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CORROSION-RESISTANT ALLOYS

John H. Culling, Kirkwood, Mo., assignor to Carondelet Foundry Company, St. Louis, Mo.

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ABSTRACT OF THE DISCLOSURE

An alloy which is resistant to corrosion by both oxidizing and reducing sulfuric acid solutions over a wide range of acid strengths. The alloy consists of between about 36% and about 46% by weight nickel, between about 33% and about 42.06% by weight chromium, between about 2.94% and about 7.84% by weight molybdenum, between about 1.95% and about 5.18% by weight copper, up to about 0.12% by weight carbon, up to about 1.50% by weight silicon, up to about 2.50% by weight manganese, up to about 2% by weight titanium, up to about 4% by weight niobium plus tantalum, up to about 0.01% by weight boron, and the balance essentially iron. Most of the alloys of the invention are readily weldable, machinable, and workable. Those which cannot be readily worked are generally hard and wear-resistant.

BACKGROUND OF THE INVENTION

This invention relates to corrosion-resistant alloys and more particularly to weldable, machinable and workable alloys which are resistant to corrosion by both oxidizing and reducing sulfuric acid solutions over a wide range of acid strengths.

Sulfuric acid is an ubiquitous industrial reagent which is generally very corrosive to most metals. The corrosivity of sulfuric acid to any given metal, however, varies widely with the strength of the acid, the temperature of the acid environment, and the nature and concentration of various contaminants. Because of the wide ranging uses for sulfuric acid, industrial process streams may be found which run the gamut of sulfuric acid concentrations; which must be handled from temperatures below room temperature up to the boiling point of the acid; and which contain an extensive variety of contaminants, e.g., other acids and salts.

For purposes of analyzing and predicting their corrosive effect on metals, acids and other corrosive agents are commonly classified as either "oxidizing" or "reducing." A reducing medium is generally defined as one which includes no component more oxidizing than the hydrogen ion or hydronium ion while an oxidizing medium is one which does contain such a component. Sulfuric acid, along with such other common materials as hydrochloric acid, acetic acid, phosphoric acid, aluminum chloride, hydrobromic acid, and hydrofluoric acid, is normally a reducing medium. At concentrations above approximately 85% by weight, however, sulfuric acid becomes an oxidizing agent. If its temperature is elevated, sulfuric acid may be oxidizing at even lower concentrations. Thus, a 60% by weight sulfuric acid solution becomes oxidizing at temperatures in excess of 150° F. Even lower concentrations of sulfuric acid can be moderately to strongly oxidizing when they contain various oxidizing acids and salts. Among the most common solutions of this type are the so-called "mixed acids," which are mixtures of sulfuric acid and nitric acid used in organic nitration processes. Other oxidizing materials, some of which may be found in industrial sulfuric acid streams, include hydrogen peroxide, ferric sulfate, silver nitrate, potassium nitrate, sodium nitrate, copper sulfate, potassium permanganate, sodium dichromate, chromic acid, calcium chloride, mercuric chloride, aqua regia, sodium hypochlorite, ferric chloride, and cupric chloride.

Because of this variety in the character of various industrial sulfuric acid streams, there are relatively few metals available which can be said to be generally useful in sulfuric acid service. For example, a metal which quite satisfactorily resists the corrosive effect of reducing-type sulfuric acid solutions may fail rapidly if a small proportion of an oxidizing agent is present, or if the temperature of the system is elevated well above room temperature. Many alloys which resist dilute sulfuric acid solutions are completely unsuitable for sulfuric acid solutions having concentrations in excess of 60% or 70% by weight. Certain other alloys are available which are highly resistant to a wide range of sulfuric acid solutions, including concentrated sulfuric acid but, for the most part, such of these alloys as have been available have suffered from undesirable mechanical or other properties. Common drawbacks of such alloys have been poor machinability and weldability, with poor workability being an almost universal problem with these alloys, i.e., essentially none of these alloys can be feasibly produced in wrought form.

SUMMARY OF THE INVENTION

Among the several objects of the present invention, therefore, may be noted the provision of novel alloys which are resistant to sulfuric acid over a wide range of concentrations; the provision of such alloys which are resistant to sulfuric acid up to 200° F. or higher; the provision of such alloys which are resistant to sulfuric acid solutions containing oxidizing contaminants; and the provision of such alloys which are weldable, machinable and workable. Other objects and features will be in part apparent and in part pointed out hereinafter.

The present invention is therefore directed to an alloy resistant to corrosion by both oxidizing and reducing sulfuric acid solutions over a wide range of acid strengths, consisting essentially of between about 36% and about 46% by weight nickel, between about 33% and about 42.06% by weight chromium, between about 2.94% and about 7.84% by weight molybdenum, between about 1.95% and about 5.18% by weight copper, up to about 0.12% by weight carbon, up to about 1.50% by weight silicon, up to about 2.50% by weight manganese, up to about 2% titanium, up to about 4% by weight niobium plus tantalum, up to about 0.01% by weight boron, and the balance essentially iron.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The alloys of the present invention are suitable as materials of construction for equipment used in reducing-type sulfuric acid solutions at temperatures up to the boiling point. As a result of the high proportion of chromium contained in these alloys, the alloys also exhibit good corrosion resistance to high temperature concentrated sulfuric acid and to sulfuric acid contaminated with oxidizing agents such as nitric acid. Except in the relatively narrow composition ranges where the alloy structure is not sufficiently austenitic, the alloys of the invention are readily weldable and machinable and, most importantly, are possessed of sufficient ductility to be shaped and processed by hot or cold-working. The alloys of the invention which are not readily workable generally possess the alternative advantageous properties of high hardness and wear resistance. In either case, these alloys are adapted for use as materials of construction for a wide variety of chemical and other industrial process equipment.

The essential constituents of the alloys of the invention are:

	Percent by weight
Nickel	36 to 46
Chromium	33 to 42.06
Molybdenum	2.94 to 7.84
Copper	1.95 to 5.18

The alloys of the invention are nickel based alloys characterized by a relatively high chromium content in conjunction with the presence of significant proportions of molybdenum and copper. It is believed that the inclusion of such relatively large proportions of chromium in an alloy containing molybdenum and copper, while generally maintaining an austenitic structure, accounts for the superior performance of these alloys in both reducing and oxidizing environments.

As optional constituents, the alloys of the invention may also contain:

	Percent by weight
Carbon	Up to 0.12
Silicon	Up to 1.50
Manganese	Up to 2.50
Titanium	Up to 2
Niobium+tantalum	Up to 4
Boron	Up to 0.01
Iron	Balance

lybdenum and other constituents for a particular alloy are established, the balance of the alloy is desirably constituted by iron, since it is abundant, inexpensive, and generally lends good mechanical properties to the alloy. If enough iron is included so as to modify the austenitic structure of the alloy, however, fabricability is adversely affected. It is, therefore, preferred that the iron content be maintained below the proportion which would introduce non-austenitic characteristics to the alloy microstructure.

The alloys of the invention are prepared by conventional methods of melting and no special conditions such as controlled atmospheres are required. In preparing the alloys, the constituents of a melting furnace charge need not be of any particular type. Thus, raw materials such as remelt scrap, copper scrap, ferro alloys such as ferrosilicon and ferromanganese and other commercial melting alloys may be used.

The following examples illustate the invention.

Example 1

100 lb. heats of seven different alloys were prepared in accordance with the invention. Each of these heats was then melted in a 100 lb. high frequency induction furnace. The compositions of these alloys are set forth in Table 1, with the balance in each case being iron.

TABLE 1.—PERCENTAGE BY WEIGHT OF ALLOYING ELEMENTS

Alloy Number	Ni	Cr	Mo	Cu	C	Si	Mn	Ti	Nb+Ta	B
960	42.68	42.06	4.91	3.93	0.10	0.69	0.60			
961	45.58	35.34	7.84	5.18	0.066	0.70	0.56			
971	41.56	33.94	3.16	3.63	0.07	0.81	0.60			
972	37.33	33.21	3.73	3.34		1.74	2.00	0.077		0.005
1,025	44.69	41.38	2.94	1.95	0.10	0.69				
1,714	43.08	37.83	3.56	3.16	0.04	0.55				
1,725	44.21	34.31	3.36	2.55	0.05	0.81				

Silicon enhances the corrosion resistance of the alloys to all strengths of sulfuric acid, and a small proportion of silicon is desirably present. However, large proportions of silicon tend to render the alloys hard and brittle, with poor welding and machining characteristics. It is preferable, therefore, to maintain the silicon content below about 1.50% to insure the workability of the alloys.

Manganese is desirably present because of its deoxidizing capabilities. Up to 8–10% of manganese can be tolerated in these alloys without adverse effect on either corrosion resistance or mechanical properties. If more than about 2.50% by weight manganese is present, however, enough manganese oxide may be present to cause attack on a furnace lining or a molding sand. Thus, the maximum manganese content of the alloys should not exceed about 2.50% by weight.

A small amount of boron improves the fabricability of the alloys. Thus, as much as 0.01% boron may be present. Higher percentages of boron are undesirable, since significantly higher proportions tend to harden the alloys or to adversely affect their corrosion resistance.

Up to about 2% titanium and up to about 4% niobium plus tantalum are useful in stabilizing any excess carbon that may be present in the alloys. These elements are also relatively corrosion-resistant and contribute as such to the corrosion resistance of the alloys. Titanium additionally contributes to the fabricability of the alloys.

A preferred embodiment of the alloys of this invention contains between about 40% and about 44% by weight nickel, between about 33% and about 35% by weight chromium, between about 3% and about 4% by weight molybdenum, and between about 3% and about 4% by weight copper. Alloys in this range combine particularly high corrosion resistance with a high degree of toughness, ductility and workability.

Normally, the alloys of the invention include a certain proportion of iron, up to about 25% by weight. Once the appropriate proportions of nickel, chromium, copper, mo-

Two standard physical test blocks and three corrosion test bars were prepared from each heat. One of the physical test blocks from each alloy was solution-annealed at 1950° F. for three hours and then oil quenched. The physical properties of the alloys, in both the annealed and the as-cast state, were measured. The as-cast physical properties of a representative number of these alloys are set forth in Table 2, and the physical properties of two of the same alloys after annealing are set forth in Table 3. The magnetic permeability of these alloys is generally less than about 1.02, in either as-cast or annealed condition.

TABLE 2.—PHYSICAL PROPERTIES OF ALLOYS, AS-CAST

Alloy	Tensile strength, p.s.i.	Yield strength, p.s.i.	Percent elongation	Brinell hardness
971	66,710	33,750	49.5	174
972	53,340	43,810	5.0	163-167
1,025	88,385	47,376	54.0	170
1,714	84,564	34,080	41.5	162
1,725	73,820	38,812	57.0	165

TABLE 3.—PHYSICAL PROPERTIES OF ALLOYS, AFTER SOLUTION ANNEALING

Alloy	Tensile strength, p.s.i.	Yield strength, p.s.i.	Percent elongation	Brinell hardness
971	67,810	42,030	10.0	217
1,025	88,493	57,630	18.5	207

The corrosion test bars were also annealed for thirty minutes at 1950° F. and oil quenched prior to machining into 1½" diameter x ¼" high discs having a ⅛" diameter hole in the center. Twelve to fourteen discs were obtained for each alloy. As machined, these discs had a surface roughness of about 32 microinches. A number of the discs of each alloy were electropolished to reduce surface roughness to about 4 microinches.

Both rough and electropolished discs were used in the comparative corrosion tests described hereinafter, comparing the performance of the alloys of the invention with a number of commercially available alloys. Because of the relatively short duration of the corrosion tests, significant differences were expected between the observed corrosion rates of rough and polished sample discs, and this is the reason for which both types of surfaces were tested. It is well-known in the art that rough surfaces often have substantially higher initial corrosion rates than do polished surfaces, especially those which are electropolished. This phenomenon is variously ascribed to the higher actual contact area presented by a rough surface, the higher chemical activity of a rough surface, and the greater difficulty in forming a protective film on a rough surface, where corrosion resistance depends on the presence of such a film. It has also been posited that machining operations, such as those involved in preparing sample discs, can cause work-induced phase changes at the metal surface. In the case of the alloys of this invention, such a phenomenon may alter the austenitic character of the alloy surface and thus reduce surface corrosion resistance. Electropolishing removes this work-transformed margin and exposes the unaffected subjacent area.

The compositions of the commercially available alloys which were used in the following corrosion tests and the respective trade designations under which they are marketed are set forth in Table 4.

After precisely six hours, the sample discs were removed from the boiling acid solution and cleaned of corrosion products. Most samples were cleaned sufficiently with a small nylon bristle brush and tap water. Those samples on which the corrosion product was too heavy for removal with a nylon brush were cleaned with a 1:1 solution of hydrochloric acid and water. After the corrosion products had been removed, each disc was again weighed to the nearest 10,000th of a gram. The corrosion rate of each disc, in inches per year, was calculated by the following formula in accordance with ASTM specification G1-67.

$$R_{ipy}=0.3937\,\frac{W_o-W_f}{ATD}$$

where

R_{ipy}=corrosion rate in inches per year
W_o=original weight of sample
W_f=final weight of sample
A=area of sample in square centimeters
T=duration of test in years
D=density of alloy in g./cc.

Results of this corrosion test are set forth in Table 5.

TABLE 4.—COMMERCIAL ALLOYS UTILIZED IN COMPARATIVE CORROSION TESTS

	Ni	Cr	Mo	Cu	Si	W	C	Mn	Co	Others
Hastelloy A	58		22		0.70		0.08	1.00	2	
Hastelloy B	61		30		0.70		0.04	0.70	2	
Hastelloy C	55	16	17		0.70	4.5	0.11	0.70	1.5	
Hastelloy D	82			3	9.0		0.10	1.00	1	
Hastelloy F	48	22	7		0.50		0.04	1.50	2	2 Ta plus Cb.
Illium G	56	22.5	6.4	6.5	0.65		0.20	1.25		
Illium R	68	21	5.0	3.0	0.70		0.05	1.25		
Illium 98	55	28	8.5	8.5	0.7		0.05	1.25		
Worthite	24	20	3	1.75	3.50		0.07	1.00		
Inconel 625	58	22	10		0.30		0.08	0.30		3.8 Ta plus Nb.
Duriron					14.5		0.50	0.50		
SR II A	15	13	6.5	6.5	0.70		0.04	1.00		
Ni-O-Nel	40	21	3	1.8	0.50		0.05	0.50		
Marker SN 42	42	18	5	2	0.70		0.05	0.70		
CF 8M	12	20	2.5		1.00		0.05	1.00		
CF 8	8	18			0.50		0.07	0.50		
Monel	67			30	0.10		0.15	1.00		
Inconel	76	15.5		0.2	0.25		0.08	0.25		
Stellite No. 25	10	20			0.50	15	0.10	0.70	50	
Carpenter 20	30	20	3	4						
Carpenter 20 Cb3	32.5	20	2.5	35	0.55		0.03	0.05		0.5 Nb; 0.5 Ti.
CD4M Cu	5	25	2	3	0.5		0.03	0.5		

Example 2

Comparative corrosion tests were conducted in a boiling mixed acid solution containing 5% by weight nitric acid and 10% by weight sulfuric acid.

Disc samples of Hastelloy B, Carpenter 20, nickel and Monel were prepared having the same dimensions as the discs prepared in Example 1. Residual machining oil and dirt were removed from all of the sample discs by cleaning them with a small amount of carbon tetrachloride. The discs were then rinsed in water and dried. Surface roughness of these discs was on the order of 4–10 microinches.

Each disc was weighed to the nearest 10,000th of a gram and suspended in a beaker containing a sufficient amount of boiling 10% sulfuric/5% nitric acid solution so that the entire sample was surrounded. The sample was suspended by means of a thin platinum wire hooked through the center hole of the disc and attached to a glass rod which rested on the top of the beaker. To insure the exposure of the discs to mixed acid solutions of substantially constant strength, frequent substitutions of beakers containing fresh boiling acid were made.

TABLE 5

[Corrosion rates in boiling 10% H_2SO_4 plus 5% HNO_3 solution]

	Surface roughness	Loss in inches of penetration per year, i.p.y.
Alloy number:		
960	32 microin	0.0089
961	do	0.00081
971	do	0.00054
1,025	do	0.0027
Hastelloy B	4–10 microin	90.5
Carpenter 20	do	0.0150
Nickel	do	(1)
Monel	do	(1)

[1] Not resistant.

Example 3

Comparative corrosion tests were conducted in boiling 10% sulfuric acid solution. Sample discs were prepared and tested in the manner described in Example 2, except that the test solution was boiling 10% sulfuric acid. The results of this test are set forth in Table 6.

TABLE 6

[Corrosion rates in boiling 10% H_2SO_4 solution]

	Surface roughness	Loss in inches of penetration per year, i.p.y.
Alloy number:		
1,025	32 microin	0.0551
960	do	0.0595
961	do	0.0246
971a	do	0.0394
971b	do	0.0262
971c	do	0.0252
971d	do	0.0378
960	4 microin	0.0000
961	do	0.0000
971a	do	0.0000
971b	do	0.0024
971c	do	0.0000
971d	do	0.0011
Inconel	4–10 microin	0.39
CF 8	do	16.5
CF 8M	do	0.86
Nickel	do	0.12
Hastelloy F	do	0.097
Hastelloy C	do	0.047
Hastelloy A	do	0.036
Inconel 625	do	0.043
Carpenter 20	do	0.037
CD4M Cu	do	0.080
Stellite No. 25	do	0.092

Example 4

Comparative corrosion tests were conducted in 65–68% nitric acid solution at 150° F. Sample discs were prepared in the manner described in Example 2. The corrosion tests were also carried out in generally the same fashion as in Example 2. Since a nonboiling test solution was involved, the beakers were placed in a thermostatically controlled water bath instead of on a hot plate. Each beaker was covered with a watch glass to minimize evaporation and it was therefore unnecessary to substitute fresh beakers during the test. The results of this test are set forth in Table 7.

TABLE 7

[Corrosion rates in 65–68% HNO_3 solution at 150° F.]

	Surface roughness	Loss in inches of penetration per year, i.p.y.
Alloy number:		
960	32 microin	0.0046
961	do	0.0022
970	do	0.0049
1,025	do	0.0038
960	4 microin	0.0000
961	do	0.0000
971	do	0.0000
1,025	do	0.0000
Nickel	4–10 microin	(1)
Monel	do	(1)
Hastelloy A	do	(1)
Hastelloy B	do	(1)

[1] No resistance.

Example 5

Comparative corrosion tests were conducted in 10% sulfuric acid solution at 176° F. Sample discs were prepared and tested in the manner described in Example 4, except that a 10% sulfuric acid solution was utilized and the temperature was maintained at 176° F. The results of this test are set forth in Table 8.

TABLE 8

[Corrosion rates in 10% H_2SO_4 solution at 176° F.]

	Surface roughness	Loss in inches of penetration per year, i.p.y.
Alloy number:		
960	32 microin	0.00735
961	do	0.00486
971	do	0.00081
1.025	do	0.00540
CD4M Cu	4–10 microin	0.004
Hastelloy A	do	0.0036
Hastelloy B	do	0.003
Hastelloy C	do	0.003
Hastelloy D	do	0.005
Carpenter 20	do	0.005
Carpenter 20Cb3	do	0.0045
Monel	do	0.009
Nickel	do	0.012
Worthite	do	0.063
Ni-O-Nel	do	0.020
Illium G	do	0.0051
SR II A	do	0.004
CF 8	do	4.5
CF 8M	do	0.197

Example 6

Comparative corrosion tests were conducted in boiling 25% sulfuric acid solution. Sample discs were prepared and tested in the manner described in Example 2, except that boiling 25% sulfuric acid was used as the test solution. The results of this test are set forth in Table 9.

TABLE 9

[Corrosion rates in boiling 25% H_2SO_4 solution]

	Surface roughness	Loss in inches of penetration per year, i.p.y.
Alloy number:		
960	32 microin	0.1620
961	do	0.0248
971d	do	0.0378
1,025	do	0.0000
960	4 microin	0.0000
961	do	0.0238
971e	do	0.0019
971f	do	0.0005
971g	do	0.0005
972	do	0.0422
Carpenter 20	4–10 microin	0.053
Carpenter 20Cb3	do	0.032
Hastelloy C	do	0.064
Monel	do	0.070
Nickel	do	(1)

[1] About 1.0.

Example 7

Comparative corrosion tests were conducted in 25% sulfuric acid solution at 176° F. Sample discs were prepared and tested in the manner described in Example 4, except that a test solution of 25% sulfuric acid was utilized and temperature was maintained at 176° F. Results of this test are set forth in Table 10.

TABLE 10

[Corrosion rates in 25% H_2SO_4 solution at 176° F.]

	Surface roughness	Loss in inches of penetration per year, i.p.y.
Alloy number:		
960	32 microin	0.00378
961	do	0.0000
971	do	0.00108
972	do	0.00594
1,025	do	0.0041
Hastelloy A	4–10 microin	0.020
Illium R	do	0.007
Carpenter 20	do	0.020
Carpenter 20Cb3	do	0.011
Inconel 625	do	0.010
Duriron	do	0.048
Marker SN 42	do	0.0158
Nickel	do	0.083
Worthite	do	0.020
Hastelloy F	do	0.060
Hastelloy C	do	0.016
CD4M Cu	do	0.200

Example 8

Comparative corrosion tests were conducted in 25% sulfuric acid solution at room temperature. Sample discs were prepared and tested in the manner described in Example 4, except that 25% sulfuric acid at room temperature was used as the test solution. The results of this test are set forth in Table 11.

TABLE 11

[Corrosion rates in 25% H_2SO_4 solution at room temperature]

	Surface roughness	Loss in inches of penetration per year, i.p.y.
Alloy number:		
1,025	32 microin	0.0000
Hastelloy A	4 microin	0.00156
Hastelloy B	do	0.001
Hastelloy C	do	0.002
Hastelloy D	do	0.001
Monel	do	0.005
Nickel	do	0.004
CF 8	do	0.088
CF 8M	do	0.046

Example 9

Comparative corrosion tests were conducted in 93% sulfuric acid solution at 210° F. Sample discs were prepared and tested in the manner described in Example 4, except that 93% sulfuric acid solution at 210° F. was used as the test solution. Results of this test are set forth in Table 12.

TABLE 12

[Corrosion rates in 93% H_2SO_4 solution at 210° F.]

	Surface roughness	Loss in inches of penetration per year, i.p.y.
Alloy number:		
960	32 microin	0.0105
961	do	0.0111
971	do	0.0146
960	4 microin	0.0000
961	do	0.0178
971	do	0.0029
972	do	0.0000
1,025	do	0.0035
Monel	4–10 microin	0.204
Illium G	do	0.060
Nickel	do	Over 0.15
Inconel	do	Over 0.27
Illium 98	do	0.0175
Hastelloy F	do	0.061

Example 10

Comparative corrosion tests were conducted in 10% hydrochloric acid solution at room temperature. Sample discs were prepared and tested in the manner described in Example 4, except that 10% hydrochloric acid at room temperature was used as the test solution. The results of this test are set forth in Table 13.

TABLE 13

[Corrosion rates in 10% HCl solution at room temperature]

	Surface roughness	Loss in inches of penetration per year. i.p.y.
Alloy number:		
960	32 microin	0.0181
961	do	0.0162
971	do	0.0173
Carpenter 20	4–10 microin	0.027
CF 8	do	0.084

Example 11

Comparative corrosion tests were conducted in 20% hydrochloric acid solution at room temperature. Sample discs were prepared and tested in the manner described in Example 4, except that 20% hydrochloric acid at room temperature was used as the test solution. Results of this test are set forth in Table 14.

TABLE 14

[Corrosion rates in 20% HCl solution at room temperature]

	Surface roughness	Loss in inches of penetration per year. i.p.y.
Alloy number:		
961	32 microin	0.0233
971	do	0.0187
Hastelloy D	4–10 microin	0.026
CF 8	do	1.22

Example 12

Corrosion tests were conducted in 50% sulfuric acid solution at 176° F. Sample discs were prepared and tested in the manner described in Example 4, except that 50% sulfuric acid solution at 176° F. was used as the test solution. Results of this test are set forth in Table 15.

TABLE 15

[Corrosion rates in 50% H_2SO_4 solution at 176° F.]

Alloy number	Surface roughness	Loss in inches of penetration per year, i.p.y.
960	32 microin	0.0057
961	do	0.0000
971	do	0.0000
1,025	do	0.0000

Example 13

Corrosion tests were conducted in 75% sulfuric acid at 176° F. Sample discs were prepared and tested in the manner described in Example 4, except that 75% sulfuric acid at 176° F. was used as the test solution. Results of this test are set forth in Table 16.

TABLE 16

[Corrosion rates in 75% H_2SO_4 solution at 176° F.]

Alloy number	Surface roughness	Loss in inches of penetration per year, i.p.y.
960	32 microin	0.2094
961	do	0.2018
971	do	0.1752
960	4 microin	0.0000
961	do	0.0000
971	do	0.0000
972	do	0.00135
1,025	do	0.0000

Example 14

Corrosion tests were conducted in 93% sulfuric acid at 176° F. Sample discs were prepared and tested in the manner described in Example 4, except that 93% sulfuric acid at 176° F. was used as the test solution. Results of this test are set forth in Table 17.

TABLE 17

[Corrosion rates in 93% H_2SO_4 solution at 176° F.]

Alloy number	Surface roughness	Loss in inches of penetration per year, i.p.y.
1,025	32 microin	0.0138
960	4 microin	0.0000
961	do	0.0000
971	do	0.0000
972	do	0.0000

Example 15

Comparative corrosion tests were conducted in boiling 40% sulfuric acid. Sample discs were prepared and tested in the manner described in Example 2, except that boiling 40% sulfuric acid was used as the test solution. Results of this test are set forth in Table 18.

TABLE 18

[Corrosion rates in boiling 40% H_2SO_4 solution]

	Surface roughness	Loss in inches of penetration per year, i.p.y.
Alloy number:		
960	4 microin	0.0000
961	do	0.0043
971	do	0.0000
1,025	do	0.0000
Carpenter 20Cb3	4–10 microin	0.040

Example 16

Comparative corrosion tests were conducted in boiling 50% sulfuric acid. Sample discs were prepared and tested in the manner described in Example 2, except that boiling 50% sulfuric acid was used as the test solution. Results of this test are set forth in Table 19.

TABLE 19

[Corrosion rates in boiling 50% H_2SO_4 solution]

	Surface roughness	Loss in inches of penetration per year, i.p.y.
Alloy number:		
960	4 microin	0.0095
961	do	0.0035
971	do	0.0138
1,025	do	0.0014
Carpenter 20Cb3	4–10 microin	0.045

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above products without departing from the scope of the invention, it is intended that all matter contained in the above description shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An alloy resistant to corrosion by both oxidizing and reducing sulfuric acid solutions over a wide range of acid strengths, consisting essentially of between about 36% and about 46% by weight nickel, between about 33% and about 42.06% by weight chromium, between about 2.94% and about 7.84% by weight molybdenum, between about 1.95% and about 5.18% by weight copper, up to about 0.12% by weight carbon, up to about 1.50% by weight silicon, up to about 2.50% by weight manganese, up to about 2% by weight titanium, up to about 4% by weight niobium plus tantalum, up to about 0.1% by weight boron, and the balance essentially iron.

2. An alloy as set forth in claim **1** having a microstructure which is substantially austenitic so that the alloy is readily workable.

3. An alloy as set forth in claim **1** wherein the nickel content is between about 40% and about 44% by weight, the chromium content is between about 33% and about 35% by weight, the molybdenum content is between about 3% and about 4% by weight and the copper content is between about 3% and about 4% by weight.

4. An alloy as set forth in claim **3** containing about 42% by weight nickel, about 34% by weight chromium, about 3.2% by weight molybdenum, and about 3.6% by weight copper.

5. An alloy as set forth in claim **1** containing about 43% by weight nickel, about 42% by weight chromium, about 4.9% by weight molybdenum, and about 3.9% by weight copper.

6. An alloy as set forth in claim **1** containing about 46% by weight nickel, about 35% by weight chromium, about 7.8% by weight molybdenum, and about 5.2% by weight copper.

7. An alloy as set forth in claim **1** containing about 37% by weight nickel, about 33% by weight chromium, about 3.8% by weight molybdenum, about 3.3% by weight copper, about 1.7% by weight silicon, about 2.0% by weight manganese, about 0.08% by weight titanium, and about 0.005% by weight boron.

8. An alloy as set forth in claim **1** containing about 45% by weight nickel, about 41% by weight chromium, about 2.9% by weight molybdenum, and about 2.0% by weight copper.

9. An alloy as set forth in claim **1** containing about 43% by weight nickel, about 38% by weight chromium, about 3.6% by weight molybdenum, and about 3.2% by weight copper.

10. An alloy as set forth in claim **1** containing about 44% by weight nickel, about 34% by weight chromium, about 3.4% by weight molybdenum, and about 2.6% by weight copper.

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HYLAND BIZOT, Primary Examiner

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75—125, 128 W, 171