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STAINLESS STEEL

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ABSTRACT OF THE DISCLOSURE

A low cost ferritic stainless steel with exceptionally good corrosion resistant properties having the following composition:

Carbon	0.1% maximum.
Manganese	2.0% maximum.
Silicon	0.5% maximum.
Chromium	6–12%.
Aluminum	2–7%.
Copper	0.2–3.0%.
Molybdenum	up to 2.0%.
Iron	balance.

wherein chromium plus aluminum is at least about 13.0% and copper plus molybdenum is at least 0.5%.

BACKGROUND OF THE INVENTION

This invention relates generally to stainless steel, and more specifically, to a new, low cost, 6 to 12 percent chromium stainless steel having corrosion resistance equal to or better than the conventional 17 percent chromium stainless steels.

The superior corrosion resistance of commercial stainless steels is primarily due to the addition of chromium to the alloy in amounts which vary from 4 to 30 percent. Since the corrosion resistance of stainless steel is more or less a direct function of the chromium content, it is well accepted that those stainless steels having large amounts of chromium are usually superior in corrosion resistance to those having lesser amounts.

The three most common stainless steels in commercial use today are the AISI (American Iron and Steel Institute) Types 410, 430 and 304 which contain about 12, 17 and 18 percent chromium respectively. Of these three most common stainless steels, AISI Type 304, having the greatest amount of chromium plus about 8% nickel, is the best for conventional corrosion resistance applications.

In addition to being one of the major constituents for corrosion resistance, chromium is also the principal cost element in most commercial stainless steels. Therefore, AISI Type 304 stainless steel, in addition to being superior in corrosion resistance, is also more expensive than AISI Types 410 and 430 or most other lower chromium stainless steel.

Because of the relatively high cost of chromium, there are continuing efforts to find replacements for at least a portion of chromium by other cheaper elements that would reduce production costs yet maintain a reasonably high degree of corrosion resistance.

In my co-pending joint patent application, Ser. No. 829,110 now Pat. No. 3,594,156, there is disclosed one such stainless steel having only 6 to 12 percent chromium, and yet having corrosion resistance characteristics equal to or greater than AISI Type 304 stainless steel. In that steel small, relatively controlled amounts of aluminum, copper, molybdenum and columbium are added to the steel to more than compensate for the reduced chromium content.

SUMMARY OF THE INVENTION

This invention is predicated upon my development of a new statinless steel wherein a portion of the chromium

content is replaced by controlled amounts of aluminum and copper and with optional additions of molybdenum. No columbium is added to this steel. This lower cost stainless steel contains chromium in amounts of from 6 to 12 percent, and yet has corrosion resistance characteristics equal to or greater than AISI Type 430 stainless steel. Although the steel of this invention is not quite as corrosion resistant as is the alloy containing columbium, i.e., it being comparable to AISI Type 430 rather than Type 304, it is substantially cheaper without additions of columbium, and further, molybdenum can be completely eliminated where economy is the major consideration.

Accordingly, it is an object of this invention to provide a new low cost stainless having exceptionally good corrosion resistance and containing from 6 to 12 percent chromium and lesser controlled amounts of aluminum and copper with optional additions of molybdenum.

It is another object of this invention to provide a new low cost statinless steel having from 6 to 12 percent chromium and yet having corrosion resistance characteristics equal to or greater than the 17 percent chromium stainless steels.

It is a further object of this invention to provide a new stainless steel having corrosion resistance characteristics equal to or greater than AISI Type 430 stainless steel and yet utilizing lesser amounts of chromium.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Although aluminum, molybdenum, and copper are known to impart some small degree of corrosion resistance to steel, I have found that there are substantial beneficial interactions between certain combinations of these elements which even further contribute to corrosion resistance. Even relatively small combined amounts of chromium and aluminum, or copper, with or without molybdenum will render exceptional corrosion resistant characteristics to a steel, I have further found that a combination of these beneficial interactions can be used as a substitute for a large portion of the chromium in stainless steels without an adverse effect on corrosion resistance. These substituted elements being cheaper in cost and being used in comparatively smaller amounts have the effect of making a high quality stainless steel cheaper to produce and yet maintaining exceptional corrosion resistance characteristics. A stainless steel in accordance with this invention therefore may have corrosion resistance characteristics equal to or better than AISI Type 430 statinless steel while containing about half, or even less than half as much chromium and low cost quantities of aluminum and copper, and molybdenum if desired to optimize corrosion resistance.

The statinless steel of this invention is ferritic and has the following general composition:

Carbon	0.1% maximum.
Manganese	2.0% maximum.
Silicon	0.5% maximum.
Chromium	6 to 12.
Aluminum	2 to 7.
Copper	0.2 to 3.0%.
Molybdenum	0.0 to 2.0%.

The balance of the steel should of course be iron (i.e., iron with other usual steelmaking impurities). The above composition range is further limited by the facts that the combination of chromium plus aluminum must be at least 13 percent or very near thereto and that the copper or combination of copper plus molybdenum must be at least 0.5 percent.

Although as little as 2 percent aluminum will be beneficial to the corrosion resistance properties of steels having the higher chromium contents, optimum results are obtained only if the aluminum is maintained within the range of 5 to 7 percent at ideal chromium contents of 6 to 10 percent. Chromium contents toward the higher end of the range will of course provide slightly better corrosion resistance. Since the improved corrosion resistance towards the extreme higher end of the range is quite slight, however, only about 8 percent chromium or from 6 to 10 percent is preferred for most applications as a practical good balance between corrosion resistance and economy. Since the foremost essential requirement is that chromium plus aluminum equal at least about 13 percent, a provision for 8 percent chromium will make it essential that at least about 5 percent aluminum be added.

Although molybdenum may be completely eliminated, copper, on the other hand, must be present in an amount of at least 0.5 percent, or at least 0.2 percent when the steel contains 0.3 percent molybdenum or more. Ideally, copper is maintained between 0.7 and 1.0 percent for optimum effect on corrosion resistance, with or without the presence of molybdenum. Additions of molybdenum should be eliminated when economy is the major consideration, but for optimum corrosion resistance, molybdenum in concentrations of at least about 1.0 percent is preferred. Increasing the molybdenum and/or copper contents above the preferred 1.0 percent each will provide only slight improvement in corrosion resistance up to about 2.0 percent each, or up to about 3.0 percent copper when molybdenum is absent. Beyond these limits no apparent improvement is obtained.

Accordingly, the preferred composition of this stainless steel, for optimum corrosion resistance at a minimum cost, would be about 8 percent chromium, 5 percent aluminum and 1 percent each of copper and molybdenum.

The effect of copper on corrosion resistance properties is actually detrimental at chromium contents below 6 percent, but of course beneficial at chromium levels above 6 percent. Therefore, the minimum chromium content of 6 percent is somewhat critical to avoid the adverse effects of copper.

Nickel, titanium and silicon additions were considered for this alloy, but neither showed any beneficial effect. Nickel and titanium are neither beneficial nor detrimental. Silicon, on the other hand, not only has a detrimental effect on corrosion resistance, but further adversely affects the metallurgical quality of the steel. Therefore, silicon should be kept at residual impurity amounts of no more than 0.5 percent.

In order to quantitatively evaluate the stainless steels of this invention, over 70 heats of steel having varying compositions were tested for actual corrosion resistance and potentiodynamic polarization. The potentiodynamic polarization test is based upon the fact that stainless steels achieve their high resistance to corrosion by their ability to spontaneously passivate (i.e., form a protective oxide film) in the corrosive environment. Although active metals such as iron can be made to passivate electrolytically by the application of an electrical current or potential in a

proper solution, the "stainless" metals inherently passivate without the applied force. The driving force for the electrochemical reaction is provided by the currents resulting from local variations in potential at the metal surface. The inherent ability to form a protective film (passivate) requires that this reaction have a thermodynamic and kinetic tendency greater than any other electrode reaction that might possibly take place.

A metal is passive if, on increasing the electrode potential toward more noble values, the rate of anodic dissolution in a given environment under steady-state conditions becomes less than the rate at same less noble potential. The tendency for passivation of stainless steels is a function of both a critical current density and a critical potential. Therefore, by measuring these parameters and comparing them with those values for commercially available stainless steels, the passivation tendency, and hence the corrosion resistance characteristics, for any experimental heat can be readily evaluated. A strong tendency to passivate is manifested by an active passivation potential and a low critical current density.

Table I below contrasts the critical current density and chemistry of AISI Type 430 stainless steel with a representative sampling of the experimental heats, most of which had compositions in accordance with this invention. AISI Type 430 stainless steel was shown to have a critical current density of 7.2 ma./cm.^{2}.

TABLE I

Example No.	Chemical composition, by weight									Critical current, ma./am.^{2}
	C	Mn	P	S	Si	Cr	Al	Cu	Mo	
AISI 430	0.610	0.65	0.020	0.007	0.52	17.10	0.01	0.05	0.05	7.2
1	0.006	0.52	0.005	0.003	<0.03	8.49	4.93	1.03	0.018	5.5
2	0.080	0.51	0.017	0.005	0.28	8.95	3.98	0.62	(1)	7.2
3	0.065	0.51	0.017	0.005	0.29	7.91	5.19	0.64	(1)	7.2
4	0.025	0.50	0.005	0.006	0.028	8.00	4.98	1.05	0.55	4.25
5	0.016	0.53	0.005	0.008	0.96	8.34	5.99	1.10	1.05	3.3
6	0.005	0.53	0.004	0.008	0.94	8.14	5.02	1.08	0.53	3.2
7	0.016	0.53	0.005	0.009	0.12	8.37	5.18	1.04	0.53	2.6
8	0.004	0.54	0.005	0.007	0.09	8.14	4.94	1.08	0.52	3.1
9	0.015	0.51	0.014	0.006	0.13	8.98	4.86	1.03	(1)	5.0
10	0.08	0.51	0.017	0.005	0.28	8.95	3.98	0.62	(1)	7.1
11	0.065	0.51	0.017	0.005	0.29	7.91	5.19	0.64	--------	7.1
12	0.015	0.51	0.014	0.006	0.13	8.98	4.86	1.03	--------	5.0
13	0.068	0.52	0.015	0.006	0.29	10.30	1.94	1.02	--------	10.0
14	0.050	0.50	0.006	0.011	0.11	7.86	4.19	0.95	--------	9.0
15	0.048	0.52	0.006	0.008	0.14	8.07	4.43	0.31	--------	14.0

[1] Not determined residual amounts.

In Table I above, it is readily apparent that the stainless steels having compositions in acordance with this invention do have equal or lower critical current densities than the AISI Type 430 stainless steel, and hence, equal or greater corrosion resistance tendencies.

Upon careful examination of the specific examples shown in the above Table I, it should be noted that the last three examples had compositions outside the critical ranges taught above. Examples 13 contained insufficient aluminum at 1.94 percent, Example 14 contained insufficient chromium plus aluminum at 12.05 percent, and Example 15 contained insufficient copper at 0.31 percent. It should be further noted that each of these examples displayed higher critical current densities than the standard, AISI 430. It may be further noted that Examples 2, 4 and 10 contained very slightly less than 13 percent combined chromium plus aluminum, namely 12.93 percent, 12.98 percent and 12.93 percent respectively. These examples were, however, sufficiently close to the 13 percent limit that they did possess the desired lower critical current densities. Examples 13 and 14 containing combined aluminum and chromium levels of 12.24 percent and 12.05 percent respectively were insufficient, and hence, substantially inferior to the standard AISI 430 steel.

The above potentiodynamic polarization tests were verified by exposing samples of my stainless steel along with samples of AISI Type 430 stainless steel to the corrosive atmosphere of a coke making plant. After seven months exposure, my stainless steels were substantially less corroded than the AISI Type 430 samples. In addition, the test heats were given chemical corrosion tests in sulfuric acid and sodium chloride. Table II below shows typical results contrasting two experimental heats with AISI Type 430. The first experimental heat was Example 12 also shown in Table I above. The second experimental heat, Example 16, is a heat (not shown in Table I) having a composition outside the scope of this invention.

TABLE II

Example No.	Heat No.	Major alloying elements				Atmosphere corrosion tests, 6 months — Weight loss, g.			Wet chemical corrosion tests	
		Cr	Al	Cu	Mo	Test #1	Test #2	Average	5% H_2SO_4 at room temp., 47 hrs., weight loss, gm.	3½% NaCl at room temp., 47 hrs., weight loss, gm.
Standard	AISI 430	17.00	(1)	0.06	0.14	0.3031	0.3204	0.3117	5.4365	0.0095
12	Z21047	8.98	4.86	1.03	(1)	0.2843	0.3233	0.3038	3.2275	0.0012
16	Z21049	8.05	3.97	0.42	0.22	0.4795	0.4860	0.4827	6.550	0.0090

[1] See footnote at end of table I.

Examination of Table II will show that the steel in accordance with this invention (Example 12) was indeed superior in corrosion resistance to AISI Type 430 steel. Example 16, which contained an insufficient amount of copper and an insufficient amount of chromium plus aluminum (12.02 percent) was inferior to AISI Type 430 steel.

I claim:

1. A low chromium ferritic stainless steel consisting essentially of up to 0.10 percent carbon, up to 2.0 percent manganese, 6 to 12 percent chromium, 2 to 7 percent aluminum, 0.2 to 3.0 percent copper, up to 2.0% molybdenum, and the balance substantially iron with the combined chromium plus aluminum content being at least about 13.0 percent, and the combined copper plus molybdenum content being at least 0.5 percent.

2. A low chromium stainless steel according to claim 1 having about 8 percent chromium, 4 to 7 percent aluminum, and about 1 percent each of copper and molybdenum.

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