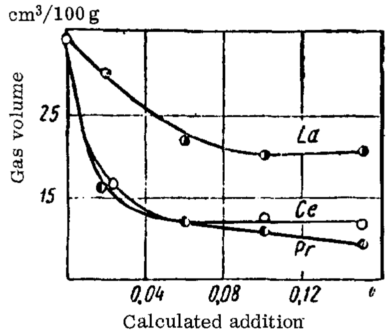

Fig. 5. The gas saturation of the alloy depending on the magnitude of the lanthanum, cerium, or praseodymium addition.

It is also possible that a certain proportion of the rare-earth metals, while dissolving in the boundary crystallite zones, strengthen the grain boundaries and inhibit the diffusion processes.

CONCLUSIONS

1. Separate additions of cerium, lanthanum, neodymium, and praseodymium to alloy EI437 produce a substantial increase in the strength and plasticity of metal in long- and short-time tensile tests at 700°, and also reduce the total contents of gases in the metal.

2. The maximum effect of rare-earth metals is observable when the residual amount of the injected addition does not exceed 0.02%.

3. By the effectiveness of their influence on the rupture strength of alloy EI437 the investigated elements range in the order corresponding to their progressively increasing melting points.

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EFFECT OF Ti, W, Mo, AND Si ADDITIONS ON THE PROPERTIES OF CHROMIUM STEEL

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In studying the corrosion resistence of the material for cold-rolled heat-exchange piping (19 x 1.5 - 38 x 3.5 mm) an investigation was carried out (with the participation of Z. A. Abramova) of the properties of four experimental chromium steel melts. (Table 1).

The investigation was conducted with 40-mm diameter rods produced by forging of 35-kg ingots. The rods were then cooled in air to assure a hardness value of HB 340-390.

The critical points for the steels (see Table 1) were determined by dilatometric method during heating and cooling at a rate of 4 deg/min, and by the method of test hardening (Ac_1 and Ac_3). The critical point values defined by both methods showed a good agreement.

Dilatometric investigation revealed that transformation occurs in the intermediate range (285-315°) if steels Kh8 and Kh8SM are being cooled slowly. Introduction of titanium, which combines with carbon, intensifies pearlite transformation. As a result of this point Ar_3 (for steels Kh8T and Kh8VT) rises and the critical cooling range becomes narrower.

Heat-exchange pipes are being used at relatively small stresses and moderately elevated temperatures (up to 350-450°). The main requirement to be met by the pipes (in addition to high resistance to corrosion) is that they should respond well to rolling. Therefore, the pipe material in the finished state must exhibit high plasticity and impact toughness values. (For example, according to the Standard Specification No. 2968-51 for ferrous metals steel Kh5M heat-exchange pipes must satisfy the following standards on delivery: $\sigma_B \geq 40$ kg/mm², $\sigma_S \geq 17$ kg/mm², $\sigma_5 \geq 24\%$, $\psi \geq 50\%$, $\alpha_k \geq 10$ kg. -m/cm², HB $\leq$ 170).

TABLE 1

CHEMICAL COMPOSITIONS AND THE CRITICAL POINTS OF THE INVESTIGATED MELTS

Grade of Steel	Contents of elements in %							Critical points in °C.			
	C	Si	Mn	Cr	Mo	W	Ti	Ac_1	Ac_3	Ar_3	Ar_1
Kh8	0,11–0,13	0,33–0,42	0,52–0,55	6,9–7,9	—	—	—	810	900	730	490 (310)
Kh8T	0,13–0,15	0,38–0,52	0,51–0,55	6,9–7,9	—	—	0,3–0,32	825	920	825	730
Kh8VT	0,09–0,13	0,47–0,59	0,38–0,56	7,1 7,8	—	0,26–0,4	0,3–0,37	835	925	850	750
Kh8SM	0,09–0,14	0,83–0,86	0,5–0,56	7,5 8	0,22–0,27	—	—	830	940	700	425 (290)

* S + P < 0.05.

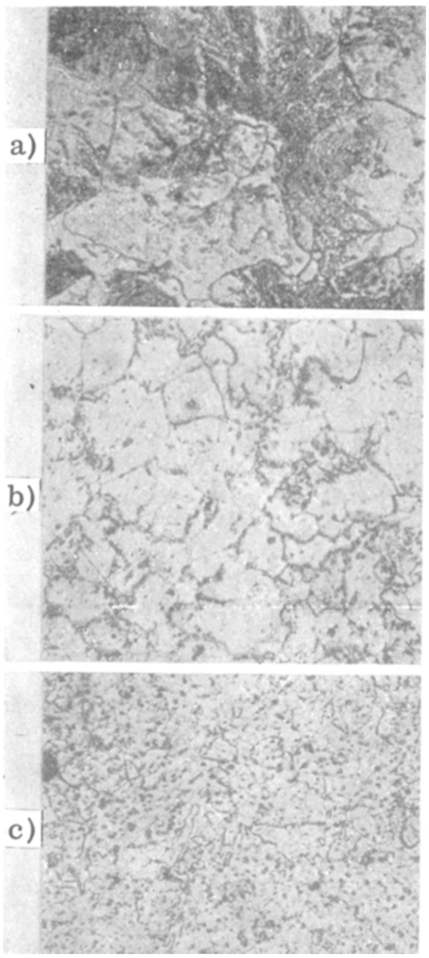

Fig. Microstructure of the investigated steels heat-treated under varying conditions (etched in 5-% HNO_3 solution in alcohol).
a - Kh8, 880° anneal, b - Kh8VT, 880° anneal, c - Kh8, 800° anneal. x 270.

Incomplete anneal at 880° and full annealing at 950-1000° with slow furnace cooling (50 deg/h) failed to assure the required mechanical properties to steels Kh8 and Kh8SM. Along with satisfactory hardness and ductility (HB $\leqslant$ 150, $\delta_6 \geqslant 24\%$) the steels exhibited low impact toughness characteristics: 1.5 and 3.4 kg.-m/cm^2 after incomplete, and not higher than 6 kg.-m/cm^2 after full annealing, respectively. Inadequate impact toughness values were also registered as a result of annealing at 880° of steels Kh8T (5.5 kg-m/cm^2) and Kh8VT (7 kg.-m/cm^2).

The microstructure of steels Kh8 and Kh8SM annealed under specified conditions (Fig. a) consisted in the main of ferrite and coarse lamellar pearlite. This coarse-grain structure with lamellar pearlite is, evidently, responsible for the steel's low impact toughness.

Tests of steels Kh8T and Kh8VT annealed at 950 and 1000° produced different results. With the hardness values remaining the same as for steels Kh8 and Kh8SM, the impact toughness turned out to be noticeably higher: 8 and 10.9 kg.-m/cm^2 (950°), and 13 and 12.2 kg.-m/cm^2 (1000°), respectively.

The microstructure of steels Kh8T and Kh8VT (Fig. b) after annealing at 880, 950, and 1000° revealed ferrite and a large quantity of punctate carbide inclusions segregated mainly along the grain boundaries.

This difference is, apparently, attributable to the presence in steels Kh8T and Kh8VT of titanium which impedes grain growth and intensifies pearlitic transformation during slow cooling.

The above data indicate that it is hard to impart a high impact toughness to 8-% Cr steel (with or without titanium) by means of (complete or incomplete) annealing. The problem may, apparently, be solved by holding the metal at a temperature slighty lower than point Ac_1. In this case the conditions are most favorable for the formation of a fine ferritic structure with minimum carbide precipitation along the grain boundaries. This assumption was borne out by tests. High temper at 800° followed by slow cooling caused the impact toughness to rise sharply in the investigated steels. The hardness value in this case was low, but ductility was found to be very high (Table 2).

The microstructure of steels annealed at 800° (Fig. c) consists of fine-grained ferrite and particles of carbides located both within the grains and, partially, along their boundaries.

TABLE 2

MECHANICAL PROPERTIES OF THE INVESTIGATED STEELS AFTER 800° ANNEAL (COOLING WITH FURNACE)

Grade of steel	σ_b in kg/mm²	σ_s in kg/mm²	δ_σ in %	ψ in %	HB	α_k in kg. - m/cm² at °C		
						20	−20	−40
Kh8	51,9	26,3	27,9	80,9	141	25,1	17,1	9,4
Kh8T	56,1	30	28,2	79	150	26,5	20,1	5,1
Kh8VT	53,5	29,5	28,7	76,1	158	26,4	18,4	8
Kh8SM	57,2	31,5	27,8	75	162	17,7	14,9	8,3

TABLE 3

IMPACT TOUGHNESS OF THE INVESTIGATED STEELS AFTER 760° TEMPER WITH SUBSEQUENT COOLING IN THE FURNACE OR IN WATER

Grade of steel	Cooling after tempering	k in kg. - m/cm² at temperatures in °C					The lowest critical-range temperature for brittleness
		20	−40	−50	−60	−90	
Kh8	with furnace	21,3 22,5 24,1 26,2	— —	—	7,4 8,5 9 9,5	0,5 0,5 2 3,6	−90°
	in water	26,2 26,7 26,7 28,6	—	—	8,3 9,2 16,1 16,1	2,9 3,1 3,3 3,8	below −90°
Kh8T	with furnace	11,3 13,6 14,2 16,3	4,5 8,4 12,6 13,2	3,7 7,6 10,4 16,6	0,5 0,5 0,7 0,8	—	between −50 and −60°
	in water	20,7 23 23,8 24,3	8,5 12,7 20,7 26,4	6,8 8,3 22,2 24,5	3,4 6,6 6,9 7,4	—	below −60°
Kh8VT	with furnace	13,9 15 15,5 16,1	6,6 7,2 7,4 9,8	—	0,7 0,8 0,8 0,8	—	between −40 and −60°
	in water	20,7 26,7 28 29,9	14,3 15 15,7 17,2	—	0,9 1,7 2,5 17,6	—	−60°
Kh8SM	with furnace	10,7 12 12 13,9	—	—	1,2 4,9 5,4 5,6	0,8 0,8 0,9 1,5	−60°
	in water	16,6 16,6 17,5 18,3	—	—	7,2 7,2 7,4 8,3	5,2 5,6 5,6 6,8	below −90°

Prolonged ageing at 300, 350, and 400° causes no embrittlement of the investigated materials. The strength characteristics of the steels also remain unchanged.

The tendency of steels to develop temper brittleness was investigated by comparing the results of impact tests for steels tempered at 760° with subsequent cooling in the furnace or in water.

The lowest critical-range temperature served as the indicator of the tendency towards temper embrittlement.

The available data (Table 3) show that all the investigated grades are susceptible to temper brittleness. This is in accord with the data of study [1] on the sensitivity of chromium steels to temper brittleness, but contradicts the statement made in paper [2] to the effect that steels alloyed solely by chromium manifest no tendency towards temper embrittlement.

In terms of their susceptibility to temper brittleness the tested steels may be classified as follows: Kh8VT, Kh8T, Kh8SM, Kh8. The higher tendency of steel Kh8SM to develop temper brittleness, as compared to steel Kh8, may possibly be explained by the fact [3] that the 0.23-% proportion of molybdenum contained in the melt was insufficient to neutralize the effect of 0.86% Si. However, in spite of the presence of 0.30% W, the sensitivity of steel Kh8VT to temper brittleness was considerably greater than that of steel Kh8.

Judging by the results of tests run in laboratory and industrial conditions [1], the rate of steels Kh8, Kh8T, and Kh8SM corrosion in sulfur-containing media, was assumed to be about the same and equal to 0.03 mm per year. This is 2-2.5 times lower than for 5-% chromium steel (12Kh5MA), samples of which we have investigated in parallel tests.

CONCLUSIONS

1. In consequence of high tempering, steels Kh8, Kh8T, Kh8VT, and Kh8SM may be imparted the mechanical properties required for the use of cold-rolled heat-exchange pipes delivered after proper heat treatment.

[1] In laboratory conditions the samples were held for 450 hours at room temperature and ambient atmospheric pressure in humid gas containing 95% N_2 and 5% H_2S. In industrial tests the samples were heated at 310° for a period of 2800 hours under 0.2 gauge-atmosphere pressure in the middle part of the AVT rectifying columm at the Novo-Ufimsk oil refinery.

2. The presence of titanium is noticeable reflected in the character of structural transformations occuring during slow cooling from temperatures above point Ac_1. The steels investigated, manifest a resistance to corrosion in sulfur-containing media two times greater than that of steel 12Kh5MA, and are in varying degrees susceptible to microstructural temper brittleness.

3. It is recommended that steels Kh8 and Kh8T be tested as materials for the manufacture of corrosion resistant heat-exchanger pipes for oil refineries and petroleum chemical works.

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VARIATION OF THE PROPERTIES OF STEELS LA1 AND EI257 AS A RESULT OF PROLONGED HEATING AT HIGH TEMPERATURES

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(The testing method was developed and work in 1951-52 completed by L. P. Nikitina).

The results of 10,000-30,000 hours-long tests of steels were published in paper [1]. Reported in the present article are the results obtained in further long-time tests lasting over periods of 40,000-55,000 hours.

The investigation was conducted with the following austenitic steels: LA-1 — used for the production of cast turbine parts, and steel EI-257 from which a high-pressure steam conduit and boiler superheaters were manufactured.

The creep tests were conducted at 580° with a stress corresponding to the conditional creep limit for creep rate v $\pm 1 \cdot 10^{-5}$% per hour. Stress-to-rupture tests were also carried out at 580° and a stress corresponding to the rupture strength value at which the time required to carry the material to failure amounts to 100,000 hours. The tests were carried out with the aid of IP-2 machines in ambient air, and with special devices for testing in superheated steam.

Cylindrical test-samples were treated simultaneously with the creep test samples in the same furnaces to ascertain the stability of certain properties of steel in the ageing process. The ageing temperature was equal to 585-590°.

The tests were conducted with interruptions over definite time intervals ("planned stoppages"). By the time of the last planned stoppage (January-March, 1960) the testing time equalled 40,000-55,000 hours.

Apart from steels LA-1 and EI-257, a welded joint of steel EI-257 made with electrodes TsT7 was also subjected to investigation. Table 1 shows the chemical compositions of the investigated melts.

Creep Tests. Tests under stress $\sigma = \sigma^{580}_{10^{-5}}$ have shown that the actual creep rate for tests lasting more than 5,000-10,000 hours in less than $1 \cdot 10^{-5}$% per hour. For stress $\sigma = \sigma^{580}_{10^5}$ it was important to evaluate the duration of the initial stage of creep. For steel LA-1 under the conditions as specified above $\Theta_I \approx$ 20,000-25,000 hours; the creep rate in the secondary creep period was about $1 \cdot 10^{-5}$% per hour (Fig. 1). For steel EI-257, after exposure to either type of heat treatment, it was found to be impossible to evaluate the duration of the initial creep, since the creep rate varied strongly during the entire period of 40,000-50,000 hours. Moreover, it should be noted that at 20,000-30,000 hours the creep rate of steel EI-257 rises sharply up to $(1.5\text{-}2) \cdot 10^{-4}$% per hour (Figs. 1-f, d, g). The above increase in creep rate is accompanied by a variation of some other properties of steel EI-257 (for example, microhardness of the grain and its boundaries).