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Creswick et al.

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[54] **HIGH-STRENGTH LOW-ALLOY STEEL**

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[52] **U.S. Cl.** ..... **148/12 F**

[51] **Int. Cl.²** **C21D 1/02**

[58] **Field of Search** ..... 148/12 F, 36

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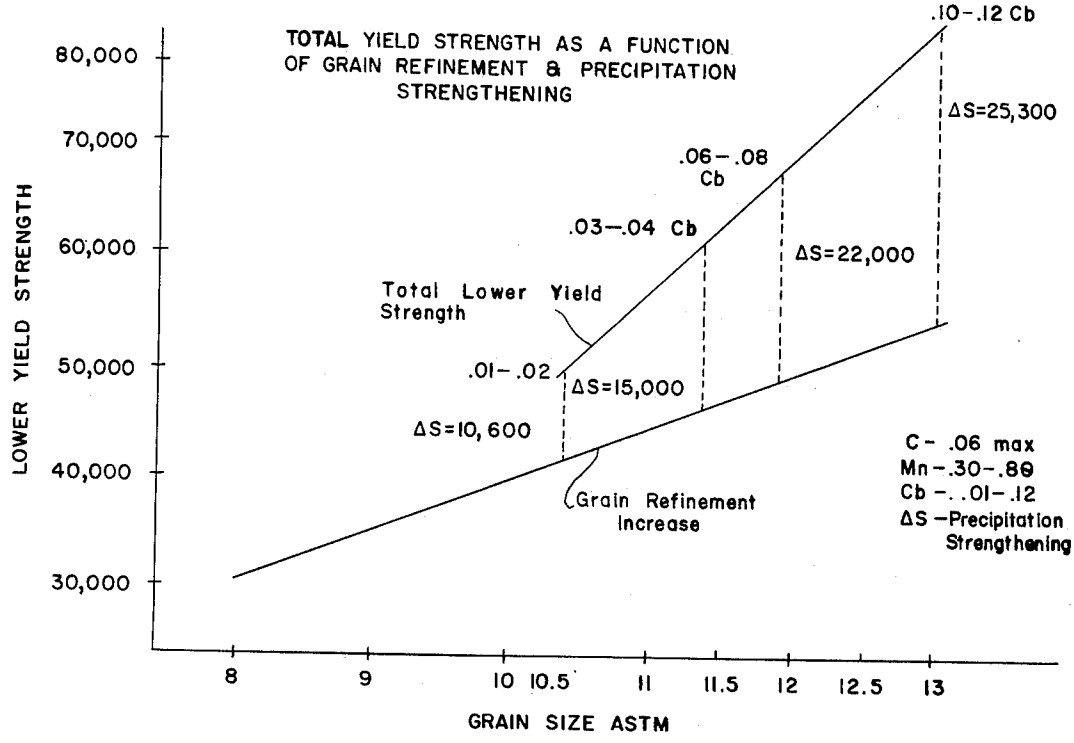
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[57] **ABSTRACT**

High strength low alloy steels having lower yield strengths in the range of from 50,000 psi to 80,000 psi and superior formability properties are disclosed.

4 Claims, 2 Drawing Figures



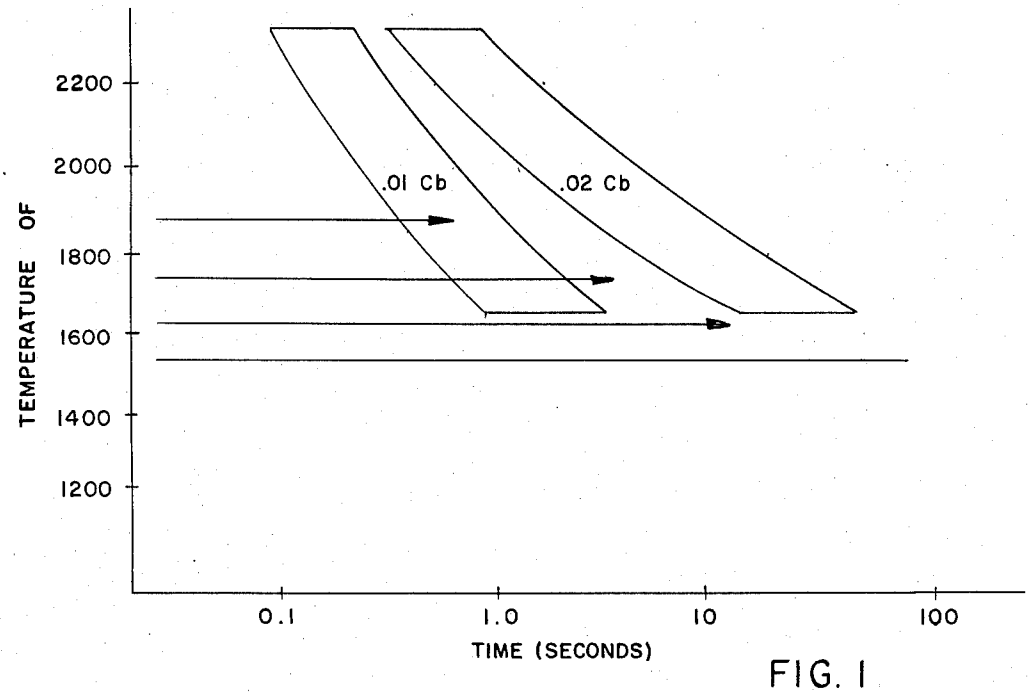

TEMPERATURE OF
2200
2000
1800
1600
1400
1200
.01 Cb
.02 Cb
0.1
1.0
10
100
TIME (SECONDS)

FIG. 1

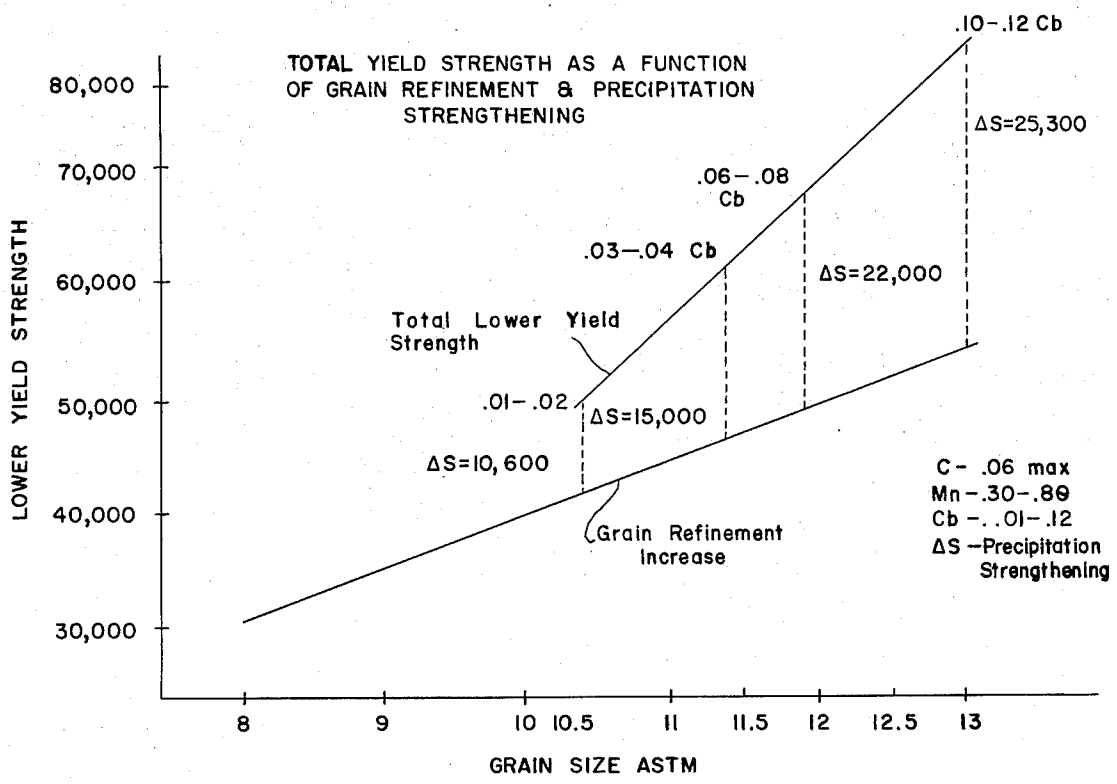

TOTAL YIELD STRENGTH AS A FUNCTION OF GRAIN REFINEMENT & PRECIPITATION STRENGTHENING
LOWER YIELD STRENGTH
80,000
70,000
60,000
50,000
40,000
30,000
.10-.12 Cb
ΔS=25,300
.06-.08 Cb
.03-.04 Cb
ΔS=22,000
Total Lower Yield Strength
.01-.02
ΔS=15,000
ΔS=10,600
Grain Refinement Increase
C- .06 max
Mn-.30-.80
Cb -..01-.12
ΔS -Precipitation Strengthening
8
9
10
10.5
11
11.5
12
12.5
13
GRAIN SIZE ASTM

FIG. 2

HIGH-STRENGTH LOW-ALLOY STEEL

The present invention relates to high strength low alloy steels and particularly to a series of high strength steels having lower yield strengths in the range of from 50,000 psi to 80,000 psi and having superior formability properties than steels presently available.

There is an ever present and increasing demand for high strength steels having good formability properties particularly drawings, biaxial stretching and uniaxial bending properties required, for example by the automotive industry for automobile bumper systems.

The process of hot strip rolling as well as the manner of controlling the temperature in such process is well known in the art thus it is not believed necessary to provide any specific details with respect to finishing or collecting stages. The present invention is concerned only with the finishing and coiling temperatures of a specific steel composition and the manner of attaining such temperature control would be an obvious expedient to one skilled in the art. According to the present invention there is provided a high strength low alloy steel strip having a minimum yield strength of 50,000 psi and good formability properties, said steel consisting essentially of, by weight, 0.10 percent maximum carbon, 0.30 to 0.80 percent manganese, 0.02 percent maximum sulphur, 0.02 to 0.06 percent aluminum, 0.01 to 0.12 percent columbium, 0.06 percent maximum cerium, the balance being iron and incidental impurities. Depending upon the composition of the steel, lower yield strengths in the range of 50,000 psi to 80,000 psi are attained. This composition when hot-rolled finished in a temperature range of 1620° to 1700°F and coiled or collected in a temperature range of 1150° to 1375°F, a unique relationship of strength and maximum formability of each of the yield strength levels in the range exists.

At each strength level, from 50,000 to 80,000 psi, the final structure of the steel is composed principally of ferrite with very limited amounts of pearlite. In conjunction with this and essential to the improved formability properties is the controlled dispersion of the columbium as columbium carbides of columbium carbo-nitrides, as will be discussed later. While pearlite is in grain boundaries and as cementite (Fe_3C) in the form of skeletal carbides, the columbium has been found to have a dual form, of row precipitates in excess of 200 Angstrom units from which the initial ferrite grains have formed and secondly, within the ferrite grain itself, as a finely dispersed carbonitride in the range of 30 to 120 Angstrom units. It may be noted in the steel composition of this invention that the level of both C and Mn is considerably lower than known steels in the same strength range which provides several major factors contributing to the improved formability properties. The low content of the steel composition of the present invention, of course, reduces the pearlite

content directly however more important the low carbon content and low manganese values act to increase the austenite to ferrite transformation temperature. It has been found that this increase or higher austenite to ferrite transformation temperature controls the proportion of the columbium that precipitates into coarse and fine dispersion in the composition and distributes the available columbium into its dual form for the purposes of grain refinement and precipitation strengthening. The coarse precipitation of columbium occurs during the hot deformation or actual rolling of the steel up to and including the final deformation, the collecting. This coarse precipitation acts to retard the recrystallization of austenite, immediately after the final deformation, until transformation to ferrite is started. Transformation from the highly deformed austenite guarantees transformation to a fixed and constant ferrite grain size. The ferrite grain size will vary according to the amount of columbium present and the temperature at which the finishing rolling is carried out. This in turn establishes the final austenite grain size prior to transformation. After transformation from the austenite to the ferrite structure, the fine precipitation from the balance of the columbium present will occur in the fully transformed ferrite. The grain size and spacing of the fine precipitate will depend on the extent of cooling (spray quenching) and the coiling or collecting temperature.

The low carbon content of the present composition as well as acting to reduce pearlite permits all of the columbium required to provide the total strengthening effect to be dissolved or to be soluble in the austenite thus assuring the maximum efficient use of the columbium.

The low carbon value together with the low manganese value of the present composition act to increase the austenite to ferrite transformation temperature whereby the proper distribution of the columbium is attained and the columbium is enabled to carry out its dual function, the coarse precipitation of columbium to provide grain refinement and the fine precipitation dispersion of columbium to provide strengthening after transformation. The increase in transformation temperature permits a higher final deformation or finishing temperature to effect grain refinement as discussed above and also permits a higher coiling temperature to effect precipitation strengthening. It is thus readily seen that the amounts of carbon and manganese present in the composition in combination with the finishing temperature and coiling temperature will permit the columbium to act effectively to provide the desired results.

I have found that for the strength level desired, a fairly precise amount of columbium content in combination with proper finishing and coiling temperatures an optimum relationship between strength and formability will be attained. The following results of test work outlines the range of these parameters;

TABLE I

Run No.	Lower Yield Point (Min) p.s.i.	C %	Mn %	Cb %	Finishing Temp. °F	Coiling Temp. °F
1	50,000	.10	.35	.01–.02	1620–1670	1350±25
2	60,000	.10	.35	.03–.04	1620–1670	1275±25
3	70,000	.10	.55	.06–.08	1650–1700	1225±25
4	80,000	.10	.75	.10–.12	1650–1700	1175±25

The prime consideration in obtaining maximum formability at each level of strength is related to the austenite to ferrite temperature which is controlled by the amount of C, Mn, Cb as well as the finishing and coiling temperatures. The temperature of coiling has been found to be most critical as such temperature establishes the final ferrite grain size and structure as well as the size and distribution of the columbium precipitate in the ferrite. The finishing temperature has also been found to be of major importance as such must be low enough to prevent recrystallization during the time span of the finish hot work to the start of ferrite transformation and must be high enough to produce the largest possible equiaxial ferrite grain size to obtain optimum formability.

Reference may be had to the drawings wherein:

FIG. 1 shows graphically the relationship between columbium content and the finishing temperature,

FIG. 2 shows graphically the relationship of strength obtained from grain refinement and precipitation strengthening.

From FIG. 1 an increase in columbium content in the composition acts to delay further recrystallization. Either a lowering of the columbium content in the composition or an increase in the finishing temperature improves the risk of recrystallization to normal austenite from which a coarse grained ferrite is transformed.

I have found that at a strength level of 50,000 psi, the optimum finishing temperature is 1620°F to 1670°F for a columbium content of 0.015 percent. When a higher finishing temperature is employed the strength of the steel drops rapidly. When a higher Mn content is present, too high a finishing temperature will require a quench rate which will produce a non-equiaxial and deformed ferrite grain. The higher finishing temperature employed will guarantee a maximum columbium precipitate in the ferrite as a percentage of the total available columbium.

The final strength of the steel product is a function of solid solution strengthening, grain size strengthening and precipitation strengthening. It may thus be readily seen that where formability is a function of a coarse grain size, and strength, to a large extent, is a function of a fine grain size, the optimum combination of strength and formability can only be attained by obtaining the maximum strengthening contribution from precipitation strengthening. In order to clarify this, the strengthening effect may be stated in equation form for example the general equation may be stated as:

L.Y.S. (ksi) = $15.0 + 4.72\,(\%Mn) + .5(D^{-1/2}) + \Delta S$

wherein L.Y.S. is lower yield strength

Mn is % manganese

$d^{-1/2}$ is the ferrite grain size intercept in inches

ΔS is the strength from precipitation strengthening

For Example 1

where Cb is .02%

Mn is .35%

$d^{-1/2}$ in $^{-1/2}$ = 50.0 (ASTM 10.5)

-continued

L.Y.S. = $15.0 + 4.72(.35) + .5(50.0) + \Delta S$

= $15.0 + 1.42 + 25 + \Delta S$

= $41.4 + \Delta S$ ksi

Where actual L.Y.S. = 52,000 psi

ΔS = 10,600 psi

and $\Delta S/.01$ Cb = 5,200 psi

Similarly the strengthening effect may be calculated for Examples 2 to 4 and are summarized in the following Table II.

TABLE II

Example No.	Average Strength Level psi	Basic Strength psi	Cb Strengthening psi	Average Cb %	Total Strengthening per .01% of Cb psi
1	52,000	30,000	22,000	.015	14,000
2	62,000	30,000	32,000	.035	9,200
3	72,000	30,000	42,000	.065	6,500
4	82,000	30,000	52,000	.100	5,200

The overall relationship of strength attained from grain refinement and precipitation strengthening is summarized in graphical form in FIG. 2. It may be noted that precipitation strengthening increases in proportion from 20 percent to 30 percent from Example No. 1 to Example No. 4. It may be further noted as shown in Table II that the total strengthening contribution of Cb through both grain size strengthening and precipitation strengthening decreases per unit of Cb as the strength increases.

In addition to the total strengthening contribution of Cb through both grain size strengthening and precipitation strengthening, the steels of the present invention also have been found to have superior formability properties at each strength level. Although there are many parameters which may be used to interpret and measure formability, two of the more significant parameters are a) the coefficient of work hardening or "n" values (stretchability) and b) the coefficient of anisotropy or "r" values (drawability). As commercially formed steel parts from hot rolled steel require both stretchability and formability a high value for both "n" and "r" is desirable. The method of determining both "n" and "r" values is well documented in the literature thus no details with respect to these determinations are deemed necessary.

In addition to the "r" and "n" values, additional parameters of the steels of the present invention were also tested, namely uniform elongation e_u under unidirectional strain and the response to biaxial stretching as measured by gridded cup samples (such test measurements being well known in the art).

In order to attain optimum formability properties or forming values in the finished product close control on certain factors during processing of the steel are necessary. Although the presence of pearlite in a steel is a fairly economical manner of obtaining both good yield point and ultimate tensile strength properties of steel it is at the same time very detrimental to attaining good forming properties. Carbon of the steel of the present invention is reduced to a low level of 0.10 percent maximum. It is maintained at this low level by the present invention by the use of the low manganese addition. The low levels of both carbon and manganese reduce the formation of pearlite and thus contribute to increasing formability properties both directly and also indirectly as control on the transformation temperature of austenite to ferrite as previously discussed.

The steel composition employed should generally be free of both exogenous and indigenous inclusions of all types. During the deoxidation stage of the metal aluminum is added to ensure an accurate level of soluble aluminum in the finished product varying from 0.02 percent to 0.06 percent aluminum. It is recognized that silicates are a major source of inclusion content which may result in deterioration of formability properties of the steel and for this reason silicon is not employed in the present invention as an alloy strengthener but is restricted as an incidental impurity, if present. The rare earth metal of the composition is added as a sulphide modifier and also acts as a general cleaning agent by reducing other oxides which may be present.

Another factor related to attaining optimum forming values resides in the development of the largest possible equiaxial ferrite grain size at each strength level desired. As previously indicated this is attained by obtaining the maximum strengthening effect from the optimum columbium precipitate both coarse and fine in the ferrite through the use of the high finishing temperature and the temperature at which coiling or collecting is effected. This is made possible through the amount of Cb and Mn employed in the steel in conjunction with the finishing and coiling temperatures. Table III illustrates the formability properties at the various strength levels and the relationship of such properties to the composition and temperatures of processing.

TABLE III

Run No.	Strength Level (Min)	Cb Content %	Finishing Temp. °F	Coiling Temp. °F	Grain Size ASTM	n	e %"	r
1	50,000	.015	1620–1670	1300 –1350	10.5–11.0	.20	22	.00
2	60,000	.035	1620–1670	1250 –1300	11.0–11.5	.18	20	.90
3	70,000	.065	1650–1700	1200 –1250	11.5–12.0	.16	17	.85
4	80,000	.095	1650–1700	1150 –1200	12.0–12.5	.14	15	.80

The finished products of the present invention were subjected to a long series of stress-life fatigue tests and results indicate that up to 2×10^6 cycles can be sustained with dynamic loads in excess of 40 percent of the ultimate tensile strengths. These results are believed to be possible because of the high working hardening components of the steels which are a function of steel cleanness.

The low carbon equivalent values of the steels of the present invention results in good weldability to both fusion and electric resistance techniques. The addition of columbium in the steels in the range outlined, which is present as the main strengthening element, has not been found harmful in the welding procedures.

In the tables above, reference is made to Run Numbers **1** through **4.** These are actual production runs made with the composition at the various levels of Cb. The strip or product was finished and coiled in the temperature ranges specified in the table to attain the strength levels of each run. It is believed that it is the combination of the elements employed in the composition with the restricted finishing and coiling temperatures used that maximum formability at each strength level is attained.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of making a high strength low alloy steel strip having a minimum yield strength of 50,000 psi and good formability properties which comprises subjecting a slab of steel having a composition consisting essentially of, by weight, 0.10 percent maximum carbon, 0.30 to 0.80 percent manganese 0.02 percent maximum sulphur, 0.02 to 0.06 percent aluminum, 0.01 to 0.02 columbium, 0.06 percent maximum cerium, the balance being iron and incidental impurities, to a hot-rolled finishing temperature in the range of 1620°to 1670°F and collecting the strip in a temperature range of 1325° to 1375°F.

2. A method of making a high strength low alloy steel strip having a minimum yield strength of 60,000 psi and good formability properties which comprises subjecting a slab of steel having a composition consisting essentially of, by weight, 0.10 percent maximum carbon, 0.30 to 0.80 percent manganese, 0.02 percent maximum sulphur, 0.02 to 0.06 percent aluminum, 0.03 to 0.04 percent columbium, 0.06 percent maximum cerium, the balance being iron and incidental impurities, to a hot-rolled finishing temperature in the range of 1620°to 1670°F and collecting the strip in a temperature range of 1250° to 1300°F.

3. A method of making a high strength low alloy steel strip having a minimum yield strength of 70,000 psi good formability properties which comprises subjecting a slab of steel having a composition consisting essentially of, by weight, 0.10 percent maximum carbon, 0.30 to 0.80 percent manganese, 0.02 percent maximum sulphur, 0.02 to 0.06 percent aluminum, 0.06 to 0.08 percent columbium, 0.06 maximum cerium, the balance being iron and incidental impurities, to a hot-rolled finishing temperature in the range of 1650°F to 1700°F and collecting the strip in a temperature range of 1200° to 1250 °F.

4. A method of making a high strength low alloy steel strip having a minimum yield strength of 80,000 psi and good formability properties which comprises subjecting a slab of steel having a composition consisting essentially of, by weight, 0.10 percent maximum carbon, 0.30 to 0.80 percent manganese, 0.02 percent maximum sulphur, 0.02 to 0.06 percent aluminum, 0.10 to 0.12 percent columbium, 0.06 percent maximum cerium, the balance being iron and incidental impurities, to a hot-rolled finishing temperature in the range of 1650°F to 1700°F and collecting the strip in a temperature range of 1150° to 1200°F.

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