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COLUMBIUM CONTAINING STEELS, PROCESS FOR THEIR MANUFACTURE AND ARTICLES PREPARED THEREFROM

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This invention relates to improvements in mild carbon steels and, in one of its more specific aspects, to a novel weldable, formable, mild carbon steel which is further characterized by high strength with increased toughness and a fine-grained metallurgical structure. The present invention also relates to a process for producing the novel steel of the invention and to mild carbon steel articles prepared therefrom.

Mild carbon steel of a given composition has mechanical or physical properties such as yield point, tensile strength and ductility which depend largely upon the grain size of the hot rolled or normalized condition. In general, a coarse grain size results in low mechanical or physical properties while a fine grain size is accompanied by greatly enhanced mechanical or physical properties. Thus, a fine grain size is of utmost importance and must be attained in some manner if high strength mild carbon steel is to be produced in the hot rolled condition.

The attainment of fine grained steels in the hot rolled condition is dependent upon a number of factors, but largely upon the composition of the steel and the hot rolling practices which are followed. For steel of a given composition and when following practical commercial practices, the production of fine grained steel in the hot rolled condition depends largely upon the degree of reduction in the final pass, the temperature during the final pass, the rate of cooling following the final pass, the sequence of reductions taking place in preceding passes and the magnitude of the over-all reduction. For example, when hot working a given ordinary mild carbon steel such as by hot rolling, the more frequent or shorter the time between the applications of pressure, the lower the temperature at which they occur but at a temperature above the critical temperature, the greater the amount of hot work, the lower the finishing temperature and the faster the rate of cooling following the last hot working step, then the finer the ultimate grain size will be. The grain size may be further reduced in a given instance by providing a steel of a composition promoting finer grain size, e.g., by providing a steel having contained elements such as aluminum, titanium or vanadium.

As a consequence of the above-mentioned factors promoting fine grain size, fine grained hot rolled products usually may be produced only in the thinner thickness of sheet gauges when following economic modern steel making practices. Uneconomic, slow mills having lower finishing temperatures extend the thickness at which fine grained hot rolled steel may be obtained. Also, the proper selection and use of contained amounts of the prior art grain refining elements mentioned above further increases this thickness. However, in the slowest mills following modern steel making practices for producing fine grained steels and even when using grain refining elements in the most effective quantities, the thickness in which fine grained hot rolled, mild carbon steels may be produced generally is not substantially over about $\frac{3}{16}$ inch when the finished steel is bed cooled. If piled or coiled, this thickness under circumstances otherwise favorable for promoting fine grain size is reduced substantially below $\frac{3}{16}$ inch and the effect of such piling or coiling is

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greater the higher the coiling or piling temperature and the larger the size of the piles or coils since these variables further reduce cooling rates.

The multiplicity of variables affecting grain size in mild carbon steels which, in turn, largely determine the physical or mechanical properties of the steel result in variations such as yield point and tensile strength that are highly undesirable from the standpoint of engineering design and fabrication. Steel requirements in all fields are exacting in these respects and some means must be provided for assuring as uniform a product as possible. This is especially true with respect to physical and mechanical properties relating to the strength and toughness of the steel, and properties relating largely to fabrication such as an ability to be readily formed, shaped and welded. Insofar as rolling practice is concerned, heretofore the requirements relating to uniformity of product have been met chiefly by limiting slab sizes so as to reduce the size of piles or coils of finished steel, by running mills at reduced speeds so as to lower finishing temperatures and similar uneconomic practices. These practices have only been partially successful and rather serve to mitigate the problem rather than cure it. Even more important, in the heavier hot rolled thicknesses especially and to a lesser extent in the thinner thicknesses, the levels of yield strength and tensile strength that it is possible to attain when operating under the most favorable metallurgical conditions are limited to relatively low values.

In addition to the above-mentioned uneconomic conditions which are invariably associated with the hot rolling of steel in accordance with prior art practices to produce a fine grained metallurgical structure, the use of strong deoxidizing elements such as aluminum, titanium or vanadium as grain refining additives is possible only when they are added in quantities such as will produce a killed steel. However, when killed steel is produced, preferably the steel is poured in big-end-up molds and the molds must be hot topped in order to prevent shrinkage cavities, i.e., "pipe" in the steel. Unless pipe is prevented from forming, separation or lamination of hot rolled plate, sheet, bar, or other products produced from the resulting ingots will occur in the central part of the thickness of the hot rolled product and thereby render the steel unsuited for most modern usages. The hot topping requirements which are necessary in the production of killed steel to eliminate pipe are expensive and reduce the shippable yield of finished steel from the ingot by very substantial quantities. These factors further increase the cost of killed steel and as a result the over-all final cost of killed steel is much higher than that of semi-killed, capped or rimmed steel. Thus, it would be highly desirable to provide an inexpensive, weldable, formable mild carbon steel characterized by high strength with increased toughness and a fine grained metallurgical structure in the hot rolled condition when hot rolled from semi-killed, capped or rimmed steel.

As is well known, mild carbon steels characterized by increased strength may be produced by increasing the carbon or manganese content, or both, substantially. However, when this is done the toughness of the steel is seriously impaired. Also, fabricability of the steel with especial reference to formability and weldability either is impossible or very expensive and not reliable. These undesirable properties of carbon steels having an increased carbon and/or manganese content result in substantially higher costs to the user and in many instances such steels may not be used for general purposes in any instance. Thus, it is apparent that increased carbon and/or manganese contents in ordinary carbon steel may be had only at the expense of other desirable properties which are essential in a steel for most modern usages.

When referring to grain size herein, unless specifically

stated to the contrary, it is understood that the ASTM grain size of the grains of ferrite and pearlite making up the metallurgical structure of mild carbon steel at temperatures substantially below the critical is intended. However, for many purposes a steel that is fine grained in the austenitic condition as determined by the well known McQuaid-Ehn test (A.S.T.M. Specification E19-46) is preferred because of increased toughness, greater immunity from grain coarsening when heated to relatively high temperatures, and other desirable properties characteristic of such steels. Heretofore, fine grained steels in the austenitic condition as determined by the McQuaid-Ehn test were producible only if fully killed and thus were costly for the reasons mentioned above.

In accordance with one important embodiment of the present invention, mild carbon, low manganese steels are provided that may be made in the incompletely deoxidized state and without hot topping. Such steels have a fine-grained metallurgical structure consisting essentially of grains of ferrite and pearlite having an ASTM grain size of 5 and higher in the hot rolled condition when hot rolled from semi-killed, capped and rimmed ingots to thicknesses up to at least $\frac{5}{16}$ inch following steel making practices for producing hot rolled fine-grained steel, a fine-grained metallurgical structure in the austenitic condition as determined by the McQuaid-Ehn test, substantially increased tensile and yield strengths, and yet are tough in accordance with the fine grained texture that is possible within the provisions of this invention. Prior to the present invention, it was considered to be impossible to prepare semi-killed, capped or rimmed steel having the above characteristics. Thus, the present invention is a major advance which was not contemplated or even remotely suggested by the prior art.

It is an object of the present invention to provide a novel, weldable, formable, incompletely deoxidized, mild carbon steel characterized by high strength with increased toughness and a fine-grained metallurgical structure in the hot rolled condition consisting essentially of grains of ferrite and pearlite having an ASTM grain size of 5 and higher when hot rolled from semi-killed, capped or rimmed ingots to thicknesses up to at least $\frac{5}{16}$ inch following steel making practices for producing hot rolled fine grained steel.

It is a further object of the present invention to provide a novel, weldable, formable, incompletely deoxidized, mild carbon steel characterized by high strength with increased toughness and a fine-grained metallurgical structure in the austenitic condition as determined by the McQuaid-Ehn test.

It is still a further object of the present invention to provide mild carbon steel having the above-mentioned characteristics that may be made without hot topping and which may be made semi-killed, capped or rimmed.

It is still a further object of the present invention to provide hot worked, weldable, formable, mild carbon steel articles produced from semi-killed, capped and rimmed steel characterized by high strength with increased toughness and a fine grained metallurgical structure as defined above, and a process for their preparation.

It is still a further object of the present invention to provide a process for treating incompletely deoxidized mild carbon steels to produce weldable, formable, incompletely deoxidized mild carbon steels characterized by high strength with increased toughness and a fine grained metallurgical structure as defined above.

Still other objects and advantages of the present invention will be apparent to those skilled in the art upon reference to the following detailed description and the specific examples.

In accordance with one important embodiment of the present invention, we have discovered that mild carbon steels containing about 0.05-0.30% carbon, 0.25-1.50% manganese, a maximum of 0.10% silicon, 0.005-0.2% columbium and the remainder iron together with incident

tal impurities possess the above enumerated properties of steels of the present invention. However, mild carbon steels containing about:

Element	Range, percent	Preferred range, percent
Carbon.....	0.05-0.30	0.15-0.20
Manganese.....	0.30-1.15	0.60-0.90
Silicon, maximum.....	0.10	0.10
Columbium.....	0.005-0.2	0.005-0.2

and the remainder iron together with incidental impurities are generally preferred for purposes of the present invention. The steels of the invention should contain a maximum of about 0.04% phosphorus and 0.05% sulfur for best results. Also, up to about 0.30% and preferably 0.15-0.30% copper may be present in instances where increased corrosion resistance is desired.

Usually, columbium should be maintained within a range of about 0.005-0.05% and, preferably, about 0.01-0.04% for best results in most instances. A columbium content above about 0.05% is preferred only in instances where a relatively small amount of hot working is to be performed and/or where the finishing temperature is extremely high such as when hot rolling $\frac{5}{8}$ inch and heavier plate with a high finishing temperature. In instances where $\frac{5}{8}$ inch and heavier plate is rolled, the degree of grain refinement which may be attained at a given columbium level may be enhanced markedly by lower finishing temperatures such as 1750° F. or below and/or by subsequently subjecting the hot rolled plate to a normalizing or solution annealing step. This is also true of lighter products but a lesser extent.

When hot rolling light plate and sheet gauges following conventional modern steel making practices for producing hot rolled, fine grained, mild carbon steel products, the columbium content generally should not exceed 0.05% and often may be considerably lower such as 0.01-0.03%.

Steels having the above composition may be regarded as mild carbon steels which have been treated with columbium and are not usually classified as alloy steels in the commercial sense. In producing the steels, ordinary mild carbon steel in the molten condition may be treated in the ladle or the mold with columbium (i.e., niobium), preferably in the form of ferro-columbium (i.e., ferro-niobium), to provide the desired contained columbium content as set forth above. In all respects other than columbium treatment of the molten steel, generally standard metallurgical practice for producing fine grain mild carbon steels may be followed and including conventional steel making practices for hot rolling mild carbon steels under conditions promoting fine grain size.

The steels of the present invention may be made as semi-killed, capped, or rimmed steel, but it is preferred for most purposes that the steel be made semi-killed. Semi-killed steel is defined on page 12 of the Metals Handbook of the American Society of Metals (1948) as being steel incompletely deoxidized to permit evolution of sufficient carbon monoxide to offset solidification shrinkage. Regardless of which of these incompletely deoxidized steels is made in order to satisfy the requirements of a specific end use, the steel of the present invention possesses the desirable properties enumerated above, is fine grained in the austenitic condition as determined by the McQuaid-Ehn test and has a fine-grained metallurgical structure consisting essentially of ferrite and pearlite having an ASTM grain size of 5 and higher in the hot rolled condition when hot rolled to thicknesses up to at least $\frac{5}{16}$ inch and often higher following prior art steel making practices for producing hot rolled fine grained steel. It has not been possible heretofore to prepare high strength fine grained steels as defined above in other than the fully deoxidized state such as killed steels.

The columbium treated mild carbon steels of the present invention may be readily hot worked and formed into weldable, formable, mild carbon steel articles characterized by high strength with increased toughness and a fine grained metallurgical structure as defined herein. Examples of such mild carbon steel articles include plate, sheet and strip steel, bars, rods, wire, structural shapes such as beams, columns, etc., as well as shapes or articles prepared or formed therefrom.

The austenitic grain size as determined by the McQuaid-Ehn test is a function of the columbium content. For example, semi-killed mild carbon steels containing 0.16% carbon, 0.78% manganese, 0.009% phosphorus, 0.024% sulfur, 0.05% silicon, varying amounts of columbium as indicated below and the remainder iron together with incidental impurities was found to have the following austenitic grain sizes as determined by the McQuaid-Ehn test upon carburizing at 1700° F. for 8 hours:

Percent columbium :	Austenitic ASTM grain size by McQuaid-Ehn test
None	3-4
0.015	6-8
0.022	7-8
0.035	7-9

From the above data, it may be seen that addition of columbium to incompletely deoxidized mild carbon steels results in a fine grain size in the austenitic condition, i.e., an ASTM grain size of 5 or higher. If columbium is not present, then the mild carbon steel is coarse grained and not satisfactory for many modern uses.

Mild carbon steels containing columbium within the ranges defined herein also have a finer grain size in the normalized or solution annealed condition. For example, upon normalizing or solution annealing hot rolled columbium bearing mild carbon steel at customary temperatures such as 1650-1700° F., the columbium bearing steel will have a finer grain size than hot rolled steel that does not contain columbium and irrespective of the grain sizes of the hot rolled steels prior to normalizing or solution annealing.

Where the language "incompletely deoxidized to an extent to permit evolution of at least sufficient carbon monoxide containing gas to offset substantial shrinkage during solidification" or "... to offset substantial solidification shrinkage" appears in the claims when referring to the molten steel or a heat of steel, it is to be understood to embrace within its meaning oxygen contents suitable for the production of semi-killed, capped and rimmed steel.

The present invention may be further illustrated by the following specific examples which are not to be taken as limiting to the spirit or scope of the appended claims. All steels mentioned in the following specific examples were made semi-killed.

This application is a continuation of our copending application Serial No. 792,983, filed February 13, 1959, now abandoned.

Example I

A heat of ordinary mild carbon steel containing 0.26% carbon, 1.05% manganese, 0.016% phosphorus, 0.020% sulfur, 0.05% silicon and the remainder iron together with incidental impurities was prepared and teemed into eleven ingot molds. During the teeming operation, ¼ pound of columbium in the form of about 46% crushed ferro-columbium (½" lumps) per ton of steel was added to number 4 ingot. Similarly, ½ pound and ¾ pound of columbium per ton of steel was added to number 5 and 7 ingots, respectively. The number 6 ingot contained no added columbium and was used as a standard test ingot. The size of the resulting ingots was about 28 x 82 x 80 inches and the weight of each was about 42,000 pounds.

The crushed ferro-columbium was added during teeming by means of a trough. A predetermined amount of crushed ferro-columbium as required for addition of the desired amount of columbium was placed in the trough, and then the trough was placed over the mold so that the flow of ferro-columbium into the mold could be accurately controlled. When the molten steel level in the mold reached one-quarter of the height of the mold, ferro-columbium addition was started and the addition was completed when the molten steel level reached approximately three-quarters of the height of the mold.

The four test ingots, i.e. the number 4, 5, 6 and 7 ingots, were removed from the molds, identified, and then slabbed, with each of the test ingots being sheared into two slabs. The resulting eight slabs were approximately 78 inches wide, 4¾ inches thick and 198 inches long. Each slab was machine scarfed. The slabbing and scarfing operations followed conventional plant practice.

A slab from each of the four test ingots was hot rolled ⅝ inch thick following the usual steel making practice for mild carbon steel as conventional in the art using a 96 inch mill. Each slab was rolled into a coil. The finishing temperature was about 1620-1665° F. and the coiling temperature was about 1120-1160° F. Following cooling, each coil was uncoiled and sheared into four or five plates. Samples of the resulting plates from each coil were taken for chemistry and physical tests.

The following data were obtained upon testing longitudinal samples taken from the outside of the coils:

Ingot No.	Columbium added, lb./ton	Contained columbium, percent	Tensile strength	Brinell hardness	Yield strength (0.2% offset)	ASTM grain size
6	None	None	79,500	160	42,800	3½
4	¼	0.010	83,100	165	53,400	5-6 and finer.
5	½	0.021	86,600	172	59,600	7-8 and finer.
7	¾	0.029	88,200	175	63,200	8-9 and finer.

Example II

Mild carbon steel containing 0.16% carbon, 0.68% manganese, 0.009% phosphorus, 0.024% sulfur, 0.08% silicon, with or without columbium as indicated in the table below and the remainder iron together with incidental impurities was prepared and hot rolled in accordance with the practice of Example I. This particular steel was hot rolled 0.275 inch thick and 22 inches wide into coils. The mechanical properties of longitudinal samples taken from the three test ingots prepared and hot rolled were as follows:

Percent contained columbium	Yield strength (0.2% offset)	Tensile strength	Brinell hardness	Percent elongation in 2 inches ¹
None	36,280	61,220	122	43
0.018	45,220	67,840	134	39
0.029	56,910	75,570	150	33

¹ One and one-half wide specimens.

Example III

Mild carbon steel was treated with columbium and hot rolled ⅝ inch thick by 74 inches wide into 20,000 pound coils in accordance with the procedure of Example I. Then, samples were taken from the interior

of the coils where the cooling rate was very slow and tested. The following data were obtained:

Percent contained columbium	Yield strength (0.2% offset)	Tensile strength	Brinell hardness	Percent elongation in 2 inches ¹
None	42,360	76,270	152	41
0.010	48,000	78,300	156	40
0.016	52,630	79,960	160	38
0.026	55,370	83,690	167	36

¹ One and one-half inch wide specimens.

The heat used in preparing the above four ingots contained 0.25% carbon, 1.05% manganese, 0.016% phosphorus, 0.020% sulfur, 0.05% silicon and the remainder iron together with incidental impurities. Ferro-columbium containing 0.67% carbon, 0.84% manganese, 5.08% silicon, 0.006% sulfur, a trace of phosphorus, 45.93% columbium and 4.28% tantalum and the remainder iron together with incidental impurities was added to give a contained columbium content as indicated in the above table.

From the data in the above table, it is apparent that columbium greatly increases the yield and tensile strength in hot rolled mild carbon steels. Increased strength in hot rolled mild carbon steels usually is accompanied by increased brittleness. However, the reverse is true for the steels of the present invention. This may be illustrated by Charpy V determinations made on plates having the same analysis given above, as follows:

Percent contained columbium	Charpy V—ft. lbs.		
	-20° F.	-40° F.	-50° F.
None	19.0	12.5	4.0
0.010	20.0	16.5	6.0
0.016	23.0	20.0	16.0
0.026	30.0	22.0	17.5

Example IV

A heat of mild carbon steel containing 0.22% carbon, 0.83% manganese, 0.008% phosphorus, 0.019% sulfur, 0.05% silicon and the remainder iron together with incidental impurities was treated with varying amounts of ferro-columbium and the resulting ingots hot rolled into plate one and one-half inches thick by 60 inches wide by 620 inches long. The amount of hot reduction, therefore, was very low. Also, the finishing temperatures were very high, somewhat above 1900° F., and the cooling rates in the piles after rolling were very low. Mechanical properties of samples taken from the four coils prepared were as follows:

Percent contained columbium	Yield strength (0.2% offset)	Tensile strength	Brinell hardness	Percent elongation in 2 inches ¹
None	41,500	76,000	152	30
0.016	51,420	84,520	168	28
0.024	55,810	89,830	180	26
0.046	57,370	90,810	182	25

¹ 0.505 inch specimens.

Example V

In the event an incompletely deoxidized mild carbon steel contains columbium within the ranges defined herein, if the steel is hot worked and subsequently normalized or solution annealed, the steel will have a finer grain size than in instances where the columbium is not present. Also, upon hot working followed by normalizing or solution annealing at the customary temperatures for mild

carbon steel such as about 1650-1700° F., mild carbon steel containing columbium within the ranges taught herein will be finer grained than similar mild carbon steel that does not contain columbium irrespective of the grain size of the hot worked product. This unusual and unexpected characteristic of columbium bearing, incompletely deoxidized, mild carbon steel is illustrated below.

Mild carbon steel containing 0.16% carbon, 0.78% manganese, 0.009% phosphorus, 0.024% sulfur, 0.05% silicon and the remainder iron together with incidental impurities was prepared, poured into ingots and the ingots hot rolled to varying thicknesses following the general procedure of Example I. Ferro-columbium was added to two of the molds in an amount to provide 0.018% of contained columbium in the resulting ingots and a third ingot containing no columbium was retained as a test ingot.

The test ingot containing no columbium was hot rolled 5/16 inch thick and found to have an ASTM grain size of number 4 in the hot rolled condition. Upon normalizing at a temperature of 1650-1700° F. for one hour, the ASTM grain size remained number 4. The same results were obtained upon solution annealing at a temperature of 1650-1700° F.

A test ingot containing added ferro-columbium in an amount to provide 0.018% of contained columbium in the mild carbon steel of this example was hot rolled 5/8 inch thick. The finishing temperature was extremely high and this resulted in an ASTM grain size of number 4 in the as-rolled condition. Upon normalizing or solution annealing under the conditions mentioned above for the steel containing no columbium, the grain was refined to an ASTM grain size of 7-8.

A second test ingot containing added ferro-columbium in an amount to provide 0.018% of contained columbium in the mild carbon steel of this example was hot rolled 5/16 inch thick. The finishing temperature was much lower than for the 5/8 inch plate and the ASTM grain size in the hot rolled condition was 8-9. Upon normalizing or solution annealing under the conditions mentioned above for the steel containing no columbium, the ASTM grain size remained 8-9.

McQuaid-Ehn tests (A.S.T.M. Specification E19-46) were run at 1700° F. on samples of the hot rolled products obtained from each of the above three test ingots. Thus, the ASTM grain sizes in the austenitic condition as distinguished from the ASTM grain sizes of the ferrite and pearlite in the as rolled condition were determined.

The steel containing no columbium was found to have an austenitic ASTM grain size of 3-4 as determined by the McQuaid-Ehn test. All steel samples taken from the hot rolled products of the two columbium-containing ingots had an austenitic ASTM grain size of 6-8 as determined by the McQuaid-Ehn test regardless of the ASTM grain size of the ferrite and pearlite in the as-rolled condition.

It will be apparent from inspecting the data of the above examples that addition of small amounts of columbium within the ranges defined herein to ordinary mild carbon steels substantially increases tensile strength and yield strength, as well as toughness. At the same time, Brinell hardness increases substantially while ductility as measured by elongation or reduction in area is little changed. There is a marked grain refining effect upon hot working the steel following usual steel making practices for hot working mild carbon steel to produce the desired product under conditions promoting a fine grained metallurgical structure. In instances where the amount of hot working or conditions of hot working are such as to result in other than an optimum amount of grain refinement, often the grain may be further refined upon normalizing or solution annealing following the usual practice for mild carbon steel. Normalizing or solution

annealing is especially effective in producing further grain refinement when preparing hot rolled plate. Thus, a smaller grain size for a given amount of columbium may be obtained by hot rolling the steel to plate under the most favorable conditions for promoting fine grain size and then subjecting the plate to a normalizing or solution annealing step. In addition to the above data, tests also show that the steel of the invention is readily weldable and formable. For example, weldments performed on light plate show no underbead cracks when welded as low as -40°F .

What is claimed is:

1. A mild carbon steel consisting essentially of about 0.05–0.30% carbon, about 0.25–1.50% manganese, a maximum of about 0.10% silicon, about 0.005–0.2% columbium and the remainder substantially all iron, the steel being the product of solidification of molten steel incompletely deoxidized to an extent to permit evolution of at least sufficient carbon monoxide containing gas to offset substantial shrinkage during solidification.

2. A mild carbon steel in accordance with claim 1 in which the steel is the product of solidification of molten steel in the semi-killed state.

3. A mild carbon steel consisting essentially of about 0.05–0.30% carbon, about 0.30–1.15% manganese, a maximum amount of about 0.10% silicon, about 0.005–0.05% columbium and the remainder substantially all iron, the steel being the product of solidification of molten steel incompletely deoxidized to an extent to permit evolution of at least sufficient carbon monoxide containing gas to offset substantial shrinkage during solidification.

4. A mild carbon steel in accordance with claim 3 in which the steel is the product of solidification of molten steel in the semi-killed state.

5. A hot worked, weldable, formable, fine grained mild carbon steel article, the article being formed of steel consisting essentially of about 0.05–0.30% carbon, about 0.25–1.50% manganese, a maximum of about 0.10% silicon, about 0.005–0.20% columbium and the remainder substantially all iron, the steel being the product of solidification of molten steel incompletely deoxidized to an extent to permit evolution of at least sufficient carbon monoxide containing gas to offset substantial shrinkage during solidification.

6. A hot worked, weldable, formable, fine grained mild carbon steel article, the article being formed of steel consisting essentially of about 0.05–0.30% carbon, about 0.30–1.15% manganese, a maximum of about 0.10% silicon, about 0.005–0.05% columbium and the remainder substantially all iron, the steel being the product of solidification of molten steel incompletely deoxidized to an extent to permit evolution of at least sufficient carbon monoxide containing gas to offset substantial shrinkage during solidification.

7. A process for treating steel comprising preparing a heat of mild carbon steel incompletely deoxidized to an extent to permit evolution of at least sufficient carbon monoxide containing gas to offset substantial solidification shrinkage, adding columbium to the incompletely deoxidized molten steel in an amount to provide a residual columbium content of about 0.005–0.2% and then solidifying the steel without substantial solidification shrinkage, the resultant steel consisting essentially of about 0.05–0.30% carbon, about 0.25–1.50% manganese, a maximum of about 0.10% silicon, about 0.005–0.2% columbium and the remainder substantially all iron.

8. A process for treating steel in accordance with claim 7 in which the step of preparing the heat results in a semi-killed molten steel.

9. A process for treating steel comprising preparing

a heat of mild carbon steel incompletely deoxidized to an extent to permit evolution of at least sufficient carbon monoxide containing gas to offset substantial solidification shrinkage, adding columbium to the incompletely deoxidized molten steel in an amount to provide a residual columbium content of about 0.005–0.05% and then solidifying the steel without substantial solidification shrinkage, the resultant steel consisting essentially of about 0.05–0.30% carbon, about 0.30–1.15% manganese, a maximum of about 0.10% silicon, about 0.005–0.05% columbium and the remainder substantially all iron.

10. A process for treating steel in accordance with claim 9 in which the step of preparing the heat results in a semi-killed molten steel.

11. A process for preparing a hot worked mild carbon steel article comprising preparing a heat of mild carbon steel incompletely deoxidized to an extent to permit evolution of at least sufficient carbon monoxide containing gas to offset substantial solidification shrinkage, adding columbium to the incompletely deoxidized molten steel to obtain about 0.005–0.2% columbium in the steel, solidifying the steel without substantial solidification shrinkage and hot working the resultant steel under conditions favorable to the formation of fine grain to form an article, the steel article consisting essentially of about 0.05–0.30% carbon, about 0.25–1.50% manganese, a maximum of about 0.10% silicon, about 0.005–0.2% columbium and the remainder substantially all iron.

12. A process for preparing a hot worked mild carbon steel article in accordance with the process of claim 11 in which the step of preparing the heat results in a semi-killed molten steel.

13. The process of claim 11 wherein the hot worked steel article is subsequently subjected to a normalizing step.

14. The process of claim 11 wherein the hot worked steel article is subsequently subjected to a solution annealing step.

15. A process for preparing a hot worked mild carbon steel article comprising preparing a heat of mild carbon steel incompletely deoxidized to an extent to permit evolution of at least sufficient carbon monoxide containing gas to offset substantial solidification shrinkage, adding columbium to the incompletely deoxidized molten steel to obtain about 0.005–0.05% columbium in the steel, solidifying the steel without substantial solidification shrinkage and hot working the resultant steel under conditions favorable to the formation of fine grain to form an article, the steel article consisting essentially of about 0.05–0.30% carbon, about 0.30–1.15% manganese, a maximum of about 0.10% silicon, about 0.005–0.05% columbium and the remainder substantially all iron.

16. A process for preparing a hot worked mild carbon steel article in accordance with the process of claim 15 in which the step of preparing the heat results in a semi-killed molten steel.

References Cited in the file of this patent

UNITED STATES PATENTS

2,194,178	Becket et al. -----	Mar. 19, 1940
2,264,355	Becket et al. -----	Dec. 2, 1941

OTHER REFERENCES

The Iron Age, October 12, 1950, pages 158 to 163.
Transactions, American Institute of Mining and Metallurgical Engineers, vol. 125, pages 571 and 572. Published in 1937 by the Institute, 29 West 39th Street, New York.