EFFECT OF RARE-EARTH METALS ON MECHANICAL CHARACTERISTICS OF CHROMIUM

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The use of chromium in technology as a constructional material possessing a series of advantages over other metals (relatively high melting point, high resistance to oxidation, low density, etc.) is limited by its high tendency towards brittle fracture and its poor ductility. The latter is due to the large effect of interstitial impurities (nitrogen, oxygen, carbon) and to features of its electronic structure [1, 2].

One of the methods for improving the technological ductility of chromium is to alloy it with rare-earth metals (REM), which combine the interstitial impurities into high-melting poorly soluble compounds. In addition, rare-earth metals increase the resistance of the surface oxide film and grain boundaries to oxidation and diffusion penetration of nitrogen into chromium at high temperatures [5, 9, 10].

A considerable amount of research [11-17] has been devoted to the mechanical characteristics of chromium with various degrees of purity, whereas the mechanical characteristics of chromium – REM alloys have hardly been investigated at all. Only the data obtained by Sims and Clark [6] from an investigation of the mechanical characteristics of Cr + 0.3% Y and Cr + 1% Y alloys at 20 and 149°C and also the data obtained by Panasyuk (Cr + 1% Y, Cr + 2.0% Y) [18] are known. There are results [19] from an investigation of the microhardness of Cr + 0.5, 1.0, and 2.0% Y and Cr + 0.5, 1.0, and 2.0% Pr alloys at temperatures between −165 and 900°C.

In the present work the mechanical characteristics of electrolytic hydrogen-refined chromium of grade ÉRKh MRTU 14-5-3-65 alloyed with scandium, yttrium, lanthanum, cerium, praseodymium, neodymium, gadolinium, and erbium were investigated, the REM comprising 0.2 wt.% of the alloy.

The preparation of the specimens for the tests included the following operations:

a) melting the alloys by a technique securing high quality and minimal contamination;

b) extrusion of cast blanks at 1200°C with a total degree of deformation of 90% (content of interstitial impurities in rods after extrusion: 0.007% N_2; 0.006-0.008% O_2; 0.006-0.007% C; < 0.0001% S, 0.04% Si);

c) rotary forging of rods with diameters between 16 mm and 7.0 mm at 800-1000°C;

d) preparation of specimens (Fig. 1);

e) recrystallization annealing of specimens under vacuum at T = 900–1150°C to a grain size of approximately 0.05-0.07 mm;

f) electrolytic polishing of the prepared specimens.

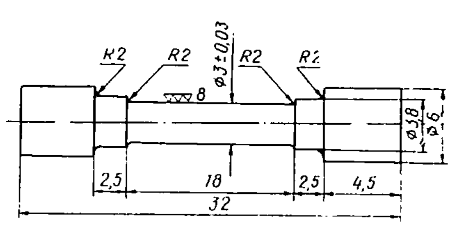

Fig. 1. Diagram of specimen for tensile tests.

The tensile tests were carried out in air at 20, 550, 700, 850, 950, and 1000°C. The clamp of the tensile machine moved at a rate of 0.5 mm/min. At each experimental point three to four specimens were tested.

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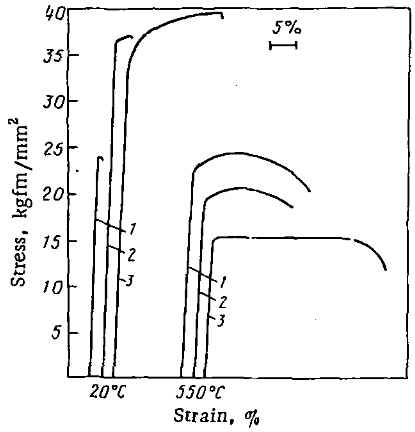

Fig. 2

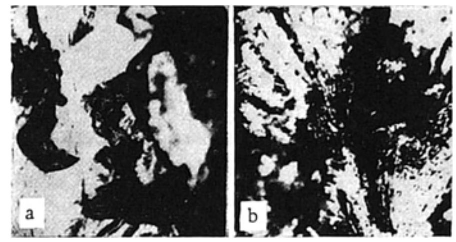

Fig. 3

Fig. 2. Tensile diagram for chromium and Cr–REM alloys at 20 and 550°C. 1) Chromium; 2) Cr + 0.5% Y; 3) Cr + 0.5% La.

Fig. 3. Fracture of specimens of chromium (a) and Cr + 0.5% La alloy (b) (optical fractograph, ×200).

TABLE 1

Composition of alloy according to charge	Content REM in alloy, %	Tensile strength, kgf/mm^2	Yield point, kgf/mm^2	Relative elongation, %	Reduction in cross section, %
Cr	—	15,2	—	0	0
Cr+0,5% Sc	—	18,4	—	0	0
Cr+0,5% Y	0,28	38,5	37,6	2,0	2,8
Cr+0,5% La	0,24	39,9	37,8	20,0	40,0
Cr+1,0% La	0,68	39,2	37,2	12,6	28,6
Cr+2,0% La	1,48	35,2	—	0	0
Cr+0,25% Ce	0,10	39,0	37,0	12,2	32,0
Cr+0,5% Ce	0,27	38,6	37,5	8,1	26,5
Cr+1,0% Ce	0,73	23,6	—	0	0
Cr+0,25% Pr	—	41,2	39,8	12,1	24,6
Cr+0,5% Pr	0,30	40,3	38,0	15,6	30,0
Cr+1,0% Pr	0,74	39,2	38,5	12,2	18,6
Cr+2,0% Pr	1,73	29,6	—	0	0
Cr+0,5% Nd	0,21	38,3	37,7	4,8	2,6
Cr+1,0% Nd	0,65	38,2	37,5	3,7	1,7
Cr+0,5% Gd	0,37	38,1	37,0	6,8	18,4
Cr+1,0% Gd	0,83	36,9	36,2	4,2	21,5
Cr+0,5% Er	0,22	30,0	—	0	0
Cr+1,0% Er	0,60	36,2	—	0	0
Cr+2,0% Er	1,39	34,2	—	0	0
Cr+3,0% Er	2,27	30,2	—	0	0

The mechanical characteristics of the alloys at room temperature are given in Table 1, from which it is seen that the addition of lanthanum, cerium, praseodymium, neodymium, and gadolinium to chromium has a favorable effect on its ductility at room temperature if their contents do not exceed 1 wt. %. The addition of more than 1% of the rare-earth metals to the alloy greatly reduces their favorable effect on the ductility of chromium. The greatest increase in ductility (δ = 20%, ψ = 40%) was achieved with a lanthanum content of approximately 0.24%.

In Fig. 2 the tensile diagrams for specimens of pure chromium and Cr + 0.5% Y and Cr + 0.5% La alloys are given for comparison.

Fractographic investigation of the fracture surfaces show that the specimens of pure chromium were subject to intercrystalline fracture, whereas transcrystalline fracture predominated in the Cr + 0.5% La and Cr + 0.5% Gd alloys. In this case the facets revealed a characteristic "stream pattern" (Fig. 3).

As seen from Fig. 4, increase in temperature leads to an almost linear reduction in the strength of both pure chromium and its alloys with rare-earth metals. Incidentally we notice that pure chromium has higher strength when heated between 550 and 850°C (Fig. 4). This is evidently due to the strengthening action of the interstitial impurities. At 850°C there is an inflection on the curve for the strength characteristics of pure chromium. The decrease in strength from 13.5-140.0 kgf/mm^2 at 850°C to 7-8 kgf/mm^2 at 1000°C can be explained by the so-called impurity softening effect. The addition of rare-earth metals to the chromium appreciably reduces the resistance of the metal to plastic deformation in the region of 550-850°C and suppresses the impurity softening effect at 850°C.

Increase in temperature also leads to considerable improvement in the ductility of chromium and its alloys with rare-earth metals, and the greatest increase in ductility is observed at temperatures in the region of 550-700°C. Comparison of the plastic characteristics (ψ, δ) of pure chromium and its alloys with 0.5% of yttrium, lanthanum, cerium, praseodymium, neodymium, gadolinium, and erbium shows that of all the investigated rare-earth metals only lanthanum secures an appreciable increase in the ductility of

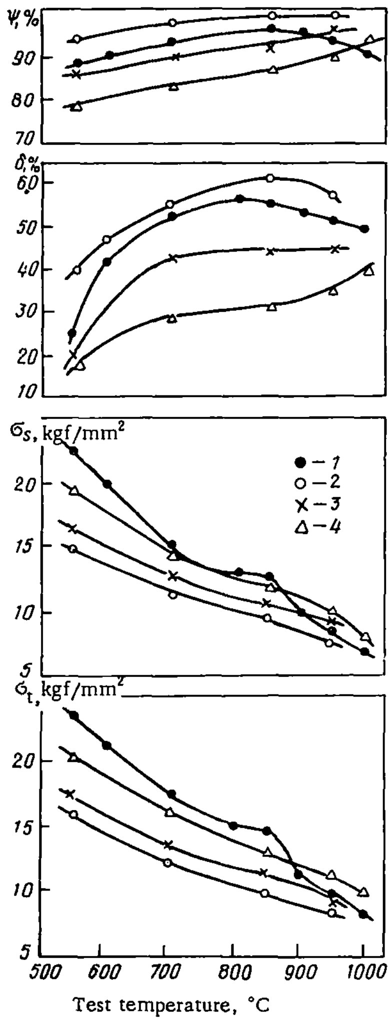

Fig. 4

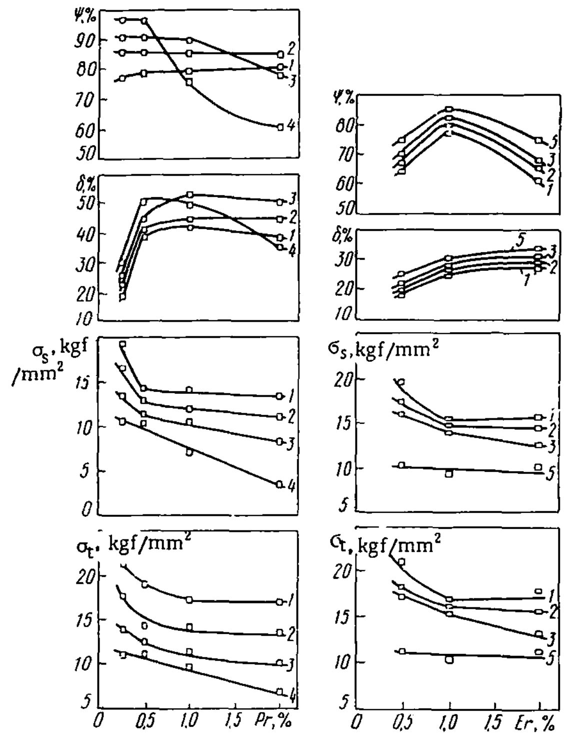

Fig. 5

Fig. 4. Dependence of mechanical characteristics of chromium and Cr + 0.5% REM (Y, La, Gd) alloys on temperatures: 1) chromium; 2) Cr + 0.5% La; 3) Cr + 0.5% Gd; 4) Cr + 0.5% Y.

Fig. 5. Dependence of mechanical characteristics of chromium at various temperatures on REM content (Pr and Er): 1) 550°C; 2) 700°C); 3) 850°C; 4) 350°C; 5) 1000°C.

chromium in this temperature range (Fig. 4 and Table 2). The alloying of chromium with cerium, praseodymium, neodymium, gadolinium, yttrium, and erbium leads to some decrease in ductility, and this is due to the unfavorable distribution of separations of the second phase (mostly at the grain boundaries) in the structure of the metal. A deterioration in the plastic characteristics of pure chromium is also observed at temperatures above 850°C, and this is evidently due to saturation of the matrix with nitrogen.

With the results from the mechanical tests on alloys of chromium with lanthanum, cerium, praseodymium, neodymium, gadolinium, and erbium presented in Table 2 and Fig. 5 it is possible to determine the effect of the concentration of the alloying element on the properties of chromium in the range of temperatures between 550 and 1000°C. It is seen that an increase in the calculated concentration of the alloying elements from 0.25 to 1% appreciably reduces the resistance to plastic deformation σ_s and also the tensile strength σ_t of chromium in this temperature range. At the same time there is a significant increase in the plastic characteristics (ψ, δ).

TABLE 2

Composition of alloy according to charge	Temperature, °C	Tensile strength σ_t, kgf/mm^2	Yield point σ_s, kgf/mm^2	Relative elongation δ, %	Reduction in cross section ψ, %
Cr+0.5% Sc	550	25,6	24,2	21,0	65
	700	19,5	16,5	32,4	78
	850	14,6	13,0	38,0	84
	1000	8,5	8,3	46,0	88
Cr+1,0% La	550	15,6	14,9	48,0	95
	700	11,0	10,8	57,0	98
	850	10,0	9,8	62,0	100
	950	8,3	6,8	55,3	98
Cr+2% La	550	15,2	14,4	53,0	95
	700	11,5	10,3	60,0	98
	850	9,5	6,8	62,0	96
	950	7,4	2,9	31,6	46
Cr+0.25%Ce	550	21,6	20,2	26,0	79
	700	19,2	18,1	36,2	80
	850	13,2	12,6	42,0	88
	950	10,5	10,4	48,0	91
Cr+0.5% Ce	550	20,4	19,8	30,0	80
	700	16,5	16,0	35,6	85
	850	13,0	12,6	42,7	88
	950	10,2	9,4	48,2	95
Cr+1.0% Ce	550	18,5	18,0	28,9	66
	700	16,1	15,0	28,3	78
	850	9,2	6,4	16,8	38
	950	9,0	5,6	10,2	26
Cr+0,5% Nd	550	19,8	18,5	23,1	78
	700	15,6	15,1	35,8	82
	850	13,2	12,8	43,4	86
	950	11,2	10,9	49,1	88
Cr+1.0% Nd	550	16,8	15,6	21,8	80
	700	14,5	13,9	36,5	82
	850	13,0	12,8	45,6	88
	950	10,6	10.5	45,0	87
Cr+1.0% Gd	550	16,8	15,9	24,6	85
	700	13,5	13,0	34,6	92
	850	11,5	11,2	42,3	95
	950	10 8	10,6	44,4	95
Cr+3% Er	550	18,8	17,9	12,7	68
	700	16,6	15	21,3	70
	850	13,7	12	26,2	67
	1000	11.0	10	28.5	71

This behavior in the mechanical characteristics of chromium with increase in the concentration of rare-earth metals arises from an increase in the activity of the rare-earth metals in the alloy and, consequently, from a higher degree of purification of the solid solution from interstitial elements.

With the alloying elements at concentrations above 1%, the mechanical characteristics of chromium in the range of temperatures between 550 and 850°C depend little on the concentration. At the same time the heating of chromium alloyed with more than 2% of cerium, praseodymium, or lanthanum above 850°C is accompanied by a sharp decrease in strength and ductility (Fig. 5 and Table 2).

The deterioration in the high-temperature ductility observed in some alloys of chromium with rare-earth metals (cerium, lanthanum, and praseodymium) can be explained by the hot-shortness effect, which arises with the appearance of low-melting phases at the grain boundaries when the rare-earth metal content is above the solubility limit.

It should be noted that the mechanical characteristics of the Cr + REM alloys are also determined by the characteristics of the individual rare-earth metals. The observed change in atomic radius (the so-called lanthanide contraction), the increase in melting point, and the increase in elastic characteristics in order the La → Lu [5, 21-29] evidently affect the characteristics of the Cr – REM alloys.

Analysis of the obtained data on the relationship between the plastic characteristics of Cr – REM alloys and temperature makes it possible to make the following generalizations.

1) The alloying of chromium with rare-earth metals in the investigated range of concentrations is capable of significantly changing the low-temperature ductility characteristics. Particularly promising in this respect is the addition of lanthanum, cerium, praseodymium, and gadolinium. The optimum rare-earth metal content of the metal is 0.2-0.7%. In the recrystallized state the alloyed chromium possesses comparatively high ductility in the region of reduced temperatures.

2) Comparison of the plastic characteristics of pure chromium and Cr + 0.5% REM alloys in the range of temperatures between 550 and 1000°C shows that the addition of lanthanum increases the high-temperature ductility of chromium, additions of cerium and praseodymium have almost no effect, and additions of neodymium, gadolinium, yttrium, erbium, and scandium reduce it somewhat.

Thus, the addition of rare-earth metals to electrolytically refined chromium has a considerable effect on its mechanical characteristics, and the effect of elements in the yttrium and cerium subgroups are not the same. To increase the ductility of chromium throughout the range of temperatures investigated it is expedient to add elements of the cerium subgroup. In the region of high temperatures additions of metals from the yttrium subgroup will clearly be more effective. Of this group Cr + 1% Y alloys have found industrial use [30].

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