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S. EPSTEIN ET AL

3,076,361

ROLLING STEEL IN FERRITIC STATE

Filed May 12, 1960

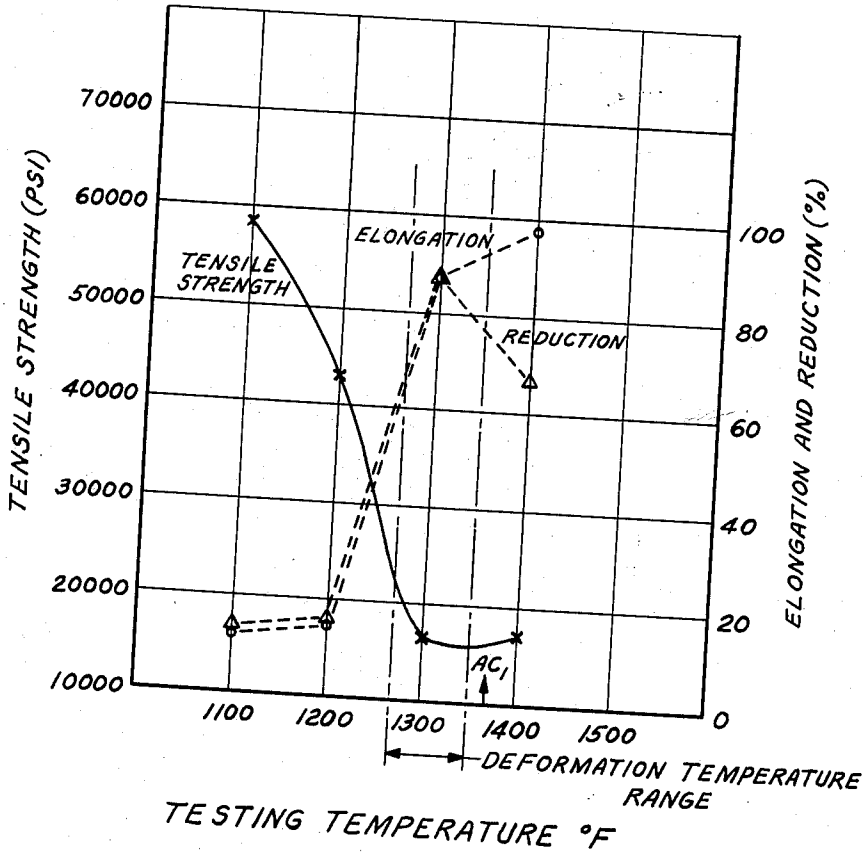
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FIG. 1

HIGH TEMPERATURE TENSILE TEST

10-120 GRADE

C	Mn	P	S	Si
1.18	.41	.019	.018	.14



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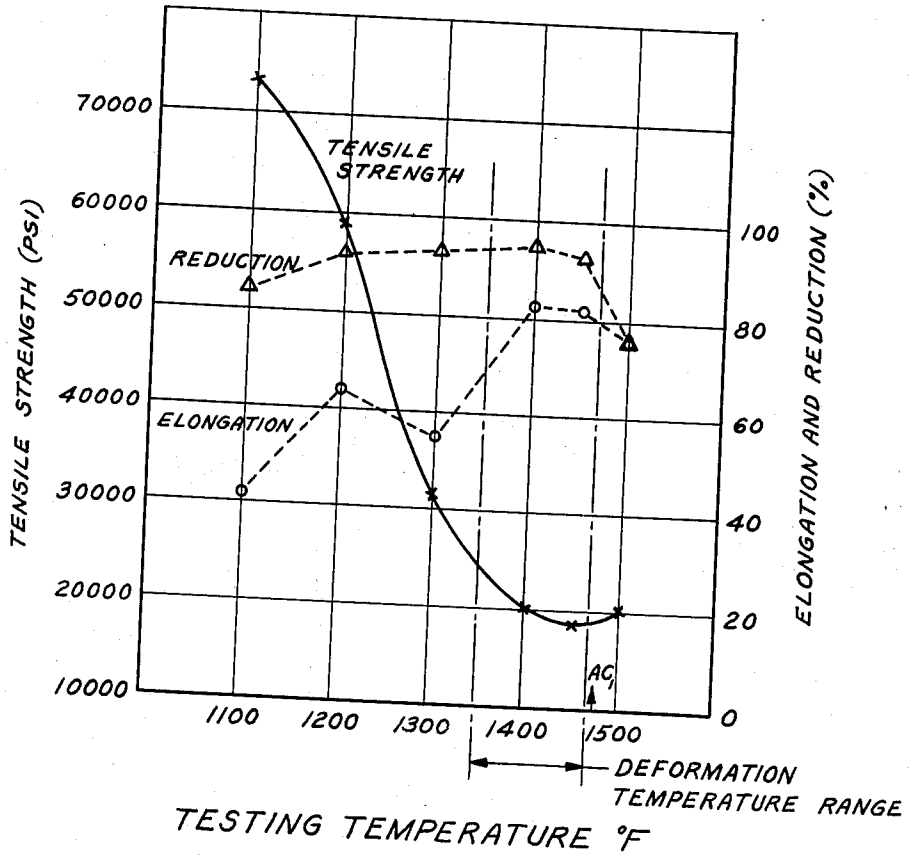
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FIG. 2

HIGH TEMPERATURE TENSILE TEST

NITRIDING 135 MODIFIED GRADE

C	Mn	P	S	Si	Cr	Mo	Al
.42	.63	.026	.026	.32	1.57	.34	1.10



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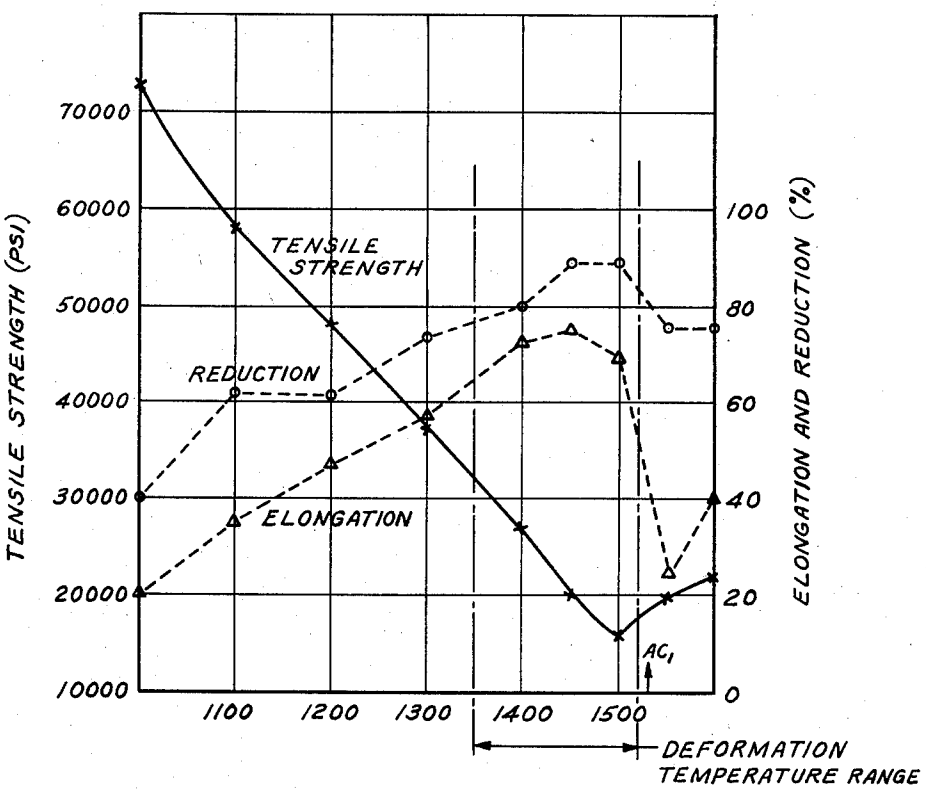
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FIG. 3

HIGH TEMPERATURE TENSILE TEST

66 HIGH SPEED GRADE

C	Cr	Mo	W	V
.83	3.97	4.73	6.37	1.88



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ROLLING STEEL IN FERRITIC STATE

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Filed May 12, 1960, Ser. No. 28,808
19 Claims. (Cl. 80—60)

This application is a continuation-in-part of application Serial No. 799,269, filed March 13, 1959, and now abandoned.

This invention relates to a method of hot rolling ferritic steels at temperatures below the lower critical point, on heating, of such steels.

In the normal hot rolling of ferritic steels the steels are heated several hundred degrees above their upper critical temperatures, at which temperatures the steel is quite soft and ductile and readily rolled. However, at these high normal hot rolling temperatures the steel is subject to appreciable decarburization and scaling which are very serious surface defects. These greatly detract from the quality of the finished product, especially where high surface hardness is necessary as in tool steel. In nitriding steel, for example, decarburization causes the nitrided layer to be weak and brittle. Decarburization and scaling may add materially to the cost of grinding the steel and otherwise preparing the surface of the product for its use in service.

Decarburization is highly undesirable and it therefore is necessary to remove the decarburized surface by grinding, or to restore carbon by a recarburization treatment—both processes being expensive and undesirable.

Furthermore, after normal high temperature rolling such steels usually must be cooled slowly from the rolling temperature to avoid excessive hardening, high residual stresses, cooling cracks, etc., and thereafter must normally be annealed or otherwise heat treated in order to attain the desired metallurgical and mechanical properties. Such heat treatment also causes decarburization and scaling.

Furthermore, with normal high temperature rolling it is difficult to attain an excellent surface finish.

It is therefore a broad object of this invention to provide a process for rolling steels which avoids the dangers of decarburization and scaling, etc. as mentioned above, and produces a rolled product of excellent surface finish and desired metallurgical and mechanical properties.

In the practice of our process we subject a billet of steel produced by conventional means to the following treatment:

(1) The billet is first given the heat treatment necessary to produce the properties desired in the finished bar. In normal prior hot rolling practice this heat treatment would be given to the bars after rolling, because the effects of any treatment given to the billet would be lost in the hot rolling. Such heat treatments may consist of annealing, normalizing, spherodize annealing, quenching and tempering, or other treatment processing designed to produce a product having specified physical properties.

(2) The billet is then treated by conventional methods to remove scale and decarburization. Such methods include chipping, scarfing, turning, grinding and/or pickling.

(3) The billet is then heated to a temperature not higher than the lower critical temperature, on heating, of the steel (the A_{c1} temperature) and not lower than 200° F. below the A_{c1} temperature, and rolled to finished size while maintaining the temperature of the steel within said range. We prefer to roll at a temperature as close to the A_{c1} temperature as possible, preferably not more than 50° to 100° F. below the A_{c1} temperature. The temperature range will vary for different steels and should be above

that at which any substantial work hardening takes place during rolling.

Bars rolled by conventional hot rolling methods must frequently be slow cooled or subjected to various thermal treatments to avoid defects such as cooling cracks, thermal ruptures, etc., associated with rapid cooling from the rolling temperature. Such treatments are unnecessary with bars produced by our method as above described.

We find that bars produced from billets in accordance with our process have excellent surface finish. The bars are substantially free from decarburization and scale and therefore do not require corrective surface treatment. Bars rolled by our method retain the metallurgical and mechanical properties of the billets from which they are formed.

FIGS. 1, 2 and 3 are graphs of high temperature tensile tests, showing tensile strength, elongation, and reduction of area at various temperatures of a 10–120 grade tool steel, of a nitriding steel, and of a high speed steel, respectively. In these graphs it is evident that the tensile strength decreases precipitately as the test temperature is raised above about 1100° F. At the same time the elongation and reduction of area increase rapidly so that the steel becomes quite soft, ductile, and plastic while it is still in the ferritic condition.

In fact, the tensile strength and the plasticity of the steel at the upper temperatures at which the steel is still ferritic approximate that of steel heated to the normal hot-rolling temperatures several hundred degrees above the upper critical temperature of the steel.

The graphs of FIGS. 1, 2 and 3 also indicate that upon heating to a temperature somewhat above the lower critical temperature on heating (the temperature A_{c1} in the graphs) the tensile strength rises and the ductility falls. This is because the austenitic condition of the steel in these temperature ranges has somewhat higher strength and lower ductility than the steel has in the upper temperatures at which it is still ferritic. Accordingly it is essential when rolling in accordance with our invention not to heat the steel above the A_{c1} critical temperature.

The temperature range below the A_{c1} temperature, within which we roll will vary with different steels. The data in the graphs of FIGS. 1, 2 and 3 indicate that the tool steel illustrated, containing carbon 1.18%, manganese .41%, phosphorus .019%, sulphur .018%, silicon .14%, has properties making it suitable for hot-rolling within an approximate temperature range of about 1380° F. to 1270° F.; that the nitriding steel illustrated, containing carbon .42%, manganese .63%, phosphorus .026%, sulphur .026%, silicon .32%, chromium 1.57%, molybdenum .34%, and aluminum 1.10% has properties making it suitable for hot-rolling within an approximate temperature range of about 1470° F. to 1350° F.; that the high speed steel illustrated, containing carbon .83%, chromium 3.97%, molybdenum 4.73%, tungsten 6.37%, and vanadium 1.88% has properties making it suitable for hot rolling within an approximate temperature range of about 1520° F. to 1350° F. These temperature ranges have been indicated by the vertical dot-dash broken lines in the graphs. In some cases it may be necessary to restrict the range of rolling temperatures still further in order to avoid exceeding the annealed hardness. For instance, if it is desired to retain the original annealed hardness of high speed steels such as shown in FIG. 3 a rolling range going no lower than 100° F. below the A_{c1} temperature is necessary.

Generally speaking, the rolling temperature should be as close to the A_{c1} temperature as possible, and above the temperature at which the tensile strength begins to rise steeply and the ductility begins to fall rapidly with small

decreases in temperature, as shown in the drawings. Rolling at temperatures below this lower limit may result in breaks, corner and surface tears, and excessive hardening. Although the temperature ranges appear to be narrow, in practice the heat gained in deforming the steel in the various roll passes offsets to a large extent the normal heat losses, making it quite feasible to keep the steel in the desired temperature range. No reheating is necessary. We have found that the lower limit for successful rolling lies approximately 200° F. below the lower critical temperature, on heating, of the steel being rolled. However, it is preferable to maintain the steel at a temperature not more than 50 to 100° below the A_{c1} temperature. It should be pointed out that each type of steel and even specific analyses of steel within such types, have ideal lower limits of temperature above which rolling will be most successful.

Among the various steels which have been investigated and which exhibit a similar temperature range for hot-rolling in the ferritic state are those steels which fall within the following ranges of composition:

Carbon Tool Steel

C, percent	Mn, percent	Si, percent	Cr, percent	Al, percent	Mo, percent	V, percent	W, percent
1.15/1.50	.20/.45	.10/.20	----------	----------	----------	----------	----------
Ball Bearing Steel							
.95/1.10	.25/.45	.20/.35	1.20/1.50	----------	----------	----------	----------
Nitriding Steel							
.38/.45	.40/.70	.20/.40	1.40/1.80	.85/1.20	.30/.45	----------	----------
High Speed Steels							
.79/.86 .73/.83	.35 max. .40 max.	.40 max. .40 max.	3.9/4.4 3.6/4.1	---------- ----------	4.75/5.25 8.0/9.0	1.75/2.05 .9/1.2	6.0/6.75 1.4/18.
Automotive Axle Steel							
.32/.38	.70/1.00	.15/.30	----------	----------	----------	----------	----------
Free Machining Steel							
						P	S
.13 max.	.70/1.00	----------	----------	----------	----------	.07-.12	.16-.23

It is here pointed out, however, that these steels are only a few examples of non-austenitic steels which can be advantageously rolled by the process of our invention. The invention is applicable to all steels which are normally non-austenitic.

For example, a nitriding steel having a lower critical temperature, on heating, of 1440° F. was rolled between 1420° F. starting temperature and 1400° F. finishing temperature without substantial work hardening; and a C1018 carbon steel having a lower critical temperature of 1370° F. was rolled in a temperature range of 1370° F. to 1350° F. without substantial work hardening.

To give a typical example of our procedure the following nitriding steel was rolled according to the invention.

C, percent	Mn, percent	P, percent	S, percent	Si, percent	Cr, percent	Mo, percent	Al, percent
.38	.60	.015	.007	.28	1.56	.37	1.17

It was desired to produce 1¼" round bars having a maximum Brinell hardness of 207. For this example 2½" diameter round billets which had been rolled from the ingot by normal hot-rolling at temperatures several hundred degrees above the upper critical temperature, on heating, were selected. These billets were first annealed to a hardness of 192–197 Brinell. All decarburization and scaling was then removed from the surface of the billets by grinding.

The billets were then heated to 1440° F., about 35° below the lower critical, and rolled into 1¼" round bars. The rolling was carried out within a temperature range of 1420° F. to 1450° F. The bars were free of decarburization and had an excellent surface. Their Brinell hardness was 201/207, so that the increase in hardness during rolling was minor.

To give another typical example, the following carbon tool steel was hot rolled into billets:

C, percent	Mn, percent	P, percent	S, percent	Si, percent
1.05	.29	.013	.011	.18

It was desired to produce bars having a maximum Brinell hardness of 187. These billets were normalized at 1600° F. and spheroidized at a temperature of 1420° F. to a hardness of 170 Brinell, and the surface defects removed by grinding. The billets were then heated to 1300° F. and rolled into bars at this temperature, which is approximately 55° F. below the lower critical temperature, on heating, for this steel. The final hardness of the rolled bars was 163–170 Brinell.

We have found that sections difficult to roll, such as sharp cornered squares, can be rolled by our process.

In ordinary hot rolling, breaks and tears are more apt to form in higher carbon and highly alloyed steels, and this may also occasionally be true in our low temperature "warm" rolling process. But just as breaks and tears can be avoided during ordinary hot rolling of these more sensitive higher carbon highly alloyed steels by paying special attention to proper grinding and annealing of the billets before rolling and by normal adjustments of the roll passes, so also, breaks and tears in the more sensitive steels can be avoided in the same way in our "warm" rolling process.

When conditioning billets prior to "warm" rolling by scarfing and pickling, light scabs may show on the bars after rolling, but when the conditioning is done by chipping instead of scarfing, and then pickling, no such scabs appear and a very good surface is obtained—much bet-

ter than the surface obtained by ordinary hot rolling at temperatures high above the upper critical.

As has been stated, the surface of the "warm" rolled steel is especially good. The surface is of good enough quality to permit the use of such "warm" rolled product in automatic cutting machines without cleaning the "warm" rolled steel, cold drawing it, machining it, or the like, preparatory to feeding it into the automatic cutting machine.

It will be clearly apparent from the foregoing description that our novel low temperature process as defined in the claims will have many advantages over the prior art rolling processes which take place at much higher temperatures in the austenitic state, e.g., we have discovered the following advantages:

(1) Substantially no decarburization occurs on the rolled bars. Accordingly, subsequent treatment of the bars to remove decarburization or to restore carbon is unnecessary.

(2) Formation of scale is substantially avoided thereby eliminating the need for removing the scale.

(3) Superior surface finish.

(4) Better sizing.

(5) Slow cooling after rolling into bars is not required.

(6) The rolled bars retain the metallurgical and mechanical properties of the billets from which they are formed.

While we have thus described our invention in considerable detail we do not wish to be limited narrowly to the exact and specific particulars disclosed, but we may also use such substitutes, modifications, or equivalents as are included within the scope and spirit of the invention or pointed out in the appended claims.

We claim:

1. The method of producing rolled shapes of non-austenitic steel comprising normalizing a billet, spheriodizing said billet, removing scale and decarburization from said billet, heating the said billet to a temperature within a range not higher than the lower critical temperature, on heating, of said steel and not lower than 100° F. below said critical temperature, and rolling said steel while within said temperature range.

2. The method of producing rolled shapes of non-austenitic steel comprising normalizing a billet, spheroidizing said billet, removing scale and decarburization from said billet, heating the said billet to a temperature within a range not higher than the lower critical temperature, on heating, of said steel and not lower than 200° F. below said critical temperature, and rolling said steel while within said temperature range.

3. The method of producing rolled shapes of non-austenitic steel comprising spheroidizing a billet, removing scale and decarburization from said billet, heating the said billet to a temperature within a range not higher than the lower critical temperature, on heating, of said steel and not lower than 100° F. below said critical temperature, and rolling said steel while within said temperature range.

4. The method of producing a rolled shape of non-austenitic steel comprising heat treating a billet to produce therein the metallurgical and mechanical properties desired in the rolled shape, removing scale and decarburization from said billet, heating the said billet to a temperature within a range not higher than the lower critical temperature, on heating, of said steel and not lower than 100° F. below said critical temperature, and rolling said steel while within said temperature range.

5. A process for the rolling of a steel billet containing C .38–45%, Mn .40–.70%, Si .20–.40%, Cr 1.40–1.80%, Al .85–1.20%, Mo .30–.45%, balance essentially iron, comprising heat treating a billet of said steel to below a desired maximum hardness, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet will remain ferritic and having as the lower limit thereof, a temperature of approximately 200° F. below the lower critical temperature, on heating, of said steel billet, and rolling said steel billet while within said temperature range and while maintaining said hardness below said desired maximum hardness.

6. A process for the rolling of a steel billet containing C .95–1.10%, Mn .25–45%, Si .20–35%, Cr 1.20–1.50%, balance essentially iron, comprising heat treating a billet of said steel to below a desired maximum hardness, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet is still ferritic and having as the lower limit thereof, a temperature of approximately 200° F. below the lower critical temperature, on heating, of said steel billet, and rolling said steel billet while within said temperature range, and while maintaining said hardness below said desired maximum hardness.

7. A process for the rolling of a steel billet containing C .79–86%, Mn 35% max., Si .40% max., Cr 3.90–4.40%, Mo 4.75–5.25%, V 1.75–2.05%, W 6.0–6.75%, balance essentially iron, comprising heat treating a billet of said steel to produce therein the metallurgical and mechanical properties desired in the rolled shape, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet will remain ferritic and having as the lower limit thereof, a temperature of approximately 100° F. below the lower critical temperature, on heating, of said steel billet, and rolling said steel billet while within said temperature range, and while maintaining said properties.

8. A process for the rolling of a steel billet containing C .73–.83%, Mn .40% max., Si .40% max., Cr 3.60–4.10%, Mo 8.00–9.00%, V .90–1.20%, W 1.40–1.80%, balance essentially iron, comprising heat treating a billet of said steel to produce therein the metallurgical and mechanical properties desired in the rolled shape, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet will remain ferritic and having as the lower limit thereof, a temperature of approximately 100° F. below the critical temperature, on heating, of said steel billet, and rolling said steel billet while within said temperature range, and while maintaining said properties.

9. A process for the rolling of a steel billet containing C 1.15–1.50%, Mn .20–.45%, Si .10–.20%, balance essentially iron, comprising heat treating a billet of said steel to produce therein the metallurgical and mechanical properties desired in the rolled shape, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet will remain wholly ferritic and having as the lower limit thereof, a temperature of approximately 200° F. below the critical temperature, on heating, of the said steel billet, and rolling said steel billet while within said temperature range and while maintaining said properties.

10. Method of producing rolled shapes of non-austenitic steel having close dimensional tolerances, free from decarburization and scale, and of specified maximum hardness, comprising heat treating a billet of said steel to a hardness not greater than said specified maximum hardness, removing any decarburized and scaled areas from the surface of the billet, heating the billet to a temperature within a range not higher than the lower critical temperature, on heating, of said steel and not lower than approximately 200° F. below said critical temperature, and rolling the billet to finished form while maintaining the temperature of the steel within said range.

11. A process for the hot-rolling of a non-austenitic steel billet while in the ferritic state, comprising removing decarburization and scale from said steel billet, heating said steel billet to the upper range of temperatures at which the steel is still ferritic, said range having as a lower limit thereof, a temperature of approximately 100° F. below the critical temperature, on heating, of

said steel billet, and rolling said steel billet within said range.

12. A process for the hot rolling of a non-austenitic steel billet while in the ferritic state, comprising removing decarburization and scale from said steel billet, heating said steel billet to the upper range of temperatures at which the steel is still ferritic, said range having as a lower limit thereof a temperature of approximately 200° F. below the lower critical temperature, on heating, of said steel billet, and rolling said steel billet while within said temperature range.

13. A process for the rolling of a steel billet containing C .38–.45%, Mn .40–.70%, Si .20–.40%, Cr 1.40–1.80%, Al .85–1.20%, Mo .30–.45%, balance essentially iron, comprising removing decarburization and scale from said steel billet, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet will remain ferritic and having as the lower limit thereof, a temperature of approximately 200° F. below the lower critical temperature, on heating, of said steel billet, and rolling said steel billet while within said temperature range.

14. A process for the rolling of a steel billet containing C .95–1.10%, Mn .25–.45%, Si .20–.35%, Cr 1.20–1.50%, balance essentially iron, comprising removing decarburization and scale from said billet, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet is still ferritic and having as the lower limit thereof, a temperature of approximately 200° F. below the lower critical temperature, on heating, of said steel billet, and rolling said steel billet while within said temperature range.

15. A process for the rolling of a steel billet containing C .79–.86%, Mn .35% max., Si .40% max., Cr 3.90–4.40%, Mo 4.75–5.25%, V 1.75–2.05%, W 6.0–6.75%, balance essentially iron, comprising removing decarburization and scale from said billet, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet will remain ferritic and having as the lower limit thereof, a temperature of approximately 100° F. below the lower critical temperature, on heating, of said steel billet, and rolling said steel billet while within said temperature range.

16. A process for the rolling of a steel billet containing C .73–.83%, Mn .40% max., Si .40% max., Cr 3.60–4.10%, Mo 8.00–9.00%, V .90–1.20%, W 1.40–1.80%, balance essentially iron, comprising removing decarburization and scale from said billet, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet will remain ferritic and having as the lower limit thereof, a temperature of approximately 100° F. below the critical temperature, on heating, of said steel billet, and rolling said steel billet while within said temperature range.

17. A process for the rolling of a steel billet containing C 1.15–1.50%, Mn .20–.45%, Si .10–.20%, balance essentially iron, comprising removing decarburization and scale from said billet, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet will remain wholly ferritic and having as the lower limit thereof, a temperature of approximately 200° F. below the critical temperature, on heating, of the said steel billet, and rolling said steel billet while within said temperature range.

18. The method of producing rolled shapes of non-austenitic steel comprising heat treating a billet of said steel to produce therein the metallurgical and mechanical properties desired in the rolled shape, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet will remain ferritic and having as the lower limit thereof, a temperature of approximately 100° F. below the critical temperature, on heating, of said steel billet, and rolling said steel billet while within said temperature range, and while maintaining said properties.

19. The method of producing rolled shapes of non-austenitic steel comprising heat treating a billet of said steel to produce therein the metallurgical and mechanical properties desired in the rolled shape, heating said steel billet to within a temperature range having as the upper limit thereof, the highest temperature at which said steel billet will remain wholly ferritic and having as the lower limit thereof, a temperature of approximately 200° F. below the critical temperature, on heating, of the said steel billet, and rolling said steel billet while within said temperature range and while maintaining said properties.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,076,361 February 5, 1963

Samuel Epstein et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Columns 3 and 4, in the table, under the heading "High Speed Steels, and under the column heading "W, percent" for "1.4/18." read -- 1.4/1.8 --; column 5, line 68, for ".38-45%" read -- .38-.45% --; column 6, line 6, for ".25-45%" read -- .25-.45% --; same line for ".20-35%" read -- .20-.35% --; same column, line 18, for ".79-86%" read -- .79-.86% --; same line, for "35% max." read -- .35% max. --.

Signed and sealed this 3rd day of September 1963.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents