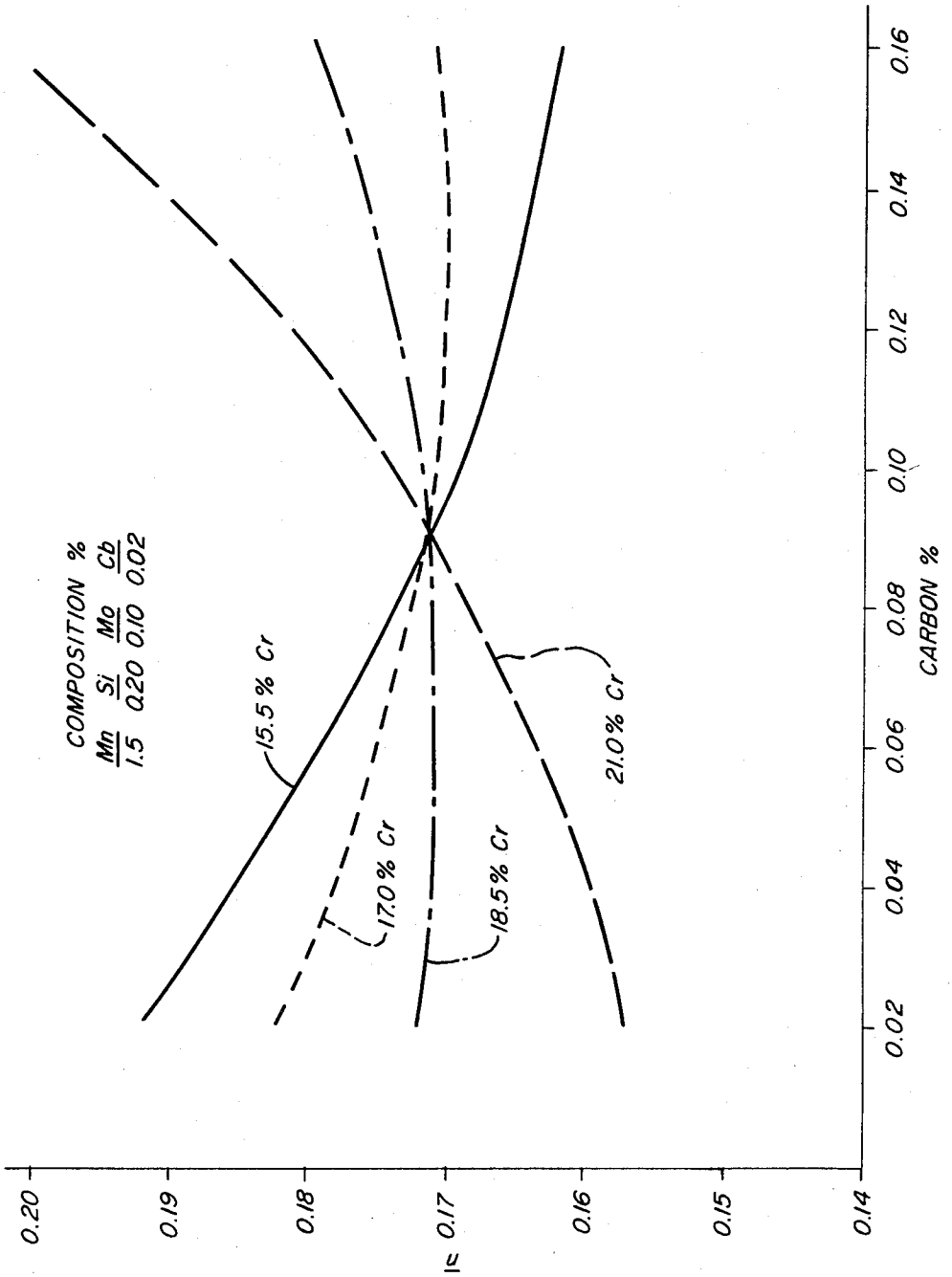
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FERRITIC STAINLESS STEELS WITH IMPROVED COLD-HEADING CHARACTERISTICS

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FERRITIC STAINLESS STEELS WITH IMPROVED COLD-HEADING CHARACTERISTICS

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ABSTRACT OF THE DISCLOSURE

A method for improving the cold-heading characteristics of ferritic stainless steels. A complex equation shows the interrelation of the various alloying elements. Within a compositional range similar to that of Type 430 steel, the cold-heading character, as represented by lowered $\bar{n}$ values, may be improved by increased amounts of Mn and Mo and decreased amounts of Si. Due to the interaction between C and Cr, it is beneficial to employ either high C in combination with low Cr or low C in combination with high Cr.

Stainless steel fasteners, such as bolts and screws, are used extensively in the building construction, chemical, and automotive industries. These fasteners are generally produced by a cold-heading (forging) operation. Materials that work harden readily are difficult to cold-head, in comparison to materials that exhibit low strain hardening rates. The strain-hardening character of a metal may be described by its strain-hardening coefficient, n, in the Ludwik equation $\sigma=K\varepsilon^n$, which closely describes the plastic portion of the true stress-true strain curves of many metals (i.e., the ferritic stainless steels). Therefore, for good cold-heading properties, low strain hardening coefficients are desired. Relatively small changes in n have a marked effect on the ease of cold-heading; thus, AISI Type 304 stainless steel, which exhibits an average n value of about 0.49, is considerably more difficult to cold-head than AISI Type 305 stainless, with an average n value of 0.45. In comparison to the austenitic stainless steels, ferritic stainless steels, such as AISI Type 430, exhibit n values of about 0.19–0.21 and are therefore easier to cold-head. However, as stainless steel fasteners become more complex with intricate configurations, and as cold-heading is conducted at higher and higher speeds, the need for ferritic stainless steels, which are even easier to cold-head, has increased.

It is therefore an object of this invention to provide annealed, ferritic stainless steel rod and wire with superior cold-heading properties.

It is another object of this invention to provide a method for tailoring the cold-heading characteristics of ferritic stainless steels for particular fastener applications.

It is a further object of this invention to provide annealed ferritic stainless steels with an average strain-hardening exponent, $\bar{n}$, no greater than 0.17.

These and other objects will be more apparent, when read in conjunction withe the appended claims and the detailed description in which:

FIG. 1 shows the interaction of carbon and chromium and their effects on $\bar{n}$ value.

Shown in Table I are the compositions of the 34 steels that were prepared as induction-furnace heats during the development of the invention. These steels can also be made by conventional practice in an electric furnace. All heats were melted under an argon cover and cast into 3-inch-thick by 8-inch-wide by 14-inch-high slab-type molds for this study. (Slab-type molds were used because it was desired to produce strip so that n values in the longitudinal, transverse and diagonal (45 degrees) directions could be determined and an average n value, $\bar{n}$, could be calculated. The average n value, n, is defined as follows:

$$\bar{n}=\frac{n0+2n45+n90}{4}$$

where 0, 45, and 90 are degrees from the rolling direction of sheet or strip.) The surfaces of each slab-type ingot were conditioned by machining. The slabs were hot rolled at 2150° F. to 0.160-inch-thick strip. The strip-finishing temperature was about 1500° F. Hot-rolled strip from each heat was given a simulated box anneal at 1450° F. for six hours and furnace cooled. The annealed strip was shot-blasted to remove scale and then cold-rolled to 0.080-inch-thick strip. The cold-rolled strip was then annealed in salt for 15 seconds at 1450° F. and air cooled. The salt-annealed 0.080-inch-thick strip was cleaned with a detergent and cold-rolled to 0.040-inch-thick strip, which was again annealed in salt for two minutes at 1450° F. and cooled. These latter annealing treatments simulated commercial continuous annealing. The processing cycle from ingot to cold-rolled and annealed strip simulated closely that which is given commercially produced AISI Type 430 stainless steel.

From the cold-rolled and annealed 0.040-inch-thick strip from each of the 34 heats, six tension-test specimen blanks were sheared. Two blanks were sheared parallel to the rolling direction (longitudinally), two blanks were sheared transverse to the rolling direction, and two blanks were sheared at 45 degrees from the rolling direction (diagonal). These blanks were then machined into test specimens, which were tension tested at room temperature and their n values determined. The $\bar{n}$ values of each steel were then calculated. The n values in the longitudinal, transverse, and diagonal directions for the steels investigated are shown in Table II. Also shown in this table are the $\bar{n}$ values for these steels.

TABLE I

[Compositions of ferritic stainless steels investigated, in percent]

Heat No.	C	Mn	Si	Cr	Mo	Cb
V9156-3	0.10	0.52	0.61	17.2	1.02	0.47
V9157-2	0.099	0.53	0.56	18.9	0.59	0.50
V9158-2	0.054	0.74	0.36	17.9	0.35	0.26
V9159-1	0.053	0.34	0.66	17.8	0.35	0.26
V9160-1	0.096	0.16	0.51	17.0	0.59	0.50
V9161-1	0.095	0.51	0.55	17.0	0.60	0.50
V9162-2	0.15	0.33	0.38	16.4	0.80	0.25
V9163-1	0.10	0.51	0.53	16.9	0.60	0.96
V9164-1	0.11	0.53	0.52	17.1	0.59	0.51
V9165-1	0.060	0.70	0.41	16.0	0.33	0.72
V9166-1	0.15	0.70	0.65	16.0	0.83	0.28
V9167-1	0.059	0.35	0.70	17.9	0.83	0.75
V9168-1	0.11	0.52	0.50	17.1	0.60	0.50
V9169-1	0.096	0.55	0.54	17.1	0.58	0.028
V9170-1	0.051	0.72	0.41	17.8	0.83	0.71
V9171-1	0.096	0.55	0.49	17.1	0.12	0.50
V9172-1	0.096	0.98	0.50	17.1	0.58	0.50
V9173-1	0.049	0.70	0.40	15.9	0.79	0.26
V9174-1	0.098	0.55	0.55	17.1	0.60	0.52
V9175-1	0.014	0.47	0.54	17.3	0.60	0.52
V9176-1	0.15	0.72	0.72	18.6	0.82	0.78
V9177-1	0.14	0.36	0.42	16.2	0.35	0.76
V1978-1	0.10	0.53	0.94	17.1	0.60	0.53
V9179-3	0.16	0.54	0.40	17.0	0.59	0.48
V9180-1	0.14	0.73	0.79	18.0	0.32	0.25
V9181-1	0.096	0.56	0.55	17.0	0.57	0.48
V9182-1	0.13	0.36	0.37	18.0	0.32	0.24
V9183-1	0.096	0.52	0.52	15.2	0.57	0.48
V9184-1	0.14	0.71	0.77	16.2	0.32	0.73
V9185-1	0.050	0.36	0.80	16.2	0.33	0.75
V9186-1	0.14	0.35	0.36	17.9	0.80	0.70
V9187-1	0.049	0.34	0.74	16.2	0.82	0.26
V9188-1	0.093	0.55	0.23	17.0	0.57	0.48
V9189-1	0.094	0.54	0.55	17.2	0.58	0.49

Note.—The above analysis reports only those elements which bear a relation to the instant invention. The various heats also contained: P—0.012–0.018; S—0.004–0.014; Ni—0.23–0.28; Cu—0.042–0.058; N—0.046–0.060.

TABLE II

[The longitudinal, diagonal, transverse, and average strain-hardening exponents of the ferritic stainless steels investigated]

Heat No.	n_0	n_{45}	n_{90}	$\bar{n}$
V9156-3	0.178	0.183	0.178	0.181
V9157-2	0.192	0.201	0.194	0.197
V9158-2	0.187	0.191	0.189	0.190
V9159-1	0.195	0.199	0.194	0.197
V9160-1	0.195	0.199	0.181	0.194
V9161-1	0.191	0.195	0.178	0.190
V9162-2	0.179	0.181	0.180	0.180
V9163-1	0.195	0.180	0.189	0.186
V9164-1	0.189	0.184	0.178	0.184
V9165-1	0.200	0 202	0 205	0.202
V9166-1	0.181	0.184	0.176	0.181
V9167-1	0.199	0.192	0.187	0.193
V9168-1	0.191	0.187	0.189	0.189
V9169-1	0.177	0.193	0.165	0.182
V9170-1	0.184	0.179	0.166	0.177
V9171-1	0.197	0.194	0.198	0.196
V9172-1	0.184	0.191	0.184	0.188
V9173-1	0.197	0.182	0.190	0.188
V9174-1	0.195	0.188	0.198	0.192
V9175-1	0.197	0.208	0.210	0.206
V9176-1	0.193	0.190	0.189	0.191
V9177-1	0.197	0.197	0.189	0.195
V9178-1	0.200	0.201	0.193	0.199
V9179-3	0.187	0.182	0.190	0.185
V9180-1	0.223	0.185	0.182	0.194
V9181-1	0.194	0.196	0.184	0.193
V9182-1	0.194	0.187	0.220	0.197
V9183-1	0.185	0.192	0.175	0.186
V9184-1	0.191	0.196	0.187	0.193
V9185-1	0.213	0.215	0.207	0.213
V9186-1	0.194	0.201	0.189	0.196
V9187-1	0.200	0.201	0.194	0.199
V9188-1	0.196	0.194	0.191	0.194
V9189-1	0.203	0.209	0.198	0.205

Analysis of the $\bar{n}$ values in Table II indicated that a relation existed between $\bar{n}$ and the compositions of the steels investigated. It was found that the relation could be expressed by the following equation:

$$\bar{n}=0.192-0.062(\%C)-0.016(\%Mn)+0.014(\%Si)$$
$$+0.0005(\%Cr)-0.021(\%Mo)+1.12(\%C-0.097)^2$$
$$+0.089(\%C-0.097)(\%Cr-17.05)$$

Inspection of this equation indicates the complexity of the problem of attempting to tailor the cold-heading properties ($\bar{n}$) of ferritic stainless steels. The quadratic effect of carbon and the interaction between carbon and chromium further complicate the problem. Although Cb also has a pronounced quadratic effect on $\bar{n}$, if present in an appreciable degree, it was found that the equation could be somewhat simplified for the normal range of Cb as an incidental steelmaking impurity, e.g., 0.01 to 0.04%. However, with the aid of this equation, certain compositions, within the broad range below, can be produced to exhibit unexpectedly improved cold-heading characteristics, as represented by $\bar{n}$ values less than 0.17.

The effects of each of the elements, within the range (in weight percent)

C	trace to 0.15%.
Mn	trace to 2.5%.
Si	trace to 2.0%.
Cr	14 to 21%.
Mo	trace to 2.0%.

is discussed below.

The consequence of the carbon-chromium interaction on $\bar{n}$ is shown in FIG. 1, at four different levels of chromium. When carbon is substantially below 0.09%, an increase in the chromium content will lower the $\bar{n}$ value of the steel, whereas when carbon is substantially above 0.09 percent, an increase in chromium will be deleterious to cold-heading properties. Thus, carbon and chromium may be employed inversely to each other to provide two different compositions, both of which exhibit desirably low $\bar{n}$ values, one with high chromium and low carbon and the other with low chromium and high carbon.

Perusal of the $\bar{n}$ equation, shows that molybdenum and manganese are both beneficial with respect to cold-heading characteristics. In a steel in which molybdenum is only present as an incidental residual impurity (e.g., about 0.1 percent), at least about 1.4% Mn should be employed to insure a desirably low $\bar{n}$ value. However, since Mn has a marked effect on strengthening of the ferrite phase, which in turn will be deleterious to cold headability, no more than about 2.5% Mn should be employed. Silicon, on the other hand, is detrimental to low $\bar{n}$ values and should generally be limited to a maximum of 0.2 percent.

If molybdenum is employed as a purposeful alloy addition, then a somewhat lower amount of manganese and higher limit of silicon can be tolerated. However, unless molybdenum is employed for its known effects (i.e., to impart resistance to pitting corrosion) it will be more economical to achieve low $\bar{n}$ values by employing manganese near the higher end of the range and silicon at the lower end.

Therefore, ferritic stainless steels with enhanced cold-heading characteristics, as represented by $\bar{n}$ values less than about 0.17 may be obtained in compositions comprising, in weight percent,

Composition 1

C	under 0.09.
Cr	19.0 to 21.0.
Mn	1.5 to 2.5.
Si	0.20 max.
Mo	0.5 to 2.0 (optional).

balance Fe and incidental residual impurities, or

Composition 2

C	greater than 0.09.
Cr	14.0 to 17.0.
Mn	1.5 to 2.5.
Si	0.20 max.
Mo	0.5 to 2.0 (optional).

balance Fe and incidental residual impurities.

Thus, if in the design of ferritic stainless steel fasteners, cost factors were of primary concern, one would look to composition 2 for production of the fastener rod, wire or other stock material, and in which composition molybdenum is only present as an incidental steelmaking impurity. Carbon would then be employed at the high end of the range and chromium at the low end of the range. On the other hand, if corrosion resistance were of primary concern, then composition 1 would be employed, with high chromium, high molybdenum, and low carbon.

I claim:

1. A method for enhancing the cold-heading characteristics of ferritic steels of the type consisting of

C	trace to 0.15%.
Mn	trace to 2.5%.
Si	trace to 2.0%.
Cr	14.0 to 21.0%.
Mo	trace to 2.0%.

balance Fe and incidental residual impurities which comprises combining the aforesaid elements in proportions in accord with the equation

$$\bar{n}=0.192-0.062(\%C)-0.016(\%Mn)+0.014(\%Si)$$
$$+0.0005(\%Cr)-0.021(\%Mo)+1.12(\%C-0.097)^2$$
$$+0.089(\%C-0.097)(\%Cr-17.05)$$

so as to achieve a value of $\bar{n}$ equal to or less than 0.17.

2. The method of claim 1 wherein molybdenum is only present in normal residual amounts and in which a low $\bar{n}$ value is achieved at low cost by employing substantially greater than 0.09% carbon in conjunction with from about 14.0 to about 17.0% chromium.

3. The method of claim 2 wherein the $\bar{n}$ is further decreased by employing more than about 1.5% Mn.

4. The method of claim 3 which comprises employing less than about 0.2% Si.

5. The method of claim 1 wherein the corrosion resistance is enhanced while achieving a low $\bar{n}$ value, which comprises employing from about 19.0 to about 21.0% Cr in conjunction with substantially less than 0.09% carbon.

6. The method of claim 5 wherein about 1.5 to 2.5% Mn is employed to further enhance the cold-heading characteristics of the steel.

7. The method of claim 6 which comprises employing less than about 0.2% Si.

8. The method of claim 7 wherein said $\bar{n}$ value is further decreased and said corrosion resistance is further increased by employing from about 0.5 to about 2.0% Mo.

9. A method for producing ferritic stainless steel fasteners which comprises combining alloying elements within the range, by weight percent

C	trace to 0.15%.
Mn	trace to 2.5%.
Si	trace to 2.0%.
Cr	14.0 to 21.0%.
Mo	trace to 2.0%.

balance Fe and incidental residual impurities to produce an alloy in amounts and proportions which satisfy the equation

$$-0.022 \geq -.062(\%C) - 0.016(\%Mn) + 0.014(\%Si)$$
$$+0.0005(\%Cr) - 0.021(\%Mo) + 1.12(\%C - 0.097)^2$$
$$+0.089(\%C - 0.097)(\%Cr - 17.05)$$

thereafter, drawing a wire from said alloy, and cold-heading said wire.

10. A fastener stock article having improved cold-heading characteristics as represented by an $\bar{n}$ value equal to or less than 0.17 comprising a ferritic stainless steel consisting of, by weight percent

C	trace to 0.15%.
Mn	trace to 2.5%.
Si	trace to 2.0%.
Cr	14.0 to 21.0%.
Mo	trace to 2.0%.

balance Fe and incidental residual impurities in which the aforesaid elements are combined in proportions which satisfy the equation

$$-0.022 \geq -0.062(\%C) - 0.016(\%Mn) + 0.014(\%Si)$$
$$+0.005(\%Cr) - 0.021(\%Mo) + 1.12(\%C - 0.097)^2$$
$$+0.089(\%C - 0.097)(\%Cr - 17.05)$$

11. The steel article of claim 10 consisting of

C	substantially greater than 0.09%.
Mn	1.5 to 2.5%.
Si	trace to 0.2%.
Cr	14.0 to 17.0%.

balance Fe and incidental residual impurities.

12. The steel article of claim 11 consisting of

C	substantially less than 0.09%.
Mn	1.5 to 2.5%.
Si	trace to 0.2%.
Cr	19.0 to 21.0%.

13. The steel article of claim 12 additionally containing from about 0.5 to 2.0% Mo.

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