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FERROUS ALLOYS AND ARTICLES MADE THEREFROM

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This invention relates to ferrous alloys and articles made therefrom and in particular to ferrous alloys having high resistance to abrasion and resistance to fracture under mechanical shock. There has long been a need for steels having a materially greater resistance to abrasion and to fracture under mechanical shock than those commercially available. For example, many cold-work applications involving wear such as cold header dies, dies for cold forming tubing, mandrels, etc. are simultaneously subject to both considerable mechanical shock and abrasion. Such articles when made of ordinary steels are relatively quickly abraded away or broken by the repeated shock of the cold forming operations and as a result are no longer useful. Cold header dies, for example, are subject to steadily recurrent mechanical shock and abrasion as the article being headed strikes the die, is formed and released to be followed by another article to be headed. This steadily recurring shock and abrasion either cuts away the die surface or the repeated shock results in fracturing the die within a relatively short period of time.

Alloys to be suitable for such cold-work applications as are described above should be forgeable, surface hardenable, resistant to the abrasive action of the article being treated, and yet have a tough fracture-resisting core. Many combinations of alloys have been tried for this purpose, however, none has proven entirely satisfactory due to the inability of the art to provide the aforementioned necessary qualities in an alloy economically feasible for the operation. It has been found generally that for cold-work applications water-hardening alloys are most desirable since they provide the tough core needed for resistance to fracture, however, prior to this invention there have been no water-hardening alloys which combine all of the desired surface hardening and abrasion-resisting characteristics with forgeability and core toughness.

I have discovered an alloy which is forgeable and water-hardening and which is suitable for the production of high surface abrasion resistance and core toughness. My invention provides a water-hardening abrasion-resisting alloy in which carbon within certain limits is added in excess of that necessary to give the desired forging and hardening characteristics, along with vanadium in an amount within certain limits such that the ratio of the vanadium in excess of about 1% to the aforementioned excess of carbon is about 4.2:1. Broadly, the composition of

my alloy lies within the following ranges of concentrations of alloying elements:

	Per cent
Carbon	0.85 to 4
Silicon	0.1 to 0.5
Manganese	0.2 to 0.7
Chromium	Less than 2
Vanadium	2 to 12

Balance substantially iron with residual impurities in ordinary amounts.

An alloy suitable for most abrasive-resisting and shock-resisting applications might have the following analysis:

	Per cent
Carbon	1.7
Silicon	0.2
Manganese	0.2
Chromium	0.1
Vanadium	4.5

Balance substantially iron with residual impurities in ordinary amounts.

It has been found that abrasion-resistance varies with the amount of vanadium and carbon added to the alloy, however, below the limits of carbon and vanadium specified above there is no noticeable decrease in abrasion-resistance while if the vanadium and carbon contents are increased beyond the upper limits indicated above the forging and hardening characteristics of the alloy are adversely affected. It must be noted of course, that to achieve the phenomenal abrasion-resistance and yet retain the desired hardening and forging characteristics it is necessary that the carbon in excess of that required to give these forging and hardening characteristics must be combined with vanadium by adding vanadium in excess of 1% in the ratio of 4.2:1 to the excess carbon.

While specific silicon and manganese ranges have been given in the above tabulation of analysis these concentrations are not critical and are those which normally result from the raw materials used in the production of my alloy and may accordingly vary within reasonable limits depending upon the raw materials used.

An alloy having a composition within the limits set forth in either of the above tabulations will be forgeable, water-hardening, and will have a tough resilient core-resistant to fracture under shock as well as being abrasive-resistant. In order to illustrate the striking resistance to abrasion characteristic of my new alloy several heats were made within the range of the above broad compositions. The abrasion-resistance of these alloys was compared with that of one of the principal alloys previously used for cold-work applications such as cold header dies and with the abrasion-resistance of an 18–4–1 tool steel taken as a standard of 100% abrasion. The results of these abrasion tests on forged and hardened pieces 1" in diameter are tabulated below along with a tabulation of the chemical compositions of the respective alloys.

Table I

Alloy	Hardening Temperature	Hardness, Rockwell C	Amount of Wear	Elec. No. 1
	°F.			Per cent
A	1500	63.0	.0013	35
B	1500	52.0	.0033	89
C	1500	63.0	.0007	19
D	1600	69.0	.0001	4
E	1600	68.0	.0001	4
F	1600	68.0	.00003	1
H	1600	65.3	.0006	16
X (Prev. used alloy)	1500	67.0	.0072	194
Electrite No. 1	----------	65.0	.0037	100

The chemical compositions of the above alloys are as follows:

Table II

Alloy	C	Si	Mn	V	Cr	W
Electrite No. 1	.77	.31	.25	1.09	4.23	17.95
Alloy X (Prev. used alloy)	1.01	.27	.44	------	------	------
A	1.33	.26	.22	4.38	------	------
B	1.56	.33	.22	6.63	------	------
C	2.17	.33	.22	9.08	------	------
D	2.24	.68	.32	7.06	------	------
E	2.82	.81	.35	9.32	------	------
F	3.33	.94	.35	11.40	------	------
H	1.48	.33	.24	4.61	.58	------

All of the alloys of my invention tabulated in Table II above were forgeable and water-hardenable. All were finished by hammering to 1⅛" square bars. Careful comparison of the composition of the test pieces and their resistance to abrasion shows the marked superiority of the alloy of my invention over alloy X, now used in cold work applications, as well as their superiority over the high speed tool steel used as a standard of abrasion resistance. The alloy previously used lost as much as 194 times the loss shown by certain alloys within the composition range of my invention. In every instance it lost at least twice as much as any of the alloys of my invention. It will be seen from Table I that the hardness values of the alloy principally used (Alloy X) and that of the alloys of my invention are in the same range. It is apparent from these tabulations that the use of increasing amounts of vanadium and carbon in proper ratio leads to tremendous increases in abrasion-resistance without materially changing the hardening characteristics from those of carbon steels having a carbon content equal to the carbon content of my alloy less an amount equal to

$$\frac{\text{per cent vanadium} - 1\%}{4.2}$$

I have found, however, that any material departure from the ratio of 4.2:1 between the vanadium in excess of 1% and the excess carbon results in marked changes in hardening and forging characteristics of the alloy. The direction and the extent of these changes depends upon the material and the extent of the departure from this ratio.

While it appears from my researches that the extraordinary abrasion-resistance of my alloy depends upon the formation of vanadium carbides which remain out of solution and accordingly do not affect the hardenability or forgeability of my alloy, I do not bind myself to this theory. The fact is, that whatever the mechanism may be and whatever theory may account for the phenomenal results of my invention, the addition of carbon and vanadium in the above described proportions does produce an unexpected and unusual abrasive-resistance which is of great technical importance, without materially effecting the hardening and forging qualities and yet retaining a tough resilient core when hardened.

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

I claim:

1. A water-hardening, abrasion-resisting and shock-resisting steel alloy comprising about 0.85% to 4% carbon, about 0.1% to 0.5% silicon, about 0.2% to 0.7% manganese, less than about 2% chromium, about 2% to 12% vanadium and the balance substantially iron with residual impurities in ordinary amounts, in which alloy the vanadium in excess of about 1% is combined with the carbon in a ratio of about 4.2:1.

2. A water-hardening, abrasion-resisting and shock-resisting steel comprising about 1.7% carbon, about 0.2% silicon, about 0.2% manganese, about 0.1% chromium and about 4.50% vanadium, balance substantially iron with residual impurities in ordinary amounts in which alloy the vanadium in excess of about 1% is combined with the carbon in a ratio of about 4.2:1.

3. A water-hardening, abrasion-resisting and shock-resisting steel alloy having carbon in excess of that necessary to give it the desired hardenability characteristics comprising about 0.85% to 4% carbon, about 0.1% to 0.5% silicon, about 0.2% to 0.7% manganese, less than about 2% chromium, about 2% to 12% vanadium and the balance substantially iron with residual impurities in ordinary amounts in which alloy the concentrations of vanadium and carbon within the given limits are adjusted so that the ratio of vanadium in excess of about 1% to the excess carbon is about 4.2:1.

4. A water-hardening, abrasion-resisting and shock-resisting steel alloy having carbon in excess of that necessary to give the desired hardenability characteristics comprising about 1.7% carbon, about 0.2% silicon, about 0.2% manganese, about 0.1% chromium, about 4.50% vanadium and the balance substantially iron with residual impurities in ordinary amounts in which alloy the concentration of vanadium and carbon within the given limits are adjusted so that the ratio of vanadium in excess of about 1% to the excess carbon is about 4.2:1.

5. A water-hardening, abrasion-resisting and shock-resisting article formed from a forgeable abrasion-resisting steel alloy comprising about 0.85% to 4% carbon, about 0.1% to 0.5% silicon, 0.2% to 0.7% manganese, less than about 2% chromium, about 2% to 12% vanadium and the balance substantially iron with residual impurities in ordinary amounts in which alloy the vanadium in excess of about 1% is combined with carbon in a ratio of about 4.2:1, said article being characterized by high resistance to abrasion and fracture under shock and by forging and

hardening characteristics comparable to steels having a carbon content less than that of the article by an amount equal to the

$$\frac{\text{per cent vanadium}-1\%}{4.2}$$

6. An abrasion-resisting and shock-resisting article formed from a forgeable abrasion-resisting steel alloy comprising about 1.7% carbon, about 0.2% silicon, about 0.2% manganese, 0.1% chromium and about 4.50% vanadium, balance substantially iron with residual impurities in ordinary amounts in which alloy the vanadium in excess of about 1% is combined with carbon in a ratio of about 4.2:1 said article being characterized by high-resistance to abrasion and fracture under shock and by forging and hardening characteristics comparable to steels having a carbon content less than that of the article by an amount equal to the

$$\frac{\text{per cent vanadium}-1\%}{4.2}$$

7. A tool for cold work applications subject to abrasion and shock formed of a forgeable abrasion-resistant steel having carbon in excess of that to give it the desired hardenability characteristics comprising about 0.85% to 4% carbon, about 0.1% to 0.5% silicon about 0.2% to 0.7% manganese less than about 2% chromium, about 2% to 12% vanadium and the balance substantially iron with residual impurities in ordinary amounts in which alloy the concentrations of vanadium and carbon within the given limits are adjusted so that the ratio of vanadium in excess of about 1% to the excess carbon is about 4.2:1, said article being characterized by high resistance to abrasion and fracture under shock and by forging and hardening characteristics comparable to steels having a carbon content less than that of the article by an amount equal to the

$$\frac{\text{per cent vanadium}-1\%}{4.2}$$

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