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HIGH STRENGTH STAINLESS STEELS

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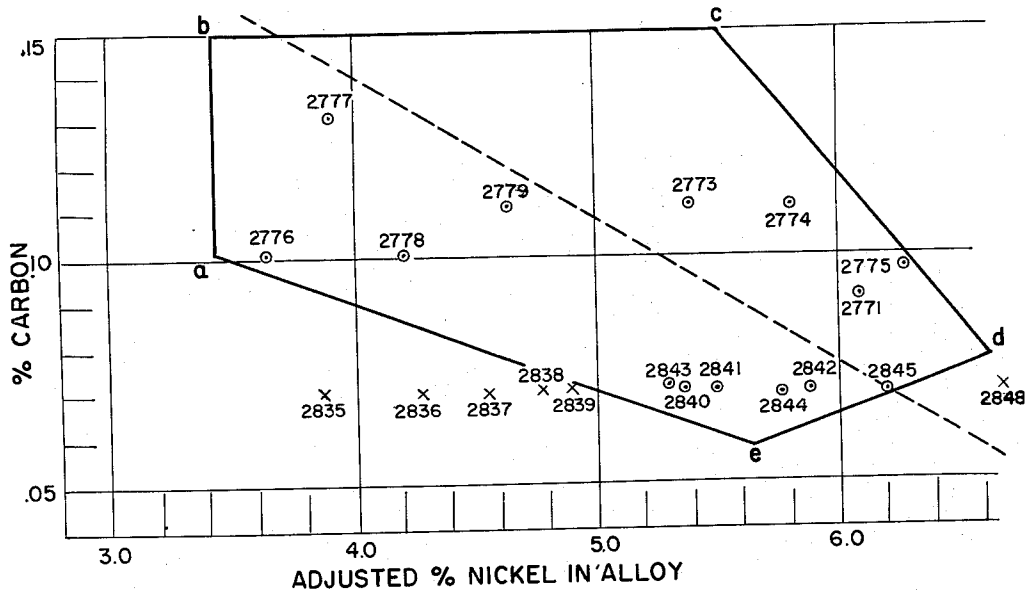


Fig. 1.

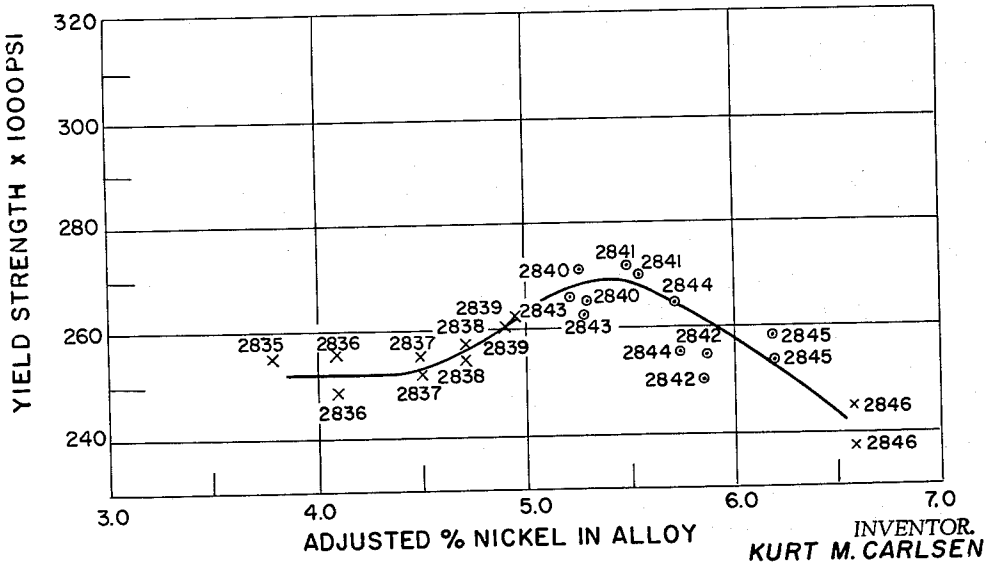


Fig. 2.

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HIGH STRENGTH STAINLESS STEELS

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This invention relates to stainless steels which are austenitic in the annealed condition. It is more particularly concerned with steels of that type in which the preponderance of the austenite is transformed to martensite by cold-working so as to raise the yield and tensile strengths of the steels to extremely high values.

A standard grade of austenitic steel is AISI type 301, which is also known as 17–7 because its nominal chromium content is 17% and its nominal nickel content is 7%. The section entitled "Wrought Stainless Steels" of Metals Handbook for 1961, published by The American Society for Metals, lists on page 416 the properties of type 301 stainless steel in the annealed and in the cold-worked conditions. Yield strength at .2% offset of conventional 301 type steel is about 33,000 p.s.i., which is typical of an austenitic steel. However, cold-working this grade greatly increases its mechanical properties. If the steel is cold-reduced about 45% to 50%, its yield strength is raised to as much as 200,000 p.s.i. The cold work transforms a portion of the austenite into martensite, and it is considered that the pronounced strengthening is caused by martensite precipitating along the slip planes of the alloy.

While it is possible to treat certain known austenitic stainless steel so as to obtain yield strengths somewhat higher than 200,000 p.s.i., that high performance either requires expensive modifications of the steel composition, or expensive treatments. It would be desirable to have available a steel no more complicated chemically than type 301, but having a yield strength on the order of 250,000 to 300,000 p.s.i.

Accordingly, it is an object of my invention to provide a simple chromium-nickel stainless steel having high yield and tensile strength in the cold-worked condition. It is another object to provide such a steel which has normal properties in the annealed condition. Other objects will appear in the course of the following description of my invention.

I have found that very high yield and tensile strengths are exhibited by cold-reduced steels of a composition similar to that of type 301 if the carbon and nickel contents are adjusted to each other in a manner to be described. In the accompanying drawings, FIGURE 1 illustrates graphically the relation between carbon and nickel in steels of my invention, and FIGURE 2 illustrates the effect of changes in nickel content on the yield strength of a steel of my invention.

The steels of my invention generally contain nickel from about 3.5% to about 6.6% and carbon from about .05% to about .15%, the nickel content being in the lower end of its range when the carbon content is in the higher end of its range, and vice versa, so that those elements may be said to be adjusted to be inversely proportional to each other. The steel contains manganese in the amounts generally found in austenitic stainless steels of the AISI 300 series, that is, not more than 2% and preferably in the range from about .90% to about 1.10%. Silicon is likewise present in amounts generally found in conventional steels of that series, that is, not more than about 1% and preferably between about .50% and .70%. The nitrogen content ranges from about .05% to about .10%. The metalloids phosphorus and sulphur and other incidental impurities are present in normal amounts. Enough chromium must be present to render

the steel austenitic in the annealed state, but the chromium content does not exceed about 18%. The minimum chromium content is about 16%.

It is known that in austenitic steels of the AISI 300 series, chromium and nickel, within limits, are interchangeable, and they are interchangeable in my steels to some extent. Within the limits of those elements which I have mentioned, I find that chromium and nickel can be interchanged in the proportion of about 1.4% chromium to 1% nickel. Because of this interchangeability, I find it convenient in the paragraphs to follow to discuss the dependence of physical properties on the chemistry of my steel in terms of "adjusted nickel" or "adjusted percentage nickel." The "adjusted nickel" is actual nickel content of each steel mentioned lowered or raised an amount depending on the difference between the actual chromium content of the steel and the value 17.4%, the proportion of chromium to nickel being that above stated.

As the carbon content of the steels herein described is raised, and the nickel content correspondingly lowered, the steels become increasingly difficult to work in the annealed state, so that the practical upper limit of carbon content is about .15%, the corresponding practical lower limit of nickel content being about 3.5%.

TABLE 1

Heat No.	C	Mn	P	S	Si	Cr	Ni	Ni*	N
2771	.09	1.06	.007	.012	.60	17.40	6.20	6.10	.088
2773	.11	.98	.012	.016	.57	17.43	5.40	------	.062
2774	.11	.95	.011	.017	.53	17.33	5.80	------	.064
2775	.09	.86	.008	.012	.48	17.20	6.30	------	.098
2776	.10	.97	.011	.017	.58	16.20	4.55	3.65	.063
2777	.13	.95	.009	.017	.58	16.24	4.85	3.95	.061
2778	.10	.89	.010	.016	.54	16.17	5.10	4.20	.063
2779	.11	.83	.011	.017	.51	16.07	5.55	4.65	.058
2835	.07	1.12	.005	.016	.65	15.80	4.63	3.84	.061
2836	.07	1.09	.005	.016	.65	15.80	4.91	4.13	.060
2837	.07	1.03	.004	.016	.62	15.74	5.36	4.57	.061
2838	.07	.98	.005	.017	.57	15.66	5.54	4.75	.060
2839	.07	1.18	.004	.016	.64	17.22	5.09	4.90	.065
2840	.07	1.03	.004	.015	.64	17.19	5.47	5.28	.067
2841	.07	1.02	.005	.014	.64	17.04	5.75	5.56	.064
2842	.07	1.07	.005	.015	.56	17.10	6.03	5.84	.061
2843	.07	1.11	.005	.014	.65	17.80	5.09	5.30	.075
2844	.07	1.09	.005	.013	.63	17.79	5.54	5.75	.073
2845	.06	1.05	.004	.014	.64	17.65	6.00	6.21	.069
2846	.07	1.02	.005	.014	.63	17.59	6.48	6.69	.067

*Adjusted.

In Table 1 are listed the designations and compositions of a number of heats of steel of my invention, as well as several heats outside the scope of my invention. In Table 2 are listed the pertinent physical properties of the steels of Table 1, both in the annealed state and after being cold reduced 55%. FIGURE 1 is a plot of carbon content against adjusted nickel content for those steels. Steels of my invention, which are identified by circles, fall within the area *a–b–c–d–e* marked out on FIGURE 1. Steels outside the scope of my invention are indicated by crosses. It will be understood by those skilled in the art that the lines marking out the area *a–b–c–d–e* in FIGURE 1 cannot be precisely located, because a physical property such as the yield strength of steel can be measured only with a fair degree of reproducibility. Furthermore, the change of yield strength with change of composition of the steel is not abrupt, as may be observed from FIGURE 2. That figure is a plot of yield strength against adjusted nickel content for steels of Tables 1 and 2 containing .07% carbon, and cold worked by reducing them 55%.

Table 2 shows that the steels falling within the area *a–b–c–d–e* of FIGURE 1 had yield strengths in the annealed condition of less than about 40,000 p.s.i., that is to say, the steels were all austenitic. The same steels after being cold-reduced about 50% all exhibited yield

strengths greater than about 250,000 p.s.i. The steels falling outside the area *a–b–c–d–e* either had yield strengths higher than about 40,000 p.s.i. in the annealed condition, thus showing that they were not austenitic, or yield strengths lower than 250,000 p.s.i. in the cold-worked condition, or both.

FIGURE 2 illustrates the high strengths obtained from an .07% carbon steel if its nickel content is critically adjusted to its carbon content in accordance with my invention. The steels plotted in FIGURE 2 which are austenitic in the annealed condition are indicated by circles, while those which are not austenitic in the annealed condition are indicated by crosses. That figure shows that an .07% carbon steel displays maximum yield strength at an adjusted nickel content of about 5.4%. That yield strength is in the neighborhood of 275,000 p.s.i. for the cold-worked steel, but in the annealed state the steel has a yield strength of less than about 40,000 p.s.i. FIGURE 2 shows that the yield strength of the steel in the cold-worked condition drops off as the adjusted nickel content is increased or reduced from its critical value for the given carbon content. The yield strength of the steel in the annealed condition likewise increases as the adjusted nickel content is reduced from its critical value. Similar curves could be plotted for steels of other carbon contents within the range of my invention. An empirically derived equation relating carbon and nickel for maximum yield strength in steels of my invention is:

$$\text{Percent Ni} = 8.3\% - 31\ (\text{Percent C})$$

That equation is plotted as a broken line in FIGURE 1.

TABLE 2

Heat No.	Annealed			Cold Rolled		
	0.2% Yield Strength, p.s.i.	Ultimate Tensile Strength, p.s.i.	Elongation, Percent	0.2% Yield Strength, p.s.i.	Ultimate Tensile Strength, p.s.i.	Elongation, Percent
2771	38,295	141,745	45.5	261,480	264,980	4.0
2773	38,000	154,750	37.5	270,900	279,720	5.4
	37,900	150,000	43.5	266,340	277,990	5.4
2774	30,435	126,975	47.0	267,300	272,830	5.8
2775	33,270	141,555	51.0	263,560	271,690	3.0
2776	33,120	211,900	12.5	301,180	305,490	3.0
2777	43,275	203,345	13.0	292,000	294,510	
2778	34,375	184,720	19.0	284,860	286,780	2.5
	39,595	189,560	19.0	283,540	283,760	2.5
2779	32,305	163,265	24.0	285,350	288,750	2.0
	37,055	179,165	20.5	289,130	290,620	3.0
2835	98,860	191,380	9.5	255,470	255,470	3.5
2836	87,365	187,195	35.5	256,210	259,240	4.1
	72,190	188,325	10.0	247,070	253,770	4.1
2837	65,925	191,150	12.5	255,540	258,460	4.5
	69,765	195,840	12.5	253,310	259,410	4.5
2838	74,905	198,450	11.5	258,270	260,290	4.7
	58,290	196,890	11.5	255,690	256,130	4.7
2839	45,470	181,710	12.5	261,620	267,510	4.9
	65,925	191,150	12.0	265,250	265,660	4.9
2840	34,410	164,475	27.0	271,820	273,140	5.2
	33,355	163,310	30.0	266,320	268,030	5.2
2841	33,530	147,790	32.5	272,610	275,650	5.5
	33,475	151,515	32.0	270,610	278,440	5.5
2842	33,715	147,980	37.5	250,930	254,930	5.8
				255,180	258,280	5.8
2843	34,160	159,075	29.5	264,680	268,330	5.3
					272,650	5.3
2844	35,740	148,605	42.0	265,650	269,320	5.75
	34,305	144,850	35.0	255,650	262,860	5.84
2845	37,850	140,100	41.5	254,000	255,230	6.2
	38,000	138,990	43.0	258,000	262,610	6.2
2846				244,400	248,470	6.6
				238,190	244,160	6.6

I claim:

1. A cold reduced austenitic-martensitic steel having a yield strength not less than about 250,000 p.s.i., said martensite being produced by cold reducing the steel about 55%, consisting of about 3.5 to about 6.5% nickel, about .05 to about .15% carbon, not more than 2% manganese, not more than 1% silicon, sufficient chromium to render the steel austenitic in the annealed condition but not more than about 18%, and the balance iron and incidental impurities in normal amounts, the carbon content and the adjusted nickel content, adjusted to a chromium content of 17.4% on the basis of 1% nickel being equivalent to 1.4% chromium, defining a point falling within the area *a–b–c–d–e* of FIGURE 1.

2. A steel as in claim 1, in which the carbon and adjusted nickel contents are related to each other by the equation:

$$\text{Percent nickel} = 8.3\% - 31\ (\text{Percent carbon})$$

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