[illegible] entry

...631

JPRS: 27,715 (8) TT: 64-51880

(10) 7 December 1964

Vegner

4 (DIE STEELS AND TITANIUM ALLOYS FOR HOT STAMPING

- USSR -)

ok ok Ok.

Kuznechno - Shtamp. Proiz.

Check paper clipped to the

AMPTIAC

(5a) U. S. DEPARTMENT OF COMMERCE
CLEARINGHOUSE FOR FEDERAL
SCIENTIFIC AND TECHNICAL INFORMATION
(5b) JOINT PUBLICATIONS RESEARCH SERVICE
Building Tempo E
East Adams Drive, 4th and 6th Streets, S. W.
(6) Washington, D. C. 20443

Price: $1.00

JPRS: 27,715

DIE STEELS AND TITANIUM ALLOYS FOR HOT STAMPING

- USSR -

Following is a translation of two articles in the Russian-language periodical Kuznechno-Shtampovochnoye Proizvodstvo (Forging and Stamping Production), No 8, Moscow, August 1964. Complete bibliographic information accompanies each article.

CONTENTS

Start

ES

PROPERTIES AND APPLICATION OF MODERN DIE STEELS FOR HOT STAMPING

/Following is a translation of an article by Yu. A. Geller and Ye. S. Golubeva in the Russian-language periodical Kuznechno Shtampovochnoye Proizvodstvo (Forging and Stamping Production), No. 8, Moscow, August 1964, pages 12-15./ p. 9

Until recently, the standard steel 3Kh2V8 was used chiefly for drop forging. In many cases this steel does not ensure the necessary stability of the dies, in spite of high tungsten alloying (8%). In many cases this steel does not ensure the necessary stability of the dies. Its basic deficiencies are low erosion resistance and insufficient viscosity. As a result, many dies prematurely brake due to the formation of a grid cracks on the surface or from breakage and spalling.

Four new die steels are included at present in the State Standard 5950-63 "Alloy Tool Steel" (Table 1) /1/.

The number of die steels of different compositions has increased to an even greater extent abroad. 15 steels are specified in the List of the United States. In addition, the List of the Federal Republic of Germany, England, and other countries /3/ specify steels that are additionally alloyed with nickel.

The conditions of the use of dies are extremely varied depending upon the nature of the deformation and the properties of the deformed metal. Therefore an increase of the stability of the dies should be ensured first of all by the proper selection of steel, taking into consideration the conditions of use.

The basic properties of the steels indicated in the State Standard, as well as the properties of the most characteristic steels, including those specified in the Listings of other countries were studied for the possibility of such selection. (Table 1).

CHEMICAL COMPOSITION AND TEMPERATURE OF HARDENING OF DIE STEELS STUDIED

Table 1

(A) Сталь	(B) Содержание химических элементов в %							Температура закалки в °C (C)
	C	Cr	W	Mo	V	Ni	Si	
4Х5В2ФС*	0,37	4,8	1,9	—	0,9	—	1,0	1080
5Х4В4МФС**	0,49	4,7	4,5	0,5	0,5	—	0,5	1120
4Х6В7С**	0,44	6,2	7,0	—	0,5	—	0,9	1120
2Х4В8	0,23	4,5	8,7	—	0,5	—	—	1160
4Х2В8*	0,43	2,4	8,8	—	0,5	—	—	1120
4Х4В8Ф	0,43	4,6	9,2	—	1,1	—	—	1160
4Х6В8Ф	0,45	6,7	8,6	—	0,9	—	—	1160
H-24 (5Х4В12Ф)***	0,54	4,5	12,3	—	1,1	—	—	1220
H-26 (5Х4В16Ф)***	0,53	4,8	16,7	—	1,2	—	—	1240
H-13 (4Х5МФС)***	0,34	4,9	—	1,1	0,9	—	1,1	1040
3Х4В2МФ	0,29	4,3	2,0	0,9	0,8	—	—	1040
4Х4В2МФ	0,32	4,3	2,0	0,9	0,8	—	—	1080
4Х4В2М2Ф	0,37	4,2	2,1	2,1	0,8	—	—	1080
4Х3В5М2Ф	0,42	3,2	5,1	2,2	0,8	—	—	1080
4Х3В5М3Ф	0,42	3,2	5,1	2,7	1,0	—	—	1120
4Х4В4М2ФН	0,43	4,6	4,7	2,2	0,9	1,2	—	1120
4Х4В8ФН	0,45	4,6	9,4	—	1,1	1,2	—	1160
4Х4В12ФН	0,45	4,7	13,4	—	1,2	1.2	—	1220

---

* Стали по ГОСТу 5950-63.
** Стали, поставляемые по ТУ.
*** Стали по марочнику США.

A -- Steel, B -- Content of Chemical Elements in %
C -- Temperature of Hardening in °C.

*Steel according to State Standard 5950-63.
**Steels supplied according to technical requirements.
***Steels according to the List of the United States.

The hardness of all steels after annealing was within the limits of NV 207-269. Thus, a change of content of the alloying elements, and consequently the composition of the steels within comparatively wide limits has little effect upon hardness and workability by cutting.

The structure of all steels after annealing is analogous to sorbitelike perlite and carbides. However, in the case of a tungsten content of more than 2--4%, the quantity and dimensions of carbides are increased and conditions of their distribution deteriorate, especially if the chromium content in the steel is simultaneously increased (Table 2). Therefore, the steels 5kh4V4MFS and 4kh6V7W possess great carbide heterogeneity (point 4--5).

SHOCK RESISTANCE (a_k), THERMAL STABILITY (T) AND CARBIDE HETEROGENEITY OF DIE STEELS

Table 2

(A) Сталь	Зерно (B)						(C)
	№ 12		№ 10		№ 8		Карбидная неоднородность
	a_k в кгм/см²	T °C	a_k в кгм/см²	T °C	a_k в кгм/см²	T °C	
4X5B2ΦC	—	—	$\boxed{4,2}$	$\boxed{600}$	3,4	640	1
5X4CB4MΦ	2,1	640	$\boxed{1,8}$	$\boxed{650}$	1,2	650	4—5
4X6B7C	—	—	$\boxed{2,1}$	$\boxed{600}$	1,6	645	4
4X2B8	3,2	580	$\boxed{2,4}$	$\boxed{650}$	2,1	660	1
5X4B12Φ	$\boxed{0,7}$	$\boxed{670}$	—	—	—	—	2—3
4X5CMΦ	$\boxed{5,4}$	$\boxed{600}$	—	—	—	—	1
3X4B2MΦ	—	—	$\boxed{5,0}$	$\boxed{600}$	4,6	640	1
4X4B2M2Φ	3,5	600	$\boxed{3,5}$	$\boxed{650}$	2,2	670	1
4X4B4M2ΦH	3,3	670	$\boxed{3,3}$	$\boxed{670}$	2,2	670	1
4X4B8ΦH	1,5	670	$\boxed{1,2}$	$\boxed{670}$	—	—	2
4X4B12ΦH	0,9	670	$\boxed{0,9}$	$\boxed{670}$	0,1	670	2—3

X = Kh
Φ = F
C = S
B = V
H = N

Note 1. Thermal stability is shown by temperature after heating up to which (1 hr) steel retains HRC 45.

2. Values of shock resistance are given for HRC 50.

3. Values of shock resistance and thermal stability, corresponding to optimum temperatures of hardening given in Table 1, are shown in parentheses.

Key: A -- Steel; B -- Grain; C -- Carbide Heterogeneity

Carbide heterogeneity decreases in steels in which part of the tungsten is replaced by molybdenum (steels 4Kh4V2M2F and 4Kh4V4M24N point 1).

Increase of carbide heterogeneity decreases durability and especially shock resistance. This deficiency of steels with an increase of tungsten and chromium appears to a greater extent in dies of large sections inasmuch as carbide heterogeneity increases with an increase of rolling section.

Tests showed that the mechanical properties of die steels strongly depend on the effective grain size during heating in the hardening process. An increase of the grain to above size No 10 achieved by an unnecessary increase of hardening temperature of the dies greatly lowers toughness, reduces the durability to some extent and, at the same time, insignificantly improves thermal stability of the majority of steel (Table 2).

The temperature of hardening which ensures preservation of the small grain and the best mechanical properties is shown in table 1.

The hardness of steels after hardening attains RC 50--60; it increases with an increase of carbon content. The hardness of 4Kh2V8 steel (0.43% C) amounts to RC 55 and is approximately 5-10 units greater than the hardness of 2Kh4V8 steel (0.23%).

Dies with a hardness of RC 45-50 are used in industry, therefore the steels studied were produced in the same hardness.

The hardenability of steel was determined during cooling in air according to method (4), which permits the distribution of hardness in a sheet 60 and 100 MM. thick or in cylindrical sample with a diameter of 120 and 200 MM to be simulated. In this case, the obtained values characterize the hardenability of heavy-gage dies.

The greatest hardenability is possessed by steel with an increased content of chromium (4Kh6V7S). The hardness of hardened plate 100 MM. thick made of 4Kh2V8 steel constitutes RC 40 and of steel 4Kh6V7S --- RC 52 (Table 3).

There is an additional increase of hardenability if the carbon content increases simultaneously with the chromium content in steel.

The hardness of steel with a 0.49% C content (5Kh4V4MFS) in 100 MM. plate attains RC 59, and the hardness of 4Kh4V4M2FN steel which contains 0.43% C is significantly less (RC 48).

Molybdenum also increases hardenability if it replaces tungsten. The hardness of plate 100 MM. thick made of 4Kh4V4M2FN steel increase to HR 48.

Steels containing an increased amount of chromium with slight alloying with tungsten (2%) or Molybdenum (1%), have low thermal stability; this is true of 4Kh5V2FS, 4Kh5MFS, 4Kh6V7S steels (see Table 2).

Steels with reduced carbon content (2Kh4V8, 3Kh4V2MF) also have low thermal stability, that is, up to 600°C. The thermal stability of other steels is within the limits of 650--670 C.

An increase of the content of vanadium from 0.5% accepted standard steel (4Kh2V8 steel) to 1.1% (4Kh4V8F steel) noticeably increases thermal stability from 650 to 670°C).

In the case of a chromium content of more than 2--3%, the thermal stability of steels with 2--8% W deteriates. Thus, with an increase of the chromium content from 2% (4Kh2V8) to 6% (4Kh6V7S) thermal stability drops to 50°.

More than other elements, tungsten improves thermal stability. Therefore this property becomes very effective when its content increases up to 8%. Thus, steel with 2% V (4Fh4V2 MF) has a thermal stability to 640°C, whereas, the thermal stability of steel 8% V(Steel 4kh4V8F) goes up to 670°C. A further increase of the tungsten content to 12% (4Kh4V12FN) and even to 16% (5Kh4V16F), accepted in the steel of certain American brands, improves thermal stability to a lesser extent (from 670 to 680°C).

Replacement of part of the tungsten by molybdenum (in a 2:1 ratio) does not change thermal stability. 4Kh4V4M2FN steel has the same thermal stability as 4Kh4V8FN steel.

Tests showed that steels alloyed by an increased quantity of tungsten (4Kh4V2Fn, 5Kh4V2F, 5Kh4V16F), are destroyed in a brittle fashion at 20° even after tempering to a hardness of RC45.

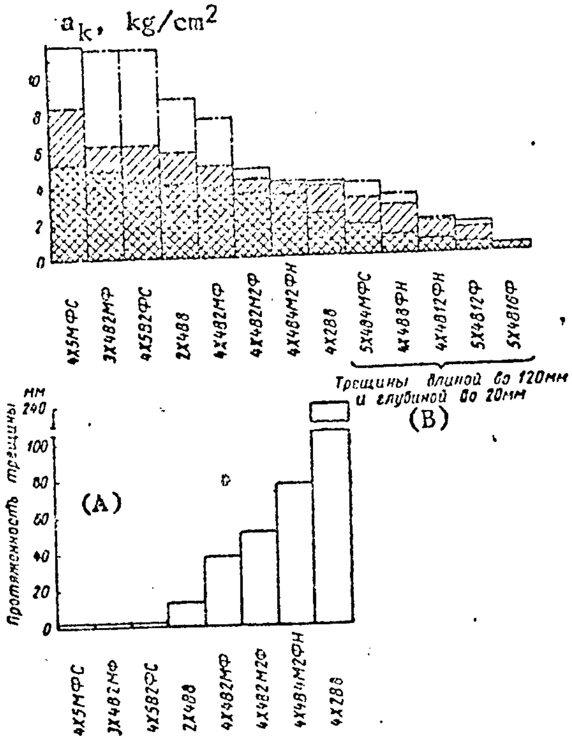
Inasmuch as dies operate during heating, data concerning mechanical properties at 550--650°C are of the greatest interest. With an increase of test temperature to 600--700°C brittle fracture in these steels was not observed. However, with an increase of the tungsten content from 8 to 120% shock resistance is sharply lowered (see figure). The shock resistance of steel with 1.2% W (4Kh4V12FN) does not exceed 0.g kg/cm^2 at 20°C and 1.8 kg/cm^2 at 650°C and for steel with 8% V (4Kh4V8FN) a_h=1.2 KGM/CM^2 at 20° and a_h=3.2 kg/cm^2 at 650°.

HARDNESS OF DIE STEELS DURING HARDENING (GRAIN SIZE NO 10) WITH COOLING IN AIR

Table 3

(A) Сталь	(B) Твердость *RC* плиты толщиной в *мм*		(A) Сталь	(B) Твердость *RC* плиты толщиной в *мм*	
	100	60		100	60
4X5B2ΦC	—	40	3X4B2MΦ	40	42
5X4B4MΦC	59	—	4X4B2MΦ	—	44
4X6B7C	52	58	4X4B4M2ΦH	48	49
4X2B8	20	40	4X4B8ΦH	46	46
4X5MΦC	47	47			

Key: A -- Steel; B -- Hardness RC of Plate Thickness in mm



Key: A -- Penetration of Crack; B -- Cracks 120 mm in length and up to 20 mm in depth.

Shock resistance and erosion resistance of die steels, hardening from optimum temperatures, tempering to hardness of RC 50. Extent of cracks is given after 50 cycles of tests.

-- a_h At 20°C. - - - a_h At 600 C. -.-.-.-. a_h At 650 C

Thus, the tungsten content in die steels is more than 6--8%; although it ensures an increase of thermal stability, it is, perhaps, inexpedient, if the die operate with dynamic loads and an intense cycle of cooling. This is also caused by the above-indicated increase of carbide heterogeneity of steels with a content of 12--16% V.

An increase of shock resistance is attained in the case of a content of more than 2%. Steel with 5% chromium and without tungsten (4Kh56MF) has a shock resistance of 5.4 kg/cm^2 at 20°C and 8.5 kg/cm^2 at 600°C. Chromium also improves the toughness of steel with a higher content of tungsten. In steels possessing an 8%W, shock resistance increases from 4.0 kg/cm^2 in the case of a 2% Cr content (4Kh2V8) to 6.5 -- 7.0 kg/cm^2 (4Kh6V7S steel) at 650°C. However, it is necessary to consider that steels with a high content of chromium have a great carbide liquation. Therefore, in larger sections they have an increased degree of carbide heterogeneity which lowers shock resistance as compared to the values, shown in the figure.

Alloying of die steels with chromium permits a high yield point to be obtained. However, such an increased yield point is only maintained at lower test temperatures (550--600°C). At these temperatures 4Kh5V2FS steel with chromium is not inferior to tungsten steels with respect to yield point, while at the same time exceeding them with respect to toughness (Table 4).

MECHANICAL PROPERTIES OF DIE STEEL DEPENDING ON TEMPERATURE OF TEST (HARDENING FROM OPTIMUM TEMPERATURES, TEMPERING TO HARDNESS RC 50)

Table 4

(A) Сталь	(B) Механические свойства при температуре испытания в °С								
	σ_b в кг/мм²			$\sigma_{0,2}$ в кг/мм²			ψ в %		
	20	600	650	20	600	650	20	600	650
4Х5В2ФС	170	120	99	144	108	90	45	46	46
4Х4В2МФ	172	128	101	152	118	97	42	46	46
5Х4В4МФС	184	105	76	160	99	72	22	51	55
4Х6В7С	178	104	75	159	97	70	36	54	66
4Х2В8	190	124	109	164	112	101	35	26	16
4Х4В8ФН	Хрупкое разрушение	130	114	Хрупкое разрушение	120	106	Хрупкое разрушение	10	10
4Х4В12ФН		124	111		114	104		10	10
4Х4В8Ф	—	130	114	—	122	106	—	16	16
4Х6В8Ф	—	106	82	—	100	77	—	38	51
3Х4В2МФ	170	118	98	153	109	—	42	51	57
4Х4В2М2Ф	175	138	116	153	128	108	36	33	24
4Х4В4М2ФН	181	131	116	159	120	106	29	24	17

Key: A -- Steel; B-- Mechanical properties at test temperature in °C.

Conversely, at higher temperatures (650°C) a more significant lowering of the durability properties of steels, containing 5% Cr (4Kh5V2FS) is observed in consequence of which it is inferior to tungsten steels with respect to the yield point.

In addition, a marked increase of relative contraction in steels with an increased chromium content is observed as a result of which, dies from these steels do not retain as well the form and dimensions of the working surface under more severe service conditions.

At 650°C, the relative contraction of 4Kh5V2FS steel amounts to 46%, which steel containing less chromium, possesses a relative contraction of not more than 16%. (Table 4).

The effect of molybdenum must be evaluated in a different manner.

Like chromium, it increases shock resistance, But in contrast to chromium, molybdenum does not lower the yield point at higher temperatures (650°C). Shock resistance of 4Kh4V8FN steel at 650°C is equal to 3.0--3.2 kg/cm^2, and the shock resistance of steels with 2% MO amounts to 4.0 kg/cm^2 (4Kh4V4M2FN) and 4.8--5.0 kg/cm^2 (4Kh4V2M2F).

Steels with molybdenum have smaller relative contraction than chromium steels. Thus the contraction of 4Kh5V2FS steels amounts to 46% at 650°C, while steels with 2% MO (4Kh4V4FMM2) is not more than 19%.

Erosion resistance, by which is meant resistance against the formation of cracks or a grid of cracks on the surface of dies due to alternating heating and cooling during use, is the most important characteristic, determining the stability of many dies.

Erosion resistance was determined[1] by the method of alternating heating and cooling of the surface layer of samples 20 mm in diameter and 60 mm in length and was characterized by the general extent of cracks appearing during repeated heating and cooling.[2]

The tests indicated, first of all, that the erosion resistance of die steels is not associated with a specific dependance upon thermal stability.

Steels with a high tungsten content (4Kh4V12FN, 5Kh4V12F and 5Kh4V16F) possess the lowest erosion resistance although they also possess higher thermal stability (see Table 2). In samples of steel, containing 2% W (4Kh4V2MF) with a hardness of RC 50, the extent of cracks alter 50 cycles amounted to 38 MM. and in samples of steel with 12% W (4Kh4V12FN), the extent of cracks increased to 120 MM after five cycles (See Figure). Furthermore, the depth of cracks in steels with 2% W as 0.1 MM. and in steels with 12% W attained 20 MM..

Steels containing molybdenum, significantly excel tungsten steels with respect to erosion resistance, although they possess an almost identical thermal stability. The thermal stability of steels with 8% W (4Kh4V8FN) and 4% W and 2% Mo (4Kh4V4M2FN) is identical (670°C), when the extent of cracks (at a hardness of RC 50 and 50 test cycles) was 120 Mm at a depth 20 MM for 4Kh4V8FN steel and 77 MM for steel with 4% W and 2% MO (4Kh4V4M2FN).

---

[1] Heating and cooling of samples were carried out on a LZ-67 high-frequency generator. The device for the tests, connected to the LZ-67 generator was mounted in the All Union Scientific Research Institute under the direction of V.V. Kukolev and M.M. Vasil'yev.

[2] The extent of the cracks was determined by summation of the lengths of the cracks through every 15--25 cycles of heating and cooling.

The erosion resistance is highest for the steels with 5% chromium, not containing tungsten (4Kh5MFS), steels with 2% W (4Kh5V2FS) and steels, possessing lowered carbon content of (2Kh4V8 and 3Kh4V2MF).

Essential data for the characteristics of die steels gives a comparison of their erosion resistance and mechanical properties. Steels revealing the highest erosion resistance also had the highest shock resistance at 20°C, as well as at increased temperatures.

The erosion resistance was highest for steels with 5% CR. and 1% MO (4Kh5MFS) and with 0.29% C, 4% CR, 2% W, 1% MO (2Kh4V2MF). Their shock resistance amounted to 5.4 KGM/CM^2 at 20°C and 11.8 kg/cm^2 at 650°C for steels 4Kh56MF steel and 5.0 KGM/CM^2 at 20°C and 11.5 kg/cm^2 at 650°C for 3Kh4V2MF. These values are higher than all the values obtained for the 3Kh2V8 standard steels.

4Kh4V12FN (0.4%C, 12%W, 1% Ni), 5Kh4V12F (0.5% C, 12%W) and 4Kh4V8FM (8%W, 1% Ni) steels possessed the lowest erosion resistance. Their shock resistance did not exceed 0.9, 0.7 and 1.2 kg/cm^2 respectively at 20°C and 1.8, 1.7 and 3.2 kg/cm^2 at 650°C. respectively.

Thus, the basic distinction of die steels of various chemical composition consists in their erosion resistance, thermal stability, and mechanical properties (especially shock resistance and plastic characteristics). In the selection of the composition of steel it is necessary to bear in mind that it is impossible to ensure the presence of each of these properties in one steel.

Proceeding from [the] data, three groups of die steels have to be distinguished.

[Yield strength]

The first group consists of those with increased shock resistance and erosion resistance, low thermal stability and sufficiently high resistance to plastic deformation ($\sigma_{0.2}$ = 120 kg/mm^2), but only during heating at temperatures not more than 500-550°C. 4Kh5V2FS steel, (State Standard 5950--63) which closely resembles 4KhSMF and 3Kh4V2MF steels (H-13 according to the United States nomenclature) belongs to this group of steels. H-13 (4Kh56MF) steel has a somewhat higher toughness and erosion resistance with somewhat increased resistance of the plastic flow at increased temperatures.

These steels are the most useful for dies of deformation of aluminum alloys during an intense rate of stamping. It is possible to subject them to fast cooling in service.

[Yield strength]

The second group consists of steels with high thermal stability, and consequently, with a significant resistance of plastic flow at 650°C ($\sigma_{0.2}$= 100 km/mm^2). However these steels possess lowered toughness and erosion resistance. 5Kh4V12F, 5Kh4V16F and 4Kh2V8 steels belong to this group. → p. 10

It is expedient to further improve the properties of the 4Kh2V8 standard steel, especially its yield point, by increasing its vanadium content to 1.1%.

Steels of the second group are recommended for dies used in the pressing of steels and copper alloys under the condition that, a) deformation is carried out at minimum dynamic loads and b) abrupt cooling of dies while in operation is avoided.

yield strength

Steels of the third group occupy an intermediate position. They combine high thermal stability (670°C) increased resistance of plastic flow to 650°C ($\sigma_{0.2}$ = 110 kg/mm^2). Satisfactory toughness (a_h = 3.3. - 3.5 kg/cm^2 at 20°C) and erosion resistance. This group includes steels ES in which part of the tungsten is replaced by molybdenum, namely 4Kh4V2MF and 4Kh4V2M2F ES steels. It is expedient to test them widely in industry. These steels are the most useful for work at moderate dynamic loads and a moderate stamping rate.

It is very significant that in contrast to steels with a high chromium content they possess a significantly smaller carbide heterogeneity. Therefore, these steels are more useful under identical conditions, than 4Kh2V8 steel for dies of large dimensions in which carbide heterogeneity may be significant.

→ p.11

BIBLIOGRAPHY

1. A.P. Gulyayev, S.L. Rustem, G.N. Orekhov and G.P. Alekseyeva "Metal Science and Treatment of Metals". 1958, No. 7.
2. Materials in Design Engineering 1960, Vol. 52, No. 7.
3. Collection of Soviet and Foreign Norms on Quality and High-Quality Steel. Promsyr'yeimport, 1962.
4. A.Ye. Pavaras and Yu. A. Geller. Scientific and Technical Information Collection. TsINTIAM, 1953, Issue 7.

1286
CSO: 1879-N/PE

Ti

POWER INDICES IN THE INDUCTION HEATING OF TITANIUM ALLOYS FOR HOT STAMPING

/Following is a translation of an article by I.I. Bezruchko and M.S. Ayzikovich in the Russian-language periodical Kuznechno Shtampovochnoye Proizvodstyo (Forging and Stamping Production), No 8, Moscow, August 1964, pp 37-38.7

Modern and progressive methods of drop forging frequently require the application of induction heating, ensuring, along with its other advantages, the high speed of the process and a small waste of metal. Induction heating of such metals as titanium and its alloys which possess a great inclination to gas saturation at high temperatures, provides an opportunity to increase the quality of production and labor productivity to a considerable extent. However, up to the present time, problems of the power indices of industrial heating of titanium alloys, selection of current frequency and other important problems, the solution of which could promote the wider introduction of this method into production, have almost not been highlighted in the periodic literature.

As it is known, such basic power indices of induction heating as inductor efficiency (inductor--billet system), specific consumption of electric power and specific power, depend upon the correctness of the selection of the current frequency.

The present article formulates the problem on the basis of experiments in the induction heating of the titanium alloy IMP2 which were conducted to determine the criteria current frequency selection, to establish the dependence of the change of inductor efficiency, specific electric power consumption and specific power on the diameter of the billet and the magnitude of the temperature drops on the basis of its section. p 15

Billets 70, 60, 40 and 25 mm in diameter were subjected to induction heating by a current, possessing a frequency of 2500 cycles per second. Billets 70, 60, and 40 mm in diameter were heated in an inductor with an internal spiral diameter of 100 mm; while billets

25 mm in diameter were heated in an inductor with an internal spiral diameter of 65 mm. Heating was supplied up to the temperature of the upper limit of the IMP2 alloy, equal to 9800. Temperature change at various points of the billet sections, consumption and temperature of water cooling the inductor, power produced by generator, and other electrical parameters were fixed during the heating process.

It has been established in practice that the following inequality should be observed for a sufficiently high total (electrical and thermal) inductor efficiency n_u = 0.55-0.7 during heating of carbon steels

$$(10 \div 6) > \frac{d}{\Delta h} > (3 \div 3{,}5),$$

where d -diamter of billet in mm;

h -hot depth of penetration of current of a given frequency in material of billet, determined by the formula

$$\Delta_h \approx 5030 \sqrt{\frac{\rho}{\mu f}} \ cм;$$

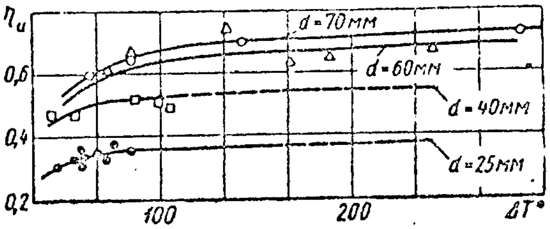
ρ -- mean value of specific resistance within temperature 200-1200°C.

f -- current frequency in cps.

μ -- magnetic permeability (in this case μ =1)

Obviously, the limits of the ratio d/Δ_h must be found for a sufficiently high efficiency of the inductor--billet system. For this purpose, a graph of the relationship of the complete inductor efficiency to the billet diameter and temperature drops along its cross section during heating of the IMP2 titanium alloy is constructed on the basis of experimental data. (Fig. 1).

Figure 1



In addition to ratio d/Δ_h, the ratio dc/d of the diameters of the inductor and billet exerts a great influence upon inductor efficiency during induction heating, and the greater this ratio is at a given frequency, the lower is the efficiency of the system.

It is clear from Fig. 1 that the lowest inductor efficiency occurrs during heating of billets 25 mm in diameter and the highest inductor efficiency occurrs during the heating of billets 70 mm in diameter.

During the heating of the IMP2 titanium alloy, possessing =1.57.10 o-hm-cm and $\mu = 1$ in the temperature interval 20--980°, the "hot depth" of penetration of a current possessing a frequency of 2500 cps, amounts to 12.5 mm.

Thus, if it is considered that the magnitudes 0.55--0.7, corresponding in Fig. 1 to the heating of billets 40--70 mm in diameter, are acceptable in practice as the limits of total inductor efficiency, then the basic inequality for the selection of current frequency will be obtained from ratio 40/12.6 and 70/12.6, i.e.,

$$6 > \frac{d}{h} > 3. \qquad (2)$$

Comparing inequalities (1) and (2), it is possible to say that during heating of non-magnetic materials with high specific electrical resistance, which titanium alloys are, the criteria for frequency selection almost coincide with analogous criteria during heating of carbon steels.

Table 1 gives the range of dimensions of titanium alloy billets for heating at standard frequencies, taking into account inequality (2)

Table 1.

Частота тока в гц (A)	Диаметр заготовки в мм (B)
50	270—550
1000	60—120
2500*	40—75
8000	20—40

*Note. Data of table may be valid for almost all brands of titanium alloys since the magnitudes of average specific electrical resistance fluctuate relatively little for the majority of alloys (within the limits 1.4-1.7) 10^{-4} ohm · cm).

Key: A -- current frequency in cps; B -- Diameter of billet, mm.

The curves shown in Fig. 1 permit the determination of the optimum limits of di/d. In the case of a temperature drop of more than 100° along the billet section, inductor efficiency increases very slowly and, for all practical purposes, can be considered to acquire a limiting value in the case of such drops. Using this as basis, it is possible to compare in table 2 the values of the limiting inductor efficiency in the case of different ratios di/d of the inductor and billet diameters

Table 2.

(A) Диаметр индуктора $d_и$ в мм	(B) Диаметр заготовки d в мм	(C) Перепад температур по сечению заготовки ΔT в °C	(D) Отношение диаметров $\frac{d_и}{d}$	(E) Предельный* к. п. д. индуктора $\eta_{и.пр}$
100	70	100	1,43	0,69
100	60	100	1,67	0,65
100	40	100	2,5	0,53

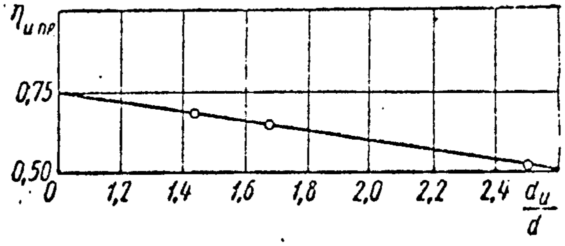
*Примечание. В таблицу не входят значения $\eta_{и.пр}$ при нагреве заготовки диаметром 25 мм, так как соотношение ее диаметра к $\Delta_{гор}$ не удовлетворяет неравенству (2).

A -- Diameter of inductor in mm. B -- Diameter of billet in mm. C -- Temperature drops along billet section in $^{\circ}$C. , D -- ratio of diameters, E -- Limiting efficiency of inductor.

*Note. The values during heating of billet 25 mm. in diameter are not included in the table, since the ratio of its diameter to Δ h does not satisfy inequality (2).

Fig. 2 illustrates the graphic relationship of the limiting inductor efficiency to the ratio of the inductor and billet diameters. The optimum values di/d are determined, on one hand, from considerations of sufficiently high efficiency and, on the other hand, from design considerations. Assuming that the limiting inductor efficiency must not be lower than 0.5--0.53, it follows from Fig. 2 that the ratio will be greater than 2.5. Being guided by requirements for the presence of an adequate thickness of electrical and thermal insulation, in the inductor, the ratio di/d is limited to the value 1.4.

Figure 2.



Thus, the optimum ratio di/d will be determined by the inequality

$$1.4 < \frac{d_n}{d} < 2.5. \qquad (3)$$

In the case of observing inequality (3), the limiting inductor efficiency acquires the values 0.5-0.7 which, for all practical purposes, is completely normal.

Results of experimental determination of specific expenditures of useful energy and useful specific power during induction heating of billets possessing different diameters, at various temperatures drops on their section are presented in Fig. 3.

It may be concluded from Fig. 3 that, during heating of titanium alloy billets 25 to 70 mm (diameter) with different temperature drops along their sections, useful specific power is found to be within the limits of 0.007 -- 0.07 kilowatt/cm^2, and specific expenditure of useful electric energy fluctuates, on the average, from 0.160 to 0.130 kw · hr/kg. The average specific expenditure of electric energy by the industrial network with proper wiring of the high frequency network and full transformer loads amounts to 0.3 to 0.4 kw · hr/kg.

Thus, it may be concluded from the data presented that a smaller specific expenditure of electric energy is ensured during the heating of titanium alloys than in the heating of carbon steels and, consequently, smaller installed capacities are required. The average efficiency of the entire billet -- 50 cps industrial network system amounts to 0.45 -- 0.47 in the heating of titanium alloys.

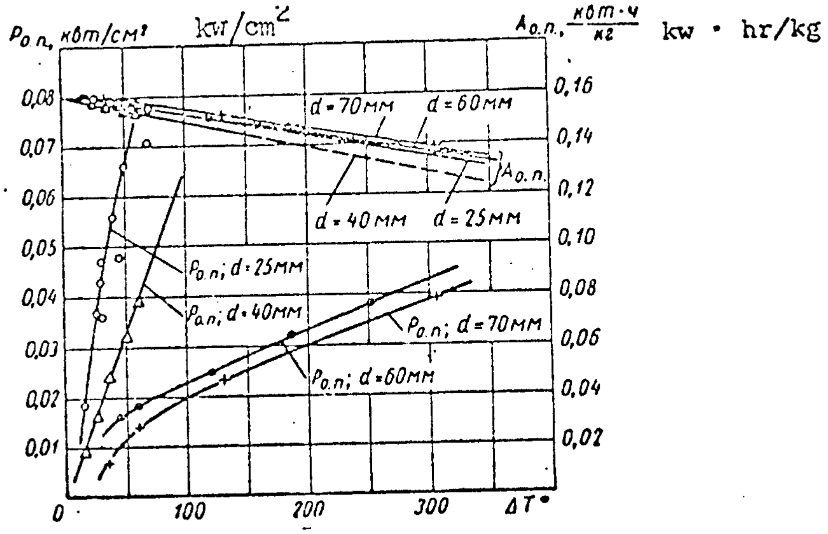


Figure 3.

1286
CSO: 1879-N/PE

- END -