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[72] Inventor **Frederick J. Semel**
Philadelphia, Pa.

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[73] Assignee **Alan Wood Steel Company**
Conshohocken, Pa.

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[54] **LOW ALLOY AGE-HARDENABLE STEEL AND PROCESS**
26 Claims, No Drawings

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Primary Examiner—Charles N. Lovell
Attorney—William Steell Jackson and Sons

ABSTRACT: A ferrite-carbide low alloy constructional steel in the as-aged condition or capable of aging having the following composition:

Carbon	0.10% max.
Manganese	0.30 to 1.50%.
Silicon	0.35 max.
Molybdenum	0.04 to 0.50%.
Niobium	0.005 to 0.075%.

Iron and impurities, balance,

and a process of manufacture including aging and techniques for rolling the same.

LOW ALLOY AGE-HARDENABLE STEEL AND PROCESS

DESCRIPTION OF INVENTION

The present application is a continuation-in-part of my copending application Ser. No. 749,274, filed Aug. 1, 1968, now abandoned, for Low Alloy Age-Hardened Steel and Process.

The present invention relates to a low alloy age-handenable steel and a process of manufacture of the same.

A purpose of the invention is to produce a ferrite-carbide low alloy constructional steel having unusual properties as the as-aged condition and having the following composition by weight:

Carbon	0.10 percent max., preferably 0.08 percent max.
Manganese	0.30 to 1.50 percent
Silicon	0.35 max.
Molybdenum	0.04 to 0.50 percent, preferably 0.08 to 0.30 %
Niobium	0.005 to 0.075 percent
Iron and impurities, balance.	

A further purpose is to incorporate in a steel of very low carbon content conjoint balanced additions of niobium and molybdenum, to hot roll the steel at a finishing temperature of below 1,700° F., to cool the steel in air or with water sprays from finished rolling, to reheat the steel to an aging temperature of between 1,000° and 1,200° F., and maintain it there sufficient to age the steel, and to cool the steel in air to room temperature, thus increasing the strength and maintaining high ductility by precipitating extremely fine niobium-molybdenum carbide particles.

A further purpose is to increase the yield strength from about 60,000 p.s.i. to about 70,000 p.s.i. by the age-hardening effect.

A further purpose is to obtain a very favorable low temperature impact resistance in the age-hardened steel of the invention by the effect of the molybdenum in reducing the segregation of various constituents at the grain boundaries, such as for example, grain boundary cementite.

A further purpose is to limit the carbon content to 0.10 percent maximum, preferably 0.80 percent maximum, in order to avoid poor impact resistance at low temperatures.

A further purpose is to obtain high formability in either the as-rolled or age-hardened steel of the invention as indicated by favorable values of reduction in area.

A further purpose is to produce a low carbon steel of exceptional resistance to hydrogen embrittlement and therefore useful for the walls of pressure vessels by incorporating balanced additions of niobium and molybdenum which will combine in the steel as carbide.

A further purpose is to produce the steel of the invention according to either fully-killed practice or where compatible with alloy content, to semikilled practice.

A further purpose is to employ as a preferred range of niobium between 0.030 and 0.050 percent and as a preferred range of molybdenum between 0.08 and 0.30 percent.

A further purpose in a steel which has low carbon and age-hardening properties imparted by balanced additions of niobium and molybdenum, is to further increase the yield point and retain ductility and cold formability by an addition of chromium in the range of 0.10 to 0.50 percent, and preferably 0.20 to 0.30 percent.

A further purpose in a constructional steel containing low carbon and having age-hardening properties imparted by a balanced addition of niobium and molybdenum, is to increase the yield point while maintaining favorable ductility and cold formability by an addition of 0.005 to 0.10 percent, and preferably 0.015 to 0.070 percent of vanadium.

A further purpose in a low carbon steel having age-hardening properties by the conjoint addition of niobium and molybdenum is to further increase the yield point by controlled additions of vanadium and chromium.

A further purpose in a low carbon steel having age-hardening properties imparted by niobium and molybdenum added conjointly, is to further enhance the yield strength while retaining ductility and cold formability by adding zirconium in the range of 0.005 to 0.16 percent, and preferably in the range of 0.03 to 0.11 percent.

A further purpose in steel having a carbon content of 0.08 percent maximum, a niobium content of 0.005 to 0.075 percent, and preferably 0.030 to 0.040 percent and a molybdenum content of 0.08 percent to 0.50 percent, is to increase the yield strength while retaining ductility and cold formability by adding 0.0005 to 0.005 percent, and preferably 0.0015 to 0.003 percent of boron.

In one aspect of the present invention, the steel of the composition discussed above can be hot rolled at a temperature above 1,700° F. (or 1,750° F. depending on alloy content) and cooled in still air. In this case there is a considerable increase in yield point and tensile strength and preservation of favorable ductility in the as-rolled condition, although the properties are not as good as those obtained after aging. Another valuable property obtained in such steels in as-rolled condition is that the grain size is finer than is obtained in a comparable niobium bearing steel without the molybdenum.

Additional properties can be imparted by cooling under water sprays from hot rolling, or by cold rolling, or by both, and the as-aged properties are enhanced thereby.

Further purposes appear in the specification and in the claims.

In the prior art low alloy ferrite-pearlite constructional steel has been produced according to semikilled practice having yield strengths of the order of 65,000 p.s.i. and having carbon contents of the order of 0.15 percent. These steels have marginal toughness as measured by low temperature impact values and low cold formability as measured by reduction in areas at room temperature. The addition of further alloying ingredients has been counterindicated because the experience has been that they have a detrimental effect on toughness and on cold formability.

Extensive efforts have been made to improve the yield point without disastrously affecting the toughness and cold formability by either quenching and tempering the steel or controlling the practice after finish hot rolling, for example by applying water sprays. Both of these expedients, while successful to a limited extent, necessitate investment in considerable capital equipment.

In the prior art in martensitic and bainitic steels, it has been found that small additions of niobium with about 0.5 percent molybdenum have produced unusual secondary hardening effects during tempering operations.

As a result of an extensive investigation of ferrite-carbide steels containing various proportions of niobium and molybdenum, I have discovered that marked increases in yield strength can be obtained with excellent toughness as measured by low temperature impact resistance and with exceptional cold-forming properties as measured by reduction in area if the carbon content does not exceed 0.10 percent, and preferably does not extend 0.08 percent, if a balanced relation is maintained between the alloying content of niobium and the alloying content of molybdenum, and if the steel is reheated and aged at a temperature of 1,000° to 1,200° F. for a time of at least 15 minutes. There is also an appreciable yield strength increase if the steel is heated up from ambient temperature and held even momentarily in the range of 1,000° to 1,200° F. and then cooled.

I have discovered furthermore that additional increases in yield strength without loss in toughness as measured by low temperature impact values and without loss in cold formability as measured by reduction in area can be obtained by adding controlled additions of vanadium, chromium, vanadium and chromium, zirconium or boron, these additions, unlike the previous experience in steels containing 0.15 percent carbon or thereabouts, not impairing the toughness.

I furthermore find that there are, in steels of the niobium-molybdenum base composition of the invention, unusual effects associated with the molybdenum content. For example, steel made according to the invention but not containing molybdenum will not exhibit any significant change in mechanical properties upon aging. Thus, it will be appreciated that the molybdenum plays an important part in producing in the steel the capability of being strengthened by an aging treatment. Yet, contrary to what might be expected, it has been found that once sufficient molybdenum has been added to effect a significant aging response, the further addition of molybdenum either has no effect or actually impairs to a slight extent the tensile properties obtained by aging. Furthermore, there is also an unusual effect on impact resistance. For example, it is well known that increasing the molybdenum content will increase the proportion of brittle transformation product formed in the steel, such as for instance, bainite, and thus it is often noted that such a procedure results in decreased toughness at low temperatures. Yet, here again, it has been found with steels of the present invention that increasing the molybdenum very substantially improves the impact resistance and this is true for both the as-rolled and aged conditions.

The steels of the present invention have rather unusual microstructure. The principal primary phase is proeutectoid ferrite and this generally occurs in the polygonal form. The principal second phase is eutectoid carbide. Depending upon alloy content and processing conditions, the eutectoid may occur in one of three easily distinguishable forms: pearlite, intermediate product, or upper bainite. In the intermediate product and bainite, the ferrite constituent is acicular. Due to the low carbon content, the proportion of eutectoid is small, generally not in excess of 10 percent by volume. A third phase, which has tentatively been identified as martensite, also occurs quite often but in very small amounts. The niobium-molybdenum carbide aging constituent is not capable of being resolved by optical microscopy.

The niobium and the molybdenum cooperate in producing a carbide age-hardening constituent and the molybdenum, presumably by its effect on transformation characteristics, significantly reduces the amount of grain boundary cementite and probably that of other grain boundary precipitates, so that strength can be increased without adverse effect on toughness as measured by low temperature impact resistance and on formability as measured by reduction in area. This is true, however, only where the carbon content does not exceed 0.10 percent, preferably 0.08 percent. At higher carbon contents, toughness and cold formability are disastrously affected by increased amount of eutectoid which is formed, whether only niobium and molybdenum are used as alloying elements, or where other additional alloying elements are employed.

It is believed that the additional elements which are beneficial to the properties when employed as alloying ingredients in addition to niobium and molybdenum function by reason of their ability to lower the A_3 transformation temperature of austenite. Thus they have an effect in tending to hold the niobium-molybdenum aging constituent in solution during the initial cooling from the finishing temperature of hot rolling, which is about 1,500° to 1,700° F. The elements which have this effect are particularly chromium, vanadium, boron and zirconium, which thus aid in retaining the aging constituent in solution during the first cooling from hot rolling, increasing the potential for hardening by later heating to the aging temperature and holding at the aging temperature.

The presence of niobium and molybdenum make it possible to raise the yield point after aging to a value just short of 70,000 p.s.i. when the steel is air cooled subsequent to rolling. If, instead, the steel is subjected to accelerated cooling after the last pass by application of water sprays, then the presence of niobium and molybdenum make it possible to raise the yield point after aging to a value somewhat in excess of 70,000 p.s.i.

Either vanadium in the range of 0.005 percent to 0.10 percent and preferably in the range of 0.015 to 0.070 percent, or chromium in the range of 0.10 to 0.50 percent and preferably from 0.20 to 0.30 percent, make it possible after aging to obtain yield points in excess of 70,000 p.s.i. without the need of water sprays after the last pass in rolling. If water sprays are used after the last rolling pass, yield points of the order of 75,000 p.s.i. are obtained.

When both vanadium and chromium are added in the aforementioned quantities, it is then possible to obtain yield points after aging of the order of 75,000 p.s.i. without the need for accelerated cooling after rolling and yield points in excess of 75,000 p.s.i. when accelerated cooling after rolling is employed.

In all of these cases and in others to be discussed, favorable low temperature impact values are obtained and the steel is cold formable as indicated by good reductions in area.

The steel is also weldable without preheat.

In some cases it is desirable to obtain higher yield points, and these can be secured by adding, in addition to niobium and molybdenum, from 0.005 to 0.16 percent of zirconium, preferably from 0.03 to 0.11 percent of zirconium. In some cases instead of using zirconium, similar high yield points are obtained by employing boron in a concentration of 0.0005 to 0.005 percent, preferably 0.0015 to 0.003 percent with the niobium and molybdenum.

In any case, as with steels made to the niobium-molybdenum base composition and those adding vanadium or chromium or combinations thereof, alloys containing either zirconium or boron also exhibit somewhat higher yield points after aging, as for example of the order of 85,000 p.s.i., if after the last rolling pass, the steel is initially cooled in an accelerated manner by application of water sprays.

I have also discovered that the yield strength can be increased by so-called strain aging, that is, by cold rolling the steel from the as-hot rolled condition, using cold reductions up to about 30 percent, and then heating up to and holding at aging temperature. The cold working greatly enhances the aging effect.

I have furthermore discovered that by hot rolling to finishing temperatures in excess of 1,700° F. (or 1,750° F., depending on alloy content) and cooling in still air, superior properties in respect to yield point, tensile strength and fineness of grain size are obtained in the steel of the invention containing niobium and molybdenum as compared to a control containing only niobium.

The steel of the invention can be produced in the basic oxygen furnace, the open hearth furnace, the induction furnace or the electric arc furnace. While the test results given below relate primarily to steels which have been fully killed by aluminum, the principles of the invention with the exception of those relating to additions of either zirconium or boron can also be applied to steels which are semikilled.

While the greatest utility of the invention is believed to be for production of steel sheet or plate in gages of 0.050 to 1 inch and preferably from 0.070 to ½-inch or even 1 inch, the invention is also applicable to the production of low alloy constructional steels (in the sense that they are used for building structures, machinery and the like) in the form of bars and shapes.

Because the steel of the invention has low carbon and some of the carbon is combined with molybdenum and niobium, it is believed to be especially desirable for applications requiring resistance to hydrogen embrittlement such as for example the walls of pressure vessels as previously mentioned.

In order to produce the aging effect according to the invention, the steel to be aged is heated from room temperature to an aging temperature between 1,000° and 1,200° F., and held at that temperature for a time of at least 15 minutes and still better 30 minutes. Typical aging times are one-half hour, one hour, two hours or four hours at temperature. Longer times will preferably be used for the lower temperatures. The steel of the invention is, however, quite resistant against overaging and good results have been obtained by aging at 1,200° F. for 16 hours, or at 1,150° F. for 100 hours.

While there is a pronounced increase in yield point from aging, it has been found surprisingly that the hardness, for example measured in Rockwell B, is not markedly increased by aging. However, this result may be due to the insensitivity of this particular hardness test.

In addition, the aging heat treatment also produces significant improvements in the low temperature impact resistance of the above steels and this is possibly the most unusual feature of the invention. For example, it is predictable from theory and it has been demonstrated by numerous investigations that any treatment that increases the yield point via the precipitation of a dispersed second phase, but otherwise effects no significant change in structure, will invariably result in a decreased value of low temperature impact resistance. Thus far, with the magnifications and resolutions available in optical microscopy, I have not observed an appreciable change in microstructure due to aging. Therefore, if this result is to be compatible with theory and prior art, it must be regarded as an indication that significant structural changes do occur during aging, but at a submicroscopic level.

EXAMPLE 1

Steel ingots are produced following fully-killed practice, and rolled into ⅜-inch plate or strip width at finishing temperatures in the range of 1,500° to 1,700° F. The analyses are within the following ranges:

C	0.10 percent max.
Mn	0.90 to 1.20 percent
P	0.020 percent max.
S	0.35 percent max.
Si	0.35 percent max.
Mo	0.04 to 0.50 percent
Nb	0.30 to 0.050 percent.

The following table compares the tensile properties of the steel as rolled with the tensile properties as-aged according to the present invention:

TENSILE PROPERTIES

	As-rolled	Aged
Yield point, p.s.i.	59,900	70,900
Tensile strength, p.s.i.		85,000
Elongation in 2 in., %	25.0	25.0
Reduction of area, %	72.0	71.0

It will be evident that aging increases the yield point about 10,000 p.s.i. without any substantial effect on the elongation or reduction in area.

The following table compares the Charpy impact in foot-pounds between the specimens as rolled and after aging, at various testing temperatures:

CHARPY IMPACT IN FOOT-POUNDS

Testing Temperature °F.	As rolled	Aged
+30	42	68
00	35	42
−20	25	38
−40	13	32
−60	Nil	27

It will be evident that the steel in the aged condition is very tough.

EXAMPLE 2

In elaboration of the results obtained in example 1, the following is the analysis of Ingot 74A which was rolled into ⅜-inch plate at a finishing temperature of 1,500° to 1,700° F., and subsequently cooled in still air

C	0.08%
Mn	1.06%
P	0.006%
S	0.023%
Si	0.030%
Ni	0.06%
Cr	0.02%
Cu	0.14%
Sn	0.011%
Mo	0.23%
Al	0.050%
Ti	0.001%
V	Nil
B	Nil
Nb	0.044%

The following table gives Charpy V-notch impact properties of longitudinal specimens tested at various testing temperatures, and comparing the specimens as rolled and cooled in air to room temperature, to specimens reheated and aged at 1,100° F. for two hours and then again cooled in still air:

Testing Temperature °F.	Impact Foot-pounds
As rolled, air cooled	
Room temp.	85.5
+30	42.0
−20	25.0
−40	13.0
Aged 1100° F., 2 hours, air cooled	
30	68.0
00	41.5
−20	38.0
−40	31.5
−60	22.0
−60	32.0

It will be evident that markedly better toughness is obtained in the aged specimens as compared with the as-rolled specimens.

It

The following table compares for plate made from Ingot 74A the yield point in p.s.i., the tensile strength in p.s.i., the elongation in 2 inches in percent and the reduction of area for various aging procedures:

TABLE 1

	Aging treatment												
	1,000° F.				1,100° F.				1,200° F.				
	30 min.	1 hr.	2 hr.	4 hr.	30 min.	1 hr.	2 hr.	4 hr.	30 min.	1 hr.	2 hr.	4 hr.	As rolled
Yield point, p.s.i.	65,900	65,900	66,700	67,400	69,900	69,500	69,600	69,600	68,700	69,100	68,700	68,000	[1] 54,100
Tensile strength, p.s.i.	82,600	82,400	82,400	82,700	84,800	84,200	83,800	84,100	83,800	83,600	83,200	82,900	85,600
Elongation in 2 in., percent	23.0	23.75	24.0	23.5	26.0	24.0	22.5	21.75	23.25	22.5	23.5	22.0	23.5
Reduction of area, percent	72.1	71.7	70.3	70.6	70.5	70.0	71.0	70.6	71.7	72.7	72.9	73.4	70.9

[1] 0.02% offset yield strength.

EXAMPLE 3

In further elaboration of example 1 and example 2, Ingot 74B was rolled as above described and converted into ⅝-inch plate, except that instead of being entirely cooled in air the steel was water sprayed after the last rolling pass. The analysis was as follows:

C	0.08%
Mn	1.06%
P	0.006%
S	0.025%
Si	0.27%
Ni	0.05%
Cr	0.01%
Cu	0.14%
Sn	0.015%
Mo	0.23%
Al	0.060%
Ti	0.001%
V	Nil
B	Nil
Nb	0.042%

The following table shows various mechanical properties of plate made from this ingot and aged at different temperatures and for different times according to the present invention. Notice that as compared with Ingot 74A of example 2, the yield points are somewhat better for the steel of Ingot 74B which was water cooled.

Cu	0.17%
Sn	0.017%
Mo	0.25%
Al	0.042%
Ti	Nil
V	0.001%
B	Nil
Nb	0.049%

The tensile properties achieved as rolled and aged one hour at 1,100° F. are shown below. These properties may be compared with the results obtained from the product of Ingot 74A of example 2 for similar aging conditions. The as-rolled and aged impact properties of the product of Ingot 79A are shown also.

TENSILE PROPERTIES

	As rolled	Aged
Yield point, p.s.i.	55,700*	71,100
Tensile strength, p.s.i.	84,200	**84,300**
Elongation in 2 in., %	18.5	**18.0**
Reduction of area, %	70.8	**70.8**

*0.2 % offset yield strength

TABLE 2

	Aging treatment													
	1,000° F.				1,100° F.				1,200° F.				As rolled	350° F., 30 min.
	30 min.	1 hr.	2 hr.	4 hr.	30 min.	1 hr.	2 hr.	4 hr.	30 min.	1 hr.	2 hr.	4 hr.		
Yield point, p.s.i	67,900	68,300	69,100	69,900	70,500	70,900	71,300	70,900	69,500	70,300	70,400	71,100	[1] 59,900	61,900
Tensile strength, p.s.i	83,400	85,700	83,200	84,000	85,400	85,100	84,800	82,800	84,200	84,800	84,100	84,900	84,400	84,800
Elongation, percent	26.5	24.0	26.5	22.0	25.0	25.25	23.0	22.0	22.0	23.75	22.75	21.75	25.0	24.0
Reduction of area, percent	71.5	72.1	73.0	69.5	71.7	70.5	71.1	71.3	69.7	71.9	72.8	72.3	.....	71.7

[1] 0.02% offset yield strength.

EXAMPLE 4

Following the procedure explained in examples 1 and 2, incorporate into the ingot vanadium in the range of 0.005 to 0.50 percent by weight, preferably in the range of 0.040 to 0.070 percent, say about 0.050 percent.

Properties comparable to those obtained in examples 1 and 2 are secured, except that the yield point is further increased by 2,000 to 3,000 p.s.i., obtaining a reliable yield point in excess of 70,000 p.s.i. with equal toughness and formability but without the need for water sprays subsequent to rolling. If water sprays after rolling are used as in example 3, then the increase in yield point is somewhat greater, about 5,000 p.s.i., so that the overall yield point of the steel approaches the 75,000 p.s.i. level.

EXAMPLE 5

Following the procedures set forth in examples 1 and 2, chromium additions are made to the ingot in the range between 0.10 and 0.50 percent by weight, preferably in the range of 0.20 to 0.30 percent, say about 0.25 percent. As with vanadium in example 4, this adds 2,000 to 3,000 p.s.i. to the yield point without water sprays after rolling or about 5,000 p.s.i. when water sprays are used, so that a reliable yield point of either 70,000 or about 75,000 is secured with otherwise equal toughness and formability.

As an instance, Ingot 79A was prepared with chromium and rolled without water sprays. The resultant plate had the following analysis:

C	0.07%
Mn	1.01%
P	0.004%
S	0.023%
Si	0.28%
Ni	0.04%
Cr	0.20%

CHARPY IMPACT IN FOOT-POUNDS

Testing Temperature °F.	As rolled	Aged
+	74	98.5
	31	98
-20	16	76
-40		59
-60		97

EXAMPLE 6

The procedures of examples 1 and 2 are followed except that the ingot contains vanadium in the range referred to in example 4 and chromium in the range referred to in example 5. Here the increase in the yield point after aging over the increase obtained with the niobium-molybdenum base composition is of the order of 5,000 p.s.i. without the need for water sprays after rolling and somewhat greater than 5,000 p.s.i., usually about 7,000 p.s.i., when the water sprays are used. Thus yield points if 75,000 p.s.i. or in excess thereof are obtained with otherwise equivalent formability and impact resistance.

To illustrate this example, Ingot 79B was made and rolled to ⅝-inch plate without the benefit of water sprays after the last rolling pass. The analysis of the plate was as follows:

C	0.006%
Mn	1.02%
P	0.005%
S	0.023%
Si	0.26%
Ni	0.04%
Cr	0.19%
Cu	0.17%
Sn	0.017%
Mo	0.25%
Al	0.037%

V	0.050
B	Nil
Nb	0.048%

The tensile and impact properties of the plate as rolled and after aging for one hour at 1,100° F. were as shown.

TENSILE PROPERTIES

	As rolled	Aged
Yield point, p.s.i.	69,950*	74,300
Tensile strength, p.s.i.	89,200	87,850
Elongation in 2 in., %	17.5	17.5
Reduction of area, %	73.8	75.1

*0.02 % offset yield strength

CHARPY IMPACT IN FOOT-POUNDS

Testing Temperature °F.	As rolled	Aged
+75	65	114
0	28.5	78.5
−20	19.0	42.0
−40		40.0
−		51.5

EXAMPLE 7

The procedure of examples 1 and 2 is followed incorporating in the ingot 0.005 to 0.16 percent by weight, preferably 0.040 to 0.11 percent, say about 0.050 percent of zirconium. This has a much more pronounced effect on increasing yield point than in the case of additions of vanadium and chromium. Reliable yield points of 80,000 p.s.i. are obtained without loss in toughness or formability. When water sprays are used subsequent to rolling as in the procedure of example 3, yield points approaching 85,000 p.s.i. are obtained.

EXAMPLE 8

The procedure of examples 1 and 2 is followed, incorporating in the ingot 0.0005 to 0.005 percent, preferably 0.0015 to 0.003 percent by weight of boron. As with zirconium, boron has a much more pronounced effect on increasing yield point than in the case of additions of vanadium and chromium. Reliable yield points of 80,000 p.s.i. are obtained without loss in toughness or formability, without the need of water sprays after the last rolling pass, and yield points up to 85,000 p.s.i. are obtained when water sprays are used.

In further elaboration of example 8, Ingot 72A was made with boron and rolled to plate without the benefit of water sprays after the last rolling pass, the plate being cooled in still air. The analysis was as follows:

C	0.06%
Mn	0.96%
P	0.010%
S	0.023%
Si	0.29%
Ni	0.06%
Cr	0.02%
Cu	0.13%
Sn	0.014%
Mo	0.51%
Al	0.065%
Ti	0.003%
V	Nil
B	0.0022%
Nb	0.037%

The following table shows various mechanical properties of the plate as rolled and aged at different temperatures and for different times according to the present invention:

TABLE 3

	Aging treatment													
	1,000° F.				1,100° F.				1,200° F.					
	30 min.	1 hr.	2 hr	4 hr.	30 min.	1 hr.	2 hr.	4 hr.	30 min.	1 hr.	2 hr.	4 hr.	As rolled	350° F., 30 min.
Yield point, p.s.i.	72,400	73,200	74,800	74,500	76,900	80,200	80,300	80,600	79,800	80,800	80,700	79,800	[1] 59,600	63,100
Tensile strength, p.s.i.	88,100	90,600	90,600	91,000	92,600	94,800	94,200	94,200	93,400	95,000	94,700	93,800	89,900	88,600
Elongation, percent	19.5	20.5	19.5	22.5	19.5	22.5	21.5	20.5	21.0	22.0	19.75	18.5	23.25	25.0
Reduction of area, percent	73.8	72.5	71.5	72.5	72.3	71.6	70.6	72.9	71.9	71.1	70.0	73.5	71.8	72.7

[1] 0.2% offset yield strength.

EXAMPLE 9

A series of tests was carried out to demonstrate the importance of molybdenum in the base composition in producing age hardening during heat treatment subsequent to rolling. In this example Ingots 65A and 65B were prepared without molybdenum but otherwise in accordance with the procedures employed in examples 1, 2 and 3. As in example 2, Ingot 65A was rolled to plate without benefit of water sprays after the last rolling pass and Ingot 65B, as in example 3, was rolled to plate with water sprays. The analyses were as follows:

	65A	65B
C	0.07%	0.07%
Mn	1.03	1.00%
P	0.008%	0.009%
S	0.017%	0.018%
Si	0.21%	0.20%
Ni	0.07%	0.02%
Cr	0.02%	0.02%
Cu	0.13%	0.12%
Sn	0.007%	0.009%
Mo	0.01%	0.01%
Al	0.059%	0.059%
Ti	0.003%	0.003%
V	Nil	Nil
B	0.0003%	0.0003%
Nb	0.038%	0.037%

The following tables show the tensile properties as rolled and after aging for various times and temperatures. Table 4 shows the results obtained with the product of Ingot 65A, and table 5, those obtained with Ingot 65B. It is evident from these findings that no appreciable increase in yield point occurs after aging unless molybdenum is present in greater than residual concentrations.

Whereas in steels having low carbon, with molybdenum and niobium within the ranges specified, aging produces specimens whose impact values at lower testing temperatures are higher than in unaged specimens, in the case of a steel without molybdenum as in Ingot 65A, the impact properties decrease after aging.

Thus for Ingot 65A, the properties were as follows:

CHARPY IMPACT IN FOOT-POUNDS

Testing Temperature °F.	As rolled	Aged
+30	193.0	199.0
00	193.5	197.5
−20	192.0	196.5
−40	180.0	193.0
−60	177.0	3.5
−60	152.0	4.0

EXAMPLE 10

The following data are offered in order to show the unusual effect of increasing the content of molybdenum in steel which is of the desired contents of carbon and niobium.

Ingot	Percent					
	71A	71B	73A	73B	91A	91B
C	0.06	0.06	0.06	0.06	0.06	0.04
Mn	0.88	0.95	0.96	0.96	1.13	1.10
P	0.013	0.006	0.007	0.007	0.003	0.004
S	0.020	0.022	0.023	0.024	0.022	0.021
Si	0.22	0.24	0.24	0.23	0.33	0.32
Ni	0.06	0.01	0.07	0.07	0.05	0.05
Cr	0.02	0.02	0.02	0.02	0.03	0.03
Cu	0.14	0.14	0.16	0.16	0.17	0.17
Sn	0.013	0.015	0.010	0.012	0.018	0.018
Mo	0.49	0.48	0.32	0.32	0.18	0.18
Al	0.056	0.058	0.053	0.053	0.057	0.064
Ti	0.003	0.003	0.003	0.003	Nil	Nil
V	Nil	Nil	Nil	Nil	Nil	Nil
B	0.0003	0.0001	0.0001	0.0001	0.0002	0.0002

The ingots bearing A designations were cooled in still air from the last pass of hot rolling, and those designated B were cooled in water sprays from said last pass.

The tensile properties corresponding to the as-rolled and aged conditions are shown in table 6 and the impact properties for these two conditions of steels from ingots having A designations are shown below. In all cases, aging was at 1,100° F. for two hours.

Testing temperature, ° F.	Charpy impact in foot-pounds					
	Ingot 71A		Ingot 73A		Ingot 91A	
	As-rolled	Aged	As-rolled	Aged	As-rolled	Aged
+30	104	134	65	105	.....	.....
0	66	75	39	95	26	76
−20	49	80	25	[1] 35	7	51
−40	24	55	7	48	.....	52
−60	19	46	.....	20	.....	12

[1] Imperfection in specimen.

A careful examination of the tensile data will reveal, as indicated earlier, that the as-aged yield points are definitely not improved and, in fact, in some cases, tend to decrease slightly as the molybdenum content is increased. On the other hand, as also mentioned earlier, the above data show that that the impact resistance of the steel is very substantially improved by increasing the molybdenum, and although these findings are consistent with the results of previous examples in that the best properties occur after aging, it will be evident that improvements occur in the as-rolled as well as the aged condition.

EXAMPLE 11

It will be evident that the carbon content of steels of the present invention is quite critical. If the carbon content is above 0.10 percent by weight, there is a marked lowering of impact properties of the as-aged steel, particularly at lower temperatures, and markedly better low temperature impact values are obtained if the carbon content does not exceed 0.08 percent.

To illustrate this, Ingots 88A and 88B were made and rolled into ¾-inch plates having compositions as shown below.

TABLE 4

	Aging treatment											
	1,000° F.				1,100° F.				1,200° F.			
	30 min.	1 hr.	2 hr.	4 hr.	30 min.	1 hr.	2 hr.	4 hr.	2 hr.	4 hr.	As rolled	350° F. 30 min.
Yield point, p.s.i	58,100	59,500	58,900	58,800	59,700	60,100	59,500	58,700	59,000	58,900	[1] 59,500	59,500
Tensile strength, p.s.i	72,100	72,500	71,700	71,900	72,700	73,100	72,300	71,800	71,900	71,500	73,100	72,300
Elongation, percent	27.5	28.0	28.5	29.5	24.5	29.0	29.5	30.5	29.0	23.0	28.5	25.5
Reduction of area, percent	75.9	76.7	76.6	77.4	76.6	76.7	76.6	77.1	77.4	77.4	76.6	76.2

[1] 0.2% offset yield strength.

TABLE 5

	Aging treatment													
	1,000° F.				1,100° F.				1,200° F.					
	30 min.	1 hr.	2 hr.	4 hr.	20 min.	1 hr.	2 hr.	4 hr.	30 min.	1 hr.	2 hr.	4 hr.	As rolled	350° F., 30 min.
Yield point, p.s.i	59,500	59,700	59,900	59,200	60,900	60,700	60,200	59,600	60,000	60,100	59,700	59,400	60,900	60,100
Tensile strength, p.s.i	73,200	72,300	72,100	72,600	73,400	73,600	72,800	72,400	72,200	73,600	72,300	71,400	73,800	72,800
Elongation, percent	25.5	25.0	29.5	20.75	29.75	28.25	28.0	26.75	31.5	26.25	28.0	29.75	26.0	30.0
Reduction of area, percent	75.2	76.4	75.4	75.1	75.4	76.6	76.5	76.5	77.1	76.8	80.0	77.3	75.6	76.6

[1] 0.2% offset yield strength.

TABLE 6.—MECHANICAL PROPERTIES AS ROLLED AND AGED AT 1,100° F. FOR TWO HOURS

	Ingot											
	71A	71A	71B	71B	73A	73A	73B	73B	91A	91A	91B	91B
	Condition											
	As rolled	Aged	As rolled	Aged	As rolled	Aged	As rolled	Aged	As rolled	Aged	As rolled	Aged
Yield point,[1] p.s.i	53,900	69,100	54,900	68,900	52,900	68,500	60,600	70,100	60,000	68,630	59,690	72,410
Tensile strength, p.s.i	80,600	81,800	81,400	82,400	80,000	80,400	82,300	81,200	83,730	82,840	82,560	82,590
Elong. in 2 in., percent	27.5	25.0	25.5	24.5	25.5	22.0	27.5	22.0	20.0	18.5	26.5	27.5
Reduction of area, percent	74.8	72.5	73.1	73.3	73.3	73.7	73.0	76.4	72.8	73.2	58.2	63.0

[1] Values relating to the as-rolled condition are 0.2 % offset yield strength.

CHEMICAL ANALYSIS

Ingot	88A	88B
C	0.16%	0.14%
Mn	1.10	1.14
P	0.004	0.004
S	0.024	0.022
Si	0.67	0.67
Ni	0.04	0.04
Cr	0.03	0.03
Cu	0.16	0.16
Sn	0.015	0.016
Mo	0.23	0.46
Al	0.052	0.048
Ti	Nil	Nil
B	0.0019	0.0016
Nb	0.043	0.044

It is to be noted that Ingot 88A has an intermediate content of molybdenum (0.23 percent) and Ingot 88B has a relatively high molybdenum content (0.46 percent), and that in both cases, the carbon contents are high in the present context, being respectively 0.16 percent and 0.14 percent.

The impact properties of these steels in both the as-rolled and aged conditions are shown below.

CHARPY V NOTCH IMPACT VALUES FROM LONGITUDINAL SPECIMENS AS AGED AT 1,100° F. FOR ONE HOUR

Ingot condition testing Temperature, ° F.	88A		88B	
	As rolled	Aged	As rolled	Aged
Room temperature	28	19	23	16.5
0	12	7.5	5.5	5.0
−20	6.5	9.0	5.5	5.0

It is very obvious from these data that increasing the carbon has adversely affected the impact resistance. Moreover, there are very clear indications in these findings to the effect that the increased carbon has completely altered the metallurgical character of the steel. For example, comparison of the room temperature impact values shows quite well that the toughness tends to decrease after aging, rather than increase. More clear, perhaps is the additional fact that these findings show an opposite trend when compared with results of the previous example. Instead of improving impact resistance, the increased molybdenum content of Ingot 88B over Ingot 88A has apparently resulted in a decrease in toughness in both the as-rolled and aged conditions.

Ingot Series	30	70
C	0.057	0.056
Mn	0.84	0.77
P	0.005	0.007
S	0.019	0.022
Si	0.08	0.08
Ni	0.02	0.02
Cr	0.03	0.02
Cu	0.10	0.08
Sn	0.006	0.007
Mo	0.16	0.02
Al	0.072	0.060
Nb	0.052	0.051

The ingots were rolled into plate of thicknesses of 1 inch, three-fourths inch, one-half inch and three-eighth inch at finishing temperatures listed, to obtain properties as-rolled followed by cooling in still air as set forth in table 7. Specimens from each plate were also aged at 1,150° F. for one hour, and cooled in still air.

It will be noted that Ingot Series 30 according to the present invention gave a considerable improvement in yield point and tensile strength in the as-rolled condition, as compared to the control, Ingot Series 70, especially in the lighter gages. This is equally true of steels adding chromium, vanadium, chromium and vanadium, zirconium or boron as above described.

TABLE 7

Ingot series	1 inch plate: Finishing temp., ° F.	Yield point, p.s.i.	Tensile strength, p.s.i.	Elongation in 2", percent	Reduction of area, percent	¾ inch plate: Finishing temp., ° F.	Yield point, p.s.i.	Tensile strength, p.s.i.	Elongation in 2", percent	Reduction of area, percent
Ingot 30 as rolled	1,900 to 1,950	51,670	71,890	28.5	68.5	1,900 to 1,590	57,160	76,390	28.5	69.0
Ingot 30 as aged	1,900 to 1,950	51,670	71,649	29.5	69.0	1,900 to 1,590	57,160	76,140	27.0	69.0
		55,170	72,890	27.5	68.0	1,900 to 1,950	59,660	77,130	27.5	68.0
Ingot 70 as rolled	1,900 to 1,500	55,420	72,890	28.0	68.5	1,900 to 1,950	59,660	77,130	27.5	68.0
		50,670	68,150	29.0	68.0	1,900 to 1,500	54,420	70,890	28.0	67.5
Ingot 70 as aged	1,900 to 1,950	50,670	67,900	30.0	68.0	1,900 to 1,500	54,420	70,890	27.5	68.0
		51,670	68,400	28.5	68.5	1,900 to 1,950	55,890	71,680	27.5	68.0
	½ inch plate					⅜ inch plate				
Ingot 30 as rolled	1,850 to 1,900	56,770	72,810	24.0	72.9	1,750 to 1,800	64,730	78,160	19.5	72.9
Ingot 30 as aged	1,850 to 1,900	56,840	73,130	24.5	72.3	1,750 to 1,800	63,930	77,960	19.0	72.5
		57,740	73,330	23.5	71.3		64,330	78,360	16.0	72.9
Ingot 70 as rolled	1,850 to 1,900	58,170	73,210	23.5	72.0	1,750 to 1,800	64,870	78,240	18.5	73.1
		54,150	68,730	25.0	71.6		57,330	70,220	15.5	72.4
Ingot 75 as aged	1,850 to 1,900	54,150	68,820	24.0	71.6	1,750 to 1,800	56,910	70,540	21.5	71.3
		54,950	69,130	24.5	71.9	1,750 to 1,800	56,510	78,540	21.0	72.9

EXAMPLE 12

The procedure of examples 1, 2 and 3 is carried out except that after completion of hot rolling, the steel is cold reduced about 15 percent. After reheating to aging temperature and then slowly cooling to room temperature, in still air, it is found that the yield point is increased beyond what would be obtained in the absence of cold working by about 10,000 to 15,000 p.s.i. This is true in all of the steel compositions of the present invention, those including molybdenum and niobium, and also those adding vanadium or chromium or chromium and vanadium, or zirconium or boron.

The best properties as-aged will be obtained by finishing at a temperature below 1,700° F. (or 1,750° F. depending on alloy content) and then cooling as rapidly as convenient, as for example, by water sprays short of quenching, and then aging as above described.

Some of the benefit from improved properties by aging can be obtained, however, by changing the finishing conditions from those discussed above, and improved properties which are a compromise (not as good as those obtained by subsequent aging) can be obtained in the hot rolled condition by this technique.

To achieve this, it is necessary to finish at a temperature above 1,700° F. (or 1,750° F. depending on alloy content), and cool in still air. Thus beneficial properties were obtained by finishing at various temperatures up to 1,900° or 1,950° F. It will be understood that in usual noncontinuous mill rolling practice the finishing temperature for the lighter gages is likely to be on the lower side and for the heavier gages on the higher side.

A series of ingots was hot rolled having the following analyses on the average:

I have also found that the addition of molybdenum to niobium containing steel of the invention has a significant effect in improving the grain size in the as-rolled condition. Molybdenum seems to have a beneficial effect over a wide range of finishing conditions.

These findings are illustrated in the following data:

Ingot series	Plate gage in inches	Finishing temperature in ° F., cooled in still air	As-rolled grain size in inverse square root of mean grain diameter in millimeters
30	1	1,900 1,950	7.26
70	1	1,900 1,950	6.45
30	¾	1,900 1,950	8.77
70	¾	1,900 1,950	7.09
30	½	1,850 1,900	9.13
70	½	1,850 1,900	8.77
30	⅜	1,750 1,800	10.00
70	⅜	1,750 1,800	9.52

Thus the samples of steel according to the invention are of significantly finer grain size than the control omitting the molybdenum. The numbers above approximate ASTM grain size numbers.

While the above examples illustrate properties obtained in sheet and plate products, these properties are also illustrative of properties which are secured in other low alloy constructional steel forms, such as bars and shapes.

It will be evident that the principles of the invention can be applied where desired by selling a steel according to the inven-

tion in the as-rolled condition and then aging after fabrication or aging in connection with a stress relief anneal after welding during fabrication.

It will be evident that in the case of compositions of alloys, the percentages are by weight.

In view of my invention and disclosure, variations and modifications to meet individual whim or particular need will doubtless become evident to others skilled in the art to obtain all or part of the benefits of my invention without copying the composition and process shown, and I, therefore, claim all such insofar as they fall within the reasonable spirit and scope of my claims.

We claim:

1. A ferrite-carbide low alloy constructional steel in the hot rolled, cooled without quenching, and directly aged condition having the following composition by weight:

carbon	0.10% max.
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.005 to 0.075%
molybdenum	0.04 to 0.50

iron and impurities, balance.

2. A steel of claim 1, having the following composition by weight in the following respect:

carbon	0.08% max.

3. A steel of claim 2, having the following composition by weight in the following respect:

molybdenum	0.08 to 0.30%.

4. A steel of claim 1, having the following composition by weight in the following respect:

niobium	0.030 to 0.050%.

5. A ferrite-carbide low alloy constructional steel in the hot rolled, cooled without quenching, and directly aged condition having the following composition by weight:

carbon	0.10% max
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.005 to 0.075%
molybdenum	0.04 to 0.50%
vanadium	up to 0.10%
chromium	up to 0.050%
zirconium	up to 0.16%

iron and impurities, balance.

6. A steel of claim 5, having the following composition by weight in the following respect:

carbon	0.08% max.

7. A steel of claim 6, having the following composition by weight in the following respect:

molybdenum	0.08 to 0.30%.

8. A steel of claim 5, having the following composition by weight in the following respect:

niobium	0.030 to 0.050%.

9. A ferrite-carbide low alloy constructional steel in the hot rolled, cooled without quenching, and directly aged condition having the following composition by weight:

carbon	0.08% max.
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.005 to 0.075%
molybdenum	0.04 to 0.50%
boron	0.0005 to 0.005%

iron and impurities, balance.

10. A steel of claim 9, having the following composition by weight in the following respect:

boron	0.0015 to 0.003%

11. A ferrite-carbide low alloy constructional steel in the hot rolled, cooled without quenching, and directly aged condition having the following composition by weight:

carbon	0.08% max.
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.005 to 0.075%
molybdenum	0.04 to 0.50%
boron	0.0005 % to 0.005%
vanadium	up to 0.10%
chromium	up to 0.50%
zirconium	up to 0.16%

iron and impurities, balance.

12. A ferrite-carbide low alloy constructional steel in the hot rolled, cooled in air, and directly aged condition having the following composition by weight:

carbon	0.10% max.
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.005 to 0.075%
molybdenum	0.04to 0.50%
vanadium	up to 0.10%
chromium	up to 0.50%
zirconium	up to 0.16%

iron and impurities balance.

13. A ferrite-carbide low alloy constructional steel in the hot rolled, cooled with the aid of a water spray short of quenching, and directly aged condition having the following composition by weight:

14. A process of making a ferrite-carbide low alloy constructional steel, which comprises hot rolling a steel having the following composition by weight:

carbon	0.10% max.
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.005 to 0.075%
molybdenum	0.04 to 0.50%

iron and impurities, balance,

directly cooling the steel to room temperature without quenching, without austenitizing, reheating the steel to a temperature of 1,000° to 1,200° F. and holding it at that temperature to age it, and cooling the steel in air to room temperature.

15. A process of claim 14, in which the steel has the following composition by weight in the following respect:

carbon	0.08% max.

16. A process of claim 14, in which the steel has the following composition by weight in the following respect:

molybdenum	0.08 to 0.30%

17. A process of claim 14, in which the steel has the following composition by weight in the following respect:

niobium	0.030 to 0.050%

18. A process of making a ferrite-carbide low alloy constructional steel, which comprises hot rolling a steel having the following composition by weight:

carbon	0.10% max.
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.005 to 0.075%

molybdenum	0.04 to 0.50%
vanadium	up to 0.10%
chromium	up to 0.50%
zirconium	up to 0.16%

iron and impurities, balance,

cooling the steel to room temperature, without austenitizing reheating the steel to a temperature of 1,000° to 1,200° F. and holding it at that temperature to age it, and cooling the steel in air to room temperature.

19. A process of claim 18, in which the steel has the following composition by weight in the following respect:

carbon 0.08% max.

20. A process of claim 18, in which the steel has the following composition by weight in the following respect:

molybdenum 0.08 to 0.30%.

21. A process of claim 18, in which the steel has the following composition by weight in the following respect:

niobium 0.030 to 0.050%.

22. A process of making ferrite-carbide low alloy constructional steel which comprises hot rolling a steel having the following composition by weight:

carbon	0.08% max.
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.05 to 0.75%
molybdenum	0.04 to 0.50%
boron	0.0005 to 0.005%

iron and impurities, balance,

directly cooling the steel to room temperature without quenching, without austenitizing reheating the steel to a temperature of 1,000° to 1,200° F. and holding it at that temperature to age it, and cooling the steel in air to room temperature.

23. A process of claim 22, in which the steel has the following composition by weight in the following respect:

boron 0.015 to 0.003%.

24. A process of making a ferrite-carbide low alloy constructional steel, which comprises hot rolling a steel having the following composition by weight:

carbon	0.08% max.
silicon	0.35% max.
manganese	0.30to 1.50%
niobium	0.005 to 0.0075%
molybdenum	0.04 to 0.50%
boron	0.0005 to 0.005%
vanadium	up to 0.10%
chromium	up to 0.50%
zirconium	up to 0.16%

iron and impurities, balance,

directly cooling the steel to room temperature without quenching, without austenitizing reheating the steel to a temperature of 1,000° to 1,200° F. and holding it at that temperature to age it, and cooling the steel in air to room temperature.

carbon	0.10% max.
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.005 to 0.057%
molybdenum	0.04 to 0.50%
vanadium	up to 0.10%
chromium	up to 0.50%
zirconium	up to 0.16%

iron and impurities, balance.

25. A process of making a ferrite-carbide low alloy constructional steel, which hot rolling a steel having the following composition by weight:

carbon	0.10% max.
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.005 to 0.075%
molybdenum	0.04 to 0.50%
vanadium	up to 0.10%
chromium	up to 0.50%
zirconium	up to 0.16%

iron and impurities, balance,

directly cooling the steel in air to room temperature, without austenitizing reheating the steel to a temperature of 1,000° to 1,200° F. and holding it at that temperature to age it, and cooling the steel in the air to room temperature.

26. A process of making a ferrite-carbide low alloy constructional steel, which comprises hot rolling a steel having the following composition by weight:

carbon	0.10% max.
silicon	0.35% max.
manganese	0.30 to 1.50%
niobium	0.005 to 0.75%
molybdenum	0.04 to 0.50%
vanadium	up to 0.10%
chromium	up to 0.50%
zirconium	up to 0.16%

iron and impurities, balance,

directly cooling the steel to room temperature with the aid of a water spray short of quenching, without austenitizing reheating the steel to a temperature of 1,00020 to 1,200°dr F. and holding it at the temperature to age it, and cooling the steel in air to room temperature.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,619,303 Dated Nov. 9, 1971

Inventor(s) Frederick J. Semel

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 8, change the word "age-handenable" to --age-hardenable--.

Column 1, line 11, the word "as" should be --in--.

Column 1, line 43, change "0.80" to --0.08--.
Column 2, line 59, change word "extend" to --exceed--.
Column 3, line 21, insert the word --the-- after "with" and before "steels".

Column 4, line 13, insert the word --the-- after "in" and before "others".

Column 4, line 46, the word "oxygen" should not be hyphenated.

Column 5, line 32, change "0.35" percent max. to --0.035-- percent max.

Column 5, line 34, change "0.30" to --0.030--.

Column 5, line 44, in the Table entitled "TENSILE PROPERTIES" under the column entitled "As-rolled" opposite "Tensile strength, p.s.i." insert the numeral --84,400--.

Column 6, line 18, the numeral opposite "Si" which is "0.030%" should be --0.30%--.

Column 6, line 45 under the heading "Aged 1100°F., 2 hours, air cooled" the numeral "30" should be --+30--.

Column 6, line 57, the word "It" should be removed.

Column 7, Table 2, under the heading "1 hr." opposite "Yield point, p.s.i." the period in "68.300" should be changed to a comma as follows: --68,300--.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,619,303 Dated Nov. 9, 1971

Inventor(s) Frederick J. Semel

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 8, line 27, in the table "TENSILE PROPERTIES" the words "% offset yield strength" should follow the number " *0.2" as follows: --*0.2% offset yield strength--.

Column 8, line 45, in the Table "CHARPY IMPACT IN FOOT-POUNDS" under the heading "Testing Temperature °F." the numeral --75-- should be inserted after the "+" and in line 46 under the heading "Testing Temperature °F." --0-- should be placed in this column.

Column 8, line 61, the word "if" before "75,000" should be changed to --of--.

Column 8, line 67, opposite the letter "C" the numeral "0.006%" should be changed to --0.06%--.

Column 9, line 15, the numeral "*0.02" should be changed to --*0.2-- and the words "% offset yield strength" should follow the number "*0.2" as follows: --*0.2% offset yield strength--.

Column 9, line 25, in the table "CHARPY IMPACT IN FOOT-POUNDS" under the heading "Testing Temperature °F." after the "-" the numeral --60-- should be inserted.

Column 10, line 50, after the Table "CHARPY IMPACT IN FOOT-POUNDS and before "Example 10" Tables 4 and 5 should be positioned.

Column 12, in Table 5, under the heading "As rolled" the footnote --1-- should be inserted before or after the numeral "60,900".

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,619,303 Dated Nov. 9, 1971

Inventor(s) Frederick J. Semel

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 11, line 55, the Table 6 should be positioned here before the table "Charpy Impact in foot-pounds".

Column 11, line 72, remove the second word "that".

Columns 13 and 14, Table 7, under the heading "1 inch plate" "Finishing temp., °F." opposite "Ingot 70 as rolled" the numbers "1,900 to 1,500" should be --1,900 to 1,950--.

Columns 13 and 14, Table 7, under the heading "3/4 inch plate" under the heading "Finishing temp., °F." opposite the words "Ingot 30 as rolled" the numbers "1,900 to 1,590" should be --1,900 to 1,950--.

Columns 13 and 14, Table 7, under the heading "3/4 inch plate" "Finishing temp.,°F." opposite "Ingot 70 as rolled" the numbers "1,900 to 1,500" should be --1,900 to 1,950--.

Columns 13 and 14, Table 7, after the first heading of "Reduction of area, percent" there should be no column of brackets but instead a space.

Column 15, line 13, change "We" to --I--.

Column 16, line 38, following the words "composition by weight:" the table of compounds in column 18, line 10 starting with "carbon 0.10% max." should be moved. In that table, column 18, line 13, the value for "niobium" is "0.005 to 0.057%" and should be -- 0.005 to 0.075%--.

Column 17, line 6, before "cooling" insert -- directly --; same line 6, after "temperature," insert -- without quenching, --;

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,619,303 Dated Nov. 9, 1971

Inventor(s) Frederick J. Semel

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 17, line 52, the value for "niobium" is "0.005 to 0.0075%" & should be as follows: --0.005 to 0.075%--.

Column 18, line 19, after the word "which" and before the word "hot" insert the word --comprises--.

Column 18, line 34, after the word "in" and before the word "air" remove the word "the".

Column 18, line 41, the value for "niobium" is "0.005 to 0.75%" and should be --0.005 to 0.075%--.

Column 18, line 49 the phrase "of 1,00020 to 1,200°dr F." is wrong and should be changed to --of 1000° to 1200°F.--.

Signed and sealed this 26th day of September 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents