

1

3,306,736

AUSTENITIC STAINLESS STEEL

Gene R. Rundell, Pittsburgh, Pa., assignor to Crucible Steel Company of America, Pittsburgh, Pa., a corporation of New Jersey

No Drawing. Filed Aug. 30, 1963, Ser. No. 305,873
1 Claim. (Cl. 75-128)

This invention relates to chromium-nickel stainless steel that is stably and completely austenitic, and more particularly to such a steel which exhibits high resistance to deformation at elevated temperature in combination with good weldability and good resistance to sensitization. My steel possesses, moreover, the corrosion resistance required of austenitic stainless steel for high-temperature and room-temperature applications. Although the prior art teaches other completely austenitic chromium-nickel steels that exhibit in part the above-indicated combination of desirable properties, no commercial steel hitherto known is equal or superior to the steel of this invention in respect to all the above-indicated properties. Moreover, the similar, prior-art, commercial steels are more costly than the steel of my invention. Accordingly, the invention affords an economical austenitic chromium-nickel steel, useful for heavy-wall steam piping in plants for generating electrical power, turbine blades, exhaust manifolds, vessels or containers for use in the chemical process industries, and many other purposes wherein one or more of the above-indicated desirable properties is required.

Accordingly, it is an object of my invention to provide a completely austenitic stainless steel exhibiting high-temperature creep strength.

It is another object of my invention to provide a steel that resists sensitizing carbide precipitation in service in the temperature range of 900° F. to 1400° F.

Still another object of my invention is to provide a completely austenitic stainless steel exhibiting good weldability.

Still another object of my invention is to provide a steel exhibiting good resistance to sensitization in the heat-affected zone produced by welding.

A further object of my invention is to provide a steel exhibiting, in combination, all the above-indicated desirable properties.

Other objects of my invention in part will be obvious and in part pointed out more fully hereinafter.

In brief summary, I have discovered that steel possessing the above-indicated combination of desirable properties may be produced by providing a completely and stably austenitic chromium-nickel steel containing small but effective additions of both columbium and boron and having a nitrogen content higher than is normal in commercial completely austenitic stainless steel. More particularly, I provide steel containing 0.005 to 0.04% columbium, 0.0005 to 0.01% boron, and 0.06 to 0.20% nitrogen. The steel also contains at least 12%, preferably 16%, of chromium, and sufficient nickel to render it completely austenitic. The steel also contains up to 0.2% carbon, up to 14% manganese, and up to 1% silicon. Essentially, the remainder of the steel is iron, except for incidental impurities. I have found that the columbium and boron contribute to the elevated-temperature deformation resistance of the steel, and the relatively high content of nitrogen makes it possible to reduce the columbium content to a very low level, this lowering the cost and improving the weldability of the steel without causing it to lose its superior elevated-temperature strength or resistance to sensitization. I have also discovered that although boron may be used in amounts of up to 0.01% without impairment of hot workability, amounts of boron over 0.002% drastically increase the susceptibility of the

2

steel to sensitization in the heat-affected zone produced by welding. Accordingly, in a preferred embodiment, useful for welding applications, the steel of my invention contains about 0.001 to 0.002% boron.

The steels of my invention may be readily distinguished from known commercial steels and those disclosed in the prior art in certain important respects. The inventive steels may be distinguished from most prior-art and commercial austenitic stainless steels in their containing an effective, but small, amount of columbium. In commercial austenitic stainless steels, columbium is usually used, when added, in an amount of at least ten times the carbon content, as an agent to precipitate the carbon remaining in the steel and thereby avoid impoverishment of the grain boundaries in chromium as the result of formation of chromium carbides, the intent of the columbium addition being to stabilize the steel against the intergranular corrosion that tends to occur when columbium, titanium, or a similar strong carbide-forming element is not added and the above-indicated grain-boundary chromium impoverishment is permitted to occur. From the above-indicated columbium range, it will be apparent that in my steel columbium is added in a considerably smaller amount, not more than about equal to the carbon content. Therefore, the function of columbium in my steel is not to combine with the carbon to form columbium carbide.

It is another important point of distinction between the steels of my invention and those of the prior art that my steels are both completely austenitic and weldable. Prior art columbium-containing austenitic stainless steels are known in which weldability (resistance to weld filler-metal cracking) is obtained by balancing the composition so that a small percentage of delta ferrite, such as about 2 to 10%, is obtained in the microstructure of the weld metal. This practice is undesirable, because it necessitates close control of all the elements affecting the ferrite-austenite balance. In addition, delta ferrite transforms to an embrittling phase upon exposure to elevated service temperatures. Furthermore, delta ferrite can, in some environments, lead to impaired corrosion resistance. In the present invention, weldability is obtained in a completely austenitic columbium-containing stainless steel by limiting the amount of columbium to a maximum of 0.04%, and including amounts of nitrogen and boron to impart the desired elevated-temperature strength and resistance to sensitization.

I find that the above-indicated objects of my invention may be achieved by alloying with iron, containing if desired small amounts of incidental impurities in quantities not sufficient to detrimentally affect the properties in any substantial manner and not inconsistent with good steel-making practice, the following elements, in percent by weight:

	Percent
Carbon -----	Up to 0.2
Manganese -----	Up to 14
Silicon -----	Up to 1
Nickel -----	6 to 30
Chromium -----	12 to 30
Nitrogen -----	0.06 to 0.20
Boron -----	0.0005 to 0.01
Columbium -----	0.005 to 0.04

A more specific range of composition for my inventive steel is as follows:

	Percent
Carbon -----	0.02 to 0.10
Manganese -----	1 to 5
Silicon -----	Up to 0.50
Nickel -----	8 to 14
Chromium -----	16 to 20

	Percent
Columbium -----	0.01 to 0.04
Boron -----	0.001 to 0.002
Nitrogen -----	Over 0.08 to 0.14

Balance iron and incidental impurities.

A preferred range of composition for my steel is as follows:

	Percent
Carbon -----	0.05 to 0.08
Manganese -----	1 to 3
Silicon -----	Up to 0.35
Nickel -----	8 to 10
Chromium -----	16 to 20
Columbium -----	0.01 to 0.03
Boron -----	0.001 to 0.002
Nitrogen -----	0.09 to 0.14

Balance iron and incidental impurities.

Although alloys from which carbon, manganese, silicon, or any of them, is entirely absent will exhibit the desired combination of properties characterizing the steels of my invention, as a practical matter, none of these alloys can be entirely eliminated in any known economical manner. On the other hand, if the specified maxima in respect to these elements are not observed, difficulties may be encountered. Carbon contents too great lead to the intergranular precipitation in elevated-temperature service of chromium carbides, with consequent detrimental effect on the corrosion resistance of the steel. Also, with increased carbon, the corrosion resistance of a welded article is impaired, and localized corrosion tends to occur in the sensitized, heat-affected zone. The disadvantage of manganese contents higher than specified is that the cost of the alloy is increased, owing to increased alloying and processing costs. With silicon contents higher than specified, the weldability of the steel is impaired.

There are reasons for the desired minima specified for carbon and manganese in the more specific and the preferred ranges above. Carbon contents lower than those indicated above are desirably avoided, because of the added cost involved in making such low-carbon alloys. Steels containing about 0.05% carbon resist creep deformation better than steels containing about 0.03% carbon; hence, the above preferred range specifies steels having 0.05% carbon or more. With manganese contents less than 1%, the beneficial effect of manganese upon weldability is lost.

If amounts of columbium and boron less than those specified above are used, the elevated-temperature creep strength and sensitization resistance of the steel are impaired. If amounts of columbium greater than those specified are used, the steel becomes difficult to weld. With the use of amounts of boron greater than about 0.005%, the hot workability of the steel begins to be impaired, and contents of boron greater than 0.01% are consequently desirably avoided. In steel to be used in

sheet or plate form for welding, the boron content is desirably limited within the more specific and the preferred ranges, to avoid localized corrosion engendered by sensitization of the heat-affected zone produced by welding.

With the use of amounts of nitrogen less than those indicated above, the elevated-temperature creep strength and the sensitization resistance of the steel are impaired. Higher nitrogen contents are contraindicated because of cost.

Phosphorus and sulfur may be present as impurities in the amounts usually permitted by commercial standards (about 0.025% maximum for each). The use of these elements in greater amounts for special purposes, such as improving strength or machinability, has not been investigated.

Tantalum may be substituted for columbium, in whole or in part, on the basis of two parts by weight of tantalum for one part of columbium.

Molybdenum may be added, if desired, in small amounts up to about 5%, the usual purpose of such addition being improvement of corrosion resistance and elevated-temperature strength.

Copper in my steel may be tolerated in small amounts up to about 1%, and even in larger amounts, up to about 3%, which may be added for special purposes.

Tungsten may be substituted for molybdenum, in whole or in part, on the basis of two parts by weight of tungsten for one part of molybdenum, but ordinarily it is disadvantageous to employ tungsten in this manner because of its high cost.

Titanium may occur in small amounts in commercial heats of my steel if it is present in the melt scrap or added for deoxidation. Titanium appears not to be a useful strengthening element, and it appears to reduce the corrosion resistance of specimens sensitized by prolonged exposure to high temperature. Accordingly, titanium would not be intentionally added to my steel, except in small amounts not over several hundredths of a percent.

Vanadium may be present as an impurity in small amounts; it is neither beneficial nor damaging.

Aluminum, rare-earth metals, calcium, or magnesium may be present in small amounts as a result of deoxidation practices.

Antimony, arsenic, tin, and lead all occur in trace amounts as residual elements in commercial steels, and all are very damaging to hot workability. Accordingly, in my steels these elements are preferably substantially absent.

So that the general nature of my invention as heretofore disclosed may be more particularly understood, I now disclose certain specific examples thereof and comparative test results.

The chemical compositions of certain steels investigated in experimental work demonstrating my invention are set forth in Table I below.

TABLE I.—COMPOSITION OF STEELS USED FOR COMPARATIVE TEST RESULTS

Steel Code	C	Mn	Si	Cr	Ni	Mo	N	B	Cb	Ta
304L-----	0.031	1.03	0.54	17.81	11.71	-----	0.025	*N.D.	N.D.	-----
B-----	0.034	1.25	0.63	17.41	11.74	-----	0.017	0.005	-----	-----
C-----	0.032	1.30	0.68	17.37	11.92	-----	0.018	0.005	0.12	-----
4-----	0.047	1.18	0.47	17.06	11.98	-----	0.024	N.D.	N.D.	-----
4C-----	0.046	1.18	0.46	17.19	11.96	-----	0.022	N.D.	0.12	-----
4B-----	0.047	1.20	0.46	16.96	11.94	-----	0.027	0.004	N.D.	-----
4CB1-----	0.051	1.22	0.47	17.23	11.84	-----	0.023	0.005	0.056	-----
4CB2-----	0.048	1.22	0.52	17.25	11.74	-----	0.022	0.005	0.097	-----
4CB3-----	0.051	1.21	0.49	17.08	11.87	-----	0.025	0.004	0.13	-----
4CB4-----	0.051	1.19	0.47	17.08	11.89	-----	0.026	0.0012	0.15	-----
4HCB-----	0.078	1.26	0.52	17.15	11.86	-----	0.023	0.004	0.10	-----
4TB2-----	0.049	1.19	0.56	17.18	11.84	-----	0.023	0.005	-----	0.071
4CB8-----	0.057	1.18	0.43	17.19	8.02	-----	0.046	0.006	0.13	-----
16-----	0.048	1.20	0.50	15.87	13.99	1.99	0.024	N.D.	N.D.	-----
16CB-----	0.048	1.22	0.50	15.31	13.97	1.98	0.025	0.004	0.16	-----
4N-----	0.056	1.86	0.22	17.35	9.15	-----	0.107	-----	-----	-----
4BN-----	0.055	1.92	0.23	17.34	9.09	-----	0.114	0.004	-----	-----
4CBN-----	0.049	1.20	0.54	17.17	11.97	-----	0.10	0.004	0.038	-----
4CBN2-----	0.053	1.98	0.27	17.41	9.23	-----	0.075	0.003	0.012	-----

*None Detected.

In each case, the balance was iron except for incidental impurities in small amounts not substantially affecting the properties. In the above table, a blank space indicates that the given element was neither added nor analyzed for. In Table I, steel 4CBN2 is a steel with my invention in its broader aspects, steel 4CBN is another steel of my invention, and the remaining steels are presented for purposes of comparison and demonstration of the pertinent technical phenomena.

Resistance to elevated-temperature deformation

The elevated-temperature resistance to deformation (creep strength) of the above steels was investigated, and the results are presented below in Tables II and III:

TABLE II

Steel Code	Stress to Rupture in 1,000 Hrs. at 1,100° F., p.s.i.	Creep-Rupture Ductility, Percent
304L.....	17,000	14
B.....	29,000	50
C.....	36,000	40
4.....	23,500	31.5
4C.....	32,000	13
4B.....	25,000	25
4CB1.....	34,500	19
4CB2.....	35,500	17
4CB3.....	36,000	14
4CB4.....	35,000	20
4TB2.....	34,500	-----
4HCB.....	37,000	21
4CB8.....	38,500	-----
4N.....	28,000	16
4BN.....	29,000	14
4CBN.....	36,000	14
4CBN2.....	35,000	24

TABLE III

Steel Code	Stress to Rupture in 1,000 Hrs. at 1,200° F., p.s.i.	Creep-Rupture Ductility, Percent
304L.....	12,000	22
B.....	18,000	60
C.....	22,000	75
4.....	14,500	31
4CB8.....	23,000	36
4CB4.....	21,500	32
16.....	19,500	35
16CB.....	28,000	64

From the above data, it will be apparent that additions of columbium and boron provide improved creep-rupture strength over a fairly wide range of carbon content. Comparison of steels C, 4CB2, and 4HCB, which all contain small additions of both boron and columbium and which have carbon contents of 0.03, 0.05, and 0.08%, respectively, reveals that in each case a creep-rupture strength greater than that of steel 304L or steel 4 (AISI Type 304) is obtained. With these steels, 1000-hour 1100° F. rupture stresses of 36,000, 35,000 and 37,000 p.s.i., respectively, as compared with the 17,000 p.s.i. and 23,500 p.s.i. rupture stress for steel 304L and steel 4, respectively, were obtained.

It also appears that additions of boron alone or columbium alone somewhat improve the creep strength of austenitic stainless steel, but the resultant strengths are lower than those obtained when the two elements are used together. Moreover, additions of boron alone appear to have little effect upon the creep strength of steel 4.

Comparison of steels 4C, 4B, 4CB1, 4CB2, and 4CB3 demonstrates several points. In completely austenitic steels with ordinary nitrogen contents of about 0.025% and 0.005% of boron, it is necessary to add about 0.15% of columbium to achieve maximum strengthening. The addition of a relatively small amount of columbium, such as about 0.05%, gives a considerable increase in strength, and although further additions are beneficial, the improvement is less rapid. Moreover, the above data demonstrate that the effect of adding boron and columbium together is greater than the effect predictable from a knowledge

of the improvement obtained when each is added separately; that is, boron and columbium, used together, provide a synergistic effect.

Comparison of steel 4B and steel 4TB2 reveals that, in steels of this kind, when allowance is made for the higher atomic weight of tantalum, the same strengthening effect is obtained when tantalum is substituted for columbium.

For best strengths, it appears desirable to keep the nickel content low. Comparison of steel 4CB3 and steel 4CB8 shows that slightly higher strength is obtained in steels containing 8% nickel than in steels containing 12%.

The foregoing data also reveal that additions of small amounts of boron and columbium have a large strengthening effect on molybdenum-containing austenitic steels, as is indicated by comparison of the 1200° F. rupture strengths of steels 16 and 16CB.

The foregoing comparisons and observations are considered to serve as a guide for the selection of austenitic stainless steels containing columbium and boron and exhibiting improved creep-rupture strength. As such, these observations will be valuable in determining an optimum composition for a particular purpose in the practice of my invention. My invention is not concerned, however, with merely the addition of small quantities of boron and columbium to obtain improved creep strength; rather, it relates to such steels which exhibit as well other desirable properties, such as improved weldability, improved resistance to sensitization as a result of prolonged exposure to elevated temperatures, and improved resistance to sensitization within a heat-affected zone produced by welding. According to my invention, I use steels containing added nitrogen and boron together with a columbium content sufficiently high to yield a substantial strength-improving effect, but nevertheless substantially lower than the approximately 0.15% columbium indicated above as required for the achievement of maximum strength at a lower nitrogen content. Moreover, with the smaller columbium contents in the steels of my invention, I obtain a completely austenitic stainless steel having improved weldability (resistance to filler weld metal cracking). At the same time the cost of the steel is less, because of its lower columbium content.

The data cited in Tables I and II demonstrate that in steels of relatively high nitrogen content, such as about 0.11%, creep strengths about as good as those of relatively low-nitrogen austenitic chromium-nickel stainless steels containing about 0.15% columbium are obtained. As a comparison of steels 4N, 4BN, 4CBN, and 4CBN2 will show, however, the desired high creep strength is not obtained if the columbium is omitted; moreover, a comparison of steels 4N and 4BN reveals that the addition of boron alone yields a relatively minor effect.

Although adding small amounts of boron and columbium (0.0005 to 0.01% boron and 0.005 to 0.04% columbium) to completely austenitic stainless steel with high nitrogen (0.06 to 0.20%) improves the creep strength, even more importantly, improvements are obtained in other respects—corrosion resistance, weldability, and resistance to weld decay, as will be more fully discussed below.

Corrosion resistance

In completely austenitic stainless steels, particularly steels subjected in service to elevated temperatures for prolonged periods of time, corrosion frequently occurs as a result of "sensitization" which is caused by precipitation of grain-boundary carbides during prolonged elevated-temperature exposure. This "sensitization" occurs almost invariably, and to a severe extent, in steels having carbon available for grain-boundary precipitation. Because of this phenomenon, an ordinary austenitic stainless steel, such as AISI Type 304, would not be used for elevated-temperature service if corrosion resistance is needed or desired. Instead, there would be employed either a low-carbon austenitic stainless steel, such as AISI Type 304L, or an austenitic stainless steel stabilized

by the addition of a strong carbide forming element, such as AISI Type 321 (stabilized by the addition of titanium in an amount at least four times the carbon content) or AISI Type 347 (stabilized by the addition of columbium in an amount at least ten times the carbon content). Naturally, the improved properties are obtained at added cost; the current market prices of AISI Types 304L, 321, and 347, exceed that of AISI Type 304 by about 15%, 26%, and 44%, respectively. From the results in Table IV below, it will be seen that the steels of my invention afford excellent resistance to sensitization, far superior to that obtainable with AISI Type 304L steel and about the same as or slightly better than that of the expensive Type 347 steel, yet it will be appreciated, considering the columbium content of the steel of this invention, the inventive steels should be appreciably less expensive than AISI Type 347 steel.

TABLE IV

Steel	Corrosion Rate, mils/mo.					
	First 48-Hr. Period	Second 48-Hr. Period	Third 48-Hr. Period	Fourth 48-Hr. Period	Fifth 48-Hr. Period	Average of Five Periods
304L.....	1.57	7.22	33.7	38.0	35.2	23.1
B.....	1.10	1.55	2.73	4.73	10.6	4.14
C.....	1.10	0.73	0.81	1.05	1.19	0.96
4.....	Not Tested—Obviously Poor					
4B.....	2.92	16.5	61.8	Test Discontinued		
4C.....	1.81	5.30	25.7	49.6	43.6	25.2
4CB1.....	1.38	2.01	2.58	2.92	3.49	2.48
4CB2.....	1.27	1.55	1.67	1.64	1.64	1.55
4CB3.....	1.07	1.04	1.27	1.37	1.60	1.27
4CB4.....	1.68	2.38	4.68	5.73	6.11	4.21
4TB2.....	1.35	1.73	2.03	2.28	2.35	1.95
4N.....	1.95	6.13	32.6	Test Discontinued		
4CBN.....	1.07	0.95	1.01	1.02	1.10	1.03
4CBN2.....	1.56	1.84	2.17	2.51	4.00	2.42
347.....	3.43	4.01	4.46	5.94	6.53	4.87

In the foregoing table, steels 4CBN and 4CBN2 are steels of my invention, and the other steels are presented for comparison, or to demonstrate phenomena indicating how the composition of my inventive steels might advantageously be varied for particular purposes.

The above results were obtained by the use of the familiar Huey test, substantially as described in ASTM Designation A262-55T. Coupons about 1 in. sq. by 0.1 in. thick were cut, solution annealed, sensitized, and then tested by immersion in 65% boiling nitric acid. The sensitization treatment was rather more severe than is usually employed, being done at 1100° F. for 24 hours, rather than at 1200° F. for one hour.

Weldability

The weldability, i.e., the resistance of the metal to weld filler metal cracking, of the inventive steels (and certain of the other steels for purposes of comparison) was determined. Numerical results were obtained, using the General Electric hot-crack susceptibility test, as more fully described in "A Weld Cracking Susceptibility Test For Sheet Materials," J. S. Boudreau, Welding Journal Research Supplement, vol. 35, pages 164S to 168S (April 1956). High ratings in the hot-crack susceptibility test are favorable. In addition to the test ratings, the following Table V also shows the visual observations made of the extent of filler metal cracking in actual test welds.

TABLE V

Steel	Weldability Rating In General Electric Hot-Crack Susceptibility Test	Extent of Filler Metal Cracking In Actual Test Welds
304L.....	1,500.....	N.D. ²
B.....	1,800.....	None.
4CB6.....	300.....	Very severe.
4CB7.....	700.....	Severe.
4CB8 ¹	3,800.....	None.
4CB9.....	700.....	Severe.
4CBN.....	700.....	N.D.
4CBN2.....	3,000 to 3,500.....	None.
347.....	900.....	N.D.

¹ Steel 4CB8 contains 2% ferrite in weld-metal.

² Not Determined.

A comparison of steels 304L and B shows that the addition of about 0.005% of boron has no detrimental effect on weldability. Steels 4CB6, 4CB7, and 4CB9 all contain 0.09% or more of columbium; all have low ratings; this indicates that in fully austenitic steels, even such relatively small amounts of columbium have a very damaging effect on weldability. Steel 4CBN, which contains only 0.038% of columbium, also has a low rating; the detrimental effect of columbium is encountered with much lower columbium contents than might otherwise be expected. The very high rating of steel 4CB8, which contained about 0.15% columbium, shows that the detrimental effect of columbium is overcome if the steel is balanced, in its respective contents of austenite-forming and ferrite-forming elements, to provide some delta ferrite; as has been previously observed, however, this invention relates to completely austenitic stainless steels, which contain no delta ferrite and consequently avoid the above-mentioned difficulties of requiring close control of all elements affecting the ferrite-austenite balance during the melting operation and containing a microstructural constituent transforming to an embrittling phase upon exposure to elevated service temperatures. Finally, a comparison of steels B and 4CBN2 shows the favorable effect upon weldability of using relatively high manganese and relatively low silicon contents.

Weld decay

Susceptibility of austenitic stainless steels in the welded condition to intergranular corrosion occurring within a heat-affected zone, typically about 1/8 in. away from and running parallel with the weld, is referred to as "weld decay." Weld decay differs from ordinary sensitization in that carbide precipitation occurs athermally, owing to the heat applied during welding, rather than isothermally, as in the case of sensitization induced by prolonged exposure to elevated temperatures.

As is disclosed by F. K. Bloom and M. E. Carruthers, "Accelerated Corrosion Testing of Chromium-Nickel Stainless Steel Weldments," ASTM Special Technical Publication No. 93, page 87, a test for determining susceptibility of welded austenitic stainless-steel samples comprises immersing a welded specimen in a solution maintained at about 176° F. and consisting of 10 weight percent of nitric acid, 3 weight percent hydrofluoric acid, and the balance water. The samples are immersed for four hours, removed from the solution, brushed clean, dried, and examined visually for evidence of weld decay.

Results of tests conducted upon various steels to determine their susceptibility to weld decay, together with the compositions of the steels tested, appear in the following Table VI.

TABLE VI

Steel	Composition, Weight Percent							Extent of Weld Decay
	C	Mn	Si	Ni	Cr	Cb	Others	
304-1	0.06	1.29	0.44	9.51	17.8			Severe.
321	0.073	1.36	0.59	9.61	18.3		0.52% Ti	None.
347	0.06	1.56	0.82	9.80	17.3	0.83		None.
4CB6	0.055	1.09	0.40	10.14	17.1	0.17	0.0014% B	None.
4CB7	0.055	1.10	0.40	10.06	17.4	0.09	0.0034% B	Severe.
4CB8	0.057	1.18	0.43	8.02	17.2	0.13	0.0056% B	Severe.
4CB9	0.064	1.06	0.43	10.0	16.8	0.11	0.0006% B	None.
4B	0.047	1.20	0.40	11.94	17.0		0.0040% B	Severe.
4CBN	0.049	1.20	0.54	11.97	17.2	0.038	0.0040% B	Severe.
304-L	0.031	1.03	0.54	11.71	17.8			Moderate.
347	0.056	1.51	0.84	12.84	18.1	0.77	0.11% Ta	None.
304-2	0.074	1.3	0.4	19	18			Severe.

¹ Nominal.

The foregoing results indicate the effect of boron content on the weld-decay susceptibility of completely austenitic stainless steels. Steels 4CB6 and 4CB9, with relatively low boron contents, exhibited no weld decay, whereas steels 4CB7 and 4CB8, which are essentially similar except for higher boron contents, exhibited severe weld decay. Accordingly, the best mode presently contemplated for practicing the invention, to afford a steel exhibiting a remarkable combination of desirable properties, is to produce a steel containing 0.001 to 0.002% boron, 0.01 to 0.03% columbium, and over 0.08 to 0.14% nitrogen, together with chromium, nickel, manganese, carbon, and silicon in appropriate quantities as above indicated, the balance being iron except for incidental impurities in amounts not detrimentally affecting the properties. With such a steel, it is possible to obtain the good creep strength that is exhibited by columbium-boron-modified completely austenitic stainless steels containing about 0.15% columbium, but without adding columbium in that amount. Such preferred steels exhibit, moreover, the excellent resistance to long-term elevated-temperature sensitization that has hitherto been available commercially only in the relatively expensive titanium- and columbium-stabilized stainless grades. Such steels also exhibit a remarkable resistance to weld filler metal cracking, i.e., remarkably good weldability, as evidenced by a value of about 3000 or greater in the General Electric hot-crack susceptibility test. Finally, as mentioned above, such steels possess good resistance to sensitization occurring in a heat-affected zone produced by welding.

While I have shown and described certain embodiments of my invention, I intend to cover as well any change or modification which may be made without departing from its spirit and scope.

I claim:

Completely and stably austenitic stainless steel exhibiting good weldability, as evidenced by a value of more than 3,000 in the G.E. hot crack test, in combination with high elevated-temperature creep strength, as evidenced by a 1000-hour 1100° F. rupture strength of over 34,000 p.s.i., said steel consisting essentially of about:

	Percent
Chromium	17.41
Nickel	9.23
Manganese	1.98
Carbon	0.05
Silicon	0.27
Nitrogen	0.075
Boron	0.003
Columbium	0.012
Balance iron and incidental impurities.	

References Cited by the Examiner

UNITED STATES PATENTS

3,107,997 7/1961 Kozlik 75—128 X

DAVID L. RECK, *Primary Examiner*.

P. WEINSTEIN, HYLAND BIZOT, *Examiners*.