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TOUGH, HIGH STRENGTH STEEL ARTICLE

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7 Claims

ABSTRACT OF THE DISCLOSURE

Steel article, such as plate, having a relatively high yield strength, e.g. 70,000 p.s.i., together with a relatively high impact resistance, e.g. 15 foot-pound Charpy V-notch impact transition temperature in the range -50° to -100° F. or lower. Microstructure is ferrite plus pearlite. Ferritic grain size is 9.5 ASTM or finer. Composition, in wt. percent:

Carbon	0.02—0.26
Manganese	1.25—1.75
Silicon	0.75—1.5
Nitrogen	0.003—0.015
Aluminum	0.01—0.08
Vanadium	0—0.07
Columbium	0—0.03
Tungsten	0—0.1

Article is hot rolled with at least 25% deformation at finishing temperature above A_1 to give microstructure containing fine grained austenite (9.5 ASTM or finer). Cooling is rapid but controlled to avoid low temperature transformation products in microstructure. Normalizing optional.

BACKGROUND OF THE INVENTION

The present invention relates generally to steel articles, such as plate having a thickness in the range $\frac{3}{16}$ to $1\frac{1}{4}$ inches or pipe skelp or structurals, and more particularly to steel articles of the type described which have both high yield strength and high impact resistance or toughness.

Conventional steel articles, such as plate, generally do not possess a combination of high yield strength and high impact resistance. For example, a conventional $\frac{3}{8}$ inch steel plate having a relatively high yield strength of about 70,000 p.s.i. as rolled has an impact resistance, expressed as 15 foot-pound Charpy V-notch impact transition temperature, no better than about 0° to 25° F.; and, for a plate thicker than $\frac{3}{8}$ inch, the impact resistance is poorer. The lower the impact transition temperature the better the impact resistance.

SUMMARY OF THE INVENTION

In accordance with the present invention, a combination of composition and treating procedures produces a steel article having a controlled microstructure of ferrite and pearlite with both high yield strength and high impact resistance. For example, steel plate having a thickness up to $1\frac{1}{4}$ inches can be provided with a yield strength of 70,000 p.s.i. together with a 15 foot-pound Charpy V-notch impact transition temperature in the range -50° to -100° F. or below.

Other features and advantages are inherent in the article and method claimed and disclosed or will become apparent to those skilled in the art from the following detailed description.

DETAILED DESCRIPTION INCLUDING PREFERRED EMBODIMENTS

A steel article in accordance with an embodiment of the present invention is hot rolled from a steel composi-

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tion having the following permissible ranges of elements, expressed in wt. percent:

Carbon—0.02—0.26
Manganese—1.25—1.75
Silicon—0.75—1.5
Nitrogen—0.003—0.015
Aluminum—0.01—0.08
Vanadium—0—0.07
Columbium—0—0.03

Tungsten—0—0.1
Phosphorus—0.05 max.
Sulfur—0.03 max.
Iron—Balance, essentially

The above described composition has both lower and higher carbon content embodiments, the lower having a carbon content less than 0.18 wt. percent and the higher having a carbon content of 0.18 wt. percent or above. In one set of preferred compositions, with either the lower or the higher carbon content, the ranges for the other elements would be as follows, expressed in wt. percent:

Manganese—1.4—1.7
Silicon—1.2—1.5
Nitrogen—0.008—0.012
Aluminum—0.02—0.05
Vanadium—0—0.03
Columbium—0—0.03
Tungsten—0—0.1
Phosphorus—0.05 max.
Sulfur—0.03 max.
Iron—Balance, essentially

The hot rolling step concludes with a finishing operation in which the article undergoes at least 25% hot rolling deformation. The finishing operation is conducted at a temperature above about the A_1 temperature for the steel, with the microstructure of the steel during the finishing operation comprising substantial amounts of austenite to provide an austenitic grain size at the finishing temperature no larger than 9.5 on the ASTM scale. The A_1 is that temperature above which the microstructure contains both austenite and ferrite and below which there is no austenite, under equilibrium conditions.

Following the finishing deformation, the hot rolled steel article is cooled at a rapid rate consistent with avoiding the formation of low temperature transformation products, e.g. bainite and martensite, and to provide a microstructure at room temperature consisting essentially of fine grained ferrite plus pearlite. As used herein, the term *fine grained* means a grain size no larger than 9.5 on the ASTM scale, it being noted that the higher the number on the ASTM scale the smaller the grain size.

The combination of: the above described steel composition; a deformation of at least 25% during the finishing operation; a finishing operation temperature, above about the A_1 temperature for the steel, which provides substantial amounts of austenite in the microstructure of the steel during the finishing operation; and the above described cooling step together provide a steel article having a ferrite grain size, at room temperature, of 9.5 on the ASTM scale or finer; and this steel article has a yield strength greater than 50,000 p.s.i. and a 15 foot-pound Charpy V-notch impact transition temperature no higher than -50° F.

The finishing procedure for a steel article having the higher carbon content (0.18 up to 0.26 wt. percent) may differ from that of a steel article having the lower carbon content (greater than 0.02 but less than 0.18 wt. percent). In each case, the deformation at the finishing operation is greater than 25%; but, for the lower carbon steel, the finishing temperature is high enough, e.g. above 1600° F., to assure a microstructure which is all austenite

during the final deformation; whereas, for the higher carbon steel, the finishing temperature need not be in a temperature region in which the microstructure is all austenite, but can also be at a lower temperature in a two phase region in which the microstructure is both austenite and ferrite, e.g. 1400° to 1500° F. This lower temperature is substantially below the higher carbon steel's A_3 temperature, that temperature above which the microstructure is all austenite and below which the microstructure is both austenite and ferrite, under equilibrium conditions.

With both carbon levels, the aim is to provide fine grained recrystallized austenite while avoiding complete recrystallization during the finishing operation. Fine austenite grains are desirable because the size of the ferrite grains in the finished article, at room temperature, is proportionate to the grain size of the austenite obtained during the finishing operation. Finer ferrite grains give increased strength.

Finishing in the lower temperature range, permissible with the higher carbon steel, produces higher strength because more of the defect structure produced by deformation is present in the final product than in the case when finishing with a higher temperature. There is less chance for the defect structure to be annealed out at the lower finishing temperature than at the higher. The lower the finishing temperature the better, from a strength standpoint. Of course, the finishing temperature would have to be high enough to maintain substantial austenite in the microstructure, e.g. above about 1300° F.

The maximum practical amount of deformation during the finishing operation is about 40%, but this limit is imposed by the construction of most conventional finishing mills rather than by the present invention. Finishing mills usually consist of a single mill stand capable of producing a maximum deformation of about 40%. If a finishing deformation as high as 60 to 80% is feasible, this would still be in accordance with the present invention. If a finishing mill has two or three stands, the finishing operation could be performed in a manner which gave substantially greater than 40% deformation. However, with such an arrangement, the deformation on the succeeding second and third stands of the finishing mill would have to be performed before complete recrystallization of the austenite grains existing after deformation on a preceding mill stand. In other words, all of the deformation on all of the two or three mill stands in the finishing mill should be performed without such delay between the stands as would allow the austenite to completely recrystallize. By preventing the austenite from recrystallizing, the strain obtained on succeeding stands would be cumulative and thus surpass the present limit of about 40% deformation obtainable with a single finishing stand. The greater the deformation, the greater the yield strength.

In accordance with the present invention, a steel article produced from the higher carbon steel would have an austenitic grain size, at the conclusion of the finishing operation, of 12 or finer; whereas, a steel article having a lower carbon content would have an austenitic grain size, at the conclusion of the finishing operation, of 9.5 or finer.

The yield strength of the higher carbon steel would be in the range of 70,000 to 85,000 p.s.i., while the yield strength of the lower carbon steel would be in the range of 50,000 to 70,000 p.s.i. The lesser yield strength of the lower carbon steel is attributable to the larger grain size and the lower carbon content.

The impact resistance of the higher carbon steel is slightly higher than that of the lower carbon steel, the 15 foot-pound Charpy V-notch impact transition temperature for the higher carbon steel being -100° F. or below versus -50° F. or below for the lower carbon steel.

The higher carbon steel article has a microstructure consisting essentially of ferrite plus pearlite with the

pearlite volume being in the range 30 to 50%. In the lower carbon steel, the pearlite volume is less than 30% and consists of fine, randomly distributed pearlite. As used herein, the term *fine* in connection with pearlite refers to e.g. pearlite lamellae about 0.1 micron wide spaced apart about 0.25 micron. Coarse pearlite typically would have lamellae about 0.6 micron wide spaced apart about 1.9 microns.

In the higher carbon steel, the faster the cooling rate the greater the likelihood of obtaining undesired low temperature transformation products such as martensite or bainite. In the lower carbon steel, low temperature transformation products are not a problem with relatively rapid cooling rates, and the faster the cooling rate the finer the pearlite.

For either the high carbon or low carbon steel, the cooling procedure can be conducted in still air or with a water spray or with air impingement; but more control must be exercised in connection with the water spray and air impingement methods when these procedures are used to cool the higher carbon steel.

In case the final microstructure contains some low temperature transformation products inadvertently obtained during cooling, these can be eliminated by normalizing the steel article. Normalizing comprises heating the article to an article temperature at which the microstructure of the steel is austenite, e.g. 1550° F. to 1750° F., depending upon the carbon content, and for a time sufficient to obtain temperature equalization throughout the article and a microstructure consisting entirely of austenite. Thereafter, the article is cooled at a rate as fast as possible consistent with avoiding the formation of low temperature transformation products. The lower carbon embodiment may be cooled faster than the higher carbon embodiment without adverse effects, and the higher carbon embodiment may be heated at a lower temperature within the range 1550° F. to 1750° F. A typical normalizing temperature for the higher carbon steel is in the range 1550° F. to 1700° F., and a typical normalizing temperature for the lower carbon steel is in the range 1600° F. to 1750° F.

The end product, after normalizing with either the higher or the lower carbon embodiment, is a steel article having a microstructure consisting essentially of fine grained ferrite plus pearlite.

The resulting steel article, whether it is the higher carbon or lower carbon embodiment, has relatively high yield strength, has relatively high impact resistance and is readily weldable without preheating and without controlling temperature between welding passes. With such properties, the article may be in the form of plate or pipe skelp. The higher carbon steel composition is useful for thicker plate in the range $\frac{3}{8}$ to $1\frac{1}{4}$ inches, and the lower carbon steel is useful for thinner plate in the range $\frac{3}{16}$ to $\frac{3}{8}$ inch.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom as modifications will be obvious to those skilled in the art.

We claim:

1. A steel article having a composition consisting essentially of, in wt. percent:

Carbon	0.02-0.26
Manganese	1.25-1.75
Silicon	0.75-1.5
Nitrogen	0.003-0.015
Aluminum	0.01-0.08
Vanadium	0-0.07
Columbium	0-0.03
Tungsten	0-0.1

and a balance consisting essentially of iron;

said steel article having a microstructure consisting essentially of ferrite plus pearlite, with a ferrite grain size no coarser than 9.5 on the ASTM scale;

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said steel article having a yield strength greater than 50,000 p.s.i.

2. A steel article as recited in claim 1 wherein: the carbon content is 0.18 to 0.26 wt. percent; said ferrite grain size is no coarser than 12 on the ASTM scale; and

said yield strength is greater than 70,000 p.s.i.

3. A steel article as recited in claim 2 wherein the volume of pearlite in said microstructure is in the range 30 to 50%.

4. A steel article as recited in claim 2 and having a 10 15 foot-pound Charpy V-notch impact transition temperature no higher than -50° F.

5. Steel plate as recited in claim 1 wherein: the nitrogen content is 0.008 to 0.012 wt. percent; the vanadium content is no greater than 0.03 wt. per-

cent; the columbium content is no greater than 0.03 wt. per-

cent; and the aluminum content is 0.02 to 0.05 wt. percent.

6. A steel article as recited in claim 1 wherein: the carbon content is less than 0.18 wt. percent; and

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the 15 foot-pound Charpy V-notch impact transition temperature is no higher than -50° F.

7. A steel article as recited in claim 1 wherein: the carbon content is less than 0.18 wt. percent; and the volume of pearlite in said microstructure is less than 30%;

said pearlite being relatively fine and randomly distributed.

References Cited

UNITED STATES PATENTS

2,837,421	6/1958	Kron	148—36
3,173,782	3/1965	Melloy et al.	75—123
3,207,637	9/1965	Matuschka et al.	148—36
3,438,822	4/1969	Allen	148—36

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