RP474

TENSILE PROPERTIES OF CAST NICKEL-CHROMIUM-IRON ALLOYS AND OF SOME ALLOY STEELS AT ELEVATED TEMPERATURES

By William Kahlbaum[1] and Louis Jordan

ABSTRACT

The tensile properties as measured in "short-time" tests were determined for a medium-manganese steel at 900° F.; for a series of cast nickel-chromium-iron alloys containing about 0.5 per cent carbon, 35 per cent chromium and from 10 to 45 per cent nickel, at a temperature of 1,550° F.; and for three tungsten-chromium-vanadium steels and four molybdenum-chromium-vanadium steels at temperatures of 850° and 1,000° F.

CONTENTS

	Page
I. Introduction	327
II. Materials	327
III. Method of testing	328
IV. Results and discussion	328
1. Medium-manganese steel	328
2. Nickel-chromium-iron alloys	329
3. Tungsten-chromium-vanadium steels	330
4. Molybdenum-chromium-vanadium steels	331
V. Summary	332

I. INTRODUCTION

The most recently published report by the Bureau of Standards on the so-called short-time tensile properties (that is, the strength under relatively rapid loading) of steels at elevated temperatures[2] gave data on several groups of low-alloy steels. Among these were tungsten-chromium-vanadium steels with and without the addition of silicon or aluminum. Tests were also reported on wrought chromium-nickel-iron alloys containing approximately 10 per cent chromium and from 25 to 60 per cent nickel. The present report deals with the tensile properties, as determined by short-time tests, of some additional similar steels and alloys.

II. MATERIALS

The materials tested consisted of (1) a steel in some respects similar to the 0.45 per cent carbon "boiler drum" steel included in the preceding paper,[3] but containing in the present case 1.08 per cent manganese; (2) a series of five cast nickel-chromium-iron alloys, all containing about 35 per cent chromium and from 10 to 45 per cent of nickel; (3) a series of three tungsten-chromium-vanadium steels and (4) a series of four molybdenum-chromium-vanadium steels. The chemical compositions of these materials are given in Table 1.

[1] Research associate, The Midvale Co., Philadelphia, Pa.
[2] William Kahlbaum, R. L. Dowdell, and W. A. Tucker, The Tensile Properties of Alloy Steels at Elevated Temperatures as Determined by the "Short-time" Method, B. S. Jour. Research, vol. 6 (RP 270), p. 199, 1930.
[3] See footnote, 2.

TABLE 1.—*Chemical composition*

Type of alloy	Designation	C	Mn	P	S	Si	Cr	Ni	V	W	Mo
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Carbon steel (medium manganese).	8/1819	0.40	1.08	0.037	0.034	0.23	------	------	------	------	------
Nickel-chromium-iron (cast).	EE1522	.57	.59	------	------	1.04	36.2	10.2	------	------	------
	EE1523	.59	.65	------	------	1.07	35.2	21.0	------	------	------
	EE1524	.54	.63	------	------	1.13	36.9	30.1	------	------	------
	EE1525	.47	.71	------	------	1.08	34.5	38.4	------	------	------
	EE1526	.36	.53	------	------	1.15	33.5	45.2	------	------	------
Tungsten-chromium-vanadium steels.	HF-1/169	.29	.51	------	------	.58	2.28	------	0.36	1.70	------
	HF-1/167	.26	.86	------	------	.69	2.25	------	.33	2.26	------
	HF-1/168	.32	1.02	------	------	.17	1.63	------	.26	2.17	------
Molybdenum-chromium-vanadium steels.	HF-1/166	.20	.45	------	------	.55	1.55	------	.26	------	0.57
	HF-1/165	.29	.88	------	------	.18	1.47	------	.22	------	.52
	HF-1/177	.31	1.38	------	------	.49	2.34	------	.29	------	.55
	HF-1/178	.21	2.23	------	------	1.33	1.28	------	.17	------	1.00

III. METHOD OF TESTING

The equipment and the method used for the short-time tension tests have been described and illustrated previously.[4, 5] All of the tests were made with a hydraulic testing machine, and measurements of strain were made with a Tuckerman optical strain gage.[6]

As in one previous work, a thermocouple mounted in the fillet of the 0.505-inch diameter test bar was used for measuring the temperature of the specimen. The temperature gradient from the center to either end of the gage length of the test bar was approximately 13° F. (7° C.).

Proportional limits were determined by plotting the differences between observed and calculated strain and taking a strain of 1×10^{-5} as indicating departure from a straight line.[7]

IV. RESULTS AND DISCUSSION

1. MEDIUM-MANGANESE STEEL

The data from tests of the 0.4 per cent carbon medium manganese (1.08 per cent) steel at room temperature and at 900° F. are given in Table 2. The point of chief interest in these results lies in the comparison they afford with similar tests made in previous work [8] on a 0.4 per cent carbon steel (boiler-drum steel) containing only a normal proportion of manganese, namely, 0.55 per cent. These previous tests of the lower manganese steel showed that it maintained a proportional limit of approximately 15,000 lbs./in.² from 600° to 750° F., but that its proportional limit decreased noticeably, to 11,000 or 12,000 lbs./in.², at a temperature of 800° F. The higher manganese steel had a proportional limit of 15,000 to 16,000 lbs./in.² at 900° F., fully 150° F. higher than the temperature at which the lower-manganese steel had an equivalent proportional limit. The higher manganese steel did not, however, show a corresponding superiority in tensile strength over the lower manganese steel at the elevated temperature.

[4] H. J. French, Methods of Test in Relation to Flow in Steels at Various Temperatures, Proc. Am. Soc. Test. Materials, vol. 26, Pt. II, p. 7, 1926; also Eng. News Record, vol. 97, p. 22.

[5] H. J. French, H. C. Cross, and A. A. Peterson, Creep in Five Steels at Different Temperatures, B. S. Tech. Papers, No. 362, 1928.

[6] L. B. Tuckerman, Optical Strain Gages and Extensometers, Proc. Am. Soc. Test. Materials, vol. 23, Pt. II, p. 602, 1923.

[7] L. B. Tuckerman, Discussion of paper by R. L. Templin, Proc. Am. Soc. Test. Materials, vol. 29, Pt. II, p. 538, 1929.

[8] See footnote 2, p. 327.

TABLE 2.—*Tensile properties of a medium manganese steel at elevated temperatures as determined by short-time tests*

Designation [1]	Temperature of test	Proportional limit	Tensile strength	Modulus of elasticity	Elongation in 2 inches	Reduction of area	Heat treatment prior to testing
	°F.	Lbs./in.²	Lbs./in.²	Lbs./in.² ×10⁶	Per cent	Per cent	
S/1819	70	[2] 32,000	86,000		27.5	53.9	1,600° F., 12 hours, air cooled; 1,200° F., 10 hours, cooled slowly.
	900	16,000	59,500	21.7	25.5	61.3	
	900	15,000	61,000	20.7	25.0	60.6	

[1] See Table 1 for chemical composition.
[2] Determined by the Midvale Co. A strain of 5×10^{-5} taken as indicating departure from a straight line.

2. NICKEL-CHROMIUM-IRON ALLOYS

The results of short-time tensile tests at 1,550° F. of cast nickel-chromium-iron alloys are given in Table 3. These alloys contained from 0.4 to 0.6 per cent carbon and about 1 per cent silicon and 35 per cent chromium. The nickel content of EE1522 was approximately 10 per cent and this increased to about 45 per cent in the last alloy of the series, EE1526.

This series showed no significant differences in the proportional limits of the various alloys at 1,550° F. There was, however, a progressive increase in the ductility of the alloy as the nickel content increased from 10 to 45 per cent, and above 30 per cent nickel there was a noticeable decrease in tensile strength.

It is in this case also of interest to recall the results of short-time tensile tests given in a previous report [9] for nickel-chromium-iron alloys containing 10 per cent chromium and either 35 or 57 per cent nickel. Only a very general correlation is possible as the earlier tests were made with maximum testing temperatures of only 1,360° F. as compared with 1,550° F. for the more recent tests; the alloys tested in the earlier work were rolled material and in the later work were "as cast"; and also the high-nickel alloy of the earlier work contained over 3 per cent tungsten.

TABLE 3.—*Tensile properties of cast nickel-chromium-iron alloys at 1,550° F. as determined by short-time tests*

Designation [1]	Proportional limit	Tensile strength	Modulus of elasticity	Elongation in 2 inches	Reduction of area
	Lbs./in.²	Lbs./in.²	Lbs./in.² ×10⁶	Per cent	Per cent
EE1522	7,000	49,000	11.6	2.5	3.4
	5,000	41,500	9.4	2.5	5.1
EE1523	5,000	49,000	14.4	3.0	4.2
		54,500		4.0	5.0
EE1524	6,000	49,000	13.2	4.0	7.3
	7,000	55,000	13.1	5.0	6.5
EE1525	6,000	44,000	14.4	8.5	13.3
	6,000	41,500	12.7	8.5	16.2
EE1526	6,000	33,500	11.0	15.5	34.0
		39,000		14.0	23.7

[1] See Table 1 for chemical compositions.

[9] See footnote 7, p. 327.

Nevertheless, it is to be noted that the tensile strengths of the cast alloys of the present series, containing 35 per cent chromium and either 10, 20, or 30 per cent nickel, were of the order of 50,000 lbs./in.^{2} and the proportional limits of the order of 5,000 to 7,000 lbs./in.^{2} at 1,550° F. as compared with tensile strengths of only 35,000 to 40,000 lbs./in.^{2} and proportional limits of 5,000 to 6,000 lbs./in.^{2} at 1,360° F. for rolled alloys containing 35 per cent nickel and 10 per cent chromium.

Increased proportional limits and tensile strengths in alloys of this type at temperatures of 1,300° to 1,500° F. appear to result from an increased chromium content rather than an increased nickel content. With this increase in strength, there is also noticeably less ductility as measured by elongation and reduction of area.

3. TUNGSTEN-CHROMIUM-VANADIUM STEEL

The chief differences in the chemical compositions of the three tungsten-chromium-vanadium steels (Table 1) were that the first of the series (HF–1/169) had a tungsten content of only 1.70 per cent, which was somewhat below the normal composition of the series; the second of the series (HF–1/167) may be considered of the normal composition, namely, about 2¼ per cent each of chromium and tungsten; the last steel of the group was low in chromium (1.63 per cent) but also had a manganese content (1.02 per cent) distinctly higher than the normal for the group.

All of these steels were tested after normalizing from 1,700° F., hardening, and tempering at 1,200° F. The hardening treatment consisted of air quenching from a temperature 50° F. above the upper critical temperature of the individual steel. The exact temperatures are shown in Table 4.

The results of the short-time high-temperature tests of these steels (Table 4) did not show any very striking differences in the behavior of the three steels. On the whole, the steel containing 1 per cent manganese (HF–1/168), with the lower chromium and the normal tungsten content, appeared to be superior with respect to the maintenance of a high proportional limit at elevated temperatures.

TABLE 4.—*Tensile properties of tungsten-chromium-vanadium steels at elevated temperatures as determined by short-time tests*

Designation [1]	Temperature of test	Proportional limit	Tensile strength	Modulus of elasticity	Elongation in 2 inches	Reduction of area	Hardening heat treatment [2]
	°F.	Lbs./in.^{2}	Lbs./in.^{2}	Lbs./in.^{2} ×10^6	Per cent	Per cent	
HF–1/169	70	[3] 92,000	128,000	--------	20.2	62.6	1,515° F., 30 minutes, air cooled.
	850	32,000	86,000	25.2	22.0	64.7	
	1,000	26,000	71,500	22.1	23.5	72.9	
HF–1/167	70	[4] 107,000	139,500	--------	19.2	59.9	1,510° F., 30 minutes, air cooled.
	850	30,000	98,500	23.6	21.5	62.3	
	1,000	16,000	77,500	22.1	23.0	70.1	
HF–1/168	70	[3] 109,000	136,500	--------	18.2	55.7	1,480° F., 30 minutes, air cooled.
	850	43,000	99,500	24.3	19.0	54.9	
	1,000	24,000	84,500	19.9	22.5	65.6	

[1] See Table 1 for chemical compositions.

[2] All specimens were normalized before the hardening treatment and tempered after the hardening treatment indicated in the last column of this table. In all cases the normalizing treatment consisted of heating at 1,700° F. for 30 minutes and cooling in air; the tempering treatment, of heating at 1,200° F. for 30 minutes and cooling in air.

[3] Determined by The Midvale Co. A strain of 5×10^{-5} taken as indicating departure from a straight line.

4. MOLYBDENUM-CHROMIUM-VANADIUM STEELS

The molybdenum-chromium-vanadium steels are listed in both Table 1 and Table 5 in the order of increasing manganese content. The second steel of the series differed from the first in that it had slightly higher carbon (0.29 per cent) and manganese (0.88 per cent) contents than the first steel of the series (0.20 per cent carbon, 0.45 per cent manganese). This difference in composition apparently accounted for a distinctly higher proportional limit and tensile strength in the steel of higher carbon and manganese contents at temperatures of 850° and 1,000° F. Further increase in the proportion of manganese, and also of chromium, in the third steel of the series (HF–1/177) resulted in a still higher proportional limit at 850° F., but produced no increase in either proportional limit or tensile strength at 1,000° F. The fourth and last steel of this series had the highest manganese content of all (2.23 per cent), about double the molybdenum content (1.00 per cent) of the other steels, and a high silicon content (1.33 per cent). This steel had tensile strengths, at the high temperatures, equivalent to or higher than the other steels of the series. Its proportional limit at 850° F. was also high. Its proportional limit at 1,000° F., however, failed to show an equivalent increase and was only of the order of the proportional limit of the first steel of this series, the low-carbon, low-manganese composition, at the corresponding temperature. In previous work [10] it has been observed that 1.25 per cent silicon had a very marked effect in lowering the proportional limit of a tungsten-chromium-vanadium steel at about 1,000° F.

TABLE 5.—*Tensile properties of molybdenum-chromium-vanadium steels at elevated temperatures as determined by short-time tests*

Designation [1]	Temperature of test	Proportional limit	Tensile strength	Modulus of elasticity	Elongation in 2 inches	Reduction of area	Hardening heat treatment [2]
	°F.	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.² ×10⁶*	*Per cent*	*Per cent*	
HF-1/166	70	[3] 60,000	104,000	----------	24.7	66.2	1,490° F., 30 minutes, air cooled.
	850	25,000	83,000	24.7	23.5	67.5	
	1,000	19,000	71,000	22.6	24.0	71.6	
HF-1/165	70	[3] 80,000	118,000	----------	20.7	65.0	1,460° F., 30 minutes, air cooled.
	850	32,000	96,000	24.0	21.5	67.5	
	1,000	26,000	81,000	21.7	23.5	74.5	
HF-1/177	70	[3] 75,000	112,000	----------	23.0	63.3	1,460° F., 30 minutes, air cooled.
	850	37,000	97,000	24.8	20.5	60.1	
	1,000	25,000	71,500	20.2	25.0	73.3	
HF-1/178	70	[3] 74,000	124,000	----------	21.5	54.4	1,460° F., 30 minutes, air cooled.
	850	36,000	104,000	23.3	23.5	63.5	
	1,000	20,000	78,500	18.9	27.0	77.4	

[1] See Table 1 for chemical compositions.

[2] All specimens were normalized before the hardening treatment and tempered after the hardening treatment indicated in the last column of this table. In all cases the normalizing treatment consisted of heating at 1,700° F. for 30 minutes and cooling in air; the tempering treatment, of heating at 1,200° F. for 30 minutes and cooling in air.

[3] Determined by The Midvale Co. A strain of 5×10^{-5} taken as indicating departure from a straight line.

[10] See footnote 2, p. 327.

V. SUMMARY

1. Short-time tensile tests at elevated temperatures were made of a medium-manganese steel; of a series of cast nickel-chromium-iron alloys containing about 0.50 per cent carbon, 35 per cent chromium, and nickel from 10 to 45 per cent; and of two series of low-alloy steels, namely, tungsten-chromium-vanadium and molybdenum-chromium-vanadium steels, all normalized, hardened, and tempered at 1,200 ° F.

2. The medium-manganese steel (1.08 per cent) had a proportional limit of 15,000 to 16,000 lbs./in.^{2} at 900° F. This is fully 150° F. higher than the temperature at which a 0.55 per cent manganese boiler-drum steel of the same carbon content (0.4 per cent carbon) possessed the same proportional limit.

3. The nickel-chromium alloys showed no marked change in proportional limit at 1,550° F. over the range of composition studied. With nickel contents over 30 per cent tensile strengths of the alloys decreased noticeably and the ductility increased.

4. A medium-manganese content (1.02 per cent) in one of the steels of the tungsten-chromium-vanadium series was accompanied by proportional limits as high as or higher than in the other steels of the series.

5. Increased manganese contents (up to 1.4 per cent) in the molybdenum-chromium-vanadium steels resulted in higher proportional limits at 850° and 1,000° F. A steel having a still higher manganese content (2.23 per cent) accompanied by high silicon (1.33 per cent) and 1.00 per cent molybdenum had a high proportional limit at 850° F., but a comparatively low proportional limit at a temperature of 1,000° F. Similarly, low proportional limits at 1,000° F. were observed in previous work with tungsten-chromium-vanadium steels having a high silicon content (1.25 per cent Si).

WASHINGTON, July 6, 1932.