MECHANICAL PROPERTIES OF STAINLESS STEELS AT 20 TO -253°C

B. M. Ovsyannikov and
E. A. Ul'yanin

UDC 669.14.018.52.84:62-974

This work concerns the effect of manganese, nickel, and chromium, the basic alloying elements that form substitution solid solutions with iron, on the mechanical properties of austenitic steels at 20 to -253°C.

The investigation was made on three groups of steels with varied concentrations of one of these elements – steels with 12% Cr and 15-30% Mn, steels with 17% Cr and 10-30% Ni, and steels with 25% Ni and 5-25% Cr (see Table 1). The initial martensite transformation temperature was below -253°C for all steels except Kh17N10. Steels Kh12G15, Kh12G20, N25Kh5, Kh17N10, and Kh17N15 underwent the martensitic transformation in tension at the testing temperatures of -196 and -253°C. In the fractures we observed cold-worked austenite and deformation martensite. In steel Kh17N10 we observed a certain amount of cooling martensite (about 15%) in addition to deformation martensite and austenite (the M_s point is at -196°C).

The mechanical properties of the steels were determined in static tensile strength tests of smooth (gauge diameter $d_0 = 5$ mm, gage length $l_0 = 25$ mm) and notched samples (notch root radius $\rho = 0.25$ mm, notch depth $t = 1.7$ mm). The stress concentration coefficient in the notch root calculated by Neiber's interpolation function was $K = 3.2$ [1].

Rods of the heats investigated were water-quenched from 1050°C. The austenite grain size was grade 4-5 (GOST 5639-65).

Effect of Manganese. With increasing manganese concentrations the yield strength increases considerably with decreasing testing temperatures (Fig. 1.). The lower the temperature the greater the rate of increase of the yield strength. The overall increase of the yield strength from +20 to –253°C is 40-55 kg/mm^2.

The character of the temperature dependence of the ultimate strength depends essentially on the structure of the steels. At room temperature the ultimate strength of steels Kh12G15 and Kh12G20 is higher than that of steels Kh12G25 and Kh12G30 because the former are hardened by deformation martensite. At -196°C the ultimate strength is approximately the same for all the steels investigated, while at -253°C the strength of the steels with 15 and 20% Mn is below that of steels with 25-30% Mn.

TABLE 1

Steel	Composition, %				
	C	Mn	Cr	Ni	Si
Kh17N (10—30)	0,04	0,5	17,0	10,2	0,5
	0,04	0,4	17,0	14,5	0,5
	0,04	0,5	17,2	20,1	0,5
	0,04	0,3	16,8	23,6	0,5
	0,03	0,4	17,0	29,1	0,4
N25Kh (5—25)	0,035	0,4	5,2	25,2	0,3
	0,03	0,4	9,7	25,2	—
	0,03	0,4	16,8	25,2	0,6
	0,03	0,4	20,2	25,6	0,6
	0,03	0,4	25,6	25,6	0,6
Kh12G (15—30)	0,10	15,4	12,2	—	0,3
	0,10	19,6	12,4	—	0,3
	0,10	24,5	12,2	—	0,3
	0,10	30,0	12,0	—	0,3

The variation of the ultimate strength with temperature for notched samples (σ_b^n) is also complex (Table 2). For steels Kh12G15 and Kh12G20 σ_b^n depends little on the testing temperature, while for Kh12G25-30 it increases sharply with decreasing temperature. The relationship between the levels of σ_b^n generally matches the relationship between the levels of σ_b.

All the steels investigated are characterized by considerable plasticity (δ, ψ, ψ^n) at room temperature. With decreasing testing temperatures the plasticity decreases sharply, particularly for steels with unstable austenite. The reduction in section for steel Kh12G15 at -253°C is 10% (6% for notched samples). The reduction in the plasticity of steels Kh12G15 and Kh12G20, which is due to the presence of deformation martensite in the chromium–manganese structure, is the reason for the reduction in strength at low temperatures and also the low ratio of σ_b^n/σ_b, which is 0.92 and 1.01 respectively for the two steels at -196°C (see Table 2, Fig. 2).

TsNIIChERMET. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 3, pp. 2-6, March, 1969.

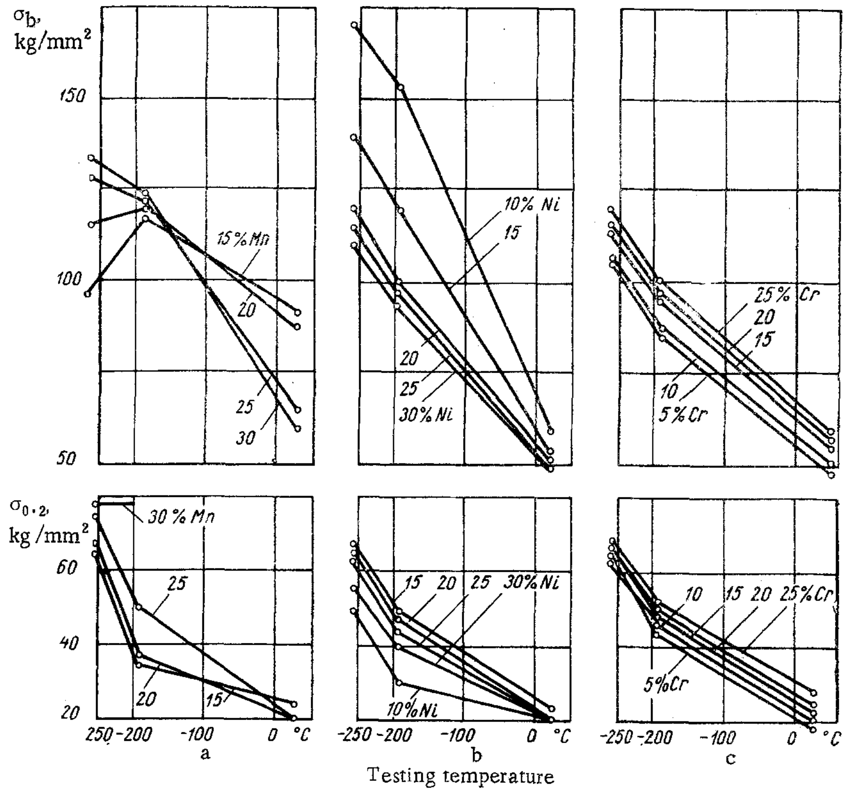

Fig. 1. Effect of manganese (a), nickel (b), and chromium (c) on the ultimate strength and yield strength at 20 to -253°C.

At higher manganese concentrations (for the same testing temperature) the plasticity increases.

Steels Kh12G25 and Kh12G30, which have a high strength and adequate plasticity at -253°C, are relatively insensitive to stress concentrations.

Effect of Nickel. Nickel (10-30%) slightly increases the yield strength of steels with 17% Cr at room temperature. At testing temperatures of -196 and -253°C the yield strength of nickel increases approximately 1 kg/mm² for each 1% nickel (see Fig. 1b).

With decreasing testing temperatures the yield strength of all the compositions investigated increases considerably; the lower the testing temperature the greater the increase. As the result of hardening, the yield strength increases from 20-22 kg/mm² at room temperature to 50 kg/mm² for steel Kh17N10 and to 67 kg/mm² for steel Kh17N30 at -253°C.

Steels Kh17N10 and Kh17N15 undergo partial martensitic transformation in tension at -196 and -253°C. The phase transformation affects the temperature dependence of the strength characteristics σ_b and σ_b^n.

In steels with unstable austenite the ultimate strength σ_b increases considerably at low temperatures (from 55-60 kg/mm² at room temperature to 140-170 kg/mm² at -253°C), while the plasticity (δ, ψ) remains fairly high. It is characteristic of steel Kh17N10 that the ultimate strength decreases sharply (from 226 to 184 kg/mm²) in notched samples as the temperature is lowered from -196 to -253°C. The reduction in cross-sectional area of the notched samples decreases at the same time (to 12.9%). These results conform with the test results for unstable chromium–manganese steels Kh12G15 and Kh12G20.

For steel Kh17N15 the values of σ_b and σ_b^n increase continuously with decreasing testing temperatures. With increasing nickel concentrations (up to 20-30%) the strength characteristics (σ_b and σ_b^n) increase at the same testing temperature t_{test}=const (see Table 2, Fig. 1b). The plasticity (δ, ψ, ψ^n) decreases slightly with the testing temperature but depends very little on the nickel concentration (see Table 2, Fig. 2).

TABLE 2

Steel	+20°C					−196°C					−253°C				
	σ_n^b, kg/mm²	σ_b^n/σ_b	ψ^n, %	ψ^n/ψ	δ, %	σ_b^n, kg/mm²	σ_b^n/σ_b	ψ^n, %	ψ^n/ψ	δ, %	σ_n^b, kg/mm²	σ_b^n/σ_b	ψ^n, %	ψ^n/ψ	δ, %
Kh12G15	127	1,38	33	0,52	57	108	0,92	6	0,56	19	120	1,25	6	0,58	10
Kh12G20	112	1,27	43	0,61	78	133	1,01	11	0,40	40	136	1,18	9	0,48	17
Kh12G25	86	1,33	53	0,75	80	143	1,20	17	0,50	39	166	1,29	13	0,42	28
Kh12G30	86	—	51	—	—	154	—	26	—	—	183	1,36	26	0,46	53
N25Kh5	66	1,47	62	0,82	75	113	1,36	57	0,70	85	130	1,21	42	0,6	79
N25Kh10	69	1,45	62	0,82	72	105	1,25	54	0,71	89	119	1,15	49	0,74	71
N25Kh15	77	1,45	61	0,83	74	115	1,20	43	0,62	86	134	1,16	41	0,64	66
N25Kh20	78	1,47	63	0,89	56	125	1,30	41	0,60	75	144	1,26	42	0,68	70
N25Kh25	87	1,60	60	0,81	55	140	1,41	38	0,54	85	154	1,31	36	0,68	67
Kh17N10	82	1,29	62	0,77	76	226	1,45	29	0,67	38	185	1,08	13	0,23	36
Kh17N15	78	1,49	56	0,71	78	160	1,30	46	0,67	64	181	1,29	36	0,58	51
Kh17N20	78	1,50	60	0,77	59	130	1,28	41	0,62	86	164	1,38	37	0,57	65
Kh17N25	79	1,39	58	0,74	54	120	1,18	41	0,63	80	160	1,36	38	0,60	69
Kh17N30	80	1,46	52	0,74	51	124	1,31	41	0,58	75	156	1,38	37	0,58	63

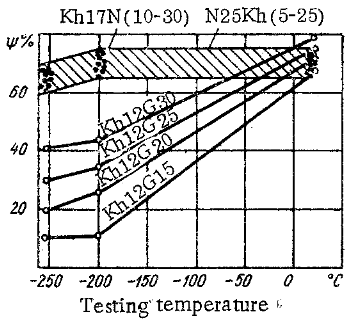

Fig. 2. Variation of reduction in section with testing temperature from 20 to -253°C.

Effect of Chromium. For the steels with 25% Ni and 5-25% Cr, as for the stable steels Kh17N20, Kh17N25, and Kh17N30, the strength characteristics (σ_T, σ_b, σ_b^n) are clearly temperature-dependent. Thus, the yield strength varies from 18-28 kg/mm² at room temperature (depending on the Cr content) to 64-68 kg/mm² at -253°C and the ultimate strength from 46-58 to 105-120 kg/mm². With increasing chromium concentrations (at t_{test} = const) σ_T, σ_b, and σ_b^n increase approximately 1 kg/mm² for each per cent chromium (see Table 2, Fig. 1c). For all compositions at all temperatures tested σ_b^n/σ_b was greater than one.

The plasticity of all compositions was high at all temperatures from 20 to -253°C and differed little from one composition to another at a given temperature. Only steel N25Kh5 had a lower plasticity (see Table 2).

It should be noted that the yield strength is greatly dependent on temperature for all the steels. The increase of the yield strength with decreasing temperature is of the same order as that for cold short low- and medium-carbon steels [2]. Thus, it cannot be concluded [3] that the tendency of a material to brittle fracture is proportional to the rate of change in the shear strength with temperature. Such a conclusion is valid only for a material with a relatively low resistance to brittle fracture.

CONCLUSIONS

1. In steels with stable austenite the yield strength and ultimate strength increase considerably with decreasing testing temperatures. The rate of increase in strength increases with decreasing temperatures.

2. The formation of nickel martensite during plastic deformation additionally increases the ultimate strength, while the plasticity of notched samples remains satisfactory down to -253°C. The formation of martensite alloyed with manganese greatly reduces the plasticity at -253°C, which in turn causes a decrease of σ_b and σ_b^n by comparison with their values at -196°C.

3. Manganese, nickel, and chromium have a negligible effect on the strengthening of austenite at 20 to -253°C.

4. The plasticity of stable chromium–nickel austenitic steel at low temperatures, determined on smooth and notched samples, depends little on the composition or temperature at 20 to -253°C; the plasticity of stable chromium–manganese austenite increases somewhat with increasing concentrations of manganese but remains lower than in chromium–nickel steel with approximately the same concentration of alloying elements at -196 and -253°C.

LITERATURE CITED

1. G. Neiber, Stress Concentrations [Russian translation], ONTI (1947).
2. Yu. E. Andrianov, D. V. Lebedev, and B. M. Ovsyannikov, Coll. TsNIIChM Reports, No. 52, Special Steels and Alloys [in Russian], Metallurgiya, Moscow (1967).
3. G. V. Uzhik, Strength and Plasticity of Metals at Low Temperatures [in Russian], Izd. AN SSSR (1957).