THERMAL EXPANSION OF ALLOYS OF THE "STAINLESS IRON" TYPE

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ABSTRACT

Data on the physical properties of low-carbon iron chromium alloys of the "stainless iron" type are desirable, because these alloys are being used to an increasing extent for various purposes, such as turbines, devices for handling acids, and the manufacture of other articles that resist corrosion. The investigation described in this paper was undertaken because no data on the thermal expansion of stainless iron were available. The paper gives results on the linear thermal expansion of nine samples of stainless iron which were obtained from various sources. The chromium content of these samples varied from 11.9 to 16.4 per cent and the carbon content from 0.09 to 0.13 per cent. Expansion determinations were made over various temperature ranges between room temperature and 1,000° C. Transformation regions were located on some of the samples. The expansion curves of all of the samples are shown and discussed.

The data relating to the critical regions indicate that an increase in the chromium content of stainless iron generally causes a slight increase in the temperature at which the transformation occurs on heating. The contraction during the transformation on heating decreases with increase in the chromium content.

The table in the summary gives average coefficients of expansion derived from data on all samples of stainless iron. The coefficient of expansion increases gradually with temperature.

Figure 8 shows a comparison of the expansion of stainless iron and pure iron.

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I. INTRODUCTION

The purpose of this paper is to supply a demand for data on the thermal expansion of low-carbon iron chromium alloys of the so-called "stainless iron" type. This type of material finds wide applications where resistance to corrosion is an important factor. No data on this subject were available.

Although stainless iron has been in commercial use for only about seven years, it has found application for surgical instruments, turbines, devices for handling organic acids, weak mineral acids, salts, and other more or less neutral bodies, and for the manufacture of other articles that resist corrosion.

This paper gives data on the linear thermal expansion of nine samples of low-carbon iron chromium alloys which were obtained from various sources. For brevity, this class of alloys will be referred to hereinafter by the commercial term "stainless iron," although the alloys are not stainless under all conditions. The differentiation of these low-carbon alloys from those of higher carbon content, commercially known as "stainless steels," is an arbitrary one. The chromium content of the samples investigated varied from 11.9 to 16.4 per cent and the carbon content from 0.09 to 0.13 per cent. Expansion determinations were made over various temperature ranges between room temperature and 1,000° C. As this research was an outgrowth of some expansion tests made for commercial concerns and the United States Government, transformation regions were not charted for all samples.

Acknowledgment is due to H. W. Bearce, W. Souder, and H. W. Gillett, Bureau of Standards, for valuable suggestions.

II. MATERIALS INVESTIGATED

Nine samples of stainless iron were investigated. All samples were 300 mm in length, and the diameter of each specimen was approximately 10 mm, except samples 1156 and 1157 (25 mm diameter). Table 1 gives the chemical analyses and the previous heat treatments.

TABLE 1.—*Chemical analyses and heat treatments of stainless iron*

Sample	Chemical analyses [1]							Heat treatment
	Chromium	Carbon	Manganese	Silicon	Nickel	Phosphorus	Sulphur	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
1117 [2]	13.5	0.13	0.56	0.35	--------	0.031	0.019	Annealed.
1156 [3]	15.9	.12	.39	--------	0.09	.016	.013	Sample 1156 annealed at 1,450° F. (approximately 790° C.).
1157 [3] 1157A [4]	16.4	.13	.16	.25	--------	.01	.01	Sample 1157 quenched in oil at 1,850° F. (1,010° C.), drawn 300° F. (approximately 150° C.).
1195 [5]	12.0	.09	.43	.33	.06	.009	.016	Annealed at 700° C. and cooled slowly.[6]
1218 [7]	11.9	.09	.60	.57	.19	.011	.007	Machined from hot-rolled bar and annealed.[10]
1218A [8]	12.2	.09	(9)	(9)	(9)	(9)	(9)	
1219 [7]	12.2	.09	.56	.31	.39	.010	.010	Machined from hot-rolled bar and annealed twice.[13]
1219A [11]	12.4	.09	(12)	(12)	(12)	(12)	(12)	

[1] Chemical analyses on samples 1117, 1157A, 1218A, and 1219A were made by C. P. Larrabee, of this bureau.
[2] Submitted by F. C. Langenberg, Watertown Arsenal, Watertown, Mass.
[3] Submitted by Bethlehem Steel Co., Bethlehem, Pa. Chemical analysis for sample 1156 was furnished by this company.
[4] Same specimen as sample 1157, turned down from 25 to 10 mm diameter after expansion test on sample 1157.
[5] Submitted by the metallurgical division of this bureau.
[6] After heat treatment the Brinell hardness was about 200.
[7] Submitted by General Electric Co., Schenectady, N. Y. Chemical analysis was made by W. C. Fedde and C. P. Larrabee, of this bureau (vanadium not detected).
[8] Duplicate of sample 1218.
[9] Not determined, but probably the same as for sample 1218.
[10] After annealing (once) the proportional limit was approximately 80,000 lbs./in.^{2}
[11] Duplicate of sample 1219.
[12] Not determined, but probably the same as for sample 1219.
[13] After a second anneal the proportional limit was about 60,000 lbs./in.^{2}

III. APPARATUS

Figure 1 of Bureau of Standards Scientific Paper No. 524 (vol. 21, p. 1, 1926) shows part of the apparatus used in this investigation. With this apparatus the expansion was accurately measured by means of micrometer microscopes which were sighted on fine wires suspended from the ends of the specimen. For a detailed description of the apparatus and the methods used the reader should refer to the paper mentioned.

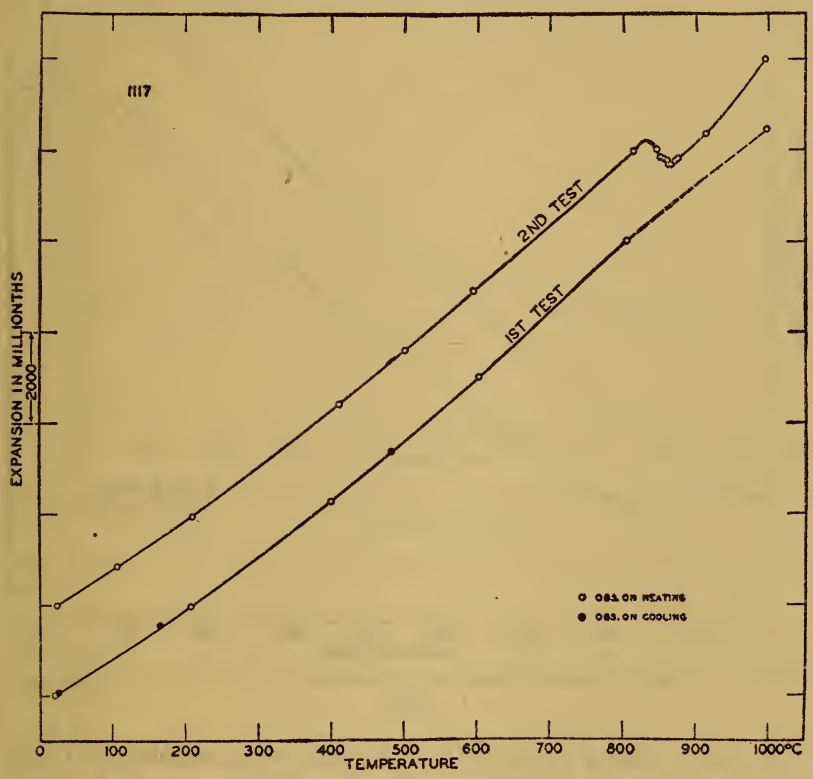

FIG. 1.—*Linear thermal expansion of stainless iron (Cr 13.5, C 0.13 per cent)*

IV. RESULTS

Expansion determinations were made on nine samples of stainless iron over various temperature ranges between room temperature and 1,000° C. Samples 1218 and 1219 were examined to 500° C., but the temperature ranges for the other specimens were extended to higher temperatures.

Figures 1 to 7, inclusive, show the observations obtained. Critical regions were located for samples 1117 (second test), 1157A, 1218A,

and 1219A. The dotted portions of some curves at high temperatures indicate that sufficient observations were not obtained (in these regions) to definitely detect the presence or absence of transformation points. After cooling to room temperature the change in length from the original length before heating did not exceed 0.044 per cent.

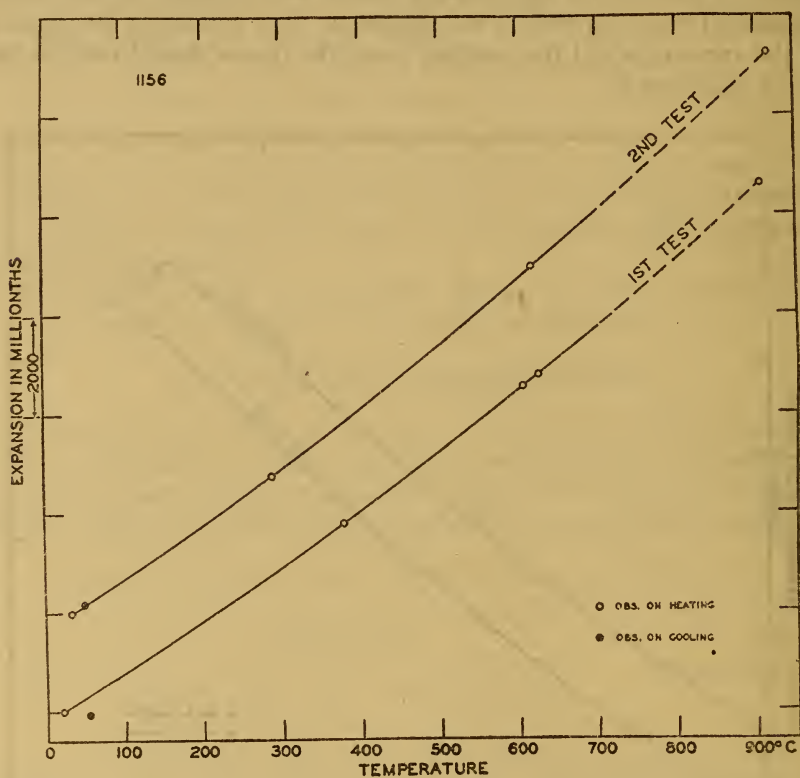

FIG. 2.—*Linear thermal expansion of stainless iron (Cr 15.9, C 0.12 per cent)*

The data relating to the critical regions are assembled in Table 2 and indicate that an increase in the chromium content of stainless iron generally causes a slight increase in the temperature at which the transformation occurs on heating. The contraction during the transformation on heating decreases with increase in the chromium content. For samples 1157A and 1218A the expansion on cooling is slightly less than the corresponding contraction on heating.

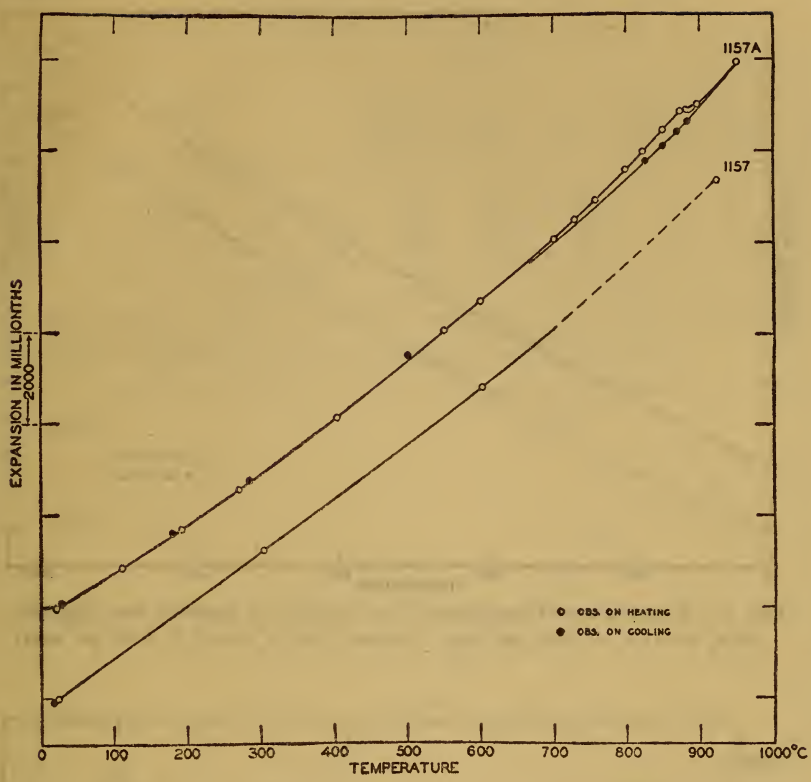

FIG. 3.—*Linear thermal expansion of two samples of stainless iron (Cr 16.4, C 0.13 per cent)*

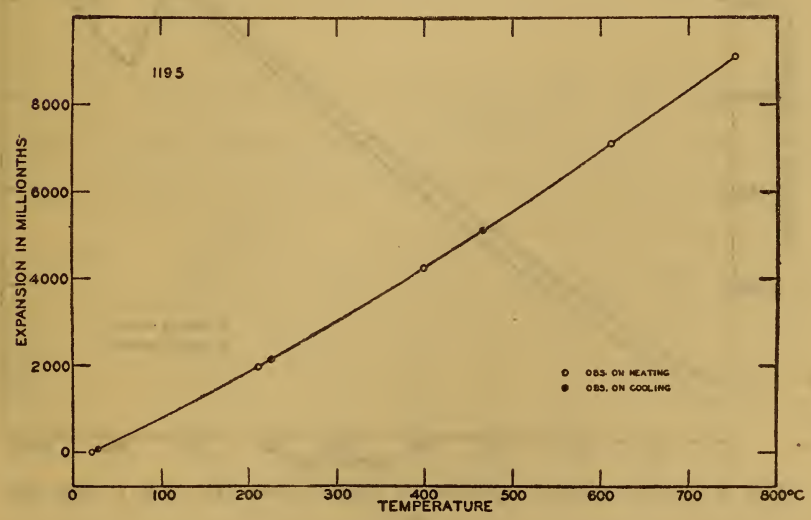

FIG. 4.—*Linear thermal expansion of stainless iron (Cr 12.0, C 0.09 per cent)*

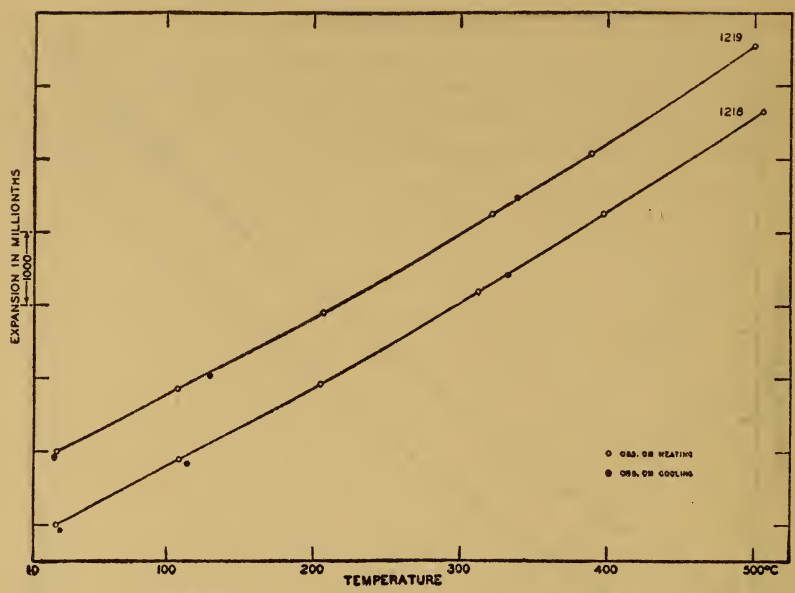

FIG. 5.—*Linear thermal expansion of two samples of stainless iron (Sample 1218, Cr 11.9, C 0.09 per cent. Sample 1219, Cr 12.2, C 0.09 per cent)*

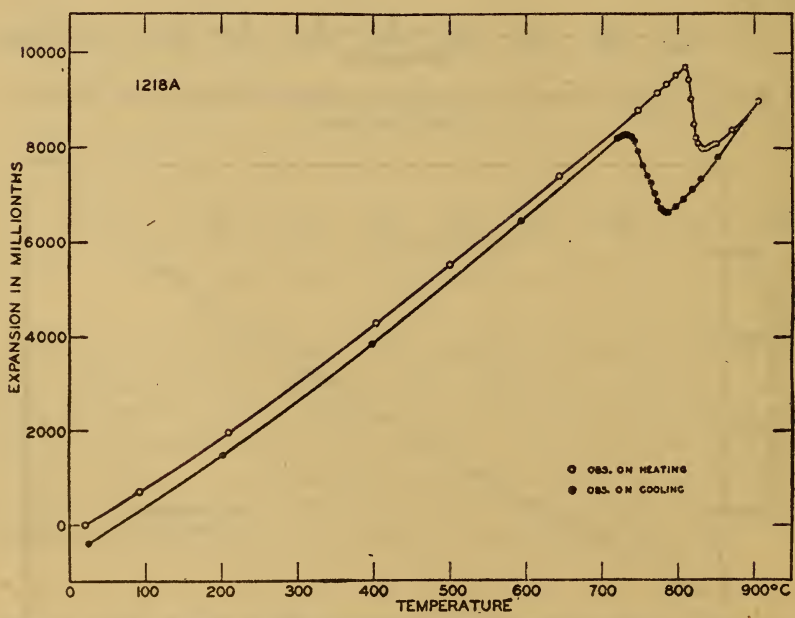

FIG. 6.—*Linear thermal expansion of stainless iron (Cr 12.2, C 0.09 per cent)*

TABLE 2.—*Transformation data*

Sample	Heating			Cooling		
	Beginning of transformation	End of transformation	Contraction	Beginning of transformation	End of transformation	Expansion
	° C.	*° C.*	*Per cent*	*° C.*	*° C.*	*Per cent*
1117 [1]	835	864	0.053			
1157A	880	888	.005	(2)	(2)	(2)
1218A	809	835	.172	782	729	0.163
1219A	788	820	.152			

[1] Second test. [2] Not detected.

The average coefficients of expansion given in Table 3 were derived from the expansion curves of Figures 1 to 7, inclusive.

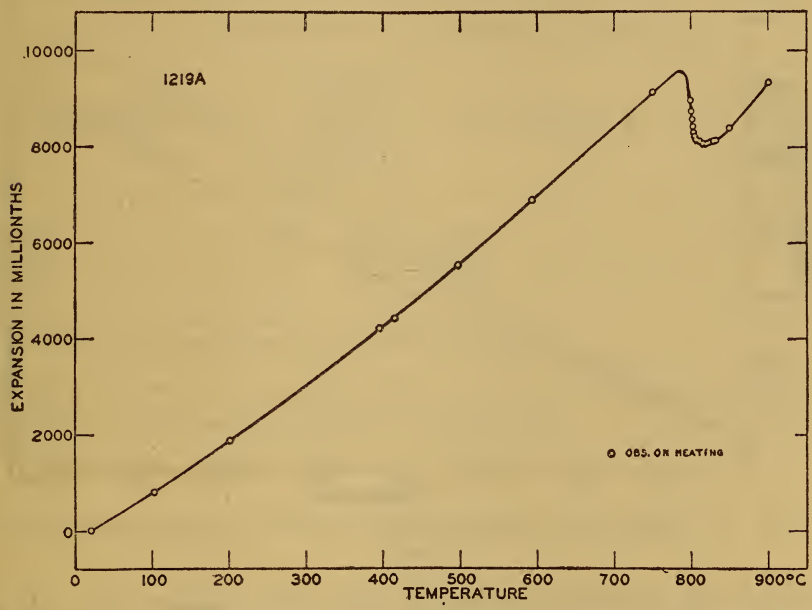

FIG. 7.—*Linear thermal expansion of stainless iron (Cr 12.4, C 0.09 per cent)*

TABLE 3.—*Average coefficients of expansion of stainless iron*

Sample	Chemical composition		Average coefficients of expansion per degree centigrade							
	Chromium	Carbon	20 to 100° C.	20 to 200° C.	20 to 300° C.	20 to 400° C.	20 to 500° C.	20 to 600° C.	20 to 750° C.	20 to 800° C.
	Per ct.	*Per ct.*	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$
1218	11.9	0.09	10.6	10.6	11.0	11.4	11.7			
1195	12.0	.09		10.2		11.2		12.0	12.4	
1218A [1]	12.2	.09	9.8	10.4	10.8	11.2	11.6	11.9	12.2	12.3
1219	12.2	.09	10.2	10.4	10.8	11.2	11.7			
1219A	12.4	.09	9.5	10.3	10.7	11.2	11.6	12.1	12.5	
1117 [2]	13.5	.13		10.4		11.3		12.1		12.8
			10.2	10.5	10.9	11.3	11.7	12.1		[3] 12.6
1156 [2]	15.9	.12				10.7		11.2		
					10.8			11.8		
1157	16.4	.13			11.7			11.8		
1157A [4]	16.4	.13	9.9	10.1	10.4	10.9	11.3	11.6	12.1	12.4

[1] On cooling, the average coefficient of contraction is 20.4×10^{-6} between 900 and 800° C. and 12.4×10^{-6} between 700 and 20° C.
[2] Values given on second line were obtained on a second heating.
[3] Coefficient of expansion between 900 and 1,000 ° C. is 19.0×10^{-6}.
[4] On cooling, the average coefficient of contraction is 12.8×10^{-6} between 950 and 20° C. and 12.1×10^{-6} between 800 and 20° C.

Examination of Table 3 shows no obvious relationship between the chemical composition and the thermal expansion. The coefficients of expansion increase gradually with temperature.

A comparison of the expansion of stainless iron and pure iron is shown in Figure 8. The average curve for stainless iron was obtained from the data on all samples investigated. The curve for a specimen of pure iron was taken from published data.[1] Up to 800° C. the expansion curve of annealed stainless steel [2] (chromium 13.1 per cent, carbon 0.30 per cent) does not differ materially from the average expansion curve for stainless iron, but there is a marked difference

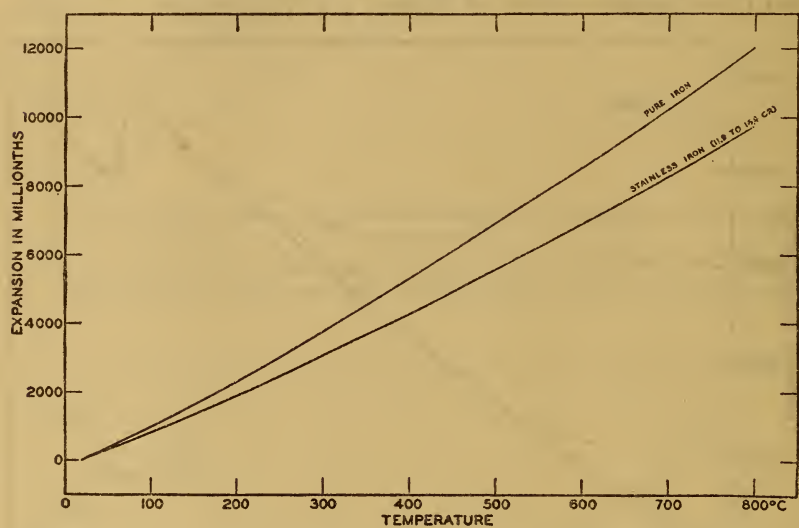

FIG. 8.—*Comparison of the linear thermal expansion of stainless iron and pure iron*

between the expansion curves for iron [3] and stainless iron. It is interesting to note that the addition of 11.9 to 16.4 per cent chromium to iron (or mild steel) caused a marked decrease in expansion.

V. SUMMARY

The investigation described in this paper was undertaken because no data on the thermal expansion of stainless iron were available. The paper gives results on the linear thermal expansion of nine samples of stainless iron which were obtained from various sources. The chromium content of these samples varied from 11.9 to 16.4 per cent, and the carbon content from 0.09 to 0.13 per cent. Expansion determinations were made over various temperature ranges between

[1] B. S. Sci. Paper No. 433, **17**, p. 611; 1922.
[2] B. S. Sci. Paper No. 426, **17**, p. 511; 1922.
[3] A 0.3 per cent carbon steel (without chromium) expands slightly less than iron.

room temperature and 1,000° C. Transformation regions were located on some of the samples. The expansion curves of all of the samples are shown and discussed.

The data relating to the critical regions indicate that an increase in the chromium content of stainless iron generally causes a slight increase in the temperature at which the transformation occurs on heating. The contraction during the transformation on heating decreases with increase in the chromium content.

The average coefficients of expansion given in Table 4 were derived from the data on all samples of stainless iron. The coefficient of expansion increases gradually with temperature.

TABLE 4.—*Average coefficients of expansion of stainless iron* [1]

Temperature range in degrees centigrade	Average coefficient of expansion per degree centigrade	Temperature range in degrees centigrade	Average coefficient of expansion per degree centigrade
	$\times 10^{-6}$		$\times 10^{-6}$
20 to 100	10.0	20 to 600	11.8
20 to 200	10.3	20 to 700	12.2
20 to 300	10.8	20 to 750	12.3
20 to 400	11.2	20 to 800	12.5
20 to 500	11.6		

[1] Chromium 11.9 to 16.4 per cent and carbon 0.09 to 0.13 per cent.

Figure 8 shows a comparison of the expansion of stainless iron and pure iron. Stainless iron expands less than iron.

WASHINGTON, October, 1927.