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FERROUS ALLOYS AND CORROSION AND WEAR-RESISTING ARTICLES MADE THEREFROM

David J. Giles, Latrobe, Pa., assignor to Latrobe Steel Company, Latrobe, Pa., a corporation of Pennsylvania

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This invention relates to ferrous alloys and particularly to ferrous alloys having high resistance to corrosion and to wear. There has long been a need for steels having high resistance to corrosion and at the same time having the ability to resist wear and abrasion and when used for moving parts to resist grabbing and galling. A good example is steel for use in the fabrication of pump shafts for use in mine pumps and the like which are subject to corrosive conditions and at the same time to the wear of friction in bearings. Other uses are for the forming of steel forgings and castings for installations where corrosive conditions and frictional wear are extremely great, as in pump bodies to be used in mine pumps. Pump shafts and pump casings used in pumping mine water are rapidly eaten away by the corrosive effects of the mine water and at the same time are subject to wear and to galling and grabbing at the bearings. In alloys for use in such applications it is desirable that the metal be either forgeable or castable into shapes approximating the final shape of the article as put in service.

The search for alloys having particular desirable properties has lead to many combinations of alloying elements including combinations with vanadium. I have found, however, that none of these combinations heretofore proposed has produced an alloy having the much needed characteristics of the alloy of the present invention. None of the alloys heretofore produced have been resistant to corrosive atmosphere and at the same time resistant to wear so that when used in installations such as mine shafting, the corrosive liquids coming from the mine would not corrode away the shaft and at the same time the shaft would be sufficiently wear resistant to prevent it being worn away at the bearings or flowing and galling or grabbing in the bearings which support it.

I have discovered an alloy which may be satisfactorily cast or forged and which will have superior resistance to corrosion and to wear and abrasion. I have found that this can be accomplished by properly controlling the carbon and vanadium content in a manner somewhat similar to that described in my copending application Serial No. 189,067, now U. S. Patent No. 2,575,218. The present invention provides an alloy which is corrosion-resisting and wear-resisting to a degree far beyond anything heretofore proposed and which at the same time is surprisingly free from galling and grabbing when used in the formation of moving parts. The alloy in general is formed by adding carbon within certain limits in excess of that necessary to give the alloy the desired forging and hardening characteristics, and vanadium in an amount again within certain limits, such that the ratio of the vanadium in excess of that

which is soluble in the matrix alloy to the aforementioned excess of carbon is about 4.2 to 1. I have found that the minimum solubility of vanadium in steel alloys of this type is approximately 1% and that the solubility extends upwardly from that point depending upon the composition of the alloy.

The corrosion and wear-resisting alloy of this invention may comprise broadly

C	About 0.5% to 4%.
Cr	About 11% to 30%.
Ni	About 0 to 15%.
Mo	About 0 to 5%.
Si	Up to about 1%.
Mn	Up to about 1%.
Co	About 0 to 3%.
Ti	About 0 to 0.5%.
Cb	About 0 to 0.5%.
Ta	About 0 to 0.5%.
V	About 3% to 13%.

and the balance substantially iron with residual impurities in ordinary amounts.

Where free-machining qualities are desired in the steel, these may be obtained by the addition of sulfur, selenium, tellurium, phosphorus or arsenic in usual and well-known amounts.

While the alloy of this invention may fall within the range of concentrations of alloying elements just enumerated and still retain its desirable characteristics it may be desirable to limit the composition to narrower ranges or concentrations of alloying elements for certain particular purposes. For example, where maximum hardenability is desired the following concentrations of alloying elements will produce an alloy having the desirable characteristics of corrosion resistance, wear resistance characteristic of my invention:

C	0.5% to 4%.
Cr	11% to 18%.
Si	Up to 1%.
Mn	Up to 1%.
V	3% to 13%.

and the balance substantially iron with residual impurities in ordinary amounts.

Where a more ductile, non-magnetic corrosion and wear-resisting alloy is desired, the alloy may comprise

C	About 0.5% to 4%.
Cr	15% to 30%.
Ni	0 to 15%.
Si	Up to 1%.
Mn	Up to 1%.
V	3% to 13%.

and the balance substantially iron with residual impurities in ordinary amounts.

Other narrow ranges within the broad range mentioned above may be particularly suitable for certain applications where different combinations of properties other than the corrosion and wear resistance common to all the alloys in this invention are desired.

In order to illustrate the corrosion resistance combined with wear resistance of my new alloy several heats were made within the broad composition range specified above. The corrosion resistance and the wear resistance of the alloys of my invention were compared with those of the principal alloy steels known for each of these properties. The results of these tests on corrosion resistance and abrasion resistance are tabulated below along with a

tabulation of chemical compositions. The compositions of the various alloys were as follows:

Table I

Identity	C	Si	Mn	Cr	Ni	V	Mo	W	Co
A	1.13	.38	.51	13.48	------	5.29	------	------	------
B	1.33	.38	.50	13.64	------	5.26	------	------	------
C	1.18	.38	.51	17.30	------	5.30	------	------	------
D	3.48	.66	.63	15.98	------	11.87	------	------	------
E	2.88	.66	.62	16.30	------	11.97	------	------	------
F	1.13	.42	.46	18.34	9.50	5.03	------	------	------
G	1.80	.38	.50	17.24	------	5.10	------	------	------
H	1.15	.33	.43	25.60	------	4.78	------	------	------
I	1.17	.24	.32	17.32	8.61	4.82	2.57	------	------
J	.11	.28	.41	12.49	.13	------	.12	------	------
Tool Steel	.77	.31	.25	4.23	.08	1.09	.71	17.95	.10
18–8	.08	.66	.48	18.41	9.43	------	------	------	------

Alloys A through I are corrosion-resisting and wear-resisting alloys made according to my invention. The alloy tabulated as "Tool Steel" is a typical 18–4–1 tool steel as marketed to the trade. The 18–8 grade is likewise a typical austenitic stainless steel as marketed to the trade. The J sample is a typical hardenable grade of stainless iron. For purposes of testing their resistance to abrasion these alloys were divided into two groups, the normally hardenable and the normally non-hardenable alloys. Each of these alloys was then subjected to abrasion tests on forged and hardened pieces 1 inch in diameter and the results of these tests are tabulated below

Table II

Normally Hardenable		Normally Non-Hardenable	
Identity	Percent Abrasion (percent removed by abrasion)	Identity	Percent Abrasion (percent removed by abrasion)
J	100	18–8	100
A	46	F	71
B	48	C	58
G	27	E	7
D	2	H	63
Tool Steel	47	I	44
		Tool Steel	30

Careful comparison of the abrasion results shows that the normally hardenable steels of my invention are equal or far superior to the 18–4–1 tool steel in resistance to wear. The normally non-hardenable steels of my invention are far superior to the corresponding non-hardenable stainless steels of the trade and in most instances compare favorably with the 18–4–1 tool steel—in one instance losing only 25% as much as the tool steel standard.

Each of these alloys excepting the tool steel were then subjected to corrosion tests by exposing to 33⅓% nitric acid after heat treatment and grinding to determine the corrosion loss. A carbon steel was included in this test to show the corrosive action of the solution on ordinary steel. The corrosion resistance of these alloys is tabulated as corrosion loss in Table III.

Table III

Identity	Material loss, gm./sq. m./hr.
F	0.0331
C	0.0434
I	0.0538
H	0.0640
G	0.1269
A	0.1620
B	0.1790
18–8	0.2630
J	0.2630
E	0.7500
Carbon Steel	14,100

In this corrosion test any values up to 0.1 are indicative of "fully resistant" alloys, and values between 0.1 and 1.0 are indicative of "satisfactorily resistant" alloys according to the "American Society for Metals Handbook" (1948), p. 561.

Further corrosion tests with copper sulphate solution were also made. It was found that none of the grades picked up copper from a drop of acidic copper sulphate applied to a polished surface for five minutes. These specimens had been heat treated to normally used conditions prior to polishing and testing. These tests with copper sulphate and dilute nitric acid indicate strongly that the alloys of this invention are not seriously limited with respect to their resistance to corrosion.

Careful comparison of the composition of the test pieces and their resistance to corrosion and to wear shows the superiority of the alloy of my invention over the 18–8 alloy now used for corrosion resistance alone and the marked superiority of their wear resistance over the wear resistance of the corrosion-resistant alloys heretofore used. None of the alloys of my invention lost as much in the abrasion test as the usual straight chrome stainless grade J. All of them were far superior to the 18–8 grade of stainless steel. The alloys of this invention were, in every case except one, equal to or superior in resistance to corrosion to the 18–8 stainless furnished to the trade and in every case were satisfactorily resistant according to the limits set up in the "American Society for Metals Handbook."

It is a pecularity among the alloys of this invention that the addition of excess carbon and vanadium in excess of that amount which is soluble in the alloy matrix in the ratio of 4.2 vanadium to 1 carbon although increasing the abrasion resistance and to some extent, the corrosion resistance, has little or no effect upon the forging and hardening qualities of my alloy over those same physical properties of an alloy without such excess carbon and vanadium. If, however, a marked departure from this ratio of 4.2 to 1 is made then a marked change in forgeability and hardenability occurs, the direction and extent of which depends upon the nature and extent of the departure.

My researches indicate that when carbon and vanadium appear in the above-described excess and ratio in the corrosion-resistant and wear-resistant alloys of my invention, they modify the characteristics of the alloy by very desirably augmenting its resistance to wear, its resistance to galling, grabbing and its corrosion resistance without masking or nullifying the other physical characteristics of the alloy. I believe that these extraordinary properties of my alloy depend upon the formation of vanadium carbides which remain out of solution and accordingly do not affect the hardenability or forgeability of my alloy. While this theory seems to be consistent with observable facts I do not bind myself thereto. The fact is that whatever the mechanism may be, the addition of carbon and vanadium in the above-described proportions does produce an unexpected and unusual wear and abrasion resistance coupled with corrosion resistance which is of great technical importance in those fields where the problem of corrosion resistance along with that of extreme wear is prevalent.

While I have described and disclosed the preferred embodiment of my invention, it is to be understood that the invention is not so limited but may be otherwise embodied and practiced within the scope of the following claims.

I claim:

1. A corrosion and wear-resisting alloy comprising about 0.5% to 4% carbon, about 15% to 30% chromium, 0 to 15% nickel, up to about 1% silicon, up to about 1% manganese, about 3% to 13% vanadium, and the balance substantially iron with residual impurities in ordinary amounts, and in which the concentrations of carbon and vanadium within the given limits are adjusted so that the ratio of vanadium in excess of that soluble in the alloy matrix to the carbon in excess of that

required to give the desired hardenability characteristics is about 4.2 to 1.

2. A corrosion and wear-resisting forged or cast article formed from a steel alloy comprising about 0.5% to 4% carbon, about 15% to 30% chromium, 0 to 15% nickel, up to about 1% silicon, up to about 1% manganese, about 3 to 13% vanadium, and the balance substantially iron with residual impurities in ordinary amounts, and in which the concentrations of carbon and vanadium within the given limits are adjusted so that the ratio of vanadium in excess of that soluble in the alloy matrix to the carbon in excess of that necessary to give the desired hardenability characteristics is about 4.2 to 1, said article being characterized by the combination of high resistance to corrosion and by high resistance to wear and abrasion and at the same time having hardening and forging characteristics comparable to steels having a carbon content less than that of the article by an amount equal to

$$\frac{\text{Per cent vanadium—amount of vanadium soluble in the alloy matrix}}{4.2}$$

3. A corrosion and wear-resisting alloy comprising about 0.5% to 4% carbon, about 20% to 30% chromium, up to about 1% silicon, up to about 1% manganese, about 3% to 13% vanadium, and the balance substantially iron with residual impurities in ordinary amounts, and in which the concentrations of carbon and vanadium within the given limits are adjusted so that the ratio of vanadium in excess of that soluble in the alloy matrix to the carbon in excess of that required to give the desired hardenability characteristics is about 4.2 to 1.

4. A corrosion and wear-resisting forged or cast article formed from a steel alloy comprising about 0.5% to 4% carbon, about 20% to 30% chromium, up to about 1% silicon, up to about 1% manganese, about 3% to 13% vanadium, and the balance substantially iron with residual impurities in ordinary amounts, and in which the concentrations of carbon and vanadium within the given limits are adjusted so that the ratio of vanadium in excess of that soluble in the alloy matrix to the carbon in excess of that required to give the desired hardenability characteristics is about 4.2 to 1, said article being characterized by the combination of high resistance to corrosion and by high resistance to wear and abrasion and at the same time having hardening and forging characteristics comparable to steels having a carbon content less than that of the article by an amount equal to

$$\frac{\text{Per cent vanadium—amount of vanadium soluble in the alloy matrix}}{4.2}$$

5. A corrosion and wear resisting alloy comprising about 0.5% to 4% of carbon, about 14.1% to 30% of chromium, 0 to about 5% of molybdenum, up to about 1% silicon, up to about 1% manganese, 0 to about 3% cobalt, 0 to about 0.5% of each of the group titanium, columbium and tantalum, about 3% to 13% vanadium, and the balance substantially iron with residual impurities in ordinary amounts, and in which the concentrations of carbon and vanadium within the given limits are adjusted so that the ratio of vanadium in excess of that soluble in the alloy matrix to the carbon in excess of that required to give the desired hardenability characteristics is about 4.2 to 1.

6. A corrosion and wear resisting article formed from a steel alloy comprising about 0.5% to 4% carbon, about 14.1% to 30% of chromium, 0 to about 15% nickel, 0 to about 5% molybdenum, up to about 1% silicon, up to about 1% manganese, 0 to about 3% cobalt, 0 to about 0.5% of each of the group titanium, columbium and tantalum, about 3% to 13% vanadium, and the balance substantially iron with residual impurities in ordinary amounts, in which alloy the vanadium and carbon concentrations are adjusted within the given limits so that the ratio of vanadium in excess of that soluble in the alloy matrix to the carbon in excess of that required to give the desired hardenability characteristics is about 4.2 to 1, said article being characterized by the combination of high resistance to corrosion and by high resistance to wear and abrasion and at the same time having hardening and forging characteristics comparable to steels having a carbon content less than that of the article by an amount equal to

$$\frac{\text{Per cent vanadium—amount of vanadium soluble in the alloy matrix}}{4.2}$$

7. A corrosion and wear resisting alloy having carbon in excess of that necessary to give it the desired hardenability characteristics comprising about 0.5% to 4% carbon, about 11% to 30% chromium, about 3.1 to 15% nickel, 0 to about 5% of molybdenum, up to about 1% silicon, up to about 1% maganese, 0 to about 3% cobalt, 0 to about 0.5% of each of the group titanium, columbium and tantalum, about 3% to 13% vanadium, and the balance substantially iron with residual impurities in ordinary amounts, and in which the concentrations of vanadium and carbon within the given limits are adjusted so that the ratio of vanadium in excess of that soluble in the alloy matrix to the excess carbon is about 4.2 to 1.

8. A corrosion and wear resisting article formed from a steel alloy comprising about 0.5% to 4% carbon, about 11% to 30% chromium, about 3.1% to 15% nickel, 0 to about 5% of molybdenum, up to about 1% silicon, up to about 1% manganese, 0 to about 3% cobalt, 0 to about 0.5% of each of the group titanium, columbium and tantalum, about 3% to 13% vanadium, and the balance substantially iron with residual impurities in ordinary amounts, in which alloy the vanadium and carbon concentrations are adjusted within the given limits so that the ratio of vanadium in excess of that soluble in the alloy matrix to the carbon in excess of that required to give the desired hardenability characteristics is about 4.2 to 1, said article being characterized by the combination of high resistance to corrosion and by high resistance to wear and abrasion and at the same time having hardening and forging characteristics comparable to steels having a carbon content less than that of the article by an amount equal to

$$\frac{\text{Per cent vanadium—amount of vanadium soluble in the alloy matrix}}{4.2}$$

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