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ALLOY STEEL

Daniel E. Krause and Clarence H. Lorig, Columbus, Ohio, assignors to Battelle Memorial Institute, Columbus, Ohio, a corporation of Ohio

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Our invention relates to alloy steels. It has to do, more particularly, with alloy steels which contain phosphorus and vanadium.

The effect of phosphorus on corrosion and mechanical properties of carbon steels and various alloy steels is well known. Its influence on atmospheric corrosion and corrosion in other media is regarded as very beneficial. By itself, or in combination with other elements, it functions as an alloy and strengthening element and, as such, produces high yield strength and yield ratio. For the above reasons, many of the newly developed low-alloy, high yield strength structural steels contain substantial percentages of phosphorus.

The remarkably great effect upon mechanical properties and corrosion resistance conferred on steels by small additions of phosphorus is demonstrated by results obtained on a series of very low carbon steels containing increasing percentages of phosphorus. Normalized bar stock of these steels had mechanical properties shown in the following table:

Base composition—0.03% C, 0.10% Mn, 0.01% Si, 0.04% S

	P, per-cent	Tensile strength lb./sq. in.	Yield strength lb./sq. in.	Elong. percent 2"	Red. of area, percent	Charpy impact ft. lb.
1	0.006	46,700	34,000	48	85	63
2	0.12	55,000	32,500	44	75	67
3	0.21	62,500	42,000	40	75	54
4	0.39	70,500	56,000	36	54	2.5
5	0.57	78,000	62,500	32	47	1

Thus, the above results indicate that phosphorus has a marked effect on the mechanical properties of steels.

In the form of 22 gauge sheet, the above indicated steels showed losses on exposure to the atmosphere for 6 and 12 months as follows:

	P, per-cent	Weight loss mg./cm.²	
		6 months' exposure	12 months' exposure
1	0.006	20.6	31.2
2	0.12	18.5	26.2
3	0.21	17.6	25.8
4	0.39	17.3	25.6
5	0.57	17.0	21.6

Thus, the above results indicate that an increase in the phosphorus content results in an increase in the corrosion resistance of the steel.

In spite of the rather remarkable influence of small amounts of phosphorus on the mechanical properties and corrosion resistance, as shown in the above tables, phosphorus by itself may be objectionable in some cold-forming and cold-drawing steels because it increases their hardness. Furthermore, in excess amounts it induces cold-shortness, increases the size of the grain, lowers the ductility and causes segregation in the ingots into which the steels are cast.

One of the objects of our invention is to provide low alloy, high strength steels having greatly improved mechanical properties, reduced grain size, increased ductility, and increased corrosion resistance to the atmosphere.

Other objects will be apparent from the following description of our invention.

We have found that additions of vanadium to phosphorus steels greatly improve their mechanical properties, reduce their grain size, increase their ductility, very materially increase their corrosion resistance to the atmosphere, and in other ways improve the phosphorus steels by suppressing some of the detrimental influences of excess phosphorus. Grain size reductions and its control by the use of vanadium in phosphorus steels assist in producing better steels of more uniform properties and with less segregation. As illustrative of the grain size reduction brought about in phosphorus steels by vanadium, two annealed sheet steels, each containing 0.12% carbon and 0.17% phosphorus, one without vanadium and one containing 0.20% vanadium, had grain counts of 4,000 and 36,000 grains per sq. in., respectively. Thus, a great decrease in grain size results from the use of vanadium in phosphorus steels.

We have found that steels containing less than 0.5% carbon, up to about 0.5% phosphorus and up to about 0.5% vanadium are readily workable both hot and cold and have decidedly better properties than steels of the same carbon and phosphorus content but containing no vanadium. For best resistance to corrosion, the carbon content should be less than 0.25% and preferably it should be under 0.15%. The carbon content may be as low as 0.01 per cent. The amount of phosphorus is limited only by its deleterious influences on other properties required of the steels. Lower carbon contents and the presence of vanadium overcome to a degree these deleterious influences and therefore allow higher phosphorus contents to be used. While the resistance to corrosion of steels is greatly improved if they contain from 0.08% to 0.50% phosphorus, we prefer to use from 0.08% to 0.25% phosphorus. We have discovered that in the presence of phosphorus, vanadium adds greatly to the resistance to corrosion of steels. While we may use percentages of vanadium as high as 0.5%, the cost of the element in some instances renders its use to this extent inadvisable. We have found that in the less costly steels, vanadium in percentages from 0.025% to 0.25% is satisfactory.

The remaining constituents of the steels, aside from iron, are those incidental to their manufacture. The sulphur is maintained low, preferably not more than 0.20%, though steels containing more than this are within the scope of our invention. The manganese is maintained under 1.5%. The preferred percentage of manganese is from 0.2% to 0.8%.

The following tables illustrate examples of steels made in accordance with the present invention and compare them with other steels. The mechanical properties were obtained on bar stock after normalizing and after annealing and the atmospheric corrosion losses were obtained on 22 gauge sheet.

	C, percent	P, percent	V, percent	Cu, percent	Condition	Tensile strength, lb. sq. in.	Yield strength, lb. sq. in.	Elong. in 2", percent	Red. of area, percent	Charpy impact, ft. lb.
1	.03	.21			Normalized	55,000	32,500	44	75	67
2	.03	.21			Annealed	52,500	29,500	44	75	7
3	.12	.17			do	63,000	39,500	38	67	30
4	.12	.31			do	76,000	51,500	34	61	10
5	.25	.18			do	77,250	42,500	30	49	14
6	.14	.17		.35	do	65,000	40,000	38	65	34
7	.14	.17		1.17	do	80,000	59,000	29	57	4
8	.12	.004	.23		Normalized	64,000	47,000	33	72	51
9	.12	.004	.23		Annealed	58,000	39,000	38	72	52
10	.12	.16	.23		Normalized	79,000	56,500	34	65	30
11	.12	.16	.23		Annealed	73,000	50,000	34	65	29
12	.03	.006			do	34,500	25,000	48	83	42
13	.13	.008			do	50,250	32,000	42	72	51
14	.06	.25	.19	1.5	Normalized	79,100	63,300	35	67	31
15	.06	.25	.19	1.5	Annealed	78,000	62,300	32	67	30

	C, percent	P, percent	V, percent	Cu, percent	Atmospheric corrosion weight loss mg/cm²		
					Condition	6 months' exposure	12 months' exposure
1	.03	.21			Normalized	17.6	25.8
2	.03	.21			Annealed	14.9	25.8
3	.12	.31			do	16.8	23.6
4	.12	.31			do	14.9	21.7
5	.25	.18			do	17.2	23.2
6	.14	.17		.35	do	16.3	22.2
7	.14	.17		1.17	do	16.0	22.7
8	.12	.004	.23		Normalized	21.0	31.0
9	.12	.004	.23		Annealed	19.0	26.7
10	.12	.16	.23		Normalized	13.1	24.8
11	.12	.16	.23		Annealed	13.1	21.4
12	.03	.006			do	20.6	33.8
13	.13	.008			do	23.0	32.7

The vanadium-phosphorus steels, having a substantial content of both elements, are characterized by having very high tensile and yield strengths relative to the tensile and yield strengths of the phosphorus steels containing only traces of vanadium or the vanadium steels low in phosphorus. They are extremely ductile. In resistance to corrosion, the vanadium-phosphorus steels are superior to the copper-phosphorus steels of the very high phosphorus types.

In some instances, part of the vanadium may be replaced by copper or the corrosion resistance and mechanical properties of the steels may be enhanced by the use of copper in addition to the vanadium content indicated above. For corrosion resistance, the use of 0.1% to 0.5% copper, in addition to the indicated vanadium content, is decidedly beneficial, although this amount of copper does not measurably increase the strength or raise the yield point. When the loss in mechanical strength, which would accompany a decrease in vanadium content, is not of serious consequence in the use of the steel, then it becomes possible to replace some of the much more costly vanadium with copper without impairing the resistance to corrosion. In this case, the use of 1 to 2 times as much copper as the vanadium which it replaces would not lessen the resistance to corrosion. On the other hand, 0.1% to 0.5% copper, in addition to the indicated vanadium content, can be used to further enhance the resistance to corrosion that results from the joint use of phosphorus and vanadium.

When the strength and yield point of steels having combinations of carbon, phosphorus, vanadium and copper which are particularly satisfactory are to be raised, we prefer to obtain the increased strength and yield point by the use of more copper rather than by the use of additional amounts of one or more of the other three elements. This preference lies in the fact that copper decreases the ductility far less for a given increase in strength and yield point than does additions of carbon or phosphorus in steels already containing carbon and phosphorus. In the presence of substantial amounts of phosphorus, more carbon is deleterious as it induces brittleness, while in a steel already containing substantial amounts of phosphorus, an increase of phosphorus very seriously effects the impact resistance and ductility. The use of vanadium merely to strengthen the steels, in most instances, is inadvisable because of its cost.

We have found that 1% copper will increase both the strength and yield point of the steels from 5,000 to 20,000 lb./sq. in. depending upon the heat treatments given them, and that additional increases of the same magnitude may be obtained through precipitation hardening. The latter may be effected with normalized steels containing 0.7% to 3% copper by holding them in, or cooling very slowly through the precipitation hardening temperature range of 750 degrees to 1050 degrees F. The preferred range of copper for improved strength and yield point is about 0.50% to 3%.

Our steel has an advantage in welding. On welding the hardening in the zone immediately adjacent to the weld is not appreciable. One of the secondary advantages of the vanadium in the steel is that it prevents a martensitic zone from forming in the steel near the weld. Another function of the vanadium is to prevent grain growth in the overheated zone adjacent to the weld. Phosphorus steel without vanadium will be coarse grained in this zone.

It will be apparent from the above description that we have provided phosphorus-vanadium steels having greatly improved mechanical properties, reduced grain size, increased ductility and increased corrosion resistance. The steel will have a yield strength in the rolled, normalized and annealed conditions of more than 40,000 lbs./sq. in, a ductility at least equal to that of plain carbon steel of equal strength, a small grain structure, and a resistance to atmospheric corrosion that is greater than that of either plain phosphorus steel of like phosphorus content or phosphorus-copper steel of like phosphorus and copper content.

The phosphorus-vanadium steels with or without copper, of the type disclosed herein, having high physical properties as well as high resistance to corrosion may be made into castings or can be fabricated into rough articles such as structural shapes, sheet, plate, wire and tubing which are to be used where resistance to corrosion, as well as high physical properties are desired.

Having thus described our invention, what we claim is:

1. An alloy steel consisting of from 0.01% to 0.5% carbon, from 0.025% to 0.5% vanadium, from 0.08% to 0.5% phosphorus, from 0.2% to 1.5% manganese, copper in an amount not over 3%, and not over 0.20% sulphur, the balance being substantially all iron.

2. An alloy steel consisting of from 0.01% to 0.25% carbon, 0.025% to 0.25% vanadium, 0.08% to 0.25% phosphorus, 0.2% to 0.8% manganese, copper in an amount not over 3%, and not over 0.20% sulphur, the balance being substantially all iron.

3. An alloy steel consisting of from 0.01% to 0.25% carbon, 0.025% to 0.25% vanadium, 0.08% to 0.25% phosphorus, 0.2% to 0.8% manganese, 0.10% to 0.5% copper, and not more than 0.20% sulphur, the balance being substantially all iron.

4. An alloy steel containing from 0.01 per cent to 0.5 per cent carbon, from 0.025 per cent to 0.5 per cent vanadium, from 0.08 per cent to 0.5 per cent phosphorus, from 0.2 per cent to 1.5 per cent manganese, copper in an amount not over 3 per cent, and not over 0.20 per cent sulphur, the phosphorus being present for the purpose of enhancing the corrosion resistance and mechanical properties of the steel and not merely as an impurity and the vanadium being present to offset the embrittling effect of phosphorus, the balance being substantially all iron, the steel having a yield strength in the rolled, normalized and annealed conditions of more than 40,000 pounds per square inch and a ductility at least equal to that of plain carbon steel of equal strength.

5. An alloy steel consisting of from 0.01% to 0.5% carbon, from 0.025% to 0.5% vanadium, from 0.2% to 1.5% manganese, copper in an amount not over 3%, not over 0.20% sulfur, and phosphorus in an amount in excess of 0.2% but less than 0.5%, the balance being substantially all iron.

DANIEL E. KRAUSE.
CLARENCE H. LORIG.