

[54] **LOW ALLOY STRUCTURAL STEEL**

[72] Inventor: **Robert Allen De Paul**, Sloatsburg, N.Y.
[73] Assignee: **The International Nickel Company, Inc.**,
New York, N.Y.
[22] Filed: **Oct. 13, 1969**
[21] Appl. No.: **865,995**

[52] U.S. Cl. 75/123 J, 75/123 K, 75/124,
75/125
[51] Int. Cl. C22c 39/20, C22c 39/14
[58] Field of Search.....75/128 V, 128 G, 123 J, 125,
75/124

[56] **References Cited**

UNITED STATES PATENTS

934,697 9/1909 Schneider 75/128 V

3,290,128	12/1966	Manganello	75/124
3,475,164	12/1960	Hydrear	75/124
3,388,988	1/1968	Nagashima.....	75/128 G
2,992,148	7/1961	Yeo.....	75/123 J
2,145,756	1/1939	Ervin	75/128 V
3,097,294	7/1963	Kubli	75/124
3,368,887	2/1968	Enis	75/124

Primary Examiner—Hyland Bizot
Attorney—Maurice L. Pinel

[57] **ABSTRACT**

Low cost, precipitation hardenable, structural steels containing carbon, nickel, molybdenum and columbium, the steels being capable of developing high strength and both ambient and low temperature toughness. Other constituents can be present, notably copper, manganese, silicon, etc.

6 Claims, No Drawings

LOW ALLOY STRUCTURAL STEEL

For constructional applications and the like, a steel should display considerable versatility in terms of adaptability and thus exhibit a variety of different mechanical characteristics each of which exceeds a prescribed minimum, (though each might not be necessary for all intended applications). A given steel may offer certain properties to an outstanding degree, e.g., yield strength, but be inferior as to others, e.g., toughness, the converse being equally true. Too, a particular steel may offer acceptable toughness only in certain mill forms, e.g., bar or rod, but not in the widely used form of plate, toughness usually being much higher in the former. Plate presents an additional difficulty in the sense that in unidirectionally rolled steels, (see Metals Handbook, 8th ed. pp. 229-231) there can be a considerable disparity in toughness, depending upon whether it is measured in the longitudinal direction (direction parallel to rolling) or in the transverse direction, the lower values usually obtaining with the latter. This variance can be sufficiently great to eliminate a steel from further consideration in the absence of cross rolling.

By way of further illustration, there are steels which manifest both good strength and toughness but are otherwise unattractive by reason of the fact that they are difficultly weldable at best, weldability being a prime virtue of any steel for general purpose application. Still other steels cannot be readily fabricated into desired shapes since they do not lend themselves to such processing techniques as cold forming.

In the light of the foregoing, the present invention is particularly addressed to the problem of providing steels which in unidirectionally rolled plate form are characterized by (a) a yield strength of about 150,000 psi or more, (b) the ability to absorb 50 ft.-lbs. of impact energy (Charpy V-Notch) in the longitudinal direction and at least 25 ft.-lbs. in the transverse direction, (c) good weldability, and (d) good formability including a reduction in area of at least about 60%. Furthermore, since it would not be unexpected for a multi-purpose steel to be used in comparatively cold regions, (e) the minimum toughness values above given should obtain down to temperatures as low as minus 40° F. Moreover, the properties should be attainable without recourse to elaborate processing and by using (f) simple air melting practice together with conventional quenching and aging techniques.

Perhaps it should be mentioned that there are a limited number of weldable, formable steels commercially produced which offer both relatively good toughness and yield strengths upwards of 180,000 psi, the maraging steels being exemplary. Very few, if any, of such steels, however, are capable of delivering the toughness qualities contemplated herein and, moreover, are, comparatively speaking, more expensive. Oddly enough, a review of commercially available steels reflects that there is a considerable gap existing between the low strength (100,000 psi) and the much higher strength steels (180,000-200,000 psi and up). Neither satisfy all the objectives above discussed accordingly, there is a need for a commercial steel intermediate the low and high strength versions but which possesses those attributes so necessary for it to be useful for constructional purposes.

In any event, it has now been discovered that a low cost structural steel of novel composition and containing correlated amounts of carbon, nickel, molybdenum, columbium, manganese, silicon and other constituents as described herein can be provided which in one package satisfies each and all of the above objectives.

Generally speaking and in accordance herewith the above objectives are attained with quenched and aged steels containing, in weight percent, about 0.06% to about 0.15% carbon, about 4% to 8% nickel, from 0.6% to 1.5% molybdenum, from 0.02% to 0.15% columbium, the sum of the carbon plus columbium not exceeding 0.24%, up to about 1.75% copper, up to about 0.8% manganese, up to about 0.5% silicon, up to 0.5% chromium, up to about 0.15% aluminum, and the balance essentially iron. Elements such as phosphorus, sulfur, nitrogen, hydrogen, oxygen and the like should be kept to low levels consistent with good commercial steelmaking practice.

Phosphorus and sulfur, if any, should not exceed 0.015% each, and the total thereof should not fall above about 0.025%. Nitrogen preferably should be held to a level below 50 parts per million to minimize formation of nitrides which could otherwise induce certain unfavorable characteristics, e.g., strain aging.

In carrying the invention into practice, the carbon should not be less than 0.06%, percent, and advantageously not less than about 0.08%; otherwise, yield strength is insufficient. On the other hand, with carbon levels much above about 0.15% weldability difficulties ensue (weld and heat affected zone "HAZ" cracking) and there is an unnecessary loss in notch toughness, notably at the lower temperatures. From 0.08% to 0.13% carbon is most satisfactory.

The nickel content should not fall below 4% or 4.5%, less the danger of inadequate strength be entertained. This constituent also imparts toughness and ductility qualities and in striving for the best combination of strength and toughness it has been found that at least about 5% or 5.5% to 6.5% or 7% nickel is of considerable advantage. Amounts exceeding about (8% do not confer additional benefits of substantial consequence, particularly in view of the added cost.

As to molybdenum, it also contributes markedly to strength and toughness with the added virtue of inhibiting the occurrence of temper embrittlement. However, amounts thereof much beyond 1.5% e.g., 2%, tend to promote embrittling characteristics through the formation of what is believed to be an iron molybdiide compound. A range of 0.8% to 1.2% molybdenum is most beneficial.

Columbium exercises a potent influence in respect of both strength and toughness and imparts a fine grain structure. Nonetheless, relatively high amounts of columbium can bring about an impairment in impact toughness, particularly at low temperatures, a result again deemed attributable to what is believed to be an iron columbide type compound. Too, when carbon and columbium are both at the top end of their ranges weldability is endangered and thus the total percentage of these constituents should not exceed 0.23% or 0.24%. Advantageously, the columbium content is maintained between about 0.05% to 0.11%. Vanadium can be used in lieu of columbium, but the latter is much preferred since it affords a more refined grain structure, a grain size of ASTM 9 or 10 or finer, than vanadium. This is beneficial to weldability.

Copper has been found to exercise a relatively potent influence in achieving good yield strength levels in heavy section sizes, particularly in respect of sections 3 inches or more in thickness, an effect due to precipitation hardening upon cooling from aging. For sections up to 3 inches, copper is not required, but about 0.5% to 1.5%, preferably 0.75% to 1.25%, is of considerable merit for 3 inch sections and above.

With regard to other constituents, manganese, although not of an absolute necessity, should be present in an amount of at least about 0.2%, advantageously at least 0.4%, to tie up sulfur and thus minimize hot workability difficulties. It should not exceed 0.8%, and preferably is not greater than 0.6% or 0.7%, to avoid weldability problems. Again, while not absolutely essential, silicon, e.g., upwards of 0.02%, does contribute to good deoxidation and is useful in "killing" the steel, if desired; however, percentages above about 0.5% detract from toughness and can cause or promote poor weldability characteristics. From 0.1% or 0.15% to 0.35% is satisfactory. Aluminum also is useful for deoxidizing purposes but significant amounts thereof can impair toughness and thus are quite unnecessary. Elements such as chromium, boron and cobalt, can be tolerated in small amounts. However, significant amounts of chromium have been found to subvert toughness; thus, whether added by way of scrap or otherwise, it should be controlled so as not to exceed 0.5%, e.g., 0.25%. Moreover, in the presence of carbon at the high end of the carbon range, about 0.12% up to 0.15%, the chromium content should not exceed 0.2% in order to minimize weldability difficulties.

Conventional steelmaking practice, including both air melting or vacuum processing, can be used in producing the sub-

ject steels. Vacuum melting does reduce the level of deoxidants needed which in turn yields a cleaner steel, although cost might be a factor. Standard cast iron ingot molds can be used for casting or pouring. Ingots should be soaked at about 2,000° F. to 2,300° F., (a preferred range being from 2,175° F. to 2,225° F.) for 2 to 4 hours depending upon the size of the ingot. Forging to the desired billet or slab size is accomplished directly from the soaking temperature. Melts can be air cooled to room temperature and subsequently reheated to the rolling temperature or equalized in a furnace following forging at the rolling temperature. With respect to hot working, rolling should be initiated over the temperature range of about 1,550° F. to 1,900° F., with a range of 1,775° F. to 1,825° F. being quite satisfactory. Rolling to the desired size and shape should

melted steel compositions, Steels 1 through 8 being within the invention whereas A through H are outside the scope thereof. All steels shown in Table I were prepared using an air induction furnace and magnesia crucible. Generally, 30-lb. ingots were prepared, the pouring temperature being about 2,750° F. Thereafter, the specimens were soaked for 2 hours at about 2,200° F., forged to 1-inch plate, then cooled, reheated to about 1,800° F. for about 1 hour, rolled to ½ -inch plate (4 inches wide, 14 inches long) in two passes, air cooled, solution treated at about 1,600° F. for about 1 hour, water quenched, then aged at about 950° F. for 3 hours and then air cooled to room temperature. All steels were unidirectionally rolled. Standard tensile blanks were cut from the longitudinal direction and standard Charpy blanks were cut from both the

TABLE II

Steel	Y.S., k.s.i.	U.T.S., k.s.i.	Elong., percent	R.A., percent	CVN Impact Toughness			
					Longitudinal		Transverse	
					R.T.	-40° F.	R.T.	-40° F.
1.....	160.0	166.5	18	67.25	71	58	36.5	37.5
2.....	155.5	160.1	17.5	68.75	58	70	47	42
3.....	167.7	171.9	20	67.2	59.75		32	
4.....	155.7	160.7	18.5	70.5	81.5	79.75	42.5	48.5
5.....	159.9	163.0	18	66	62	65.5	40	37.75
6.....	166.4	169.2	16.5	16.2	48.5	45.75	37	34.75
7.....	154.5	157.6	16.5	74.25	90	86	29	30
8.....	154.1	155.6	18.0	68.0	67	63	44	39
A.....	137.6	143.1	20	71	98	88	52.5	50.75
B.....	162.6	172.0	17	64.5	50	38	30	25.75
C.....	169.6	177.2	17	63.5	50	44	34	31
D.....	155.9	162.3	18	67.25	62	54	34	26
E.....	106.3	113.9	23	74.5	122	113.25	67	66.25
F.....	142.9	148.5	18.5	68.25	78	82	85	42.5
G.....	168.2	178.9	17	64.5	44	50.25	30	25
H.....	156.1	161.6	17.5	63.0	50	53	33	28

be accomplished over a finishing temperature range of 1,350° F. to 1,850° F., e.g., 1,600° F. to 1,750° F. Below 1,700° F. is preferred. Attractive properties can be achieved with finishing temperatures as low as 1,350° F., which falls into the ferrite plus austenite region. The material can be air cooled or water cooled and advantageously is sprayed or quenched following rolling.

If a solution treatment is employed, it should be conducted over the temperature range of about 1,500° F. to 2,000° F. for a period of about ½ hour to 3 hours, 1 hour being preferred. If the steels are water quenched relatively quickly after final hot rolling, the steels can be directly aged for maximum yield strength without the need for a solution treatment. Upon quenching, the steels are then aged within the range of about 800° F. to 1,150° F. for ½ hour to 12 hours. The solution and aging treatment temperatures are advantageously carried out over the temperatures of 1,550° F. to 1,650° F. (1 hour) and 900° F. to 1,000° F. (2 to 4 hours), respectively. Cold forming, where desired, should be effected prior to aging.

For the purpose of giving those skilled in the art a better appreciation of the advantages of the invention, there is given herein data illustrative of the properties characteristic of the subject steels. In Table I there is presented a series of air

longitudinal and transverse directions. The results (average values) are reported in Table II.

The above data reflect that steels within the invention are characterized by an excellent combination of strength and toughness coupled with good ductility and reduction of area values. In marked contrast, Alloys A through H all failed in one or more respects. Alloy A, low in carbon, was notable for its lack of strength (also true for molybdenum deficient Alloys E and F) whereas excessive carbon Alloys B and C (also high molybdenum Alloy G) exhibited inadequate toughness. As will be detailed hereinafter, Alloys B, D and H cracked upon welding.

A careful perusal of the data in Tables I and II further confirm the considerable difference in toughness, i.e., the ability to absorb impact energy, which can be expected when a comparison is made between longitudinal and transverse measurements. As previously indicated herein, this is rather common metallurgical behavior with unidirectionally rolled steels. This disparity, however, can be greatly narrowed by cross rolling as evident from the data set forth in Tables III and IV below, the steels having been processed much in the same manner as the steels in connection with Table I except that cross rolling was applied.

TABLE I

Steel	C, percent	Ni, percent	Mo, percent	Cb, percent	Mn, percent	Si, percent	Al, percent	Fe, percent
1.....	0.14	6.05	0.98	0.09	0.53	0.29	0.04	Bal.
2.....	0.09	6.00	0.98	0.08	0.54	0.28	0.04	Bal.
3.....	0.11	9.6	1.01	0.11	0.56	0.29	0.13	Bal.
4.....	0.10	6.0	0.98	0.05	0.55	0.28	0.04	Bal.
5 ¹	0.11	5.9	0.90	0.10	0.64	0.15	0.09	Bal.
6 ²	0.12	6.2	0.95	0.10	0.70	0.17	0.10	Bal.
7 ³	0.10	5.85	0.93	0.10	0.47	0.23	0.04	Bal.
8.....	0.08	5.45	0.94	0.08	0.53	0.28	0.05	Bal.
A.....	0.05	6.0	0.98	0.09	0.55	0.31	0.05	Bal.
B.....	0.16	6.50	1.08	0.13	0.58	0.30	0.06	Bal.
C.....	0.23	6.05	0.98	0.09	0.53	0.31	0.05	Bal.
D.....	0.11	6.03	0.99	0.15	0.53	0.36	0.05	Bal.
E.....	0.11	5.93	n.a.	0.09	0.56	0.33	0.04	Bal.
F.....	0.12	6.0	0.49	0.09	0.56	0.31	0.05	Bal.
G.....	0.11	6.0	1.94	0.10	0.50	0.28	0.05	Bal.
H.....	0.10	6.0	0.98	0.10	0.57	0.32	0.05	Bal.

¹ Contained 0.49% Cu.

² Contained 1.03% Cu.

³ 300 lb. heat (poured at 2,850° F.).

n.a. = not added.

Bal. = balance iron and impurities; all steels contained less than 0.02% phosphorus and 0.01% of sulfur except Alloy H which contained 0.024% and 0.012% of P and S, respectively.

TABLE III

Steel	C, percent	Ni, percent	Mo, percent	Cb, percent	Mn, percent	Si, percent	Al, percent	Fe, percent
9.....	0.13	6.0	1.0	0.10	0.64	0.27	0.08	Bal.
10.....	0.11	6.07	0.95	0.06	0.57	0.22	0.076	Bal.
11.....	0.11	6.07	0.93	0.19	0.69	0.28	0.076	Bal.
12.....	0.13	6.10	1.00	0.25	0.58	0.28	0.077	Bal.

TABLE IV

Steel	Y.S. k.s.i.	U.T.S. k.s.i.	Elong., percent	R.A., percent	CVN Impact Toughness			
					Longitudinal		Transverse	
					R.T.	-40° F.	R.T.	-40° F.
9.....	161.5	165.3	18.0	63.5	44	42	44	40
10.....	160.0	164.9	18.0	64.0	47	40	43	39
11.....	159.2	164.5	17.5	60.0	40	35	33	32
12.....	157.8	163.7	17.5	60.5	42.5	40	38.5	35

The minimum toughness level of 50 foot-pounds required herein in connection with unidirectionally rolled alloys need not obtain for cross rolled steels. In the latter case, the steels should nonetheless exhibit a minimum toughness of 25 foot-pounds, preferably at least 30 foot-pounds.

Since, as noted herein, alloys to be used for constructional type applications should manifest good weldability characteristics, various compositions were studied in respect of susceptibility to cracking. In this regard, bead on plate tests were conducted using plates 3 inches in width, 6 inches in length and one-half inch thick, the plates having been solution treated for 1 hour at 1,600° F., water quenched, aged 3 hours at 950° F. and then air cooled. The faces of the plates were surface ground and then two beads were deposited along the length of the plate, one at 16 inches per minute, representative of automatic welding speeds, and one at 60 inches per minute as a thermal shock test. Each deposit was made at 15 volts and 250 amps. Observation of cracking was made at a magnification of 30X. The compositions and cracking behavior are noted in Table V.

TABLE V

Steel:	C, percent	Ni, percent	Mo, percent	Cb, percent	Other ¹	Weld cracking bead at 16 i.p.m.	Behavior bead at 60 i.p.m.
1.....	0.14	6.05	0.98	0.09		None.....	None.
2.....	0.09	6.00	0.98	0.08		do.....	Do.
4.....	0.10	6.0	0.98	0.05		do.....	Do.
B.....	0.16	6.50	1.08	0.13		Cracked.....	Do.
C.....	0.23	6.05	0.98	0.09		None.....	Cracked.
D.....	0.11	6.03	0.99	0.15		1 small crack.....	Do.
H.....	0.10	6.0	0.98	0.10	0.012S, 0.024P.....	Severely cracked.....	Do.
J.....	0.15	6.06	0.95	0.11	0.34 Cr.....	2 small cracks.....	Do.
13.....	0.10	6.04	0.96	0.10	0.34 Cr.....	None.....	None.

¹ Balance of steels iron and impurities with manganese, silicon and aluminum contents being within invention.

As will be seen from the data given in Table V, than while steels within the invention failed to exhibit defects, this was not the case concerning steels beyond the invention. Alloys B and C reflect that high carbon contributes to cracking, a result which also follows when the combined percentage of carbon plus columbium (Alloy D) is too high. Alloy H serves to emphasize that phosphorus and sulfur should be maintained at low levels, i.e., at least below 0.02% each. Alloys J and 13 are included to illustrate that chromium can bring about cracking particularly at high carbon levels. Accordingly, if chromium must be present then it should not exceed 0.2% when the carbon is from 0.12% to 0.15%. Automatic MIG and manual covered electrode welding techniques have also been successfully carried out on steels in accordance herewith.

The steels of the present invention are particularly applicable for structural application, e.g., pressure vessels, high pressure tubes, cold forged products, high strength fabricated structures of various shapes, etc., although they can be used, of course, wherever the above described combination of properties is deemed beneficial. They can be produced in the usual mill forms including not only plate but bar, rod, forgings, etc.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

I claim:

1. An alloy steel possessing a yield strength of at least about 150,000 psi, an impact toughness of at least 50 ft.-lbs. in the longitudinal direction and at least 25 ft.-lbs. in the transverse direction at temperatures down to at least -40° F., and good weldability and formability, said steels being devoid of vanadium and consisting of from about 0.06% to about 0.13% carbon, about 5% to 8% nickel, from 0.6% to 1.0% molybdenum, from 0.02% to about 0.11% columbium, the sum of carbon plus columbium not exceeding about 0.23%, up to about 1.75% percent copper, up to about 0.8% manganese up to 0.5% silicon, up to 0.5% chromium, the chromium not exceeding about 0.2% when the carbon content is 0.12% or more, up to 0.15% aluminum and the balance essentially iron.

2. A steel in accordance with claim 1 containing from 0.8% to 1.2% molybdenum.

3. A steel in accordance with claim 1 in which chromium, if any, does not exceed 0.25 percent.

4. A steel in accordance with claim 1 which in a section size of 3 inches or more contains at least 0.5% copper.

5. A steel in accordance with claim 1 containing from 0.2% to 0.7% manganese.

6. An alloy steel possessing a yield strength of at least about 150,000 psi, an impact toughness of at least 50 ft.-lbs. in the longitudinal direction and at least 25 ft.-lbs. in the transverse direction at temperatures down to at least -40° F., and good weldability and formability, said steel consisting of from about 0.06% to about 0.13% carbon, about 5% to 8% nickel, from about 0.8% to about 1.2% molybdenum, metal from the group consisting of columbium and vanadium in an amount from about 0.05% to about 0.11 the sum of the carbon plus columbium not exceeding about 0.23%, up to about 1.75% copper, up to about 0.8% manganese, up to 0.5% silicon, up to 0.25% chromium, the chromium not exceeding about 0.2% when the carbon content is 0.12% or more, up to 0.15% aluminum and the balance essentially iron.

* * * * *