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CASE-HARDENED, WORKED STEELS

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This invention relates to the improvement in mechanical and physical properties of steel by a process capable of being employed in the cold-finishing of steel, as in the cold-finishing of steel bars, rods, wires, and the like steel products.

It is an object of this invention to produce and to provide a method for producing steel products having new and improved physical and mechanical properties, with new and different surface chemistry characteristics and properties.

More specifically, it is an object of this invention to provide a method applicable to the processing of steels of the type which strain harden and harden by some mode of precipitation when worked at elevated temperature to improved and to change physical and mechanical properties of the steel, and it is a related object to produce a new and different steel product having new and improved combinations of physical and mechanical properties, such as resistance to wear, corrosion, fatigue, etc.

This application is related to the copending applications Serial Nos. 518,411, 518,412, 518,413, and 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.

The inventions of the aforementioned copending applications are addressed to the method for the improvement of physical and mechanical properties of steel by the process which includes the step of working the steel as by advancement of the steel through a 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, or at a temperature within the range of 200° F. to 1100°–1200° F. In accordance with the teaching of the aforementioned copending applications, the temperature of the steel in the elevated temperature reduction step has considerable influence on the improvements secured in physical and mechanical properties of the steel. By controlling temperature, chemistry, and amount of reduction, it is possible selectively to adjust physical and mechanical properties developed in the steel over a fairly wide range while enhancing the uniformity of physical and mechanical properties in the steel from heat to heat by comparison with hot-rolled steels.

This invention embodies the concepts set forth in the aforementioned copending applications in combination with the treatment of the steel prior to taking the elevated temperature reduction step to effect a diffusion transfer at elevated temperature followed by quenching or otherwise cooling the steel from diffusion temperature to ambient temperature, or to approximately the temperature for advancing the steel directly to the die for the elevated temperature reduction step. The term "diffusion transfer" will hereinafter be defined with reference to the previous treatment of the steel to case the steel, as by means of carburizing, but it will be understood that other diffusion transfer processes may instead be employed, such as nitriding, cyaniding, carbonitriding, and the like, to introduce elements which change the chemistry of the steel, at least in the surface portions.

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As used herein, the term "physical and mechanical properties" is meant to include tensile strength, yield strength, hardness, ductility, elongation, residual stress, warpage, corrosion resistance, wear resistance, and the like. It has been found, for example, as described in the aforementioned copending applications, that machinability characteristics of the steel and such properties as tensile strength, yield strength, proportional limit, impact strength, and hardness are more beneficially affected when, as described in the copending applications Serial Nos. 518,414 and 518,413, the steel is advanced through the die to effect reduction in cross-sectional area while the steel is at a temperature within the range of 450–850° F. These same concepts carry over into the process described and claimed herein wherein the elevated temperature reduction step is employed in combination with the previous step of carburizing the steel or providing another case by diffusion transfer processes well known to the art.

As in the aforementioned copending applications, the trend of the improvements in physical and mechanical properties, and the extent of improvements in any one of the properties, is influenced by the temperature of the steel being reduced, the chemistry of the steel, and the amount of reduction that is taken. The rate of cooling of the steel after elevated temperature reduction has very litle influence on the properties and character of the steel with the exception that lower stress levels are secured and a preponderance of compressive stresses can be provided in the steels when the steels are rapidly cooled, as by quenching following the elevated temperature reduction step, and especially when the elevated temperature reduction step is taken while the steel is at a temperature within the range of 750° F. to the lower critical temperature of the steel composition.

Steels that respond in the manner described to the combination of steps of diffusion transfer, as by carburizing, prior to elevated temperature reduction can be classified quite generally as steels of the type which strain harden and harden by some mode of precipitation or other rearrangement when worked at a temperature within a range of 200° F. to the lower critical temperature for the steel composition. Typical of the class of steels are the hot rolled, non-austenitic steels which have a pearlitic structure in a matrix of free ferrite.

For effecting reduction at elevated temperature (ETD), the steel may be advanced through a die such as a draw die, extrusion die, or roller die to effect reduction in cross-sectional area. While the process of rolling is not equivalent to the process of drawing or extrusion, it has been found that many of the characteristics and properties capable of being developed in steels in the elevated temperature reduction step are also capable of development when the elevated temperature reduction step is taken in a rolling operation while the steel is at a temperature within a range of 200° F. to the lower critical temperature of the steel composition.

The process cycle of carburizing followed by elevated temperature reduction provides a unique diffusion reduction concept which produces steels having a hard, high strength, and decarb-free surface with an attractive appearance, coupled with a high strength core. The hardness of this surface is markedly improved over the same surface not subjected to working at elevated temperatures. This subsequent working after carburizing also influences the diffusion process to carry it deeper into the steel and more uniformly. Problems of retained austenite are also markedly reduced. The process is capable of continuous, rapid, and economical operation to produce steels having improved properties, as compared to conventional cold drawn carburized steels, or elevated temperature drawn carburized steels.

As used herein, the terms "diffusion" and "carburizing" are intended to have their normal meaning in the steel trade. Diffusion can be defined briefly as involving the movement of atoms within a solution. The net movement is usually in the direction from regions of high concentration toward regions of lower concentration in the attempt to achieve homogeneity of the system, which may be a liquid or gas or, as in the present instance, a solid metal. Carburizing is a diffusion-transfer process wherein carbon is introduced into the steel by bringing the steel into intimate contacting relation with a carbonaceous material, in the form of a solid, liquid, or gas, and heating to a temperature above the transformation range for the steel and holding at that temperature for an amount of time sufficient to give the desired case to the steel. Carburizing is generally followed by quenching to produce a hardened case. The time and temperature relationship influences the depth of case, as is well known in the art.

Carburizing eliminates the decarb in the steel and hardens the surface of the steel, thereby markedly to increase the endurance limit of the elevated-temperature-drawn steel by comparison with the results secured with steels having decarb still in the surface. Carburizing increases the amount of carbon in the surface of the steel. The case may be formed to various depths, depending on the time and temperature of carburization. Ordinarily the case will be formed to depths of about 0.030" to 0.060", but the desired results may be secured by elevated-temperature reduction of steels having a depth of case within the range of 0.001" to 0.100".

The treatment after carburizing can be varied. The steel can be quenched rapidly to cool the steel to room temperature, followed by reheating the quenched steel to the elevated temperature desired for taking the elevated temperature reduction step. The carburized steel can be air cooled to ambient temperature and then reheated to the temperature desired for the elevated temperature reduction step. The carburized steel can be quenched or air cooled to temperatures above ambient temperature, such as to a temperature slightly below the temperature desired for elevated temperature reduction, followed by reheating to the desired temperature, or the carburized steel can be quenched or otherwise cooled to temperatures corresponding to the temperature desired for the elevated temperature reduction step, followed immediately by reduction of the steel at the desired temperature. While elevated temperature reduction of the carburized and quenched steel is intended to include reduction of the steel while at a temperature within the range of 200° F. to the lower critical temperature for the steel composition, it is preferred to effect the desired reduction in cross-sectional area while the steel is at a temperature within the range of 450° F. to the lower critical temperature for the steel composition.

The concepts of this invention will hereinafter be illustrated by reference to the processing of two steels which can be taken as representative. These include C–1144 and 4140 having the following ladle analyses in which the major ingredients, other than iron, are set forth:

Grade	Heat number	Chemistry						
		C	Mn	P	S	Si	Cr	Mo
C–1144	YST. 57357	.45	1.51	.018	.28	.22	------	------
4140	YST. 55865	.43	.88	.018	.020	.26	.86	.18

The procedures for processing the steels for illustrating the practice of this invention will now briefly be described.

Hot rolled steel bars "as received" were descaled by pickling in sulphuric acid and limed to prevent rusting. The hot rolled, pickled, and limed bar stock was pack-carburized (Houghton Quicklite A carburizing compound) and heated to a temperature of about 1600° F. for twelve hours. The carburized material utilized for the step-quenched process followed by immediate drawing was quenched in a salt bath to various temperatures for extraction of heat from the carburized steel. Another group of the carburized material was air cooled to room temperature and then reheated in a suitable heat treating furnace to the desired temperature for taking the elevated temperature reduction step.

The steel bars to be drawn were lubricated in advance of drawing, and then the steels were advanced through a draw die to take a reduction in cross-sectional area. For use in the practice of this invention, the bars of C–1144 steel were ⅝" in diameter, and the bars of the 4140 steel were originally $^{11}/_{16}$" in diameter.

The properties for which data has been developed are intended to have their usual meaning in the steel art. As used herein, the term "warpage factor" is directly related to residual stresses. 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 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. 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 represent the flare caused by the presence of residual stresses. The flare is considered positive, indicating a preponderance of tensile stresses at the surface of the steel, if the bar expands upon slotting. The flare is considered negative, indicating a preponderance of compressive stresses at the surface of the steel, if the ends move toward the cut made through the diameter. The warpage values determined 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

While the carburizing step described embodies the technique of pack-carburizing, it will be understood that other systems for carburizing can be employed and that, instead of carburizing, elevated temperature reduction can be carried out after the steel has been treated by other diffusion transfer techniques, such as cyaniding, nitriding, carbonitriding, chromizing, and the like.

In the described system, the depth of case, the carbon content of the case, the grain size, the rate of carburization, and the carbon gradient have some effect on the increase in endurance limit and wear resistance, as well as on some of the other properties of the steel. The carburizing temperature of 1600° F. was arbitrarily selected as representative of a number of temperatures which might have been employed above the transformation range of the steel. The temperature of 1600° permits good diffusion of the steel and results in a smooth gradient of carbon from the case to the core.

It will be apparent from the results that the new combination of a diffusion process coupled with working at elevated temperature provides for improvements in the properties of the steel over conventional carburized steels or steels which are cold drawn or elevated temperature drawn as defined in the aforementioned copending appli-

Table I

C-1144:
- Diffusion process of carburizing
- Quenched to indicated temperature
- Drawn to take a 9.8% reduction
- Air-cooled after drawing

Carb. fce. temp., ° F.	Quench fce. temp., ° F.	Time in quench fce., Sec.	Temp. of draw, ° F.	Pull, lbs.	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elong., 1.4″, percent	Red. of area, percent	Hardness, DPN		
									S	MR	C
------	------	------	H.R.	------	108,000	70,500	23.0	46.1	213	220	234
------	------	------	C.D.	9,160	120.750	111,400	13.0	27.3	213	220	234
------	------	------	ETD [1]	7,442	137,500	137,000	8.0	33.9	296	276	278
------	------	------	As Q. (W)	------	290,000	236,500	6.0	20.0	677	492	458
------	------	------	As Q. (O)	------	246,000	179,000	0.7	4.0	565	450	436
1,600	470	60	560	17,748	174,000	168,000	7.1	24.8	716	318	324
1,600	470	180	520	18,320	182,000	179,000	7.1	21.3	757	365	343
1,600	680	60	650	11,450	163,000	161,500	7.1	32.1	544	326	333
1,600	680	180	665	12,023	166,000	163,500	8.6	32.2	552	346	350
1,600	900	60	790	11,450	143,000	133,500	12.1	38.6	440	309	296
1,600	900	180	805	12,023	145,000	130,000	10.0	39.2	408	301	312
1,600	1,200	60	1,000	6,870	114,500	86,500	15.7	42.4	356	241	234
1,600	1,200	180	970	8,015	113,000	87,500	17.1	43.4	320	245	238

[1] Data at approximate peak of ETD curve=630° F.

Table II

C-1144:
- Diffusion process of carburizing
- Quenched to indicated temperature
- Drawn to take 9.8% reduction
- Quenched in oil after drawing

Carb. fce. temp., ° F.	Quench fce. temp., ° F.	Time in quench fce., Sec.	Temp. of draw, ° F.	Pull, lbs.	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elong., 1.4″, percent	Red. of area, percent	Hardness, DPN		
									S	MR	C
------	------	------	H.R.	------	108,000	70,500	23.0	46.1	213	220	234
------	------	------	C.D.	9,160	122.250	112,500	11.0	37.6	241	258	258
------	------	------	ETD [1]	7,442	137.000	137.000	8.0	35.8	291	285	276
------	------	------	As Q. (W)	------	290,000	236,500	6.0	20.0	677	492	458
------	------	------	As Q. (O)	------	246,000	179,000	0.7	4.0	565	450	436
1,600	470	60	550	17,748	198,000	180,750	5.7	18.6	770	402	371
1,600	470	180	500	18,320	183,000	180,000	7.1	21.1	770	352	336
1,600	680	60	650	11,450	162,000	160,000	10.0	36.2	688	303	291
1,600	680	180	660	12,023	164,500	163,200	9.3	34.4	526	333	330
1,600	900	60	800	11,450	141,500	131,500	13.6	45.2	409	299	293
1,600	900	180	810	12,023	150,000	147,100	12.9	38.9	438	318	318
1,600	1,200	60	1,040	6,870	114,000	84,600	21.4	45.3	334	241	241
1,600	1,200	180	980	8,015	114,500	88,000	20.0	46.7	343	243	238

[1] Data at approximate peak of ETD curve=630° F.

Table III

C-1144:
- Diffusion process of carburizing
- Air-cooled to room temperature
- Drawn to take a 9.8% reduction
- Air-cooled after drawing

Temp. of draw, ° F.	Pull, lbs.	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elong., 1.4″, percent	Red. of area, percent	Hardness, DPN		
						S	MR	C
H.R.	------------	108,000	70,500	23.0	46.1	213	220	234
1,600 [1]	------------	105,000	66,000	22.9	46.5	347	208	213
C.D.	12,022	115,500	114,000	14.3	41.5	330	258	249
450	8,587	119,500	119,000	10.7	34.8	356	253	249
630	10,305	130,500	130,000	7.9	34.4	390	276	271
780	9,160	134,000	127,800	12.1	37.1	394	291	280
1,000	8,015	111,000	85,800	19.3	42.8	348	234	230

[1] Air-cooled carburized steel which is subsequently drawn at temperatures indicated on following lines.

Table IV

C-1144:
Diffusion process of carburizing
Air-cooled to room temperature
Drawn to take a 9.8% reduction
Quenched in oil after drawing

Temp. of draw, ° F.	Pull, lbs.	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elong., 1.4″, percent	Red. of area, percent	Hardness, DPN		
						S	MR	C
H.R.	----------	108,000	70,500	23.0	46.1	213	220	234
C.D.	12,022	117,000	117,000	11.4	32.6	324	264	262
460	8,587	116,500	116,500	11.4	37.1	356	247	247
700	10,305	140,000	138,000	7.9	31.7	397	296	307
1,000	8,015	114,000	87,600	18.6	42.3	352	245	241

Carburized steel subsequently drawn at temperatures indicated.

Table V

4140:
Diffusion process of carburizing
Quenched to indicated temperature
Drawn to take a 12.5% reduction
Air-cooled after drawing

Carb. fce. temp., ° F.	Quench fce. temp., ° F.	Time in quench fce., Sec.	Temp. of draw, ° F.	Pull, lbs.	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elong., 1.4″, per-cent	Red. of area, per-cent	Hardness, DPN		
									S	MR	C
------	------	------	H.R.	------	140,000	105,750	15.0	42.8	310	307	301
------	------	------	C.D.	14,312	159,000	153,500	8.0	39.3	305	301	301
------	------	------	ETD [1]	11,450	171,500	168,500	10.0	46.9	365	336	330
------	------	------	As Q. (O)	------	292,000	246,000	12.9	44.1	600	429	468
1,600	680	60	800	12,595	200,000	198,000	17.9	61.0	490	438	438
1,600	680	180	720	17,175	223,500	223,000	12.9	56.3	539	420	420
1,600	900	60	850	10,305	161,000	125,400	15.7	37.1	429	350	343
1,600	900	180	820	10,877	162,145	141,500	16.4	44.8	409	350	330
1,600	1,200	60	960	8,015	161,000	102,000	17.1	33.0	420	330	318
1,600	1,200	180	1,000	8,015	168,000	105,900	16.4	31.7	371	333	325

[1] Data at approximate peak of ETD curve = 680° F.

Table VI

4140:
Diffusion process of carburizing
Quenched to indicated temperature
Drawn to take a 12.5% reduction
Quenched in oil after drawing

Carb. fce. temp., ° F.	Quench fce. temp., ° F.	Time in quench fce., Sec.	Temp. of draw, ° F.	Pull, lbs.	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elong., 1.4″, per-cent	Red. of area, per-cent	Hardness, DPN		
									S	MR	C
------	------	------	H.R.	------	140,000	105,750	15.0	42.8	310	307	301
------	------	------	C.D.	14,312	164,000	152,000	9.5	44.0	322	318	312
------	------	------	ETD [1]	11,450	177,500	173,000	9.5	44.9	365	350	336
------	------	------	As Q. (O)	------	292,000	246,000	12.9	44.1	600	429	468
1,600	680	60	800	12,595	206,000	195,000	18.6	54.8	481	458	468
1,600	680	180	730	17,175	231,000	231,000	11.4	50.9	554	458	433
1,600	900	60	840	10,305	209,000	120,000	14.3	67.3	580	386	371
1,600	900	180	820	10,877	202,000	131,400	----	----	486	411	374
1,600	1,200	60	960	8,015	288,500	215,500	11.4	69.1	513	504	495
1,600	1,200	[2] 180									

[1] Data at approximate peak of ETD curve = 680° F.
[2] No data available.

Table VII

4140:
Diffusion process of carburizing
Air-cooled to room temperature
Drawn to take a 12.5% reduction
Air-cooled after drawing

Temp. of draw, ° F.	Pull, lbs.	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elong., 1.4″, percent	Red. of area, percent	Hardness, DPN		
						S	MR	C
H.R.	----------	140,000	105,750	15.0	42.8	310	307	301
1,600 [1]	----------	163,000	109,800	13.6	35.3	408	350	356
230	17,175	163,000	148,800	10.0	38.0	391	328	312
505	13,740	167,000	160,000	12.9	46.5	444	347	330
650	12,995	171,500	169,250	12.1	51.7	475	356	336
780	13,167	161,500	156,000	13.6	53.2	490	336	330
1,000	9,732	130,000	118,250	20.7	58.5	438	282	271

[1] Air-cooled carburized steel subsequent drawn at temperatures indicated.

Table VIII

4140:
Diffusion process of carburizing
Air-cooled to room temperature
Drawn to take a 12.5% reduction
Quenched in oil after drawing

Temp. of draw, ° F.	Pull, lbs.	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elong., 1.4″, percent	Red. of area, percent	Hardness, DPN		
						S	MR	C
H.R.	----------	140,000	105,750	15.0	42.8	310	307	301
230	17,175	171,000	159,000	5.7	20.6	416	356	378
515	13,740	160,000	153,000	12.1	49.4	464	324	324
650	12,995	172,000	171,000	12.1	50.9	468	343	330
790	13,167	158,000	154,800	13.6	48.5	479	330	330
1,000	9,732	127,000	108,000	22.9	57.8	438	276	268

cations. Favorable characteristics, such as improved endurance limit, wear resistance, surface finish, and corrosion resistance are secured at the high strength levels characteristic of elevated temperature reduction, as described in the aforementioned copending applications. Comparable improvements were made available in the steels which were air-cooled after carburizing and then re-heated to the temperature desired for the elevated-temperature-reduction step.

It will be understood that the term "bar stock," as used in the specification, may include bars, rods, wire, tubing, and the like metal products. It will be further understood that modifications may be made with respect to the carburizing steps, the time and temperature of quench, the temperature of the steel during the elevated-temperature-reduction step, and the after treatment, as well as the methods for heating, re-heating, and quenching, without departing from the spirit of the invention, especially as defined in the following claims.

We claim:

1. The metallurgical process for treating steel of the non-austenitic type having a pearlitic structure in a matrix of free ferrite comprising the combination of steps of heating the steel to a temperature above its transformation range while in surface contact with the material for diffusion transfer onto the surface of the steel, cooling the steel and subsequently taking a reduction in cross-sectional area by working the steel while the steel is at a temperature within the range of 200° F. to the lower critical temperature for the steel composition.

2. The metallurgical process for treating steel of the non-austenitic type having a pearlitic structure in a matrix of free ferrite comprising the combination of steps of carburizing the steel and then advancing the carburized 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 for the steel composition.

3. The metallurgical process for treating 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 heating the steel to a temperature above its transformation range while in contact with a material for diffusion transfer into the steel, cooling the steel and subsequently taking a reduction in cross-sectional area by working the steel while the steel is at a temperature within the range of 450° F. to the lower critical temperature for the steel composition.

4. The metallurgical process for treating 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 heating the steel to a temperature above its transformation range while in contact with a material for diffusion transfer into the steel, quenching the steel to ambient temperature and subsequently taking a reduction in cross-sectional area by working the steel while the steel is at a temperature within the range of 200° F. to the lower critical temperature for the steel composition.

5. The metallurgical process for treating 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 heating the steel to a temperature above its transformation range while in contact with a material for diffusion transfer into the steel, air-cooling the steel from the temperature of diffusion and subsequently taking a reduction in cross-sectional area by working the steel while the steel is at a temperature within the range of 200° F. to the lower critical temperature for the steel composition.

6. The metallurgical process for treating 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 carburizing the steel and then 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 for the steel composition.

7. The metallurgical process for treating 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 carburizing the steel and then advancing the steel through a draw die to take a reduction in cross-sectional area in a drawing operation while the steel is at a temperature within the range of 200° F. to the lower critical temperature for the steel composition.

8. The metallurgical process for treating 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 carburizing the steel and then advancing the steel through an extrusion die to take a reduction in cross-sectional area by an extrusion operation while the steel is at a temperature within the range of 200° F. to the lower critical temperature for the steel composition.

9. The metallurgical process for treating 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 carburizing the steel and then rolling the steel to effect a reduction in cross-sectional area in a rolling operation while the steel is at a temperature within the range of 200° F. to the lower critical temperature for the steel composition.

10. A steel product having new and improved characteristics produced by the method of claim 6.

11. The metallurgical process for treating 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 compo-

sition comprising the combination of steps of heating the steel to a temperature above its transformation range while in contact with a material for diffusion transfer into the steel, cooling the steel and subsequently taking a reduction in cross-sectional area by working the steel while the steel is at a temperature within the range of 200° F. to the lower critical temperature for the steel composition.

12. The method as claimed in claim 11 in which the steel is air-cooled subsequent to the elevated temperature reduction step.

13. The method as claimed in claim 11 in which the steel is quenched following the elevated temperature reduction step.

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