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(71) Applicant: AK STELL PROPERTIES, INC. [US/US]; 9227 Centre Pointe Drive, West Chester, OH 45069 (US).

(72) Inventors: COMSTOCK, Robert, J.; 509 Southwick Place, Trenton, OH 45067 (US). **PARASKOS, George, A.**; 6369 Timbers Court, Mason, OH 45040 (US).

(74) Agents: SCHOEN, Ann, G. et al.; Frost Brown Todd LLC, 3300 Great American Tower, 301 East Fourth Street, Cincinnati, OH 45202 (US).

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(54) Title: HIGH FORMABILITY DUAL PHASE STEEL

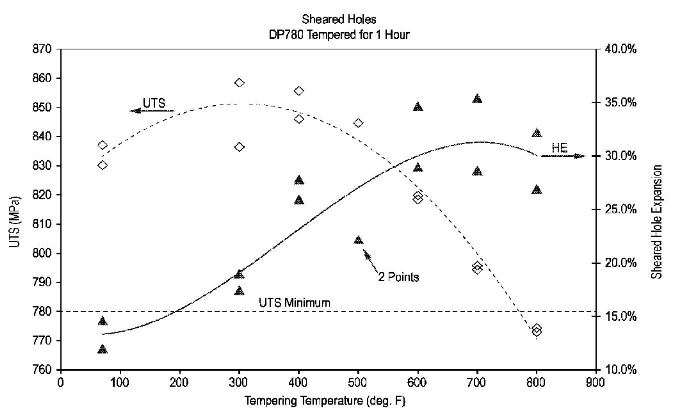

FIG. 1

(57) Abstract: To improve the formability of dual phase steels, the marten site phase is tempered. It may form a ferrite-carbide structure. The tempering step occurs after marten site has been formed in the dual phase steel. The tempering step can occur in a box annealing step or it can be performed in a continuous fashion, such as on a continuous annealing, continuous tempering heat treating, or continuous coating line. The tempering step can further comprise a temper rolling on a temper mill after the heating step.

HIGH FORMABILITY DUAL PHASE STEEL

PRIORITY

[0001] This application claims priority to U.S. Provisional Application Serial No. 62/192,897, entitled HIGH FORMABILITY DUAL PHASE STEEL filed on July 15, 2015, the disclosure of which is incorporated by reference herein.

BACKGROUND

[0002] Dual phase steels are well-known and widely used in applications that require high strength steels such as automotive applications. They typically comprise ferrite and martensite phases. These steels are considered to have limited formability with respect to bending and to edge stretching, which is typically measured using the known method of hole expansion.

[0003] During bending or edge stretching of a standard dual phase steel, the martensite phase undergoes little deformation, thus leaving the ferrite to accommodate most of the strain. As the strain increases, the ferrite begins to reach the limits of its ductility and voids begin to form at the ferrite-martensite interfaces. The voids then can form cracks as the strain further increases.

SUMMARY

[0004] To improve the formability of dual phase steels, the martensite phase is tempered. It may form a ferrite-carbide structure. The tempered martensite structure has lower strength than the original martensite. This lower strength allows the strain in the bending or stretching steel to be more uniformly distributed throughout the material, thereby minimizing void formation in the material.

[0005] In one embodiment, the tempering step is performed in a box annealing step. The box annealing step occurs after martensite has been formed in the dual phase steel. For example, it can occur after heat treatment in a continuous annealing line, or it can occur after the steel has been heat treated and coated in a hot dip line, for example with a metal coating such as aluminum, zinc, lead, or an alloy of one or more of these metals.

[0006] In another embodiment, the tempering step is performed in a continuous fashion, such as on a continuous annealing, continuous tempering heat treating, or continuous coating line after the formation of martensite. The heat for the tempering step can be provided by induction heaters or other strip heating methods.

[0007] In some embodiments, the tempering step can further comprise a temper rolling on a temper mill after the heating step.

DESCRIPTION OF THE FIGURES

[0008] Fig. 1 depicts the improved hole expansion ratio for dual phase steel strip with a tensile strength of 780 MPa as a function of temperature.

[0009] Fig. 2 shows a stress-strain curve for dual phase steel strip with a tensile strength of 980 MPa without a tempering heat treatment and after a tempering heat treatment in box annealing furnace in accordance with one embodiment.

[0010] Fig. 3 shows the calculated relationship between the mean diffusion distance of carbon during tempering and yield strength for dual phase steel strip with a tensile strength of 980 MPa.

[0011] Fig. 4 shows the calculated relationship between the mean diffusion distance of carbon during tempering and yield strength for dual phase steel strip with a tensile strength of 780 MPa.

DETAILED DESCRIPTION

[0012] The martensite phase in dual phase steel is tempered, using time at temperature, transforming some or all of the martensite to ferrite and cementite. Cementite is carbide. The time and temperature of the tempering heat treatment must be long enough and hot enough to promote that transformation such that the hole expansion and bending test values improve the desired amount. The time and temperature of the heat treatment must not be so long, nor so high, that the material tensile strength decreases below desired minimum values, or the material's yield strength increases above desired maximum values. The exact time and temperature for any given tempering step is able to be determined by one skilled in the art following the teachings of this application. The tempering step comprises heating the steel strip. The tempering step may further comprise a temper rolling after the heating step.

[0013] Tempering is controlled by diffusion of carbon and is dependent on the time at temperature. A cumulative diffusion distance of carbon in cm, x, can be used to define the magnitude of tempering:

$$x = (2Dt)^{1/2}$$

where t is the time, in seconds, at temperature and D is the diffusivity in cm^2/s.

x, a function of time (t) and Temperature (T), can be the sum of x_n values under various time and temperature conditions:

$$x = x_1(t_1, T_1) + x_2(t_2, T_2) + x_3(t_3, T_3) + \ldots + x_n(t_n, T_n)$$

The diffusivity is defined by the following Arrhenius type equation:

$$D = D_o e^{-Q/RT}$$

where Q is the activation energy = 32,000 cal/mol,

$D_o = 0.15\ cm^2/s$,

R = 1.987 cal/(mol K),

and T is the temperature in Kelvin.

[0014] While increased tempering improves formability, it also increases the steel's yield strength and introduces yield-point elongation (YPE). Steel users have yield strength requirements for the various classes of dual phase steels. As a result, the amount of tempering may need to be limited to adhere to yield strength requirements. The diffusion distance, x, is correlated with yield strength for two dual phase steel classes, DP780 and DP980. Therefore, heat treatments can be developed using the above equations that will give maximum tempering, which will give the best formability, while staying within the required yield strength range.

[0015] In one embodiment, a coil of dual phase steel strip is subject to a tempering heat treatment using standard steel production box annealing equipment or baking type equipment for steel coils after the appropriate martensite-ferrite microstructure has been developed. Alternatively, this box tempering, using box annealing equipment, may occur after the steel strip has been coated, for example with zinc, aluminum, lead, or an alloy of one or more of these coatings. Such coating can be applied by any conventional process, including electrolytic or hot dip coating methods. The box annealing can occur after, or be combined with, subsequent heat treatments, such as the alloying of a zinc coating with the base dual phase steel to create a galvannealed coating. After the box annealing, the steel strip may also be temper rolled to improve the shape of the strip, to remove yield point elongation, or to oil the strip. For certain embodiments, and particularly for dual phase steels, such box annealing is suitable for tempering.

[0016] In another embodiment, the tempering heat treatment can be applied using a continuous process, such as a continuous annealing line or a continuous coating line or a continuous heat treating line. In one embodiment, the continuous heating process comprises induction heating. As with the box anneal process, the continuous tempering heat treatment step can occur after the steel strip has been cold rolled, or after it has been coated. The continuous tempering heat treatment can also be followed by a temper rolling step.

[0017] **Example 1**

[0018] Dual phase steel with a nominal tensile strength of 780 MPa was manufactured using a typical process for such dual phase steel strip. After cold rolling and galvanizing, the steel strip was subject to a one-hour laboratory anneal cycle at various temperatures in a dry nitrogen atmosphere. The resulting improved hole expansion is shown in Fig. 1.

[0019] **Example 2**

[0020] Two coils of dual phase steel with a nominal tensile strength of 780 MPa were manufactured using a typical manufacturing process for such dual phase steel strip. After cold rolling and galvanizing, the two coils were subject to a box anneal cycle at 550°F for 24 and 30 hours respectively in a dry nitrogen gas atmosphere. The results are reported in Table 1 below:

Table 1

Temperature (°F)	Temper Time (hrs)	YPE (%)	Yield Strength (MPa)	Tensile Strength (MPa)	Hole Expansion Ratio (%)
Standard Product	0	0	512	855	16
550	24	0.5	608	811	32
550	30	1.8	740	834	47

[0021] The 24 hour cycle had low yield-point elongation (YPE) and a yield strength close to that of the standard product, but double the hole-expansion ratio (HER). A longer tempering time of 30 hours further increased the HER, but significantly increase the amount of YPE and the yield strength.

[0022] **Example 3**

[0023] Two coils of a dual phase steel with a nominal tensile strength of 980 MPa were manufactured using a typical manufacturing process for such dual phase steel strip. After cold rolling and galvanizing, the two coils were subjected to a box anneal cycle at 550°F for 30 hours in dry nitrogen gas atmosphere. After box annealing, the coils were temper rolled on a temper mill to 0.27% maximum, and 0.12% average.

[0024] <u>Hole Expansion Tests.</u> Using a hemispherical punch test with a ¾ inch diameter sheared hole, the average hole expansion increased from 14% in the dual phase steel before the tempering treatment to 31% after the tempering treatment. Using a conical punch test with a 10 mm sheared hole, the average hole expansion increased from 16% in the dual phase steel before the tempering treatment to 29% after the tempering treatment. The average diameter of the expanded hole was determined from an average of the longitudinal, transverse, diagonal 1 and diagonal 2 diameters. The percent hold expansion at failure was determined using an average of the three samples. The piercing die clearance was 17% in the ¾ inch samples and 12.8% in the 10 mm samples. These results are listed in Table 2.

Table 2

Before Tempering with Box Annealing Equipment		Thickness (inches)	Hole Expansion (%) (3/4 inch diameter sheared hole)	Hole Expansion (%) (10 mm diameter sheared hole)
AAA	Front	0.0559	10	16
AAA	Tail	0.0564	17	17
ABA	Front	0.0556	18	16
ABA	Tail	0.0557	9	14
		Average:	14	16

After Tempering with Box Annealing Equipment		Thickness (inches)	Hole Expansion (%) (3/4 inch diameter sheared hole)	Hole Expansion (%) (10 mm diameter sheared hole)
AAA	Front	0.0560	33	33
			32	26
AAA	Tail	0.0560	30	34
			33	29
AAA	Cold Spot	0.0558	33	29
ABA	Front	0.0558	32	25

			26	26
ABA	Tail	0.0555	34	28
		0.0561	28	27
ABA	Cold Spot	0.0557	31	30
		Average:	31	29

[0025] Tensile Properties. The average longitudinal tensile strength in the dual phase steel after standard processing was 151 ksi (1040 MPa). This strength dropped to an average of 144 ksi (995 MPa) after the tempering treatment. No sample had a tensile strength below 143 ksi (986 MPa). Details are reported in Table 3 below. Transverse tensile strength in the dual phase steel strip averaged 154 ksi (1062 MPa). This strength dropped to 148 ksi (1018 MPa). Details are reported in Table 4 below.

[0026] After the tempering treatment, a 1 to 2% yield point elongation ("YPE") developed and the yield strength increase from 95 to 135 ksi (655 to 931 MPa). The total elongation also dropped from 16% in the dual phase steel without any tempering treatment to 13% after the tempering treatment. These results are also listed in Tables 3 and 4. Examples of stress-strain curves for both the standard and tempered products are shown in Fig. 2.

Table 3 Longitudinal Tensile Properties

Before Tempering with Box Annealing Equipment		YPE (%)	YS (ksi)			TS (ksi)	TS (MPa)	Elong. (%)
			Upper	Lower	0.2%			
AAA	Front	0	N/A	N/A	93.1	150.6	1039	16

AAA	Tail	0	N/A	N/A	98.6	151.8	1047	16
ABA	Front	0	N/A	N/A	95.0	152.2	1050	16
ABA	Tail	0	N/A	N/A	95.6	149.4	1030	16
	Average:	0			95.6	151.0	1041	16

After Tempering with Box Annealing Equipment		YPE (%)	YS (ksi)			TS (ksi)	TS (MPa)	Elong. (%)
			Upper	Lower	0.2%			
AAA	Front	1.8	135.6	134.3	135.5	143.0	986	14
		2.0	137.6	136.3	137.1	144.3	995	13
AAA	Tail	1.1	132.7	131.7	132.6	144.8	998	14
		1.1	132.9	132.0	132.8	144.5	997	14
AAA	Cold Spot	0.9	134.4	133.0	134	144.9	999	13
ABA	Front	1.7	134.7	133.7	134.5	144.3	995	14
		1.6	134.4	132.9	134.2	143.0	986	13
ABA	Tail	1.1	134.3	133.5	134.4	145.0	1000	13
		1.6	136.4	134.7	136.4	145.9	1006	13
ABA	Cold Spot	1.0	132.7	131.5	132.4	142.9	986	14
	Average:	1.4	134.6	133.4	134.4	144.3	995	13

Table 4 Transverse Tensile Properties

	YPE (%)	YS (ksi)		

Before Tempering with Box Annealing Equipment			Upper	Lower	0.2%	TS (ksi)	TS (MPa)	Elong. (%)
AAA	Front	0	N/A	N/A	94.4	153.3	1057	15
AAA	Tail	0	N/A	N/A	94.1	153.0	1055	15
ABA	Front	0	N/A	N/A	97.8	156.1	1077	14
ABA	Tail	0	N/A	N/A	94.2	153.6	1059	15
	Average:	0			95.1	154.0	1062	15

After Tempering with Box Annealing Equipment		YPE (%)	YS (ksi)			TS (ksi)	TS (MPa)	Elong. (%)
			Upper	Lower	0.2%			
AAA	Front	1.6	138.6	137.6	138.4	146.1	1008	13
		1.6	138.7	138.0	138.6	146.4	1010	13
AAA	Tail	1.1	134.1	133.5	134.0	146.7	1012	14
		1.0	132.9	131.8	132.7	146.4	1010	13
AAA	Cold Spot	0.6	134.3	134.1	134.1	149.5	1031	14
ABA	Front	1.5	136.7	135.5	136.8	146.2	1008	13
		1.4	137.0	136.3	137.1	146.9	1013	14
ABA	Tail	1.6	140.2	139.3	140.2	150.1	1035	12
		1.6	140.5	139.9	140.5	149.3	1030	14
ABA	Cold Spot	0.5	133.2	132.8	133.0	148.9	1027	13

	Average:	1.3	136.6	135.9	136.5	147.7	1018	13

[0027] 90° Bend Test. Before the tempering treatment, the dual phase steel could withstand a minimum r/t of 2.5 before exhibiting a crack that was visible without the aid of a microscope. “r/t” is radius of the bend divided by the thickness of the steel strip. After the tempering treatment, the dual phase steel did not exhibit visible cracks at r/t of 1.2, which was the smallest radius die available. These tests were run in the “hard” direction, i.e., the bend axis runs parallel to the rolling direction. The results are given in Table 5.

Table 5 90° Bend Test

Before Tempering with Box Annealing Equipment		2.8 r/t (4.0 mm die)	2.5 r/t (3.5 mm die)	2.1 r/t (3.0 mm die)	1.8 r/t (2.5 mm die)	1.4 r/t (2.0 mm die)	1.2 r/t (1.75 mm die)	zero-T
IAAA	Front	Pass	Pass	Fail	Fail	Fail		
AAA	Tail	Pass	Pass	Pass	Fail	Fail		
ABA	Front	Pass	Pass	Fail	Fail	Fail		
ABA	Tail	Pass	Pass	Edge crack	Fail	Fail		

After Tempering with Box Annealing Equipment		2.8 r/t (4.0 mm die)	2.5 r/t (3.5 mm die)	2.1 r/t (3.0 mm die)	1.8 r/t (2.5 mm die)	1.4 r/t (2.0 mm die)	1.2 r/t (1.75 mm die)	zero-T
AAA	Front	Pass		Pass	Pass	Pass	Pass	

		Pass		Pass	Pass	Pass	Pass	
AAA	Tail	Pass		Pass	Pass	Pass	Pass	
		Pass		Pass	Pass	Pass	Pass	
AAA	Cold Spot						Pass	
ABA	Front	Pass		Pass	Pass	Pass	Pass	
		Pass		Pass	Pass	Pass	Pass	
ABA	Tail	Pass		Pass	Pass	Pass	Pass	Fail
		Pass		Pass	Pass	Pass	Pass	
ABA	Cold Spot						Pass	

[0032] Scanning Electron Microscopy. The ferrite-martensite structure in the particular dual phase steel of this example is typically very fine and not easily resolved using an optical microscope. After the tempering treatment, the transformation of the martensite to ferrite and carbides was resolved using a scanning electron microscope.

[0033] Summary. The box anneal tempering treatment of the two dual phase steel coils doubled the hold expansion capabilities, from 15% to 30%, and greatly improved the bending properties while maintaining the minimum tensile strength of 142 ksi (980 MPa). Tempering did return YPE into the product, which resulted in an increase in the average yield strength from 96 to 135 ksi (662 to 931 MPa)

[0034] **Example 4**

[0035] The higher temperatures in the particular box annealing equipment used for testing resulted in some variation and elevated yield strengths in the final results for dual phase steel with a nominal tensile strength of 980 MPa, as seen in the results reported in Table 6 below:

Table 6

Temperature (°F)	Temper Time (hrs)	YPE (%)	Yield Strength (MPa)	Tensile Strength (MPa)	Hole Expansion Ratio (%)
Standard Product	0	0	659	1041	16
450	9	1.2	1038	1128	
550	10	1.8	881	966	
550	30	1.4	920	995	29

[0036] Example 5

[0037] The tempering behavior of dual phase steel with a nominal tensile strength of 980 MPa was better controlled with lower tempering temperatures, in the laboratory, which may then require longer tempering times, as shown in Table 7 below:

Table 7

Temperature (°F)	Temper Time (hrs)	YPE (%)	Yield Strength (MPa)	Tensile Strength (MPa)
Standard Product	0	0	681	1029
220	24	0	684	1008
265	24	0	695	1035
285	24	0	741	1041

[0038] Example 6

[0039] A tempering heat treatment was conducted on a dual phase steel having nominal tensile strength of 980 MPa on a paint line using its induction heaters. The temperature of the strip was measured on exiting of the induction heaters and before coiling. Three conditions were investigated and described in Table 8:

Table 8

Temperature out of Inductors (°F)	Coiling Temperature (°F)	YPE (%)	Yield Strength (MPa)	Tensile Strength (MPa)

Standard Product	0	0	689	1058
590	115	1.8	973	1051
600	250	2.1	989	1058
700	275	2.6	991	1033

[0040] As the strip temperature out of the inductors and coiling temperature is decreased, so does the yield strength and the amount of YPE. The strip temperature control of such a continuous process will allow the yield strength and YPE to be lowered down to the original yield strength and zero YPE if desired.

[0041] **Example 7**

[0042] The dual phase 980 yield strength data in Examples 3, 4, and 5 are plotted as a function of the calculated diffusion distance x, in micrometers, in Figure 3. Using Figure 3 and the diffusion equations presented above, a heat treatment can be developed that will produce a tempered product with a desired yield strength for DP980. For example, if a tempered DP980 product having an 800 MPa yield strength is desired, time and temperature combinations can be chosen such that yield x is approximately 1 micrometer. In another example, if a tempered DP980 product have a 950 MPa yield strength is desired, time and temperature combinations can be chosen such that yield x < 100 micrometers or such that yield x < 10 micrometers.

[0043] **Example 8**

[0044] The dual phase 780 yield strength data in Example 2 are plotted as a function of the calculated diffusion distance x, in micrometers, in Figure 4. Using Figure 4 and the diffusion equations presented above, a heat treatment can be developed that will produce a tempered product with a desired yield strength for DP780. For example, if a tempered DP780 product having a 600 MPa, or lower, yield strength is desired, time and temperature combinations need to be chosen such that yield x < 90 micrometers. In another example, if a tempered DP780 product having a

720 MPa yield strength is desired, time and temperature combinations need to be chosen such that yield x < 110 micrometers.

What is claimed is:

1. A method of improving the formability of a dual phase steel strip comprising ferrite and martensite, the method comprising the step of temper heat treating the dual phase steel strip at a temperature and for a time sufficient to transform at least a portion of the martensite to ferrite and cementite.

2. The method of claim 1 further comprising the step of temper rolling the dual phase steel after the temper heat treating step.

3. The method of claim 1 wherein the temper heat treating step occurs after the strip has been cold rolled.

4. The method of claim 1 wherein the temper heat treating step occurs after the strip has been coated with a coating.

5. The method of claim 1 wherein the temper heat treating step is a box annealing step.

6. The method of claim 1 wherein the temper heat treating step is a continuous temper heating step.

7. The method of claim 6 wherein the continuous temper heating is provided by induction heating.

8. A method of improving the formability of a dual phase steel having a nominal tensile strength of 780 MPa comprising the step of temper heat treating the dual phase steel strip at a temperature for a time such that yield x < 110 micrometers.

9. The method of claim 8 wherein the yield x < 90 micrometers.

10. A method of improving the formability of a dual phase steel having a nominal tensile strength of 980 MPa comprising the step of temper heat treating the dual phase steel strip at a temperature for a time such that yield x < 100 micrometers.

11. The method of claim 10, wherein the yield x < 10 micrometers.

12. The method of claim 11, wherein the yield x is approximately 1 micrometer.

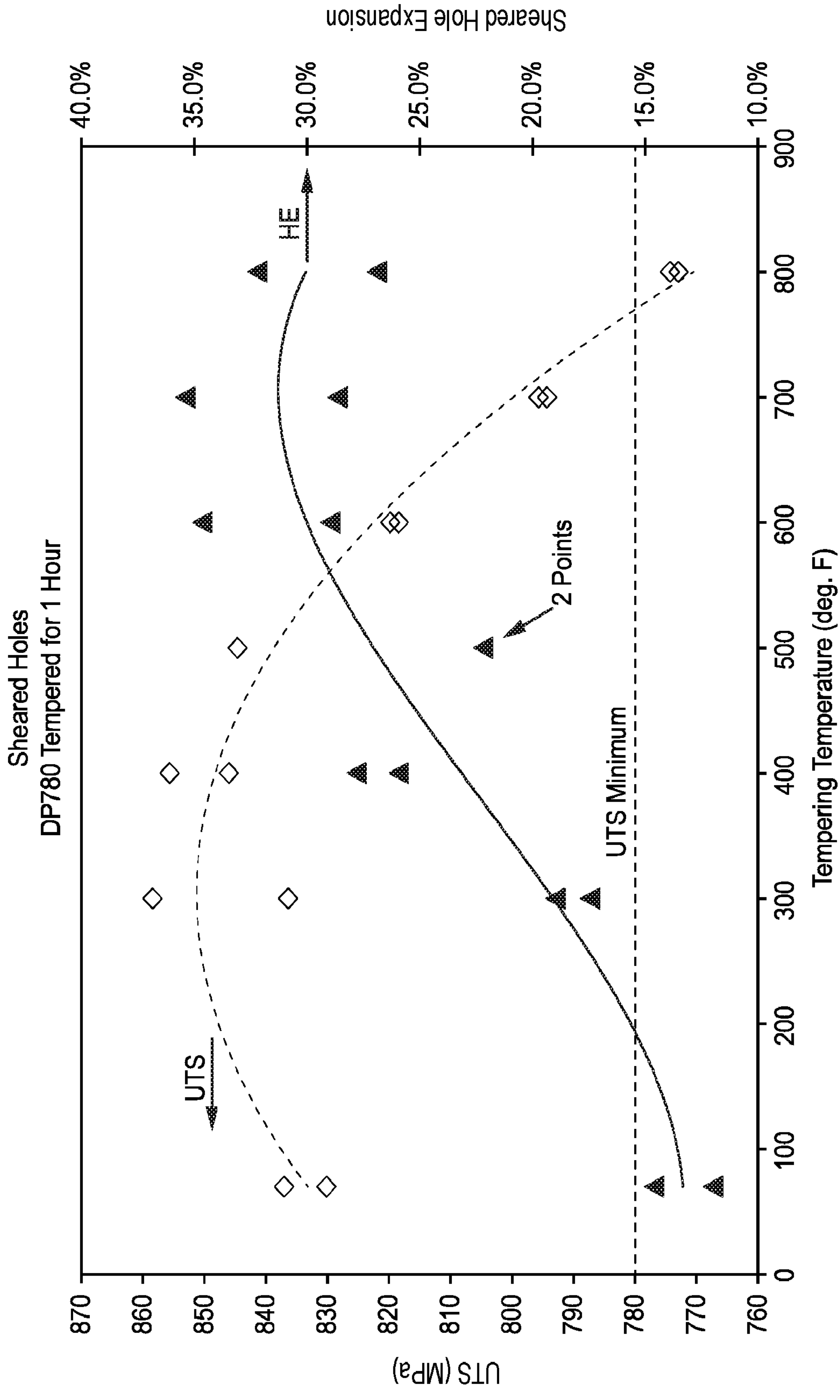
Sheared Holes
DP780 Tempered for 1 Hour
Sheared Hole Expansion
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
HE
UTS
2 Points
UTS Minimum
UTS (MPa)
870
860
850
840
830
820
810
800
790
780
770
760
0
100
200
300
400
500
600
700
800
900
Tempering Temperature (deg. F)

FIG. 1

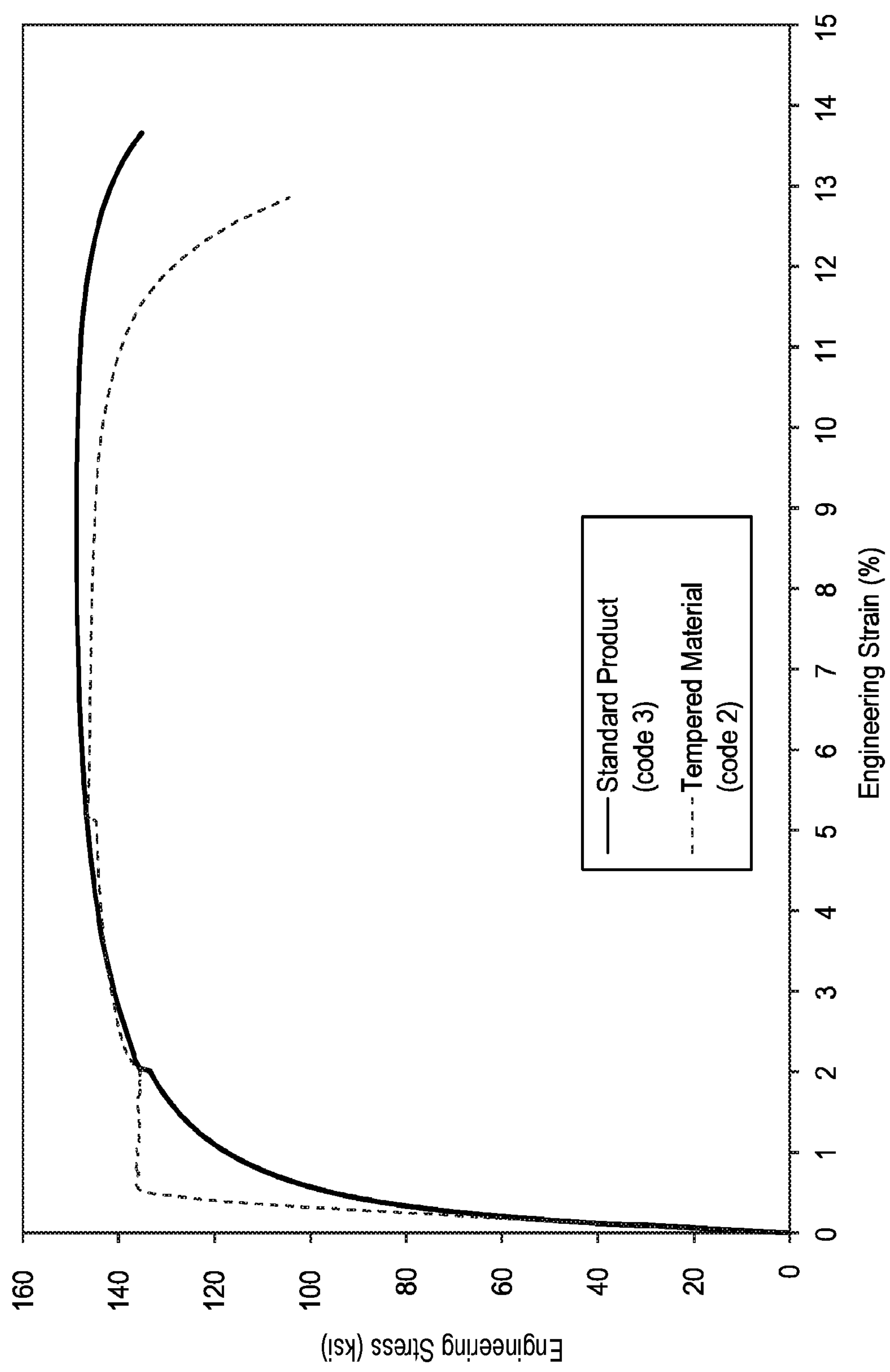
Engineering Stress (ksi)
Engineering Strain (%)
Standard Product (code 3)
Tempered Material (code 2)
0
20
40
60
80
100
120
140
160
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

FIG. 2

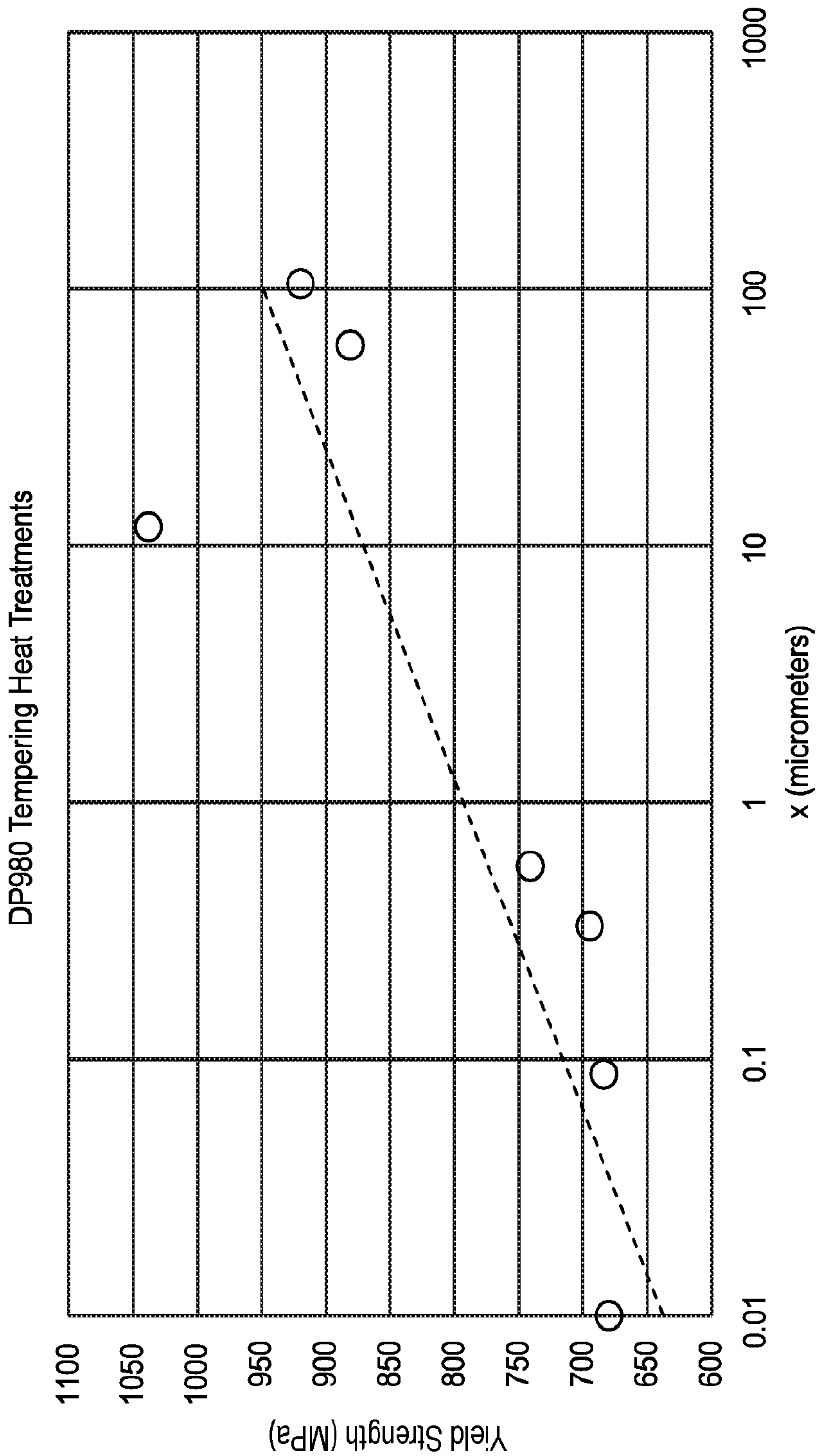
DP980 Tempering Heat Treatments
Yield Strength (MPa)
1100
1050
1000
950
900
850
800
750
700
650
600
x (micrometers)
0.01
0.1
1
10
100
1000

FIG. 3

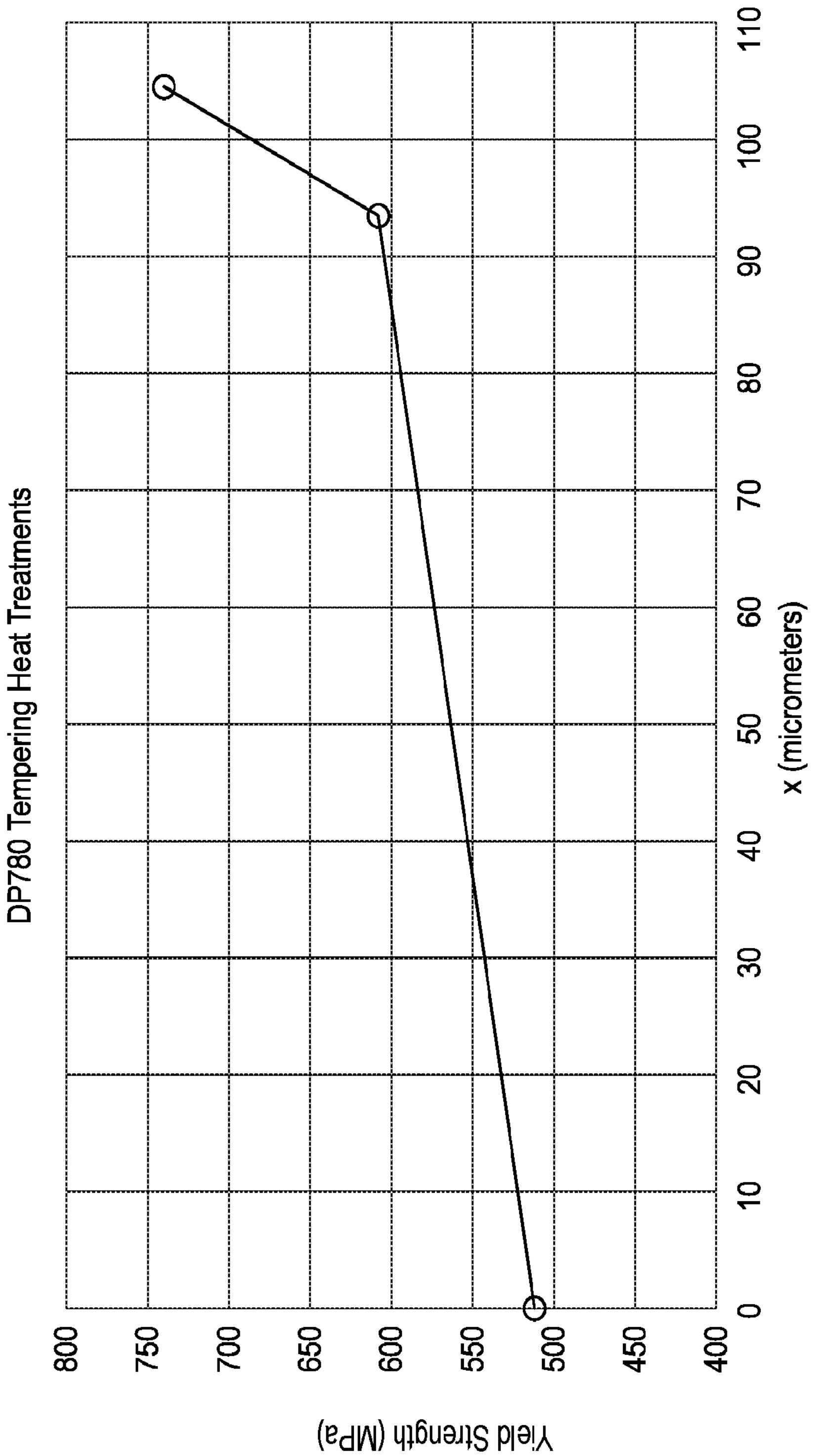
DP780 Tempering Heat Treatments
Yield Strength (MPa)
800
750
700
650
600
550
500
450
400
x (micrometers)
0
10
20
30
40
50
60
70
80
90
100
110

FIG. 4