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COLD-FINISHED STEELS AND METHOD FOR MANUFACTURING SAME

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This invention relates to a new and improved metallurgical process for improving physical and mechanical properties of steel, and it relates more particularly to a process capable of use in the cold-finishing of steel to improve physical and mechanical properties of the steel.

This invention constitutes a modification over the processes described in the copending applications Serial No. 518,411, Serial No. 518,412, Serial No. 518,413, and Serial No. 518,414, filed June 27, 1955, now Patents No. 2,767,837, No. 2,767,835, No. 2,767,836 and No. 2,767,838, respectively.

It is an object of this invention to produce and to provide a method for producing steel products having improved mechanical and physical properties.

Another object of this invention is to provide a method which has application in the cold-finishing of steels wherein the properties and characteristics of the steels are materially changed to increase the uniformity of properties and characteristics of steels of corresponding chemistry from heat to heat, to expand the range of physical and mechanical properties capable of being developed in the steels, to modify the combinations of physical and mechanical properties in steel thereby to produce steels capable of use in specific applications, and to produce steel products having new and improved characteristics and physical and mechanical properties of greater value.

In the aforementioned copending applications, the inventive concepts reside in a method for the improvement of physical and mechanical properties of steel by the processing of the steel in an elevated-temperature-reduction step, wherein, for example, the steel is advanced through a die to take a reduction in cross-sectional area while the steel is at a temperature within the range of 200° F. to the lower critical temperature for the steel composition or a temperature of about 1100°–1200° F. Depending upon the temperature at which the steel is advanced through the die, various physical and mechanical properties can be markedly changed by comparison with the same steels, given an equivalent reduction by advancement of the steel through an equivalent die but while the steel is at ambient temperature. Thus, by controlling the temperature of the steel advanced through the die and by the control of chemistry and the amount of reduction, it has been made possible, in a cold-finishing operation, as the term is used in the trade, to produce steel products having new and improved physical and mechanical properties and other characteristics not heretofore available in steels fabricated by other means.

In a number of copending applications filed concurrently herewith, description is made further of modifications in the elevated-temperature-reduction concept wherein the steel is subjected to a cold reduction step in advance of the elevated temperature reduction, wherein the steel is given a normalized structure, as by normalizing the steel, prior to advancement of the steel through the die to effect reduction in the cross-sectional area while the steel is at an elevated temperature, and wherein the steel is subjected to an annealing operation

to provide an annealed structure in the steel for advancement in the elevated-temperature-reduction step. In each of these processes, utilization continues to be made of the characteristics of the steel to strain-harden and to harden by some mode of precipitation when worked at elevated temperature to produce steels having a new and improved combination of properties and characteristics. The processes described in the aforementioned copending applications and in the applications filed concurrently herewith, the elevated-temperature-reduction step is carried out with the hot-rolled steel without effecting a phase change in the steel prior to or during the elevated-temperature-reduction step.

In a further copending application, filed concurrently herewith, new and improved combinations of properties have been developed in steel by the combination of steps which includes heating the steel to austenitizing temperature and rapidly cooling the steel, as by quenching the steel, to produce a phase change in the steel, tempering the steel and then subsequently processing the austenitized and tempered steel in an elevated-temperature-reduction step as described in the aforementioned copending applications, as by advancing the steel through a die to take a reduction in cross-sectional area while the steel is at a temperature within the range of 200° F. to the lower critical temperature (1100°–1200° F.). It has now been found that still further new and novel steel products having new and different combinations of properties and characteristics can be produced when, in the cold-finishing of the steel, the steel is heated to austenitizing temperature and rapidly cooled as, for example, by means of an oil or water quench, to produce a phase change in the steel and then subsequently, without tempering the quenched steel, taking an elevated-temperature-reduction as described in the aforementioned copending applications as by advancing the steel through a die to effect reduction in cross-sectional area while the steel is at an elevated temperature within the range of 200° F. to the lower critical temperature for the steel composition. In most instances, the lower critical temperature will lie closely to a temperature within a range of 1100°–1200° F.

Included among the physical and mechanical properties influenced by processing steels in the manner described are the strength properties of the steel, including tensile strength, impact strength, yield strength, flexural strength, and the like, and other properties such as elasticity, elongation, hardness, surface roughness, machinability, proportional limits, and the like. The more significant improvements secured in steels processed in the manner embodying features of this invention reside in the higher elastic and impact-strength properties produced in the steels without loss of the high strength levels which are secured by elevated-temperature-reduction, as described in the aforementioned copending applications.

The same phenomena of the improvements in physical and mechanical properties of steels secured by reduction at elevated temperature, as described in the aforementioned copending applications, is capable of development also in steels in which the described phase change has been effected by austenitizing and quenching to room temperature except that a broader range of properties is capable of being developed with greater uniformity of properties from heat to heat by comparison with hot-rolled steels. Material and significant improvements are secured in the properties of elasticity and impact strength of the steels at comparable strength levels, as previously pointed out, and the elevated-temperature-reduction step capable of being taken while the steel is at a temperature in the range of 200° F. to the lower critical temperature for the steel, and preferably at a temperature within the range of 200°–900° F.

The characteristics described are capable of development with hot-rolled steels of the type which are generally cold-finished by the processes of drawing or extrusion. Steels which may be used in the practice of this invention are of the type which strain-harden or harden by some mode of precipitation in hot-rolled condition when worked at an elevated temperature. Representative are the easy-to-draw steels or non-austenitic steels having a pearlitic structure in a matrix of free ferrite. These may be distinguished from the hard-to-draw, high-speed, or carbon-tool steels, or the high-alloy steels and stainless steels. In the process of austenitizing and quenching, the structure of the steel is converted to one that contains either bainite or martensite, alone or in combination. The austenitized and quenched steel is relatively hard to draw at room temperature but can be drawn or otherwise reduced in cross section when the reduction step is taken while the steel is at an elevated temperature within the range described of from 200° F. to the lower critical temperature for the steel composition, and preferably while at a temperature within the range of 200°–900° F.

In the process embodying the features of this invention, the temperature of the steel in the elevated-temperature-reduction step, the chemistry of the steel and the amount of reduction that is taken in the steel have influence on the combination of characteristics and properties that are capable of being developed in the steel product. By the proper selection of temperature, chemistry, and reduction, it is possible to produce steels having widely varying physical and mechanical properties, and it is possible selectively to produce steel products having desirable and low stress characteristics thereby to produce new and improved steels having new and different applications and having combinations of characteristics which differ substantially from the steels processed by the other methods described in the aforementioned copending applications, and to produce steels having characteristics and properties which differ from steels of the type which have heretofore been produced by various other techniques.

Treatment of the steels after the elevated-temperature-reduction step, as by slow cooling in air or by quenching rapidly to cool the steel, has very little effect upon the characteristics and properties developed in the steel, with the exception that rapid cooling tends more to produce steels having lower levels of stresses and tends to produce steels having a preponderance of compressive stresses to provide steels characterized by compressive warpage.

As used herein, the term "elevated temperature reduction" is meant to include the step of cold-finishing steels wherein the steel is advanced through a die, as in a draw die, extrusion die, or roller die, to effect reduction in cross-sectional area while the steel is at a temperature within the range of 200° F. to the lower critical temperature for the steel composition, and preferably at a temperature within the range of 200°–900° F. While non-equivalent from the standpoint of the process, many of the characteristics described are also capable of being developed by other processes for working steel to effect reduction in cross-sectional area while the steel is at the desired elevated temperature, such, for example, as by the process of rolling steels to effect reduction in cross-sectional area while the steel is at an elevated temperature within the range described.

The phrase "austenitizing" and quenching is means to relate to the usual meaning of the term as employed in the steel trade and as defined in the steel handbooks. Briekly described, it relates to the step of heating the steel to austenitizing temperature for the steel composition, usually within the range of 1500°–1600° F., followed by rapid cooling of the steel to room temperature, as by means of an oil quench or water quench to freeze the phase change which has been made to take place in the steel. The steel product of the austenitizing and quenching step is believed to be formed of a structure which contains bainite or martensite, or combinations thereof.

In subsequent portions of this description, data will be given of the properties developed by the processing of steels in accordance with the practice of this invention. The advantage of quenching, as compared to air-cooling after drawing, or otherwise reducting the steel in cross-section in the elevated-temperature-reduction step, appears to reside principally in reduction in the residual stress characteristics when use is made of a temperature in the upper range, preferably above 750° F. in the elevated-temperature-reduction step. As a result, it will be expedient, in the following data, to illustrate the differences as between air-cooling and quenching in but a few of the examples, it being understood that similar reduction in stresses and warpage will be secured in other steels processed at equivalent temperature in the elevated-temperature-reduction step.

The concepts of this invention will be illustrated by reference to the processing of four steels which may be taken as representative of the classes of steels that can be employed. These representative steels will be referred to as C–1018, C–1144, C–1080, and 4140 steels. The following is a ladle analysis of these steels, in which the major ingredients, other than iron, are set forth:

Grade	Chemistry						
	C	Mn	P	S	Si	Cr	Mo
C–1018	.18	.88	.015	.037	.06	------	------
C–1144	.45	1.51	.018	.28	.22	------	------
C–1080	.86	.79	.010	.031	.20	------	------
4140	.43	.88	.018	.020	.26	.86	.18

Procedure

The hot-rolled steel bars, as received, were descaled by pickling in sulphuric acid and limed to prevent rusting.

All of the hot-rolled, pickled, and limed bar stock was then heated to austenitizing temperature in a suitable heat-treating furnace. For austenitizing, the steels were heated to the following temperature:

	°F.
C–1018	1600
C–1144	1500
C–1080	1500
4140	1550

While at austenitizing temperature, the steels were quenched for rapid reduction of their temperature to ambient temperature by immersion in an oil bath. It will be understood that other means for rapidly cooling the austenitized steel to ambient temperature may be employed and that such other means are well known to the trade.

The austenitized and quenched steels were drawn at room temperature for the development of comparative data in a cold reduction step, while others of the austenitized and quenched steel bars were re-heated to the desired elevated temperature for advancement through the die in the elevated-temperature-reduction step. For such purpose, the austenitized and quenched steel bars can be re-heated in a gas-fired furnace or other suitable heating furnace employed in the metal art. In the development of the data, reduction in cross-section at elevated temperaure was effected by advancing the steel through a draw die to effect the desired reduction in cross-sectional area. The steel bars were lubricated in advance of drawing with a suitable compound. In the development of the comparative data, the conditions of drawing and at the temperatures of drawing and the amount of reduction were kept as uniform as possible. In the

development of the data, steels of the following diameters were used:

C–1018	¾" round
C–1144	⅝" round
C–1080	9/16" round
4140	11/16" round

The terms employed in the presentation of data have the usual meaning in the metal art, with the exception possibly, of the term "warpage factor." Warpage factor is directly related to residual stress. The warpage value is an indication of the concentration and character of the longitudinal stresses present in steel. The residual stress is obtained by means of a warpage test wherein the length of the test piece is determined as being five times the diameter plus two inches. The test pieces are slotted through a diameter for a distance five times the diameter of the piece. The length of the slot is recorded and the maximum diameter perpendicular to the slot is also recorded. The differences between the diameter before slotting and after slotting represents the flare caused by the presence of residual stresses. The flare is considered positive, indicative of a preponderance of tensile stresses in the steel, if the bar expands upon slotting. The flare is considered negative, indicative of preponderance of compressive stresses in the steel, if the ends move toward the cut made through the diameter. The warpage values determined for evaluation are calculated on the following equation:

$$\text{Warpage factor}=\frac{(D_0)(D_F)}{(L_S)^2}\times 100$$

where

D_0=the original diameter of the bar before cutting the slot

D_F=the diameter differential before and after cutting the slot (flare)

L_S=length of slot

Table I

[C–1018: Austenitized at 1600° F. Reduced 17.2% before drawing. Air-cooled after drawing.]

Temp. of Draw, ° F.	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll [1]	68,375	46,875	36.0	67.9	+.021	87.0	151
Hot Roll [1] as Quenched	164,000	109,500	11.5	22.6	−.400	17.0	371
295	225,000	198,000	1.4	2.0	−.322	3.0	448
380	189,000	183,000	1.4	1.0	+.012	3.0	458
470	156,750	155,000	9.5	15.0	−.034	5.0	343
670	163,500	162,500	11.5	25.5	−.052	8.3	336
720	133,500	13,500	14.5	53.7	−.012	26.0	296
810	115,000	108,500	21.0	66.6	−.023	[2] 69.7	258
930	95,500	84,000	24.5	67.9	−.017	[2] 77.0	213
1,030	94,000	79,000	28.0	72.0	−.029	[2] 113.0	226

[1] Not drawn.
[2] Averaged values for a fibrous fracture—not a clean break test.

Table II

[C–1018: Austenitized at 1600° F. Reduced 17.2% before drawing. Quenched in water after drawing.]

Temp. of Draw, ° F.	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll [1]	68,375	46,875	36.0	67.9	+.021	87.0	151
Hot Roll [1] as Quenched	164,000	109,500	11.5	22.6	−.400	17.0	371
290	163,500	162,000	5.0	23.1	+.328	5.7	336
400	157,000	156,000	5.0	22.6	+.449	8.7	336
450	158,500	157,500	8.0	16.5	−.058	13.3	291
660	178,500	178,500	3.5	9.1	−.058	7.3	402
710	130,500	129,000	11.0	43.6	−.115	10.0	336
810	113,500	105,000	21.0	58.1	−.086	[2] 65.7	249
945	100,000	85,500	27.5	70.7	−.121	[2] 99.0	220
1,010	100,500	85,000	27.5	65.3	−.275	[2] 106.3	213

[1] Not drawn.
[2] Averaged values for a fibrous fracture—not a clean break test.

Table III

[C–1018: Austenitized at 1600° F. Reduced 30.8% before drawing. Air-cooled after drawing.]

Temp. of Draw, ° F.	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll [1]	68,375	46,875	36.0	67.9	+.021	87.0	151
Hot Roll [1] as Quenched	164,000	109,500	11.5	22.6	−.400	17.0	371
350	181,000	180,500	5.1	17.0	+.535	6.0	324
490	164,000	164,000	5.8	22.6	+.369	18.0	343
530	198,500	198,500	2.2	9.7	+.287	2.0	438
690	156,000	156,000	11.5	46.5	+.159	21.0	343
760	136,000	132,000	16.0	58.8	+.025	[2] 47.3	324
830	131,000	123,000	21.0	60.2	+.013	[2] 64.3	318
930	101,000	90,000	26.0	66.3	+.064	[2] 72.7	230

[1] Not drawn.
[2] Averaged values for a fibrous structure—not a clean break test.

Table IV

[C-1018: Austenitized at 1600° F. Reduced 30.8% before drawing. Water-cooled after drawing.]

Temp. of Draw, ° F.	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll [1]	68,375	46,875	36.0	67.9	+.021	87.0	151
Hot Roll [1] as Quenched	164,000	109,500	11.5	22.6	−.400	17.0	371
340	164,000	161,750	5.0	28.8	+.178	14.0	301
480	182,000	180,500	0.7	1.0	+.159	5.3	307
540	181,500	180,000	5.0	16.5	+.178	4.7	402
720	158,500	156,000	11.4	44.9	+.159	18.0	364
770	157,500	154,000	18.0	53.7	+.006	34.5	350
830	121,250	113,000	21.0	66.3	−.070	[2] 67.7	271
930	105,250	95,000	24.5	68.6	−.121	[2] 87.0	230

[1] Not drawn.
[2] Averaged values for a fibrous structure—not a clean break test.

Table V

[C-1144: Austenitized at 1500° F. Reduced 21.6% before drawing. Air-cooled after drawing.]

Temp. of Draw, ° F.	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll [1]	108,000	70,500	23.0	46.1	+.004	32.7	220
Hot Roll [1] as Quenched	246,000	179,000	0.7	4.0	+.184	8.0	450
500	294,000	267,000	3.6	8.8	+1.333	4.6	526
630	272,000	202,500	6.0	22.1	+.816	7.0	502
660	258,000	249,960	7.1	24.0	+.681	24.6	458
715	215,000	208,500	11.4	38.9	+.447	29.3	438
805	174,500	166,000	14.0	47.3	+.227	35.0	336
865	159,250	148,500	15.0	44.9	+.134	38.0	336
960	135,000	127,500	27.5	52.1	+.021	55.0	291

[1] Not drawn.

Table VI

[C-1080: Austenitized at 1500° F. Reduced 15.7% before drawing. Air-cooled after drawing.]

Temp. of Draw, ° F.	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll [1]	144,500	76,000	12.5	17.0	+.025	4.7	296
Hot Roll [1] as Quenched	[2] 204,000				−.061	2.0	436
600	337,000	315,000	3.6	12.5	−.064	4.3	490
635	289,000	280,500	7.1	24.1	+.163	7.0	479
710	254,000	237,000	11.1	33.1	+.124	11.0	502
760	214,500	193,500	11.5	36.7	+.070	11.7	438
845	184,500	150,750	13.0	31.2	+.039	18.7	364
900	163,750	140,000	14.5	34.4	+.023	26.3	330

[1] Not drawn.
[2] Estimated from averaged hardness values of quenched specimens—Material appears to be very brittle and difficult to machine in the "as quenched" condition.

Table VII

[4140: Austenitized at 1550° F. Reduced 19.9% before drawing. Air-cooled after drawing.]

Temp. of Draw, ° F.	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll [1]	140,000	105,750	15.0	42.8	−.004	9.0	307
Hot Roll [1] as Quenched	286,000	231,000	12.1	42.8	+.409	25.7	448
630	324,250	318,000	8.0	25.0	+.478	8.3	610
715	244,000	243,750	4.3	16.0	+.427	21.3	490
830	198,500	196,000	10.0	36.2	+.210	36.7	429
915	187,000	178,750	14.0	50.9	+.096	43.3	402
1010	158,250	151,250	18.0	59.5	+.045	[2] 73.7	336

[1] Not drawn.
[2] Averaged value for a fibrous structure—not a clean break test.

It will be apparent from the foregoing data that the parabolic curve characteristic of the improvements in strength properties developed by elevated temperature reduction, as described in the aforementioned copending applications, is also capable of development in steels processed with the combination of steps embodying the features of this invention. The steels which are austenitized and quenched and then reduced at elevated temperature are capable, by the elevated-temperature-reduction step, to provide the increase in strength properties, at least through the central portion of the elevated-temperature range.

In many instances, the austenitized and quench-hardened steels could not even be drawn to effect reduction in cross-sectional area while at room temperature, whereas the steels could be reduced in cross section when further processed in accordance with the teaching of this invention by taking the elevated-temperature-reduction step. Improvements have been experienced in the tensile-strength properties in the austenitized and quench-hard-

ened steels drawn at elevated temperature when compared to the strength properties developed in the same steels drawn at room temperature for an equivalent reduction. The improvements in tensile strength and other strength properties appear to be maximized in the range of 400°–850° F., and more broadly within the range of 200°–900° F. The same type of improvements is secured in yield strength, hardness, and ductility, as measured by percent elongation and reduction in area, without limitation as to air-cooling or quenching the steels after the elevated-temperature-reduction step. The range of properties of the austenitized and quench-hardened steels which are reduced at elevated temperature differs from those capable of being developed by elevated-temperature reduction alone of hot-rolled steels. In addition, improvements are secured in machinability.

The data which will hereinafter be set forth compares the properties capable of being developed in steels processed in accordance with the practice of this invention with the properties available in the same steels during various stages of the process and with other methods for processing to take an equivalent reduction at equivalent temperature, as in the elevated-temperature-reduction process of the aforementioned copending applications. In the presentation of data in the following tables, the values have been arbitrarily selected as the better of the values for the respective properties processed within the described temperature range. For example, higher tensile strengths and yield strengths are available in steels drawn at temperatures within the range of about 200°–900° F., while the higher values of elongation and reduction in area are developed in steels drawn at temperatures within the upper portion of the elevated-temperature-reduction range.

In the tables, the following abbreviations have been used:

(A)=Air-cooled after drawing
(O)=Quenched in oil or water after drawing
ETD=Drawn at elevated temperature
AQCD=Austenitized and quenched steel which has been drawn at ambient temperature
AQD=Austenitized and quenched steel which has been drawn at elevated temperature

Table VIII

C–1080:
(*a*) At 545° F. (*g*) At 580° F.
(*b*) At 1000° F. (*h*) At 920° F.
(*c*) At 450° F. (*i*) At 530° F.
(*d*) At 380° F. (*j*) At 930° F.
(*e*) At 1030° F. (*k*) At 690° F.
(*f*) At 720° F.

Process	Total Red., Percent	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor Range	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll		68,375	46,875	36.0	67.9	+.021	87.0	151
Cold Drawn	17.2	103,000	103,000	13.0	52.1	−.003	23.0	223
ETD(A)	17.2	116,250(*a*)	116,250(*a*)	27.5(*b*)	58.8(*b*)	−.001–−.184	11.7(*c*)	266
Hot Roll as Quenched		164,000	109,500	11.5	22.6	−.400	17.0	371
AQCD(A)	17.2	225,000	198,000	1.4	2.0	−.322	3.0	448
AQD(A)	17.2	189,000(*d*)	183,000(*d*)	28.0(*e*)	72.0(*e*)	+.012–−.052	26.0(*f*)	458
Cold Drawn (A)	30.8	112,000	112,000	11.5	48.9	−.019	17.3	249
ETD(A)	30.8	129,250(*g*)	129,250(*g*)	20.0(*h*)	52.5(*h*)	−.057–−.121	38.0(*h*)	271
AQCD(A)	30.8	181,000	180,500	5.1	17.0	+.535	6.0	324
AQD(A)	30.8	198,500(*i*)	198,500(*i*)	26.0(*j*)	66.3(*j*)	+.369–+.013	21.0(*k*)	438

Table IX

C–1144:
(*a*) At 660° F. (*d*) At 960° F.
(*b*) At 940° F. (*e*) At 920° F.
(*c*) At 500° F. (*f*) At 520° F.

Process	Total Red., Percent	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor Range	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll		108,000	70,500	23.0	46.1	+.004	32.7	220
Cold Drawn(A)	21.6	132,750	118,750	13.0	34.4	+.732	18.0	266
ETD(A)	21.6	150,250(*a*)	145,000(*a*)	15.0(*b*)	42.3(*b*)	+.711–+.170	35.3(*b*)	318
Hot Roll as Quenched		246,000	179,000	0.7	4.0	+.184	8.0	450
AQD(A)	21.6	294,000(*c*)	267,000(*c*)	27.5(*d*)	52.1(*d*)	+1.333–+.021	55.0(*d*)	526
Cold Drawn	21.6	133,000	127,500	9.0	31.2	+.789	22.3	258
ETD	21.6	152,250(*a*)	147,500(*a*)	16.0(*c*)	40.6(*c*)	+.740–+.050	32.0(*e*)	324
AQD(O)	21.6	301,000(*f*)	298,000(*f*)	19.5(*d*)	51.7(*d*)	+1.127–0	48.0(*d*)	600

Table X

C–1080:
(*a*) At 610° F. (*d*) At 600° F.
(*b*) At 940° F. (*e*) At 900° F.
(*c*) At 815° F.

Process	Total Red., Percent	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor Range	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll		144,500	76,000	12.5	17.0	+.025	4.7	296
Cold Drawn(A)	15.7	170,500	148,500	5.0	14.5	+.077	3.3	324
ETD(A)	15.7	189,000(*a*)	186,000(*a*)	10.0(*b*)	12.4(*b*)	+.077–−.038	5.0(*c*)	378
Hot Roll as Quenched		204,000				−.061	2.0	436
AQD(A)	15.7	337,000(*d*)	315,000(*d*)	14.5(*e*)	34.4(*e*)	+.163–−.064	26.3(*e*)	490

Table XI

4140:
(a) At 595° F. (d) At 1010° F.
(b) At 960° F. (e) At 915° F.
(c) At 630° F.

Process	Total Red., Percent	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, 1.4", Percent	Red. of Area, Percent	Warpage Factor Range	Izod Impact, 70° F., Ft.-Lbs.	Hardness, DPN, MR
Hot Roll		140,000	105,750	15.0	42.8	−.004	9.0	307
Cold Drawn(A)	19.9	165,000	162,000	9.0	44.0	+.083	4.3	336
ETD(A)	19.9	189,500(a)	189,000(a)	16.5(b)	49.4(b)	+.211−+.064	15.0(b)	394
Hot Roll as Quenched		286,000	231,000	12.1	42.8	+.409	25.7	448
AQD(A)	19.9	324,250(c)	318,000(c)	18.0(d)	59.5(d)	+.478−+.045	43.3(e)	610

From the foregoing data, it will be apparent that in many of the properties, particularly in the strength properties and in the properties which indicate elasticity, considerable improvement is secured by the combination of steps which includes austenitizing and quenching followed by reduction in cross section at elevated temperature when compared to the system for processing steels by the use of an elevated-temperature-reduction step alone. It will be apparent also that the improvements are made available without limitation by means of treating the steel subsequent to drawing, as by air-cooling or quenching, and it will be evident further that the foregoing improvements can be developed in the steel in which high reductions are taken as well as low reductions. The improvements in residual stress characteristics follow the same general pattern as are made available by the elevated-temperature-reduction step, whether austenitized and quenched prior to reduction or whether reduction is taken on the hot-rolled steel without previous treatment.

By the combination of steps comprising austenitizing and quenching to effect a phase change followed by reduction at elevated temperature, steels having new and improved characteristics and new combinations thereof can be secured with particular emphasis on improvements in elasticity, machinability, strength properties, and hardness.

It will be understood that changes may be made in the details of processing the steel and its method of handling without departing from the spirit of the invention, especially as defined in the following claims.

I claim:

1. The metallurgical process for improving the characteristics of steel of the non-austenitic type having a pearlitic structure in a matrix of free ferrite comprising the combination of steps of austenitizing the steel and quenching the austenitized steel to effect a phase change to martensite and then advancing the martensitic steel through a draw die to effect reduction in cross-sectional area in a drawing operation while the steel is at a temperature within the range of 400° F. to the lower critical temperature for the steel composition.

2. The metallurgical process for improving the characteristics of steel of the non-austenitic type having a pearlitic structure in a matrix of free ferrite comprising the combination of steps of austenitizing the steel and quenching the austenitized steel to effect a phase change to martensite and then advancing the martensitic steel through an extrusion die to effect reduction in cross-sectional area in an extruding operation while the steel is at a temperature within the range of 400° F. to the lower critical temperature for the steel composition.

3. The metallurgical process for improving the characteristics of steel which strain-hardens and which hardens by some mode of precipitation when worked at a temperature between 200° F. and the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel and quenching the austenitized steel to effect a phase change to martensite, and then working the martensitic steel to effect reduction in cross-sectional area while the steel is at a temperature within the range of 400° F. to the lower critical temperature for the steel composition.

4. The metallurgical process for improving the characteristics of steel which strain-hardens and which hardens by some mode of precipitation when worked at a temperature between 200° F. and the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel, quenching the austenitized steel to form martensite and then advancing the martensitic steel through a draw die to effect reduction in cross-sectional area in a drawing operation while the steel is at a temperature within the range of 400° F. to the lower critical temperature for the steel composition.

5. The metallurgical process for improving the characteristics of steel which strain-hardens and which hardens by some mode of precipitation when worked at a temperature between 200° F. and the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel, quenching the austenitized steel to form martensite and advancing the martensitic steel through an extrusion die to effect reduction in cross-sectional area in an extrusion operation while the steel is at a temperature within the range of 400° F. to the lower critical temperature for the steel composition.

6. The metallurgical process for improving the characteristics of steel which strain-hardens and which hardens by some mode of precipitation when worked at a temperature between 200° F. and the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel, quenching the austenitized steel to form martensite and then rolling the martensitic steel to effect reduction in cross-sectional area in a rolling operation while the steel is at a temperature within the range of 400° F. to the lower critical temperature for the steel composition.

7. A steel product having new and improved characteristics produced by the method of claim 3.

References Cited in the file of this patent

UNITED STATES PATENTS

1,018,369	Potter	Feb. 20, 1912
2,435,511	Rice	Feb. 3, 1948
2,448,753	Weesner	Sept. 7, 1948

OTHER REFERENCES

Alloys of Iron and Carbon, vol. 1 Epstein, pp. 177–178, 1936.

Metal Progress, May 1945, p. 938.

Dunn: Iron and Steel Engineer, pages 51–57 and 77, July 1946.