 4 mm.

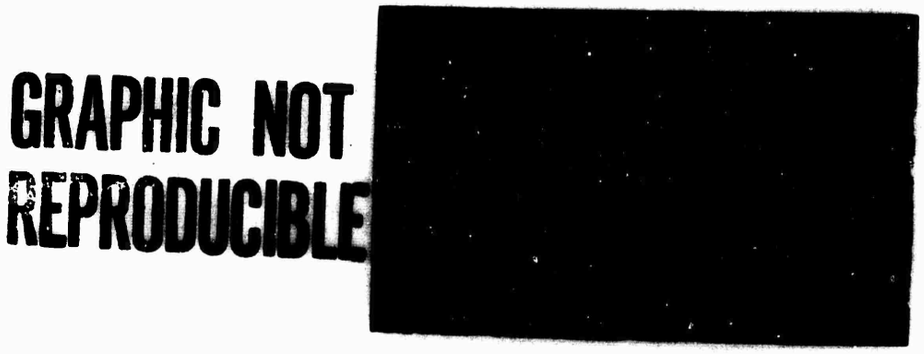

Fig 7. Macrostructure of welded sample (line of demarcation of wires is seen), X8

Fig 8. Microstructure of welded joint (line of dark inclusions is conspicuous, X200.

Table 4

Диаметр проволоки до протяжки a мм.	Последовательность и степень обжатия (∅ фильера) b мм	Место разрушения c
6	5,8; 5,6; 5,17	d Не разрушилась
5	4,5; 4,33; 4,0	e Разрыв по шву

a - Diameter of wire before drawing mm; b - Sequence and degree of reduction (diameter of drawplate); c - Place of failure; d - No failure; e - Failure in seam.

From data of Table 4 it is clear that drawing to a smaller diameter of wire from SAP with welded joints, is possible. During drawing of wire having 6 welded joints with degree of reduction of 30 and 40% (diameters of initial section constituted 6 and 5 correspondingly) there was one failure in a joint and the drawing was done without preliminary determination of optimum speeds and sequence of drawing.

Conclusions

1. This study showed that obtaining by the method of fusion of satisfactory welded joints of wire from SAP is possible.

2. During welding using optimum conditions the structure of the welded joint is uniform (in magnitude and locations of particles of aluminum and oxide of aluminum). Strength of welded joint is close to or equal to strength of basic material of wire.

3. Welded joints of wire from SAP are able to sustain deformation during drawing.

4. For welding of wire from SAP of diameter from 4 to 10 mm the most useful machine is the type MSKN with power of 100 kilovolt amperes, which is one of a series of welding machines developed by VNIESO. An industrial version of the machine should have arrangements for reliable holding and fast removal of welded wire of any length, a mechanism for exact centering of joint, and also an attachment for adjustment of secondary voltage in the range from 2.5 to 8 volts.

5. Mastering of welding of wire from SAP will allow industrial production and drawing of wire from the basic brands of SAP.

STRUCTURE AND PROPERTIES OF WELDED JOINTS OF WELDABLE SAP
(p 148 of source)

M.V. Poplavko, I.N. Gerasimenko

One of the urgent and the most complicated problems is fusion welding of SAP and guarantee of high quality welded joints. In connection with this there appeared the the necessity of development of the technology of welding and determination of properties of the welded joints.

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Fig 1. Appearance of seam in hand argon arc welding with application of welding wire AK and flux AF-4a.

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Fig 2. Appearance of seam in automatic argon arc welding with application of welding wire AMg-6.

In the first stage of work the sheet material (SAP) was hand argon arc welded with application of filler of brand AK and automatic argon arc welded with unmelted electrode with filler wire AMg6.

In both cases the process of welding progressed sufficiently stably with satisfactory penetration and good forming of seam (Fig 1 and 2).

With use of welding wire of brand AK the seam usually has a uniform structure characteristic for the given material (Fig 3).

With application of filler wire of brand AMg6, in the structure of the seam sometimes it is possible to observe separate oxidized inclusions (Fig 4). For the purpose of improvement of forming of seam and its properties we developed the filler wire B40 of the following composition:

1.58% Mg; 1.64% Ni; 0.31% Mn; 0.14% Si; 0.10% Ti; 0.1% Be, remainder aluminum

GRAPHIC NOT REPRODUCIBLE

Fig 3. Structure of metal of seam with application of filler wire AK.

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Fig 4. Structure of metal of seam with application of filler wire AMg6.

In the process of test welding of plates it was noticed that with application of this wire there is ensured good forming of seam and proper continuity of metal. On Fig 5 is shown the facing and reverse sides of seam, and on Fig 6 -- an X-ray photograph of the seam. The uniform structure of the seam, and also the good alloying with the basic material (Fig 7) promote an increase of quality of the welded joints.

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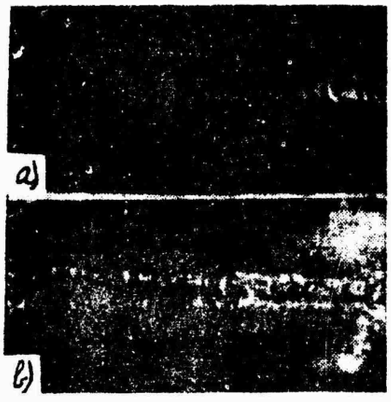

Fig 5. Facing (a) and reverse (b) side of seam, made with application of wire B40.

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Fig 6. X-ray photograph of welded seam, made with application of wire B40.

Testing on inclination to crack formation was done on a cross-like sample (Fig 8). No cracks in metal of seam and or heat-affected zone were revealed.

In connection with this, there was great interest in the determination of the properties of basic material and welded joints obtained with use of the wire B40 and AK. (Participated in work of V.I. Il'ina)

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Fig 7. Alloying of metal of seam with basic metal (filler B40).

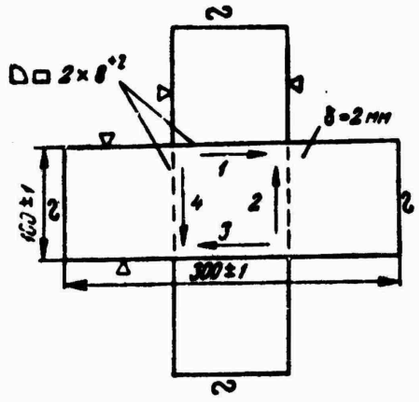

Fig. 8. Cross-like sample for determination of inclination of metal of seam and basic to crack formation during welding.

With this goal we welded plates using a nonconsumable electrode in a medium of argon with application of flux AF-4a, where in view of the high refractoryness of SAP we used somewhat heightened conditions of welding (Table 1).

Table 1

Conditions of Hand Argon Arc Welding of SAP

Толщина материала a мм	Диаметр вольфрамового прутка b мм	Сила тока c а	Диаметр присадочной проволоки d мм
1,0	2,0	65—70	3,0
1,5	2,0	80—105	3,0
2,0	2,5	110—135	3,0

Key: a - Thickness of material mm; b - Diameter of tungsten rod mm; c - Current intensity a; d - Diameter of filler wire mm.

Welding of plates was done end to end on a copper substrate with through penetration and reverse forming of seam.

From the welded plates we prepared two series of samples: with strengthening of seam and without strengthening of seam. Samples were subjected to short-time tensile tests at 20, 350 and 500C for determination of their strength with use of the above-mentioned brands of filler wire. All

samples were cut along direction of rolling since it was assumed that in this direction there are obtained lower strength parameters. Furthermore, we made tests of standard samples of welded joints in bending. Results of tests are given in Table 2.

Table 2

Mechanical Properties of Welded Joints of SAP Thickness of Sheets 1.5 mm (6.8% Al_2O_3)

a Марка присадочной проволоки	b Температура испытания °C	Предел прочности при растяжении кГ/мм² c		Угол загиба град f
		с усилением шва d	без усиления шва e	
B40	20	19,3—27,8	—	41—70 / 54,8
B40	350	8,5—9,7 / 9,1	—	—
B40	500	4—4,7 / 4,23	3,6—4,6	—
AK	20	23,1—26,8 / 25,4	21,0—24,8	31—63 / 48,1
AK	350	5,75—8,8 / 7,51	6,8—8,8	—
AK	500	3,3—4,7 / 4,1	2,8—3,5 / 3,23	—

a - Brand of filler wire; b - Temperature of test C; c - Ultimate strength in tension kg/mm^2; d - with strengthening of seam; e - without strengthening of seam; f - Angle of bend in degrees.

As can be seem from Table 2, the plastic properties of seams made with the filler wire B40 are somewhat higher than seams with the wire AK.

For comparison of properties of basic material and welded joints we prepared and tested in tension two series of samples, cut lengthwise and across direction of rolling. We welded sheets from SAP, containing 6.8 and 7.4% Al_2O_3. Results are given in Table 3-6.

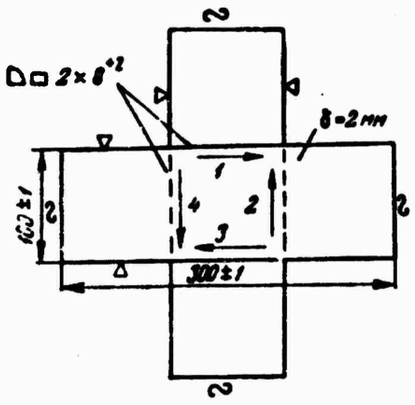

Fig 8. Cross-like sample for determination of inclination of metal of seam and basic to crack formation during welding.

With this goal we welded plates using a nonconsumable electrode in a medium of argon with application of flux AF-4a, where in view of the high refractoryness of SAP we used somewhat heightened conditions of welding (Table 1).

Table 1

Conditions of Hand Argon Arc Welding of SAP

Толщина материала a мм	Диаметр вольфрамового прутка b мм	Сила тока c а	Диаметр присадочной проволоки d мм
1,0	2,0	65—70	3,0
1,5	2,0	80—105	3,0
2,0	2,5	110—135	3,0

Key: a - Thickness of material mm; b - Diameter of tungsten rod mm; c - Current intensity a; d - Diameter of filler wire mm.

Welding of plates was done end to end on a copper substrate with through penetration and reverse forming of seam.

From the welded plates we prepared two series of samples: with strengthening of seam and without strengthening of seam. Samples were subjected to short-time tensile tests at 20, 350 and 500C for determination of their strengtn with use of the above-mentioned brands of filler wire. All

samples were cut along direction of rolling since it was assumed that in this direction there are obtained lower strength parameters. Furthermore, we made tests of standard samples of welded joints in bending. Results of tests are given in Table 2.

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Mechanical Properties of Welded Joints of SAP Thickness of Sheets 1.5 mm (6.8% Al_2O_3)

a Марка присадочной проволоки	b Температура испытания °C	Предел прочности при растяжении кГ/мм² c		Угол загиба град f
		с усилением шва d	без усиления шва e	
B40	20	19,3—27,8	—	41—70 / 54,8
B40	350	8,5—9,7 / 9,1	—	—
B40	500	4—4,7 / 4,23	3,6—4,6	—
AK	20	23,1—26,8 / 25,4	21,0—24,8	31—63 / 48,1
AK	350	5,75—8,8 / 7,51	6,8—8,8	—
AK	500	3,3—4,7 / 4,1	2,6—3,5 / 3,23	—

a - Brand of filler wire; b - Temperature of test C; c - Ultimate strength in tension kg/mm^2; d - with strengthening of seam; e - without strengthening of seam; f - Angle of bend in degrees.

As can be seem from Table 2, the plastic properties of seams made with the filler wire B40 are somewhat higher than seams with the wire AK.

For comparison of properties of basic material and welded joints we prepared and tested in tension two series of samples, cut lengthwise and across direction of rolling. We welded sheets from SAP, containing 6.8 and 7.4% Al_2O_3. Results are given in Table 3-6.

As can be seen from the tables, the strength of the basic material and welded joints of samples cut across rolling are higher than longitudinal.

For test of strength of basic material containing 7.4% oxide of aluminum and of welded joints obtained with application of filler wire B40, we tested two series of samples, cut lengthwise and across direction of rolling (Table 5 and 6).

Table 3

Strength of Basic Material (SAP) at Different Temperature (6.8% Al_2O_3). Thickness of Sheet 1.5 mm

Температура испытания °С (a)	Предел прочности в σ кГ/мм²	
	вдоль проката (c)	поперек проката (d)
20	21,0—31,0 / 27,6	32,6—33,0 / 32,9
350	8,1—8,7 / 8,3	9,0—9,3 / 9,16
500	3,7—3,8 / 3,76	3,7—4,4 / 4,03

a - Temperature of test C; b - Ultimate strength in kg/mm²; c - along rolling; d - across rolling.

Table 4

Strength of Welded Seam With Strengthening (filler B40) 6.8% Al_2O_3

Температура испытания °С (a)	Предел прочности в σ кГ/мм²	
	вдоль проката (c)	поперек проката (d)
20	20,7—25,7 / 22,0	26,2—29,2 / 27,8
350	7,4—8,9 / 8,1	9,2—10,3 / 9,73
500	3,6—4,2 / 3,87	4,0—4,2 / 4,13

a - Temperature of test C; b - Ultimate strength in kg/mm²; c - along rolling; d - across rolling.

Table 5

Strength of Basic Material (SAP) at Room Temperature (7.4% Al_2O_3).. Temperature of test 200

Толщина материала мм (a)	Предел прочности (b) кГ/мм²	
	вдоль проката (c)	поперек проката (d)
1,5	28,0—30,2 / 29,4	24,8—31,1 / 29
1,0	28,5—31,0 / 29,6	30,1—31,6 / 30,75

a - Thickness of material mm; b - Ultimate strength kg/mm²; c - along rolling; d - across rolling

Table 6

Durability of Welded Joints of SAP on Samples with Strengthening of Seam (7.4% Al_2O_3). Thickness of Material 1.5 mm

Температура испытания °C (a)	Предел прочности (b) кГ/мм²	
	вдоль проката (c)	поперек проката (d)
20	20,4—24,3 / 22,9	30,7—33,9 / 31,7
500	5,1—5,4 / 5,62	5,7—6,1 / 5,86

a - Temperature of test C; b - Ultimate strength kg/mm²; c - along rolling; d - across rolling.

As can be seen from Table 6, strength of welded samples cut across rolling is higher than longitudinal, and failure occurs in the basic material in the heat-affected zone.

Conclusions

1. In the process of tests on inclination to crack formation (cross-like sample) it was established that SAP welds without cracks.

2. Application of filler wire B40 allows us to obtain comparatively strong seams. For obtaining hermetic welded joints special technology is required.

REPROCESSING OF WASTE SAP (P 153 of source)

N.A. Davydova, E.A. Kuznetsova, B.I. Matveev, A.A. Gelman

In obtaining of half-finished products of details from SAP there are formed large wastes in the form of press-remainders, extrusion ends, sheet and wire cutoff and small waste in the form of shavings during machining of details. Direct use of these wastes during manufacture of half-finished products from SAP has tremendous value for lowering the cost of the latter. In connection with this, the authors studied different methods of processing of waste SAP.

In practice successful application is made of the method of briquetting of small waste of the most diverse alloys and steels. If briquettes from small waste are subjected to significant deformation (pressing or rolling), there are obtained half-finished products of quite high quality. With this method of reprocessing of waste, losses are significantly less than during resmelting. If one were to consider that remelting of SAP is practically impossible, application of this method of use of waste SAP has great importance. Proceeding from this, we studied different methods of crushing of large waste, and also the influence of degree of cruashing on structure and properties of half-finished products of SAP.

The best method of mechanical crushing from the point of view of economy and simplicity would be crushing of big waste in crushers. However, as shown by experiments, in view of the high viscosity of SAP, crushing in the usual hammer crusher did not give positive results, since there occurred only some crumpling of metal on the surface. In connection with this it was decided to study the method of crushing of waste by cutting.

With this goal, milling of rods from SAP was used to prepare shaving of the most diverse dimensions. The big shavings had a thickness of 0.2-0.5 mm, length and width from 1 to 5 mm, bulk weight constituted 0.3-0.5 g/cm^3. Big shavings was obtained on a lathe. Small shavings were made on a special milling machine adapted for processing of powder compact metal. The conditions under which we crushed the waste were the following: table feed 0.09 mm/turn, speed of rotation of Table 7 rpm, speed of rotation of horizontal milling cutter 4500 rpm.

The obtained shaving was subjected to abrasion in special drums. In this case its bulk weight was increased from 0.26 to 0.65-0.85 g/cm^3. In Table 1 are given the mechanical properties of rods, pressed from big and small

shavings of SAP with content of aluminum oxide 15.2%.

Table 1

Mechanical Properties of Rods of SAP Obtained From Different Shavings

a Вид стружки	при 20°				при 500°			
	$\sigma_в$ кг/мм²		δ %		$\sigma_в$ кг/мм²		δ %	
	max	min	max	min	max	min	max	min
c Крупная стружка	40,5	37,6	7,0	5,4	11,5	9,6	2,0	1,0
d Мелкая стружка:								
e до истирания	41,7	38,5	6,0	2,0	12,4	12,0	1,2	0,4
f после истирания <100 мк	41,0	39,5	4,0	2,5	13,5	11,5	0,6	0,4

a - Form of shaving; b - At; c - Big shaving; d - Small shaving; e - before abrasion; f - after abrasion <100 mk.

From Table 1 it is clear that with decrease of dimensions of shaving, strength increases at all temperatures and elongation drops. However, the general level of properties remains high enough. It is necessary to note that for rods from coarse shavings the tendency to delamination is greater than with small shavings, therefore small are better.

A large influence on quality of half-finished products obtained from crushed waste is shown by the parameters of their manufacture: temperature of heating of crushed waste before briquetting, specific pressure of briquetting, temperature and degree of deformation during hot pressing. For determination of the influence of temperature of heating of crushed waste of SAP before their briquetting on mechanical properties of rods and the content in them of aluminum oxide we selected temperatures of 400, 450, 500, 600°. Specific pressure during briquetting in all cases constituted 40 kg/mm^2. After briquetting at these temperatures the density of the briquette oscillated within the limits 2.0-2.15 g/cm^3. Further compaction of these briquettes at 450° increased the density to 2.75-2.8 g/cm^3, i.e. to the density of pressed half-finished products. Results of tests are given in Table 2.

Table 2

Dependency of Mechanical Properties and Content of Aluminum Oxide in Pressed Rods on Temperature of Heating

Температура нагрева перед брикетированием a °C	b При 20°		b При 500°		Содержание окиси алюминия в прутках c %
	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %	
20	—	—	—	—	14,0
400	36,0	6,0	10,0	—	14,2
450	37,3	5,0	12,0	—	14,7
500	37,0	4,2	13,0	0,9	14,3
550	—	—	10,0	2,0	14,2
600	36,0	6,0	7,0	1,8	14,8

a - Temperature of heating before briquetting C;
b - At; c - Content of aluminum oxide in rods%.

As can be seen from Table 2, preliminary heating of crushed waste in interval of temperatures 400-600C practically does not affect mechanical properties at room temperature or content of oxide of aluminum. However, high-temperature heating of shavings at 600C worsens properties of rod at 500C. This pattern is also observed during heating of powder before its briquetting.

Regarding influence of specific pressure of briquetting on density and mechanical properties of rods from secondary SAP, the pattern basically remains the same as in obtaining of rods from primary powder: density of briquette increases with specific pressure of briquetting while the mechanical properties of pressed half-finished product and its final density practically do not depend on the specific pressure.

Temperature of hot pressing, conversely, renders a significant influence on mechanical properties of pressed half-finished products from secondary SAP (Table 3). With increase of temperature of heating of billets from 450 to 500C, ultimate strength of pressed rod is increased from 36 to 39 kg/mm^2, and elongation is increased correspondingly.

Increase of strength and plasticity can be explained by the fact that at the higher temperatures there occurs best sintering and, apparently, certain redistribution of aluminum oxide. Thus, for guarantee of best mechanical properties of secondary SAP at normal temperatures it is best to heat the billets to 550-580C.

Table 3

Influence of Temperature of Heating of Billets Before Hot Pressing on Mechanical Properties of Secondary SAP. Test at 20C.

Температура нагрева заготовок a °C	$\sigma_в$ кГ/мм²	δ %
450	36,0	5,0
500	37,1	4,8
550	38,0	5,0
580	39,0	6,0

a - Temperature of heating of billets C.

Table 4

Change of Mechanical Properties of Secondary SAP Depending Upon Degree of Deformation. Test at 20C

Степень деформации a %	$\sigma_в$ кГ/мм²	δ %
67	33,8	0,8
84	37	1,5
90	37,5	2,0
97	37,8	4,1

a - Degree of deformation%.

For investigation of influence of degree of deformation on change of mechanical properties we pressed rods with degree of deformation 67, 84, 90 and 97%. Investigation of macrostructure of rods pressed with different degrees of deformation showed the following. At a degree of deformation of 67% the central layers of the rod underwent almost no changes, the form and location of particles of shaving are easily seen. Peripheral layer is deformed approximately to a depth 5 mm, separate particles of shaving no longer can be noted since they are strongly stretched along direction of pressing. Rod with degree of deformation of 84% has in the core a structure, stretched in direction of pressing, but the peripheral layers are deformed to a significantly larger degree: rods pressed with degree of deformation of 90 and 97% have completely deformed structure all thru the section.

In Table 4 is given the dependency of mechanical properties of these rods on degree of deformation. With increase of degree of deformation from 67 to 97% the ultimate strength increases by 3.5-4 kg/mm^2, and elongation from 0.8 to 4.1%, i.e. almost by five times. In obtaining of secondary SAP it is best to use a degree of deformation of more than 90%. However, if the half-finished products subsequently have to be subjected to significant deformation, then degree of deformation during hot pressing of secondary SAP may be decreased to 80%.

This investigation allowed us to select optimum temperatures of heating of crushed waste before their briquetting and of billets for hot pressing, and also optimum degrees of deformation in obtaining of secondary SAP.

After that we conducted a comparative investigation (both in laboratory and in factory conditions) of properties of half-finished products of SAP, obtained directly from powder and crushed waste (briquetting with heating and without heating). From powder SAP-2, containing 16% of aluminum oxide, we pressed rods while from their waste we obtained secondary SAP. Temperature of heating of billets for hot briquetting and hot pressing was identical and constitued 470-500C, degrees of deformation also were identical in all cases (95-98%). Average results of tests are given in Table 5.

Data given in Table 5 indicate that secondary SAP pressed from waste (shaving) obtained by machining has satisfactory mechanical properties.

The plasticity of secondary SAP is higher than primary. Such a variation is also observed in secondary pressing of primary SAP. This is explained by the fact that the shaving itself already has a deformed structure and further

Table 5

Mechanical Properties of Rods From Primary and Secondary SAP

Исходный материал a	Брикетирование b	Диаметр прутка мм c	d При 20°				d При 500°			
			$\sigma_в$ кГ/мм²		δ %		$\sigma_в$ кГ/мм²		δ %	
			max	min	max	min	max	min	max	min
e Первичный САП	Горячее g	50	43,4	40,1	2,8	1,4	—	—	—	—
		18	45,3	42,7	4,4	2,8	14,0	12,5	1,6	1,0
e Первичный САП	Холодное h	14	45,4	43,7	4,0	3,4	14,4	12,7	1,6	0,8
f Вторичный САП	Горячее g	14	44,2	42,5	5,6	4,0	14,9	13,3	2,2	1,6
f Вторичный САП	Холодное h	14	43,5	42,4	5,0	4,0	15,2	13,9	2,0	—

a - Initial material; b - Briquetting; c - Diameter of rod mm; d - At; e - Primary SAP; f - Secondary SAP; g - Hot; h - Cold.

deformation of it evokes insignificant lowering of ultimate strength and more significant increase of elongation.

We investigated the microstructure of briquettes, billets and finished pressed half-finished products from secondary SAP. Since the initial raw materials for secondary SAP are crushed waste of primary SAP, then it is natural that secondary material preserves completely the structure of SAP. Thanks to this, the mechanical properties of secondary SAP hardly differ from properties of primary SAP, with the exception of elongation. However, the microstructure in both cases is practically identical for definite conditions of obtaining of rods (Fig 1). In connection with the fact that the elongation of secondary SAP is higher its microstructure should differ from primary SAP. Nonetheless it is possible with confidence to say that inasmuch as secondary SAP is pressed from crushed shaving which consists of an aluminum matrix with distributed dispersed oxidized particles, then as a result of the repeated briquetting, sintering, compaction and hot pressing there occurs a certain redistribution of crushing of aluminum oxide, the result of which is some increase of elongation.

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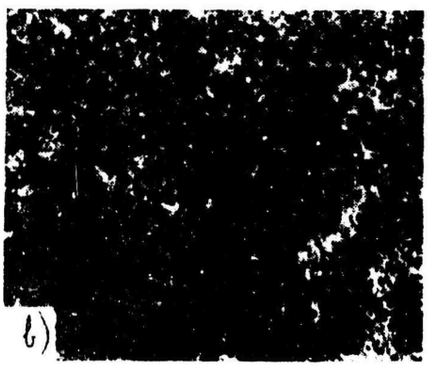

Fig 1. Microstructure of SAP rod
a - primary, b - secondary

Conclusions

By means of mechanical crushing of waste SAP into small shavings, subsequent briquetting and pressing, we can obtain high quality half-finished products, whose mechanical properties differ insignificantly from the properties of half-finished products from primary SAP.

SAS WITH LOW COEFFICIENT OF LINEAR EXPANSION
(p160 of source)

I.N. Fridlyander, N.S. Klyagin,
R.A. Krivenko

(B.I. Babichev, V.S. Rudometov, V.V. Ivanov,
B.D. Firyulin participated in this work)

A considerable lowering of the coefficient of linear expansion of aluminum is in principle possible by means of introduction of large quantities of elements having a coefficient of linear expansion significantly lower than for aluminum. (B.G. Livshits, Physical Properties of Alloys, Chapter, "Thermal Expansion", Metallurgy Publishing House, 1960; M.P. Slavinskiy, Physical and Chemical Properties of Elements, Metallurgy Publishing House, 1952). However, then there are obtained fragile alloys which are difficult to cost and to press. (Smith, SAE Journal, 1959, vol. 66, No 9, pp. 48-50). There is interest in the manufacture of such alloys by the method of powder metallurgy.

In this work we conducted an investigation of alloys of the system Al—Si alloyed with different elements having a comparatively low coefficient of linear expansion (Table 1). (Heinrich Herbst, Patent FRG, No 970904, 1958).

Obtaining of initial powders was done by two methods: atomization of alloy of given composition on a sprary installation and crushing of shaving of finished alloy in a ball mill.

Diagram of spray installation is shown in Fig 1. Melted metal is poured into a graphite crucible. In the bottom part of the crucible there is a hole, closed by a graphite stopper to regulate the speed of supply of metal from crucible to spray nozzle. After achievement of temperature of atomization the stopper is raised the required height and metal enters the nipple.

Stream of metal ensuing from nipple is broken up by a flow of nitrogen, bursting from the spray burner under a pressure of 3-5 atm. Under the action of shower cooling the smallest drops of alloy are crystallized and, dropping on a pan filled with water, are finally cooled.

Table 1

Physical Properties of Investigated Additions

Наименование элемента или химического соединения (a)	Температура плавления (b) °C	γ г/см³	α·10⁶
(c) Кремний	1430	2,32—2,40	6,95
(d) Железо	1539	7,87	11,5
(e) Никель	1455	8,5	13,3
(f) Цирконий	1750	6,53	6,83
(g) Титан	1820	4,54	7,14
(h) Карбид кремния	2400	2,2—2,4	4,0—4,5

a - Designation of element or chemical compound; b - Temperature of fusing C; c - Silicon; d - Iron; e - Nickel; f - Zirconium; g - Titanium; h - Silicon carbide.

The body of spray installation is continuously cooled by water. In the hearth there is an inspection window for observation of the process of atomization and a valve for exit of excess nitrogen. For the purpose of simplifying the process of atomization and observance of rules of safety engineering certain operations are automated, control of these operations is remote. As a result of atomization we obtained powders with particles of round form, having dimensions from 5 mk to 1 mm.

The second method of obtaining the initial powders was grinding of shavings of the alloy in a ball mill. Conditions of grind were selected separately for every alloy. Magnitude of particles of powder, having in this case a flat form, was somewhat larger.

The process of obtaining the half-finished products (rods) consisted of two operations: hot briquetting, and pressing. Before briquetting the initial powders were poured into tubes with covers of sheet duralumin and heated to a temperature of 500C which was sustained for 1.5-2.0 hours. This temperature ensured noticeable lowering of resistance of material to plastic flow.

Then the powders were briquetted in a container with plunger heated to 460C. Specific pressure in all cases was the maximum (88.5-92.0 kg/mm^2). Briquettes were turned and were subjected heating. Temperature of heating was changed

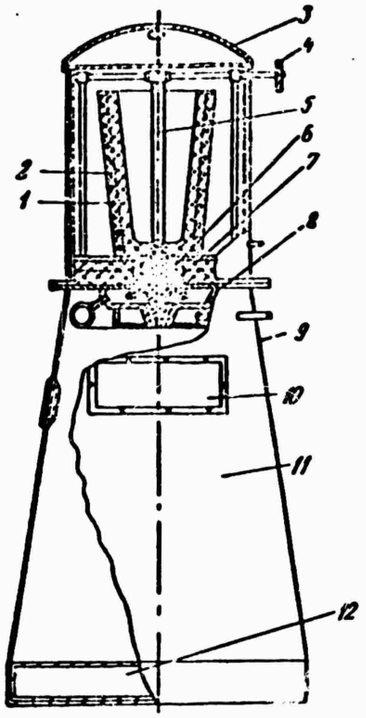

Fig 1. Diagram of spray installation

1) graphite crucible, 2) heater of crucible, 3) cover, 4) mechanism of control of stopper, 5) stopper, 6) heater of nipple, 7) nipple, 8) spray nozzle, 9) body, 10) inspection window, 11)hearth, 12) pan.

depending upon plasticity of alloy from 500 to 640C. From the heated briquettes we pressed rods. Technology of pressing was developed taking into account difficulties encountered during pressing of fragile, difficult-to-press powders: briquettes were pressed in plated tubes using designed spherical dies specially for this purpose with orifices of different diameters.

Subsequently we studied the structure, mechanical and physical properties of the finished rods. Mechanical properties were determined on samples prepared from rods of diameter 14-15 mm.

During the investigation of binary alloys of the system Al-Si it was found that after deformation from the cast state, the highest strength is shown by the alloys, close in composition to eutectic Silumin (Fig 2). With

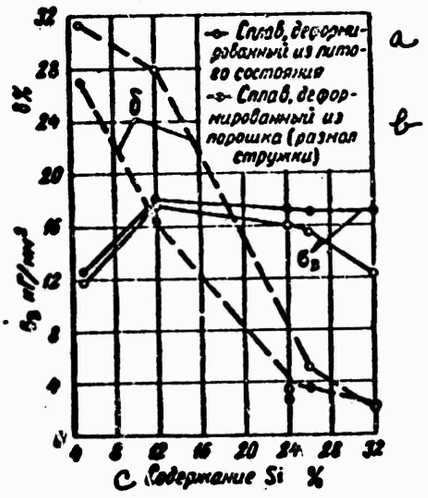

Fig 2. Dependency of mechanical properties of alloys of system Al-Si on content of silicon.

a - Alloy, deformed from cast state; b - Alloy, deformed from powder (grinding of shavings); c - Content Si%.

deviation from the eutectic composition the strength of the alloys drops. Plasticity of alloys decreases with increase of content of silicon. This apparently is explained by the presence of big primary segregations of silicon which lower the plasticity, promoting the increase of inclination of alloy to embrittlement. During the investigation of the group of alloys obtained by deformation of powder prepared by grinding of shavings, it turned out that just as in the preceding case, maximum strength is shown by the alloys of eutectic composition. With increase of content of silicon to 24.0% the strength of the alloys drops insignificantly and with a further increase of content of silicon practically is not changed. Plasticity of alloys prepared from powders is on the average one and a half times lower than the same alloys deformed from the cast state. At a content of 32% Si this different disappears. Consequently, in powder alloys increase of quantity of silicon above 12% does not lead to sharp drop of strength, in distinction to alloys deformed from the cast state.

During the analysis of the above mentioned data it was established that of all the alloys of this system the best strength properties and the lowest coefficient of linear expansion are shown by the alloy containing 25-30% Si (remainder aluminum).

In subsequent investigations the alloy Al — 25% Si was subjected to alloying by different elements with the purpose of a still larger lowering of its coefficient of linear expansion.

Addition of iron to alloy deformed from the cast state lowers its strength (Fig 3); increase of content of iron in powder alloys from 1 to 5% (in obtaining of powder by grinding of shavings) evokes a significant increase of their strength; further increase of content of iron leads to a lowering of strength characteristics; strength of alloys from powder obtained by atomization of melt with content of iron up to 8% is not lowered and remains significantly higher than in the preceding cases (see Fig 3). In these regularities we see clearly the positive quality of the powder method. Results of investigations conducted confirm the possibility of obtaining by the method of powder metallurgy a finely-dispersed structure even for alloys containing a large quantity of insoluble phases; their strength not only is not lowered, but sometimes even increases with a considerable increase of the concentration of insoluble or slightly-soluble additions.

In the next group of alloys we studied the influence of additions of from 5 to 17% nickel (Fig 4). The strength of powder alloys, especially those prepared from atomized powder, is significantly higher than for the same alloys obtained by deformation from the cast state. However, strength of all the alloys of the system Al--Si--Ni is increased with increase of content of nickel while the elongation practically is not changed.

Consequently, addition of nickel more favorably affects properties of alloy than addition of iron. Best mechanical properties in given group of alloys are shown by alloys with 5-7% Ni. These alloys also have the lowest coefficient of linear expansion.

It is necessary once again to emphasize that obtaining of alloys by one of the methods of powder metallurgy (especially atomization) leads to a sharp increase of strength, as compared to the usual methods of casting and pressing (Fig 5).

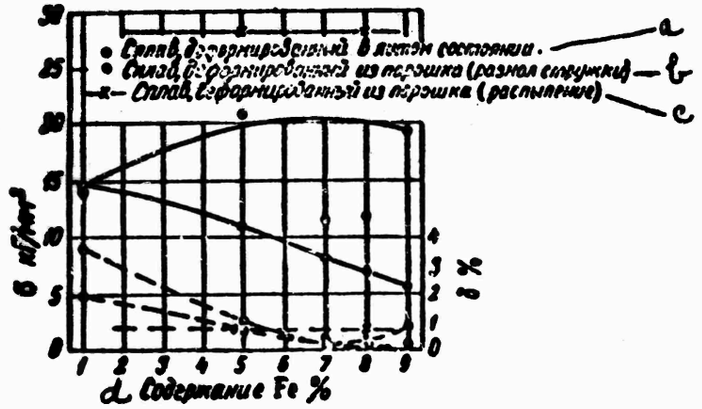

Fig 3. Dependency of mechanical properties of alloys of system on content of iron.

a - Alloy deformed in cast state; b - Alloy deformed from powder (grinding of shavings); c - Alloy, deformed from powder (atomization); d - Content Fe %.

Fig 4. Dependency of mechanical properties of alloys of system Al--Si--Ni on content of nickel.

a - Alloy, deformed from cast state; b - Alloy, deformed from powder (grinding of shavings); c - Alloy, deformed from powder (atomized); d - Content Ni %.

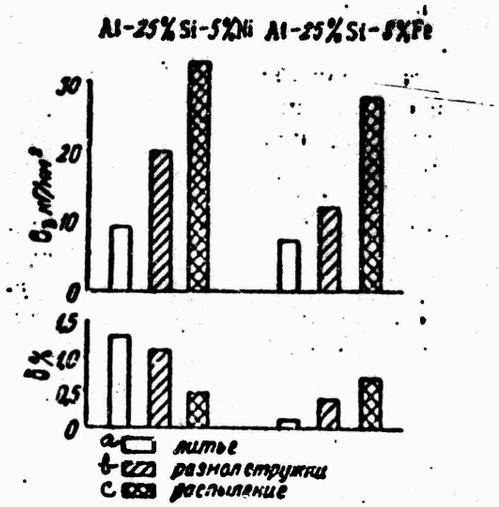

Fig 5. Dependency of mechanical properties of alloys on method of their preparation.

a - casting; b - grinding shavings; c - atomization

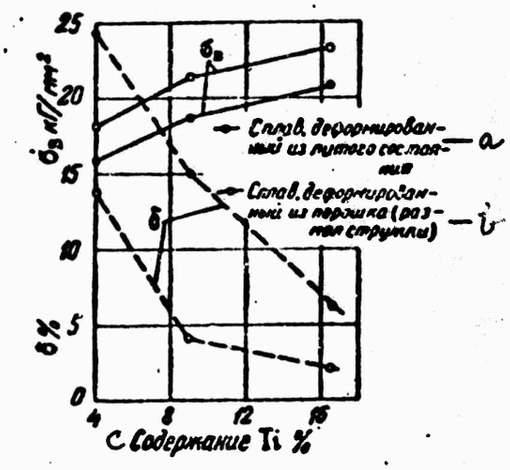

Fig 6. Dependency of mechanical properties of alloys of system Al--Ti on content of titanium.

a - Alloy, deformed from cast state; b - Alloy, deformed from powder (grinding of shavings); c - Content Ti %.

Dependency of investigated mechanical properties of alloys of system Al — Ti on content of titanium is presented on Fig 6. Strength of alloys obtained from powder is significantly higher than the same alloys prepared by casting. Elongation is somewhat higher in the latter case.

Then we investigated alloys with additions of silicon carbide (SiC). Initial powders of alloys of system Al—Si—SiC were prepared by the method of mixing of powders of alloys Al—Si and SiC. The strength of the obtained alloys is sufficiently high with 10% SiC $\sigma_в$= 24.7 kg/mm^2, δ = 3.9%; with 20% SiC $\sigma_в$= 25.0 kg/mm^2, δ = 1.4%).

Simultaneously with investigations of mechanical properties we determined the coefficient of linear expansion of all the enumerated alloys (Table 2).

Table 2

Coefficient of Linear Expansion of Investigated Alloys (powder is obtained by grind of shaving)

Химический состав сплава (остальное Al) a %	$\alpha \cdot 10^6$	b Примечание
5% Si	24,0	
	22,2	
12% Si	21,5	
21% Si	18,5	
26% Si	17,07	
32% Si	17,02	
25% Si—1% Fe	17,00	
25% Si—5% Fe	16,90	
25% Si—7% Fe	16,40	c Для распыленного сплава α=16,00·10^{-6}
25% Si—8% Fe	16,80	
25% Si—9% Fe	18,00	
25% Si—5% Ni	15,45	c Для распыленного сплава α=14,00·10^{-6}
25% Si—5,5% Ni	15,30	
25% Si—8,5% Ni	15,00	
25% Si—9,5% Ni	16,40	
25% Si—4,5% Ni—2,5% Zr	16,90	
4% Ti	20,20	
9% Ti	18,70	
13% Ti	17,70	
5% Si—10% SiC	16,40	
5% Si—20% SiC	16,00	

a - Chemical composition of alloy (remainder Al)%;
b - Note; c - For atomized alloy.

In the group of binary alloys of the system Al—Si the value of α drops with an increase of content of silicon, which has a low coefficient of linear expansion. With the maximum content of silicon (32.0% Si) the coefficient of linear expansion of the alloy is equal to 17.02·10^{-6}. By

adding iron to the alloys containing 25% Si we can obtain a lower value of α. However, lowering of α continues only to content in alloy of not more than 7% Fe, already at 8% Fe the coefficient of linear expansion again starts to grow fast. It is necessary to note that a lower coefficient of linear expansion is shown by alloys obtained from powder prepared by atomization.

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Fig 7. Microstructure of alloy Al—24% Si in state as deformed from ingot (a) and from powder obtained by grinding of shavings (b) ×500.

Coefficient of linear expansion of alloys, alloyed by nickel, is somewhat lower than all the other groups of alloys. With an increase of content of nickel there is observed a tendency to further lowering of α but just as in alloys alloyed by iron, the lowering occurs only to a definite limit : already at 9.5% Ni the value of α again is increased. Introduction in the alloy of 2.5% Zr did not lead to lowering of α (see Table 2).

Titanium more effectively lowers the coefficient of linear expansion of binary alloys with aluminum than, for instance, silicon; already at content 16% Ti $\alpha = 17.7 \cdot 10^6$, while at a content of 24% Si $\alpha = 18.5 \cdot 10^6$. Obviously it will be valuable to subject to further alloying the binary alloys of the system Al—Ti with the purpose of still larger lowering of the coefficient of linear expansion.

Alloys of the system Al—Si—SiC possess high mechanical properties and a low coefficient of linear expansion, where the more silicon carbide in the alloy the lower α.

On Fig 7 (a,b) is given the microstructure of hypereutectic Silumin with 24% Si, deformed in cast state, and also of the powder alloy (prepared by grinding of shavings). The sharp difference between structures is explained by the different methods of preparation of alloys; powder alloys have strongly crushed structure, the big crystals of

primary segregations of silicon are turned into very small fragments of irregular form. The same tendency is also revealed for alloys Al—25% Si—5% Fe (Fig 8) and Al—25% Si—5% Ni (Fig 9).

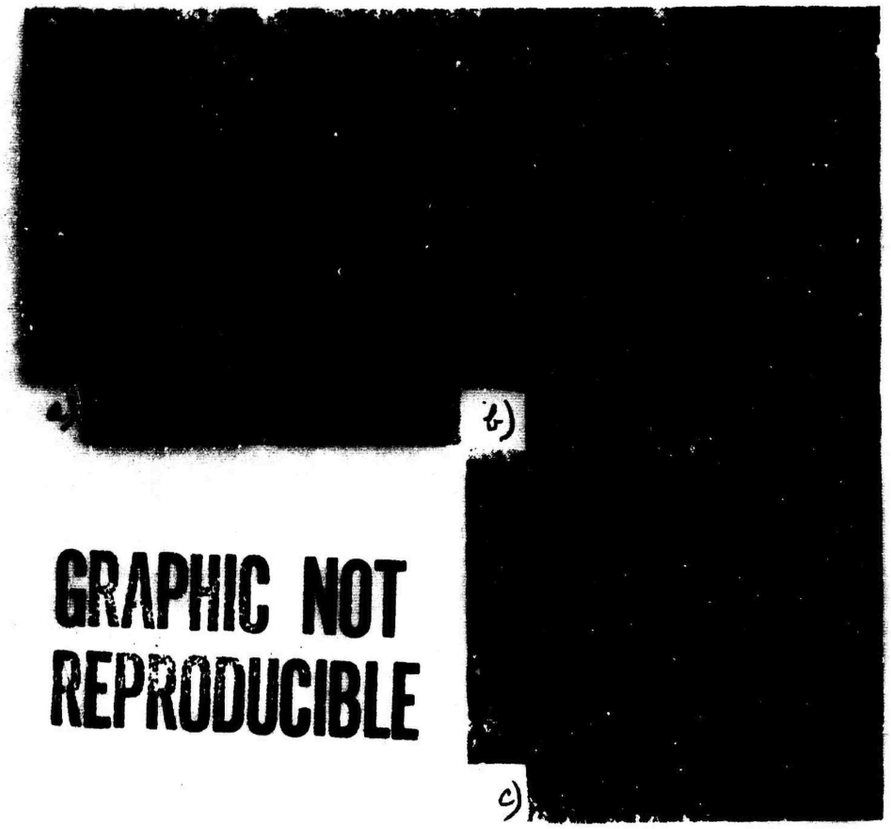

Fig 8. Microstructure of alloy Al—25% Si—5%Fe in state deformed from ingot (a), from powder obtained by grinding of shavings (b), and deformed from atomized powder (c), X500

The microstructure of powder alloys with additions of Zr, Ti and SiC is analogous to the microstructure of the alloys of the above-mentioned systems.

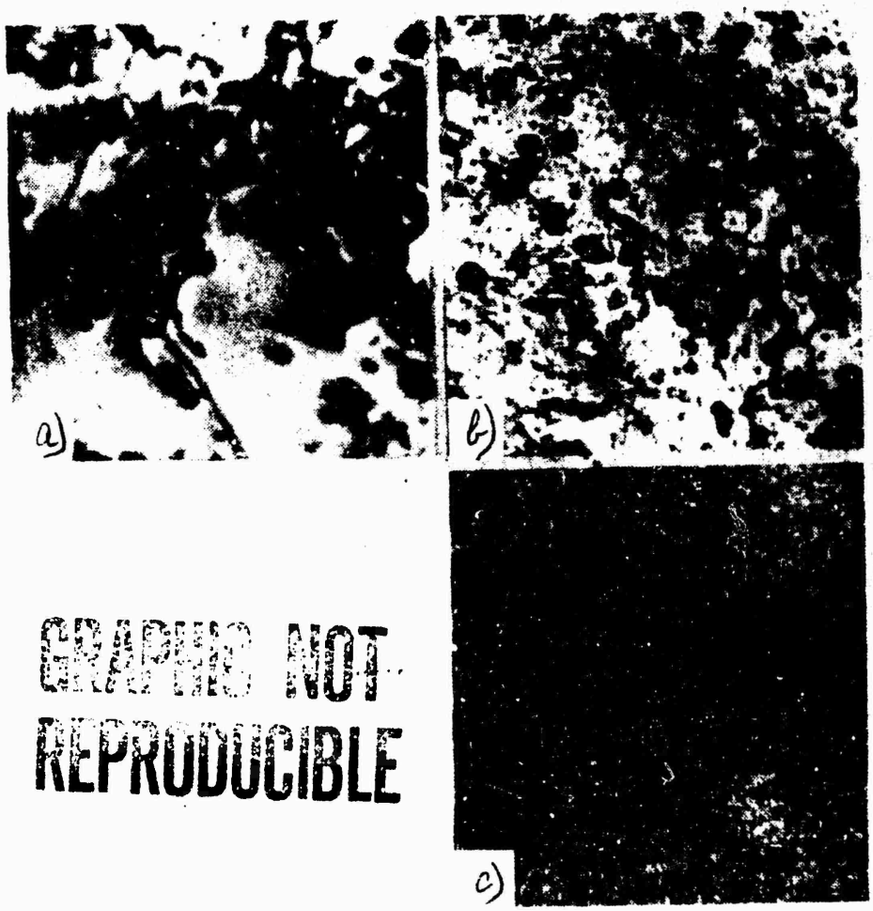

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Fig. 9. Microstructure of alloy Al--25% Si--5%Ni in state deformed from ingot (a), from powder obtained by grinding of shavings (b), and deformed from atomized powder (c), X500.

OBTAINING OF STANDARD ALUMINUM ALLOYS BY THE METHOD OF POWDER METALLURGY
(p 169 of source)

I.N. Fridlyander, G.D. Agarkov, N.S. Klyagina, R.A. Krivenko

The obtaining of deformed half-finished products from ingots of aluminum alloys in a number of cases is associated with significant difficulties. During casting of certain alloys considerable rejects are obtained due to cracks and heterogeneity of structure (intermetallic inclusions, light crystallites, slag and oxidized inclusions etc.) Furthermore, in the process of deformation there can appear a macrocrystalline or mixed structure, macrocrystalline rim and so forth.

The target of this work was the study of possibilities of obtaining of high quality deformed half-finished products from aluminum alloys by the method of powder metallurgy. We also had an interest in checking the influence of aluminum oxide on the properties of standard aluminum alloys.

The investigation was conducted on alloys B96 and D16. Initial powders of the alloys were prepared by two methods: mixing of powders of components of the alloy, and atomization of prepared alloy on a special spray installation.

The process of pressing of the powders consisted of three operations: cold briquetting, hot compacting and pressing of rods. During cold briquetting the powder was poured into tubes which were placed in container of press and there were subjected to compression under the necessary pressure. Briquettes were turned by 1-2 mm and then compacted (after preliminary preheating); the obtained billets were turned, heated and pressed into rods. During briquetting the billets were held under maximum pressure (90-100 kg/mm^2) for 1.0-1.5 min. Temperature of heating before compacting and pressing of rods constituted 400C for 1.5-2.0 hours.

For alloy B96 obtained by the method of powder metallurgy, we retained the conditions of heat treatment applied during the usual method of its manufacture.

Influence of homogenization was investigated on cermet alloy B96 prepared by mixing of powders of components (Fig 1). Homogenization somewhat worsens the strength of such alloy, while its elongation practically is not changed. In the usual cast alloy there exist the coarse excess inter-

metallic phases which embrittle the alloy, lowering its strength and plasticity. During transition of these phases in the process of homogenization into the solid solution, the plasticity and strength of the metal grows. In the cermet alloy coarse inclusions of excess phases are absent and the beneficial action of homogenization cannot appear. The diffusion processes in cermet metal go faster than in the usual metals, therefore in the process of homogenization there is observed an intense burning out of magnesium, on the average by 4-9%, and oxidation of zirconium by 20-25%. Consequently, homogenization, which is used during production of half-finished products from cast alloy B96, is not advisable for cermet procurement.

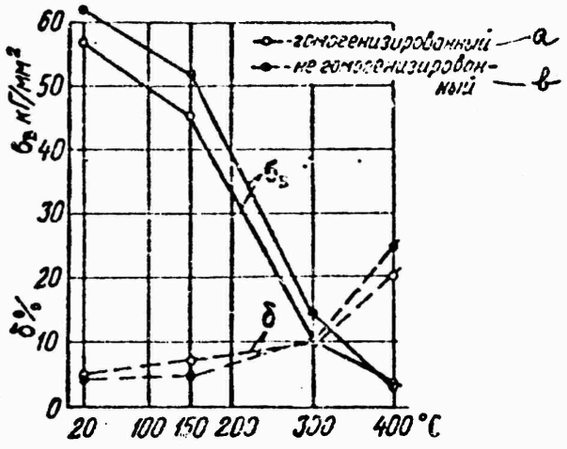

Fig 1. Influence of homogenization on mechanical properties of cermet alloy B96.

a - homogenized; b - not homogenized.

Influence of heat treatment (quenching and aging) on properties of cermet alloys B96 and D16 essentially depends on the content in them of aluminum oxide (Table 1). Quenching of alloy B96 was done from a temperature of 470C after holding for 40 min, alloy D16 -- from 500C after holding 40 min; aging of alloy B96 was at the conditions: heating ot 140C, holding 16 hours; alloy D16 was subjected to natural aging for twenty-four hours.

Heat treatment significantly increases the strength of alloys and lowers their elongation for small contents of aluminum oxide, but does not change the properties for high content of aluminum oxide. Apparently, in the first case the powder alloys conduct themselves just as the alloys

obtained by casting, here strengthening is attained by the formation of a supersaturated solid solution and its subsequent disintegration.

In case of a large quantity of aluminum oxide we have the mechanism of hardening peculiar to SAP; hardening by soluble phases is not observed. Alloy B96 with a small content of aluminum oxide has high strength after heat treatment, which may be still increased with the help of certain technological measures described below.

Table 1

Influence of Heat Treatment on Mechanical Properties of Alloys B96 and D16 (powders of alloys were prepared by method of mixing)

a Сплав	b Содержание Al_2O_3 %	c До термообработки		d После термообработки	
		$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %
B96	3—4	33,9	9,5	62,4	3,5
	10—11	42,6	3,8	43,3	3,6
Д16	3—4	16,4	11,0	26,4	9,7
	10—11	40,1	2,4	40,7	3,9

a - Alloy; b - Content Al_2O_3%; c - Before heat treatment; d - After heat treatment.

With a large content of Al_2O_3 the strength of alloy B96 and D16 is almost identical; it is not changed after heat treatment and is equal to the strength of SAP with the same content of aluminum oxide. Consequently, production of alloys with a high content of aluminum oxide is of no value; more expedient in this case is the use of the usual SAP. At high temperatures the alloy B96 with a small content of aluminum oxide conducts itself analogously to the usual alloy B96 -- its strength is noticeably lowered and elongation increases rapidly (Fig 2). Alloy B96 with 10-11% Al_2O_3 is weakened less intensely and the ultimate strengths of both alloys become equal at 400C. The elongation of alloy B96 with 10-11% Al_2O_3, in distinction from the usual SAP, grows; in this there appears the action of alloying additions of magnesium, zinc and others. Elongation of alloy D16 with both high and low content of aluminum oxide with increase of temperature is practically not

changed up to 400C (Fig 3). The ratesof lowering of strength are approximately identical. Probably, for the alloy D16 obtained by mixing of powders the content of 3-4% of aluminum oxide is sufficient to suppress the usual mechanism of dispersion hardening.

Significant improvement of properties of the alloy is attained with its preparation from atomized and not mixed powders (Table 2).

The content of aluminum oxide in alloys obtained from powders prepared by atomization consituted 3-5%, in alloys from mixed powder — 3-4%. During mixing of powders of the separate components of the alloy equalizing of composition occurs through the diffusion processes which take place in the solid body. These processes are slow and probably during our technology of the manufacture of cermet alloys are not fully completed, especially in the alloy D16. The alloy in the liquid state possesses high homogeneity, and in atomized powders the degree of homogeneity of structure is significantly higher than in mixed, which explains, obviously, the increase of strength of alloys (and especially alloy D16) when the atomized powders are used.

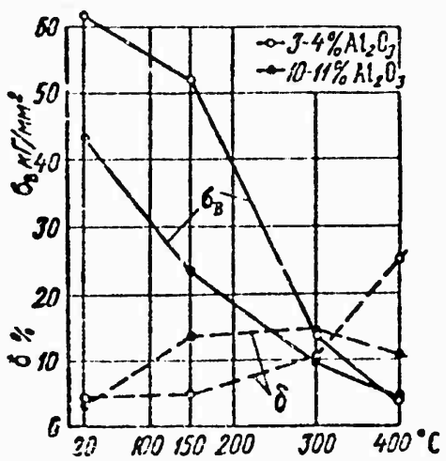

Fig 2. Change of mechanical properties of cermet alloy B96 depending upon content of aluminum oxide.

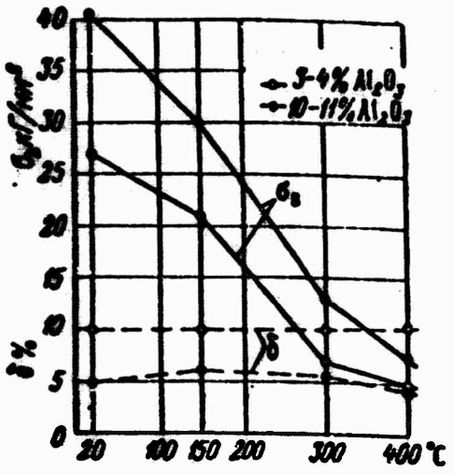

Fig 3. Change of mechanical properties of cermet alloy D16 depending upon content of aluminum oxide.

We also studied the influence of size of particles of the initial powder on mechanical properties of the alloys investigated.

Table 2

Influence of Method of Preparation of Initial Powders on Mechanical Properties of Rods of Diameter 13 mm From Alloys B96 and D16 (temperature of test 20C)

Марка сплава	b Смешение		c Распыление	
	$\sigma_в$ кГ/мм²	δ %	$\sigma_в$ кГ/мм²	δ %
B96	62,5	4,3	72,1	5,4
Д16	41,1	14,7	57,5	17,9

a - Brand of alloy; b - Mixing; c - Atomization

Crushing of particles of atomized powder (in investigated limits 5-100 mk) did not have any influence on the properties of alloy B96 (Fig 4), but improved the properties of alloy D16 — (Fig 5).

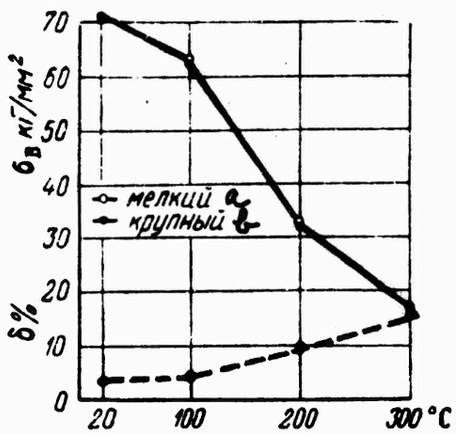

Fig 4. Influence of coarseness of particles of powder on mechanical properties of cermet alloy B96.

a - small; b - big

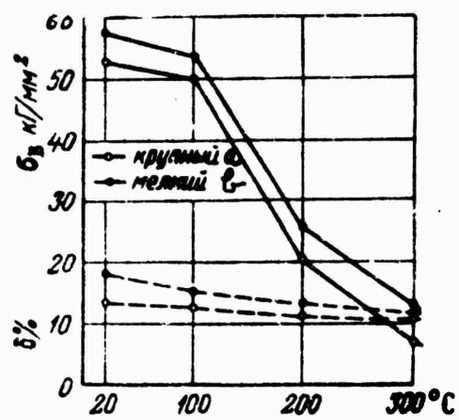

Fig 5. Influence of coarseness of particles of powder on mechanical properties of cermet alloy D16.

a - big; c - small

Influence of method of preparation of cermet alloy B96 on its structure is well illustrated in Fig 6.

In the structure of the alloy prepared by mixing of powders, one may see a large quantity of coarse segregated hardening phases (Fig 6,a). Structure of alloy prepared from atomized powders is highly dispersed and is

uniform (Fig 6,b). With a small quantity of aluminum oxide (3-4%) the structure of the alloy obtained by mixing of powders is characterized by big segregations of the hardening phases; with a high content of aluminum oxide (10-11%) there will be formed an extraordinarily fine-grained uniform microstructure with a great number of impregnations of aluminum oxide.

In this case the microstructure of alloy B96 is similar to the microstructure of SAP (Fig 7).

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Fig 6. Microstructure of cermet alloy B96 (3-4% Al_2O_3) prepared by mixing of powders (a) and from atomized powders (b), X500.

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Fig 7. Microstructure of cermet alloy B96 with high content (10-11%) of Al_2O_3, X500.

Conclusions

Using the new powder method of production of half-finished products from standard aluminum alloys we have established the following:

1. Alloys, initial powders of which are prepared by the method of atomization, possess significantly higher properties than alloys whose powders are obtained by the method of mixing of separate components.
2. Decrease of size of particles of powder leads to significant increase of mechanical properties of the alloy D16. The mechanical properties of alloy B96 were not affected by change of dimension of particles of initial powder (in investigated limits).
3. Powder alloys B96 and D16 with large content of aluminum oxide (more than 10%) act approximately like SAP, and alloys with small content of aluminum oxide -- act analogous to the usual cast alloys, but differ from them in a more uniform structure.

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