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STEEL

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This invention relates to steels, and provides new and improved steels characterized by novel and commercially valuable properties.

We have discovered that the addition of columbium in amounts between 0.02% and 1% to so-called "plain carbon" and certain "low alloyed" steels effects a marked and surprising improvement in the properties of such steels. One important effect of the columbium addition is to refine the grain-size of the steel, and this grain refinement is retained and maintained even at elevated temperatures up to and somewhat above the critical range. Another effect, which is doubtless at least in part a result of the grain refinement, is the improvement of the tensile strength of many of the steels. Further, the impact strength is increased, and this improvement is marked even at subzero temperatures. There is also an increase in the resistance of the steels to rusting and hot oxidation. The deep-drawing and cold-rolling characteristics of the steels are improved. The hardenability of the steels by heat treatment is somewhat decreased, and there is less distortion of the steel when it is rapidly cooled from elevated temperatures. The ratio of yield point to maximum stress is increased, the increase depending upon the columbium and carbon contents of the steels: the increase is greater in the steels having the lower carbon and columbium contents.

Steels included in our invention are:

A. Plain carbon steels containing carbon in amounts not exceeding 1% and preferably not exceeding 0.6%, silicon in amounts up to 1%, manganese in amounts up to 2%, and suitable amounts of columbium, the remainder iron.

B. Chromium steels containing carbon in amounts not exceeding 0.6% and preferably not over 0.4%, 0.25% to less than 2% chromium, silicon in amounts up to 1%, manganese in amounts up to 2%, suitable amounts of columbium, and the remainder iron.

C. Chromium-nickel steels containing, in addition to the ingredients of the chromium steels, 0.05% to 5% nickel. The manganese preferably does not exceed 1%.

D. Molybdenum steels containing carbon in amounts up to 0.6% and preferably not over 0.4%, 0.05% to 1% molybdenum, manganese in amounts up to 2%, silicon in amounts up to 1%, suitable amounts of columbium, and the remainder iron.

E. Molybdenum-nickel steels containing, in addition to the ingredients of the molybdenum steels, 0.05% to 5% nickel. The manganese in these steels preferably does not exceed 1%.

F. Chromium-molybdenum steels containing carbon in amounts up to 0.6% and preferably not over 0.4%, 0.25% to 2% chromium, 0.05% to 1% molybdenum, silicon in amounts up to 1%, manganese in amounts up to 2%, suitable amounts of columbium, and the remainder iron.

Suitable amounts of columbium to be added to these steels according to the present invention are from 0.02% to 1%. Usually, it will not be necessary or desirable to exceed 0.5% columbium, and the most useful range is within the limits 0.05% to 0.25%. In general, the greater amounts of columbium should ordinarily be used in the steels containing the greater amounts of carbon, within the ranges specified above.

One of the most valuable properties of the columbium containing steels of the invention is that of retaining its normally fine grained structure at elevated temperatures, which property is attained without detrimentally affecting other important physical properties. The expedients heretofore customarily employed to refine the grain size of carbon and low-alloyed steels have, in most cases, either detrimentally affected the toughness of the steels, or failed to prevent coarsening of the grain size at elevated temperatures, during fabrication for instance, or both. The coarsening of the grain is considerably aggravated in a case carburizing process, and in such a process the addition of columbium to the steel is especially advantageous, as illustrated by the data in Table I which gives the experimentally determined grain number (A. S. T. M. Specification E 19–33) of the cases of a series of steels after carburizing for eight hours at each of three different temperatures. In each case, the grain size of the core was smaller than that of the case.

Table I

Composition of steel (remainder iron)					Grain No. of case after carburizing 8 hours—		
% C	% Mn	% Si	% Cb	Other metals	At 925° C.	At 975° C.	At 1025° C.
0.16	0.46	0.29	None	None	3 to 5	3 to 5	1 to 4
0.15	0.45	0.27	0.017	None	3 to 8	3 to 8	2 to 8
0.17	0.48	0.26	0.45	None	7 to 8	5 to 8	5 to 8
0.41	0.77	0.27	None	None	2 to 4	1 to 4	1 to 4
0.33	0.80	0.27	0.06	None	5 to 7	4 to 7	5 to 7
0.43	0.74	0.22	0.36	None	6 to 8	6 to 8	5 to 8
0.77	0.75	0.22	None	None	1 to 3	1 to 3	1 to 3
0.94	0.75	0.25	0.04	None	5 to 7	4 to 6	4 to 6
0.93	0.73	0.24	0.18	None	6 to 7	6 to 7	5 to 8
0.97	0.72	0.19	0.41	None	5 to 8	5 to 8	5 to 8
0.15	1.50	0.16	None	None	1 to 3	1 to 3	1 to 3
0.17	1.61	0.33	0.12	None	5 to 8	5 to 8	5 to 8
0.52	1.68	0.36	0.11	None	5 to 8	5 to 8	4 to 8
				% Ni			
0.16	0.36	0.16	None	3.49	2 to 6	2 to 6	2 to 7
0.37	0.40	0.17	None	3.52	5 to 9	3 to 8	2 to 7
0.17	0.47	0.31	0.10	3.45	6 to 9	6 to 9	5 to 8
0.34	0.35	0.13	0.08	3.46	5 to 7	5 to 7	4 to 7
0.47	0.80	0.31	0.08	3.42	4 to 7	4 to 6	4 to 6

Table I—Continued

Composition of steel (remainder iron)					Grain No. of case after carburizing 8 hours—		
% C	% Mn	% Si	% Cb	Other metals	At 925° C.	At 975° C.	At 1025° C.
				% Cr			
0.18	0.45	0.24	None	0.75	3 to 7	1 to 8	1 to 3
0.22	0.46	0.27	0.10	0.75	7 to 8	5 to 8	5 to 8
0.49	0.68	0.24	0.07	1.05	4 to 6	4 to 6	4 to 7
0.28	0.53	0.36	0.06	2.94	8	8	3 to 7
0.46	0.78	0.78	0.11	0.51	6 to 8	5 to 8	5 to 7
				% Mo			
0.17	0.43	0.19	None	0.33	2 to 8	2 to 6	1 to 5
0.35	0.42	0.16	None	0.31	2 to 5	1 to 6	1 to 3
0.18	0.37	0.18	0.084	0.32	6 to 8	6 to 8	6 to 8
0.33	0.40	0.17	0.10	0.16	7 to 9	9	9
				% Ni % Cr			
0.13	0.42	0.16	None	1.25 0.44	2 to 7	2 to 6	1 to 6
0.34	0.41	0.13	None	1.34 0.47	3 to 9	3 to 8	2 to 4
0.14	0.43	0.21	0.09	1.24 0.59	4 to 8	5 to 7	3 to 8
0.39	0.43	0.12	0.07	1.27 0.61	4 to 8	4 to 8	3 to 7
0.47	0.60	0.14	0.11	1.61 0.68	4 to 8	4 to 6	4 to 7
0.17	0.41	0.31	None	3.40 1.25	3 to 8	2 to 6	1 to 6
0.32	0.38	0.18	None	3.57 1.49	4 to 7	3 to 7	2 to 4
0.14	0.36	0.16	0.08	3.45 1.46	6 to 8	6 to 8	5 to 8
0.34	0.37	0.14	0.10	3.53 1.46	4 to 6	6 to 7	3 to 8
				% Ni % Mo			
0.18	0.50	0.22	None	1.74 0.24	4 to 7	1 to 6	1 to 5
0.31	0.42	0.09	None	1.74 0.25	8	2 to 7	2 to 8
0.15	0.44	0.23	0.09	1.72 0.22	9	9	9
0.40	0.43	0.23	0.10	1.77 0.14	9	8 to 9	8 to 9
				% Cr % Mo			
0.20	0.80	0.24	None	0.58 0.21	3 to 7	1 to 6	1 to 5
0.35	0.68	0.15	None	0.96 0.25	3 to 5	1 to 6	1 to 6
0.15	0.67	0.20	0.09	0.63 0.22	7 to 8	5 to 8	5 to 8
0.37	0.71	0.27	0.10	1.00 0.17	4 to 7	4 to 7	4 to 7
0.51	0.64	0.23	0.10	1.03 0.10	5 to 6	5 to 7	4 to 7

In general, the grain refining effect is roughly proportional to the columbium content up to a certain optimum amount of columbium, which optimum content depends chiefly on the carbon content of the steel. The grain refinement of a maximum 0.1% carbon steel reaches substantially its greatest degree at about 0.1% columbium; a 0.15% carbon steel at about 0.15% columbium; a 0.35% carbon steel at about 0.18% columbium; and a 0.5% carbon steel at about 0.25% columbium. The presence of chromium, molybdenum, or vanadium reduces somewhat these optimum amounts of columbium. A moderate excess of columbium above the optimum and below the maximum specified above (1%), will not ordinarily adversely affect the properties of the steel to a serious extent.

The influence of columbium on the tensile and impact properties of the steels under consideration is indicated by the data appearing in Tables II and III which show the experimentally determined yield point in thousands of pounds per square inch (Y. P.), maximum stress in thousands of pounds per square inch (M. S.), percentage elongation in a 2 inch gage length (El. %), and reduction in area (R. A. %), all on 0.505 inch diameter A. S. T. M. standard tensile test pieces; and also the Izod impact value in foot pounds as determined on a standard Izod machine with an initial energy level of 120 foot pounds and a standard specimen one centimeter square provided with a 45° notch.

Table II

Composition of steel (remainder iron)				Y. P. 1000 lb/sq. in.	M. S. 1000 lb/sq. in.	El. percent	R. A. percent	Izod ft.-lb.
Percent C	Percent Mn	Percent Si	Percent Cb					
As-rolled								
0.09	0.30	0.20	None	48	57.5	35	63	76
0.08	0.25	0.20	0.28	60.5	65	26	69	93
0.10	0.33	0.42	0.65	24	58.5	40	80	98
Air cooled from 900° C.								
0.09	0.30	0.20	None	41	55	39	64	82
0.08	0.25	0.20	0.28	55	60.5	27	68	95
0.10	0.33	0.42	0.65	22.3	57.6	40	81	92
Quenched in water from 900° C.; and drawn at 150° C.								
0.16	0.46	0.29	None	64.5	100	17	55	42
0.15	0.45	0.27	0.017	72.5	89	27	63	75
0.17	0.48	0.26	0.45	71	81.8	31	71	75
Air cooled from 925° C.								
0.16	0.46	0.29	None	46.5	66.8	33	55	72
0.15	0.45	0.27	0.017	50	67.5	33	62	72
0.17	0.48	0.26	0.45	50	63.5	36	69	75
Quenched in water from 850° C.; and drawn at 550° C.								
0.41	0.77	0.27	None	101.5	125.5	19	51	37
0.38	0.80	0.27	0.06	91.5	110.5	21	57	47
0.43	0.74	0.22	0.36	87	105	24	55	49
Cooled in air from 875° C.								
0.41	0.77	0.27	None	62	91	25	48	15
0.38	0.80	0.27	0.06	65	90.5	21	57	28
0.43	0.74	0.22	0.36	64.5	86	24	56	40

Table III

Composition of steel (remainder iron)							Y. P.	M. S.	El. percent	R. A. percent	Izod ft.-lb.
Percent C	Percent Mn	Percent Si	Percent Cr	Percent Ni	Percent Mo	Percent Cb					
Quenched in oil from 850° C.–900° C.; drawn in air at 150° C.–425° C.											
0.18	0.45	0.24	0.75	-------	-------	-------	61	97	22	50	33
0.22	0.46	0.27	0.75	-------	-------	0.10	72	116	19	40	34
0.35	0.43	0.25	2	-------	-------	-------	191	204	9	37	7
0.32	0.33	0.15	1.83	-------	-------	0.11	193	218	9	37	11
0.41	0.40	0.25	2	-------	-------	0.43	197	217	9	37	9
0.13	0.42	0.16	0.44	1.25	-------	-------	71	100	24	60	57
0.18	0.43	0.21	0.59	1.24	-------	0.09	68	108	20	66	46
0.44	0.75	0.25	0.65	1.5	-------	-------	181	204	10	35	9
0.49	0.75	0.25	0.65	1.5	-------	0.42	177	194	12	44	10
0.17	0.43	0.19	-------	-------	0.33	-------	58	88	26	68	74
0.17	0.45	0.25	-------	-------	0.35	0.17	47	72	35	67	81
0.18	0.50	0.22	-------	1.74	0.24	-------	81	117	18	43	34
0.16	0.45	0.25	-------	1.75	0.25	0.18	55	94	26	69	77
0.20	0.80	0.24	0.58	-------	0.21	-------	99	125	13	38	21
0.18	0.75	0.25	0.6	-------	0.25	0.23	77	119	21	45	49

Table III—Continued

Composition of steel (remainder iron)							Y. P.	M. S.	El. percent	R. A. percent	Izod ft.-lb.
Percent C	Percent Mn	Percent Si	Percent Cr	Percent Ni	Percent Mo	Percent Cb					
Cooled in air from 850° C.-900° C.											
0.18	0.45	0.24	0.75				59	72	35	67	72
0.22	0.46	0.27	0.75			0.10	59	76	34	69	79
0.35	0.43	0.25	2				102	149	11	23	5
0.32	0.33	0.15	1.83			0.11	71	113	20	59	33
0.41	0.40	0.25	2			0.43	136	191	10	18	6
0.13	0.42	0.16	0.44	1.25			47	69	34	66	75
0.14	0.43	0.21	0.59	1.24		0.09	60	73	30	54	79
0.44	0.75	0.25	0.65	1.5			105	148	12	32	4
0.49	0.75	0.25	0.65	1.5		0.42	121	161	9	18	7
0.17	0.43	0.19			0.33		52	70	34	61	72
0.17	0.45	0.25			0.35	0.17	55	87	31	70	80
0.18	0.50	0.22		1.74	0.24		52	87	27	52	49
0.16	0.45	0.25		1.75	0.25	0.18	57	77	35	69	52
0.20	0.80	0.24	0.58		0.21		53	90	24	48	20
0.18	0.75	0.25	0.6		0.25	0.23	44	82	31	63	73

It will be observed from the data of Tables II and III that, in the steels containing up to about 0.3% carbon, the addition of up to about 0.1% columbium increases the yield point, maximum stress and ratio of yield point to maximum stress. The ductility is only slightly affected. As the columbium is increased above 0.1%, the softening effect of the columbium begins to predominate, the yield point and maximum stress are decreased, and the ductility is substantially increased. As the carbon content is increased above 0.3%, and as other alloyed additions are made, the effects of columbium on the tensile properties are reduced, particularly if the steels are heat treated.

It will also be noted in Tables II and III that the addition of columbium raises the impact strength of the steels, and that the improvement is greatest in the high carbon steels and those containing chromium.

As mentioned above, the addition of columbium to the plain carbon and low alloyed steels considerably increases their impact strength at subzero temperatures. As little as 0.2% columbium raises the impact strength at —100° C. to 10 foot pounds or more.

Table IV contains impact data obtained in the manner described in connection with Tables II and III, except that the samples under the heading "—78° C." were cooled about an hour at —78° C. in a bath of acetone and frozen carbon dioxide before testing; and the samples under the heading "—100° C." were cooled about an hour at —100° C. in liquid propane which in turn was cooled with liquid air, before testing. After cooling, the specimens were rapidly transferred from the cooling medium to the Izod machine and tested. The time required for the transfer and test was in all cases less than ten seconds.

Table IV

Composition of steel (remainder iron)					Izod impact ft.-lbs., at—		
Percent C	Percent Mn	Percent Si	Percent Cb	Other metals	+28° C.	—78° C.	—100° C.
0.21	0.4	0.3	None	None	56	4	2
0.18	0.5	0.3	0.08	None	58	16.5	5
0.20	0.5	0.3	0.20	None	67	30	10
0.24	0.7	0.4	0.32	None	67	34.5	15
0.20	0.6	0.3	0.67	None	74	37	21.5
0.23	0.6	0.4	0.73	None	84	75	40
0.17	1.6	0.3	0.12	None	86	50	
0.17	0.5	0.3	0.10	3.5% Ni	73	50	
0.22	0.5	0.3	0.10	0.75% Cr	79	37	
0.16	0.4	0.2	0.10	1% Cr, 0.2% V	83	69	
0.14	0.4	0.2	0.09	0.6% Cr, 1.2% Ni	79	69	
0.15	0.4	0.2	0.09	0.22% Mo, 1.7% Ni	68	70	
0.18	0.8	0.3	0.46	0.8% Cr, 1.05% Cu	82	86	82

The presence of columbium substantially increases the resistance of these steels to hot oxidation and, although the columbium steels are not to be considered oxidation resistant in the sense that high chromium steels, for instance, are oxidation resistant, the increase in resistance will be valuable in many uses of the steels. Table V presents data illustrating this effect of columbium.

Table V

Composition of steel (remainder iron)				Percent loss in weight after 1,176 hours at 650° C.
Percent C	Percent Mn	Percent Si	Percent Cb	
0.09	0.30	0.20	None	10
0.09	0.15	0.74	None	5.7
0.06	0.41	0.28	0.41	4.4
0.07	0.41	0.41	0.94	2.8

The invention is based on the above-described discoveries and comprises new alloy steels and articles composed thereof, having in addition to 0.02% to 1% columbium, substantially the limits of composition indicated in Table VI.

Table VI

Type of steel	Composition limits (remainder iron)			
	Percent C	Percent Mn	Percent Si	Other metals
C	Up to 1	Up to 2	Up to 1	None.
Cr	Up to 0.6	Up to 2	Up to 1	0.25 to 2% Cr.
Cr-Ni	Up to 0.6	Up to 1	Up to 1	0.05 to 5% Ni, 0.25 to 2% Cr.
Mo	Up to 0.6	Up to 2	Up to 1	0.05 to 1% Mo.
Mo-Ni	Up to 0.6	Up to 1	Up to 1	0.05 to 5% Ni, 0.05 to 1% Mo.
Cr-Mo	Up to 0.6	Up to 2	Up to 1	0.25 to 2% Cr, 0.05 to 1% Mo.

The articles of the invention include articles deep-drawn from the steel of the invention; articles having a core containing less than 0.5% carbon and a carburized case containing more than 0.8% carbon, and 0.02% to 1% columbium throughout, the remainder of the composition being as shown in Table VI; parts of machines and of other apparatus, required to withstand stress at moderately elevated temperatures; articles, composed of the steel of the invention, designed for use to resist impact shock at subzero temperatures; and pressure vessels, composed of the steel of the invention, designed to withstand two or three dimensional stress at subzero temperatures.

It will be appreciated that the specific examples herein are given by way of illustration, and that the invention is not limited to or by such examples.

We claim:

1. Low alloyed steel containing carbon in an amount not exceeding 0.6%; manganese in an amount not exceeding 2%; silicon in an amount not exceeding 1%; a substantial amount of at least one carbide forming metal of the group consisting of chromium and molybdenum, the chromium being less than 2% and the molybdenum not exceeding 1%; 0.02% to 0.5% columbium which imparts to said steel a fine-grained structure which persists at all temperatures up to and somewhat above the critical range, increased ductility, increased impact strength at normal and subzero temperatures, improved hot and cold workability, and increased resistance to hot and cold oxidation, but does not impart substantial age hardening properties; and the remainder iron.

2. Steel containing carbon in an amount not exceeding 0.6%, manganese in an amount not exceeding 2%, silicon in an amount not exceeding 1%, 0.25% to less than 2% chromium, 0.02% to 0.5% columbium which imparts to said steel a fine-grained structure which persists at all temperatures up to and somewhat above the critical range, increased ductility, increased impact strength at normal and subzero temperatures, improved hot and cold workability, and increased resistance to hot and cold oxidation, but does not impart substantial age hardening properties, the remainder iron.

3. Steel containing carbon in an amount not exceeding 0.6%, manganese in an amount not exceeding 2%, silicon in ar amount not exceeding 1%, 0.05% to 1% molybdenum, 0.02% to 0.5% columbium, the remainder iron.

4. Steel containing carbon in an amount not exceeding 0.6%, manganese in an amount not exceeding 2%, silicon in an amount not over 1%, 0.05% to 1% molybdenum, 0.25% to less than 2% chromium, 0.02% to 0.5% columbium, the remainder iron.

5. Case carburized article having a core containing less than 0.5% carbon and a carburized case containing more than 0.8% carbon, the core and case being composed of steel containing, aside from carbon, manganese in an amount not exceeding 2%; silicon in an amount not exceeding 1%; a substantial amount of at least one carbide forming metal of the group consisting of chromium and molybdenum, the chromium being less than 2% and the molybdenum not exceeding 1%; 0.02% to 0.5% columbium which imparts to said carburized article a fine-grained structure, increased ductility, and increased impact strength at normal and subzero temperatures; and the remainder iron.

6. Article used to resist, at subzero temperatures, impact shock or multidimensional stress, which article is composed of a low alloyed steel containing carbon in an amount not exceeding 0.6%; manganese in an amount not exceeding 2%; silicon in an amount not exceeding 1%; a substantial amount of at least one carbide forming metal of the group consisting of chromium and molybdenum, the chromium being less than 2% and the molybdenum not exceeding 1%; 0.02% to 0.5% columbium which imparts to said article increased impact strength at subzero temperatures; and the remainder iron.

7. Machine element subject to impact stress at elevated temperatures below 500° C. and composed of a low alloyed steel containing carbon in an amount not exceeding 0.6%; manganese in an amount not exceeding 2%; silicon in an amount not exceeding 1%; a substantial amount of at least one carbide forming metal of the group consisting of chromium and molybdenum, the chromium being less than 2% and the molybdenum not exceeding 1%; 0.02% to 0.5% columbium which imparts to said element a persistent fine-grained structure, increased ductility, and increased impact strength at working temperatures, remainder iron.

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