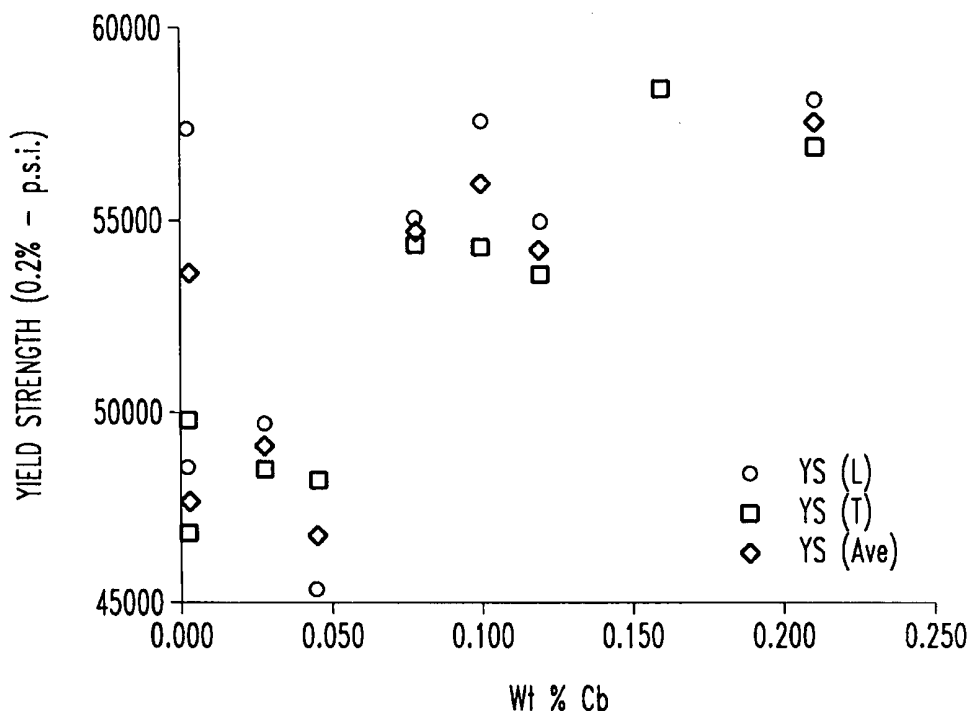




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification ⁶ : C22C 38/58</p>	<p>A1</p>	<p>(11) International Publication Number: WO 99/32682 (43) International Publication Date: 1 July 1999 (01.07.99)</p>
<p>(21) International Application Number: PCT/US98/27602 (22) International Filing Date: 23 December 1998 (23.12.98) (30) Priority Data: 60/068,541 23 December 1997 (23.12.97) US (71) Applicant (for all designated States except US): ALLEGHENY LUDLUM CORPORATION [US/US]; 1000 Six PPG Place, Pittsburgh, PA 15222-5479 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): UNDERKOFLE, James, W. [US/US]; 545 Center Church Road, McMurray, PA 15317 (US). TIMMONS, William, W. [US/US]; 1356 Timberwood Drive, Pittsburgh, PA 15241 (US). BAILEY, Ronald, E. [US/US]; 313 Oak Forest Drive, Pittsburgh, PA 15216 (US). (74) Agents: PUGH, Robert, J.; Allegheny Teledyne Incorporated, 1000 Six PPG Place, Pittsburgh, PA 15222-5479 (US) et al.</p>		<p>(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p>Published <i>With international search report.</i></p>

(54) Title: AUSTENITIC STAINLESS STEEL INCLUDING COLUMBIUM



(57) Abstract

An austenitic stainless steel of the 201 series includes, in weight percent, greater than 0.003 % Cb. Also disclosed is a method for providing a high strength 201 series stainless steel wherein the method includes preparing a heat of a 201 series stainless steel and maintaining the Cb in the heat at a level, in weight percent, greater than 0.003 %.

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TITLE

Austenitic Stainless Steel
Including Columbium

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CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority from United States provisional patent
20 application Serial No. 60/068,541, filed December 23, 1997.

STATEMENT REGARDING FEDERALLY
SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

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BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to stainless steel alloys and more particularly to the
T201LN stainless steel alloy, and still more particularly to strengthening the T201LN alloy
30 through the addition of columbium (Cb).

Description of the Prior Art

Materials which are used at sub-zero temperatures should have good ductility, toughness and strength, which are all properties that are achievable with most of the austenitic stainless steels. The T201LN alloy was specifically designed for such applications and is unique in that it is designated as an acceptable material for applications in which high yield and ultimate strengths are specified. The T201LN alloy, which is disclosed in United States Patent No. 4,568,387 to Ziemianski, the entire disclosure of which is incorporated herein by reference, is an austenitic stainless steel having good low temperature properties of austenitic stability, elongation and strength. As described in the '387 patent, the compositionally-balanced T201LN alloy consists essentially of, in weight percent, 0.03% carbon max., 6.4 to 7.5% manganese, up to 1.0% silicon, 16 to 17.5% chromium, 4.0 to 5.0% nickel, up to 1.0% copper, 0.13 to 0.20% nitrogen, and the balance iron. The T201LN alloy is characterized by austenitic stability, high room temperature strength, minimized sensitization to welding, and high strength and ductility at low temperatures.

Although the T201LN alloy has been successfully used in sub-zero applications, the strength requirements cannot always be achieved in all gages to satisfy the specifications of some cryogenic applications. Therefore, it would be desirable to develop methods to reliably increase the strength of the T201LN alloy so that it may more reliably exceed the mechanical requirements of material specified for cryogenic applications. Recent interest has also surfaced in increasing the strength of the T201LN alloy to expand its use in structural applications where it may possible be used to replace carbon steel in the production of truck frames and other applications.

Industry attempts to produce high strength 201 series stainless steel have until now involved simply evaluating the alloy to determine how much, if any, of the alloy meets the

strength requirements. Modifying the amount of nitrogen during melt has also been attempted. In any event, alloys are milled and the strength characteristics are tested. Alloys which do not meet the strength requirement would be scrapped. Extremely high scrap rates were anticipated based on prior production, to a lower 38,000 psi yield strength. Therefore, a
5 more reliable means of producing higher strength 201 series stainless steel is needed.

SUMMARY OF THE INVENTION

The present invention relates to methods for reliably producing high strength 201 series stainless steel. The method focuses on the influence of Cb on the mechanical
10 properties of the T201LN alloy. Laboratory heats of T201LN alloy, which were significantly alloyed with nitrogen (~0.15%) to stabilize the austenite, were made with varying amounts of Cb (as low as possible up to approximately 0.20%) to determine the influence the Cb would have on the mechanical properties of the alloy. It was found that a significant increase of at least 5 k.s.i. is obtained in both the yield and ultimate strengths as the Cb level is increased
15 above 0.075%, and approximately 10 k.s.i. at Cb levels above 0.150%. The percent elongation is decreased from about 55% to 48%, measured hardness is increased from about 89 Rb to about 98 Rb, and grain size is decreased from about ASTM 6.5 to about ASTM 10 as Cb content is increased from about 0.003% to about 0.210%.

Testing has shown that above a residual level of Cb (0.003%), impact energy
20 increases as Cb content increases to about .10% at the three temperatures tested. Impact energy decreases at above about .10% Cb. Ductility remains relatively high at -50°F and 70°F. A decrease, but not a complete loss, of ductility occurs at a very low test temperature of -320°F.

Accordingly, an object of the present invention is to reliably increase the strength of the T201LN alloy so that it may exceed the mechanical requirements of material specified for cryogenic applications. In this regard, a .06% to .10% addition of Cb to a slightly modified version of studied T201LN alloy has been shown to improve the mechanical characteristics of the alloy for applications in temperatures down to -320°F.

It is a further object of the present invention to reliably increase the strength of the T201LN alloy for temperatures above -50°F. In this regard, a .10% to .20% addition of Cb has been shown to improve the mechanical characteristics of the alloy for applications in temperatures above -50°F.

In light of the foregoing, the present invention is directed to an austenitic stainless steel of the 201 series that includes, in weight percent, greater than 0.003% Cb. The present invention also is directed to a method for providing a high strength 201 series stainless steel wherein the method includes preparing a heat of a 201 series stainless steel and maintaining the Cb in the heat at a level, in weight percent, greater than 0.003%.

Other objects and advantages of the invention will become apparent from the following description of certain presently preferred embodiments thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows ferrite maps made on ½" thick slices, taken from the bottom of the laboratory produced ingots, which were then polished and etched before measurements (FN) were obtained with the Magne-Gage;

FIG. 2 is a schematic illustration of the tensile and subsize Charpy specimens which were used to obtain the mechanical data for this study (with all dimensions in inches);

FIG. 3 is a plot of the yield strength (0.2% offset), obtained from tensile specimens of the laboratory melted material of T201LN alloy, as a function of Cb;

FIG. 4 is a plot of the ultimate strength, obtained from tensile specimens of the laboratory melted material of T201LN alloy, as a function of Cb;

5 FIG. 5 is a plot of the ferrite content, as measured with the Magne-Gage, of the as-tested laboratory material, on the tensile blanks;

FIG. 6 is a plot of the magnetic response as measured with the Magne-Gage on the tensile samples after mechanical testing;

10 FIG. 7 is a plot of the % elongation, obtained from tensile specimens of the laboratory melted material of T201LN alloy, as a function of Cb;

FIG. 8 is a plot of the hardness, obtained from tensile specimens of the laboratory melted material of T201LN alloy, as a function of Cb;

FIG. 9 is a plot of the grain size as a function of Cb obtained by metallographic examination of micros taken from laboratory melted material of T201LN alloy;

15 FIG. 10 is a plot of the impact energies as a function of Cb content for the testing of subsize Charpy samples (~0.180" except the data which are circled) at -320, -50 and 70°F;

FIG. 11 is a plot of the percent shear as a function of Cb content for the testing of subsize Charpy samples (~0.180" thick) at -320, -50 and 70°F; and

20 FIG. 12 is a plot of the lateral expansion as a function of Cb content for the testing of subsize Charpy samples (~0.180" thick) at -320, -50 and 70°F.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Initial testing was conducted which involved making Cb additions to T201LN

material to provide four heats comprising the following additions of carbon, nitrogen, and Cb.

Heat #	C	N	C+N	Cb	Avg. Yield	Avg. Tensile	Grain Sizes	Plates with #6 Grain Size	
								Yield	Tensile
2C152	.018	.176	.194	.011	48,000	96,100	6	48,000	96,200
2C153	.014	.175	.199	.013	48,950	95,600	5-6	50,450	96,850
2C077	.022	.170	.192	.030	48,333	96,533	5-7	49,700	97,300
2C078	.025	.180	.205	.050	52,550	101,867	6-8	53,450	103,800

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The initial testing involved providing eleven groups of plates from the four heats as

follows:

Heat No.	I.D. No.	Gage	R.T. Yield	R.T. Tensile	Elong.	G.S.	Ft/Lbs. - 320F	Size	Lateral Expan. - 320F
2C077	21301	.370	46,700	95,400	59.7	5	55.5/52/59.5	3/4	30/30/30
	91114	.437	49,700	97,300	59.1	6	44.5/47/55.5	3/4	37/44/38.5
	24006	.437	48,600	96,900	61.8	7	68/53/64	3/4	44/36/43
2C078	21303	.370	52,000	101,000	57.5	8	42/43/42	3/4	33/36.5/32
	21302	.437	53,450	103,800	58.3	6	60/60/60	Full	28/26/31
	24005	.437	52,200	100,800	61	7	66/50/63	3/4	40/31/41
2C152	24007	.370	48,000	96,200	60.3	6	60/66/51	3/4	41/45/33
2C153	24008	.370	49,100	96,800	59.2	6	63/59/63	3/4	43/39.5/43
	24009	.370	48,300	95,000	61.2	5	67/67/79	3/4	42/44/50
	91242	.370	51,800	96,900	58.9	6	75/76/72	3/4	35/37/33/5
	24010 Original	.370	46,600	93,700	61	5	54/55/50	3/4	35.5/37/34.5
	24010 Retest	.370	47,500	93,800	63	5			
	24010 2% Stretch	.370	57,300	96,700	56.9	5	55/40.5/49.5	3/4	37/26/35/5

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All plates from all four heats showed excellent impact and lateral expansion values at 320°F. The standard composition had been marginal at times and was of concern to the intended cryogenic tank fabricators. The pressure vessel code requires a minimum of 15 mils

lateral expansion after welding. The average lateral expansion values of 201LN prior to this trial were 31 mils. The average of the high Cb heat was 35 and the other heats averaged 39. This is the expected improvement due to the more austenitic compositions of this trial.

The three heats of .17% to .18% nitrogen without Cb did not have sufficiently high
5 enough yield or tensile strength after processing from ingots. Several groups were marginal and one plate failed with a 93,700 psi tensile versus 95,000 psi minimum. (Slip # 24010, Heat 2C153, yield strength was 46,600 psi).

The fourth heat (Heat 2C078) as shown has acceptable strength, which appears to result from the .05% Cb addition, as is discussed later. Finer grain size also results from the
10 high Cb content. All plates with #6 grain size were shown by heat to separate that variable from the comparison.

During rolling, all plates had work below 1600° F. The first two heats had more reduction below 1500° F via a 1500° F hold in the reheat furnace at 150% of the final gage except for one plate of 21302. This plate was direct rolled without reheat like the second two
15 heats (2C152 and 2C153). This plate still had work below 1500° F and compares favorably with the reheated plates.

Heat 2C078 shows considerably higher yield and tensile strength than the other heats without as much Cb. Impact and lateral expansion values at -320° were also very good. There is no restriction in the applicable specifications against the addition of Cb or other
20 elements. The lower Cb (.03%) heat 2C077 does show that level of Cb to be insufficient.

Earlier 201LN sheet experience over .17% nitrogen found blistering and porosity to be a problem. None of the plates from the above heats showed any blistering or porosity. Product checks found up to .198% nitrogen. If only nitrogen was used for strength, it would

appear that more than .20 % nitrogen would be needed, but this has not been tried recently.

There is reluctance to continuous cast over .16% nitrogen.

The initial rolling of 2200° F oxidizing atmosphere was changed to 2150° F reducing atmosphere after seeing a rough surface due to heavy scale. No evidence of intergranular attack was seen after dip pickling. It was thought that the hot rolling roughness may have had a deleterious effect on the test properties. Room temperature tensile samples were polished without improving the properties. However, for the -320° F tensile test, improvement was seen in the elongations when a subsize round was used versus the flat sample which had several cracks starting at the hot rolled surface roughness.

There is no minimum tensile properties at -320° F currently, but earlier data show low elongations in certain 201L plates at -320° F.

Shown below are the -320°F and corresponding room temperature (R.T.) results:

Heat #	I.D.#	Sample Size	Sample Type	Test Temp. (°F)	Yield PSI	Tensile PSI	Elong. %
2C078	21302	.464"x 2"	Flat	-320	100,400	134,400	4.5
"	21302	"	Flat	-320	115,900	134,500	5.0
"	21302	.250x1.0	Round	-320	106,100	218,400	25.0
"	21303	.350x1.4	Round	-320	103,055	186,542	20.0
"	21303	.350x1.4	Round	-320	102,649	192,701	19.3
2C077	91114	.350x1.4	Round	-320	90,314	196,397	21.4
"	91114	.350x1.4	Round	-320	104,772	176,382	20.0
2C078	21302	.437x2.0	Flat	R.T.	53,450	103,800	58.3
"	21303	.370x2.0	Flat	R.T.	52,000	101,000	57.7
2C077	91114	.437x2.0	Flat	R.T.	49,700	97,300	59.1

Previous 201LN product was annealed at 2025° F with later plates using 1950° F. An anneal study done on hot rolled samples from heat 2C078 showed 1950° F to be the best choice. All plates in this study were annealed at 1950° F.

Due to concerns about diminishing the impact properties, none of the plates were stretcher leveled initially.

After plate 24010 failed the tensile strength, it was given a 2% stretch to evaluate the effects. The results shown after the first two roller levelled results show a large yield and notable tensile increase. The impact properties were still acceptable after stretching. It is clear that they were not greatly diminished, if at all. Impact testing recognizes that a test may be low due to testing variance. This one sample with 40.5 ft. lbs. and 26 mils lateral expansion is still above acceptable values.

These increases in strength from stretching can be expected to be lost in the welded joints of the tank and do not contribute to the true strengthening of the product as does a compositional change. Special weld procedures currently used by the largest 201LN potential customer are adding to the total fabrication cost due to the need to preserve the marginal tensile properties of the standard 201LN plate. These improvements in the composition for higher tensile strength would be of value.

As is described in greater detail below, additional testing was performed. Three laboratory heats of T201LN were melted with various additions of Cb in the range of 0.003-0.210%. The material was hot rolled to ~3/16" (4.76 mm) and annealed at 1950°F. Tensile and subsize Charpy specimens were obtained from each of the plates for mechanical testing. Measurements were made on the tensile specimens before and after testing to determine the ferrite content of the plate and the stability of the austenite. Micros were also obtained from the ends of the tensile specimens which were then polished and etched so that the grain size could be measured.

A significant increase of at least 5 k.s.i. is obtained in both the yield and ultimate strengths as the Cb level is increased above 0.075%, and approximately 10 k.s.i at Cb levels

above 0.150%. The percent elongation is decreased from about 55% to 48%, measured hardness is increased from about 89 Rb to 98 Rb, and grain size is decreased from about ASTM 6.5 to ASTM 10 as Cb content is increased from 0.003% to 0.210%. Above a residual level of Cb (0.003%), impact energy is increased slightly as Cb content increased at the three
5 temperatures tested up to .10% Cb. Ductility remains relatively high at -50 and 70°F. A decrease, but not complete loss, of ductility occurs at a very low test temperature of -320°F above .10% Cb. The addition of Cb enhances the mechanical properties of the T201LN alloy.

Based on the data obtained on laboratory melted and processed material, an addition of approximately .075% Cb is sufficient to enhance the strength mechanical properties of this
10 alloy without significantly degrading any of the other mechanical properties.

The specific procedure and results of the additional testing were as follows. Three fifty pound VIM laboratory heats were melted to the general chemistry aims of the T201LN alloy which is commercially produced. Table 1 contains the chemistries of the three laboratory heats that were melted for this study along with the minimum, average and
15 maximum of the three commercial heats of T201LN which were previously melted. The first heat, RV #1184, was melted to examine the influence of Cb additions in the range 0.01-0.10% by weight on the mechanical properties of T201LN. However, the final chemistry of this first heat was slightly off the commercial chemistry of T201LN. Therefore a second heat, RV #1185, was melted. Later in the investigation, it was decided to examine the influence of
20 slightly higher Cb contents (up to 0.20%) on the mechanical properties of this alloy, so a third and final heat, RV #1212, was melted. Once each heat was melted, it was cast into three seventeen pound ingots with the Cb content adjusted to various levels in between the pouring of the three individual ingots/heat. The purpose of this was to have essentially three identical

alloys from which the influence of the varying Cb content on the mechanical properties of the alloy could be studied.

A half-inch slice was cut from the bottom of each ingot which was then polished and etched so that ferrite maps could be obtained on the as-cast material. The Ferrite Number (FN) measurements were obtained along a half-inch by half-inch grid on each of the 2-3/8" square ingot slices with the Magne-Gage to ascertain the stability, with respect to austenite, of these alloys. These ferrite maps are shown in Figure 1 for heats RV #184, RV #1185 and RV #1212 respectively. The ingots were ground and heated to 2150°F (~1 hr TAT) for hot working. They were cross rolled to obtain a width of seven inches and then hot rolled to an aim gage of ~ 0.1875". Each panel was then annealed at 1950°F for six minutes (TAT) followed by grit blasting and pickling. Tensile specimens were cut and machined from each of the plate samples in both the longitudinal and transverse directions. Charpy v-notch impact specimens were also cut and machined from each of the plate samples from the transverse direction. A schematic of the tensile and subsize Charpy specimens (0.394" x thickness of the plate material) used in this study are shown in Figure 2.

Samples were cut from the ends of the tensile specimens for microstructure evaluation after the mechanical tests were completed. These were mounted, polished and electrolytically etched in 10% oxalic acid at 6V for 20 - 30 seconds to reveal the general grain structure. The grain size of each sample was estimated per ASTM E 112 using the comparison procedure with the following two exceptions. The first is that the photomicrographs were taken at a magnification of 106X instead of 100X. The second is that the photomicrographs were compared to standards from Plate I and not Plate II, which is the recommended standard for austenitic stainless steels. Therefore, the grain sizes measured in this report should be used only to characterize and compare the material which is described within this report.

However, it should be noted that these minor variations in the grain size measuring technique should not significantly alter the grain size and/or the trend (grain size as a function of Cb content).

Table 2 contains the results which were obtained on or from the testing of the tensile specimens. Table 3 contains the results obtained from testing of the Charpy specimens. The results obtained from duplicate test specimens were averaged to simplify the graphical representation of the data. Where both longitudinal and transverse specimens were tested, an average of all the samples is also given. An example of this is the data which are plotted in Figures 3 and 4 of the yield (0.2% offset) and ultimate strengths, respectively, as a function of Cb content. As can be seen, both plots show an increase in the strength of T201LN as the Cb content is increased from ~0.003 to 0.210%. A significant increase of at least 5 k.s.i. is seen in both the yield and ultimate strengths as the Cb level is increased above 0.075%. The increase is approximately 10 k.s.i. at Cb levels above 0.150%. In Figure 3, there is an abnormally high yield strength associated with a low Cb level material (RV #1184 - Ingot A) which does not conform to the trend shown by the rest of the data. However, it should be noted that this material had the highest ferrite level (~2.5%) as measured on the tensile blanks, before testing.

Figure 5 is a plot of the ferrite content measured on the tensile blanks before testing. Only three of the materials examined in this study had a significant amount of ferrite. The first two of these are from the laboratory heat RV #1184 (ingots A & B) which did not match the commercially produced chemistry. The higher ferrite levels observed in this heat are due to the higher chromium and molybdenum and lower nickel and manganese contents. The cause of the higher-than-expected ferrite level in the material from ingot C of laboratory heat RV #1185 is unknown but may be due to fluctuations in the heat treating process which

reduces the ferrite level from that which is found in the as-cast material (shown in Figure 1) to that in the final product.

The magnetic response (FN) was also measured along the shaft of the tensile specimens after testing to determine the presence of martensite which is a measure of the austenite stability. These data are shown in Figure 6 for future reference. This measurement is an indication of the amount of martensite in the material. However, the relationship between this measurement and actual amount of martensite is not known and therefore should only be used for comparison between these samples.

The elongation and hardness measurements obtained from the tensile testing and the grain size obtained from the metallographic examination of micro cut from the tensile specimens (from the ends which were not deformed during testing) are shown in Figures 7, 8 and 9, respectively. The percent elongation decreases (Figure 7) and the measured hardness (Figure 8) of the material increases as the Cb content of the material increases.

The data that were obtained from impact testing of the subsize Charpy specimens (i.e. < 0.394" thick) included the impact energies (Figure 10), percent shear (Figure 11) and the lateral expansion of the samples (Figure 12) as a function of Cb for three different temperatures (320°F, -50°F and 70°F). It should be noted that the data points in Figure 10 which are circled were obtained from the material of Heat RV #1212, ingot A, which was accidentally rolled to a lighter gage (0.157") than that of the rest of the material which was rolled to a gage of ~0.180 - 0.185". Due to the fact that the impact energy is dependent upon the cross-section of the sample being tested, these samples (from Heat RV#1212) would have had at least 18% higher impact energy if they were the correct thickness (~0.180 - 0.185"). Therefore, these data were not considered when examining the impact energy, % shear and lateral expansion trends as a function of Cb content.

The impact energies initially increase and then decrease as the Cb content increases. Very little, if any, loss of toughness was observed between the testing at 70 and -50°F. However, the tests that were completed at -320°F showed a decrease in the toughness of the material above .10% Cb. However, it should be noted that the impact properties at this
5 temperature still show a respectable level of toughness.

The Cb addition up to .10% was successful in increasing the strength of this alloy without significantly degrading any of the other mechanical properties tested. Examination of the data suggests that about .075% Cb is an appropriate addition to achieve the desired mechanical properties.

10 Due to the fact that Cb is a strong stabilizer (i.e., retards the formation chromium carbides at grain boundaries), the addition of Cb to this alloy may allow the maximum carbon content to be relaxed and still be acceptable from a corrosion standpoint. This addition of Cb along with a slight increase in the carbon content may insure the enhanced mechanical
15 properties needed for these new markets (additional strength and toughness due to the increased austenite stability). Therefore, a variation of the T201 grade (Cb 0.100% & C 0.060% max.) may produce an acceptable product in the as-welded condition.

Based upon the results obtained on laboratory produced material, the addition of Cb acts as a grain refiner and enhances the mechanical properties of the T201LN alloy. It was concluded that a significant increase of at least 5 k.s.i. is obtained in both the yield and
20 ultimate strengths as the Cb level is increased above about 0.075%, and an approximately 10 k.s.i. increase is obtained at Cb levels above 0.150%. Further, the percent elongation is decreased from about 55% to 48%, measured hardness is increased from about 89 Rb to 98 Rb and grain size is decreased from ASTM 6.5 to ASTM 10 as Cb content is increased from 0.003% to 0.210%. In addition, above the residual level of Cb (~0.003%), the impact energy

is increased as Cb content is increased up to about .10% at the three temperatures tested.

Ductility remains relatively high at -50 and 70°F. At above about .10% Cb, a decrease, but still acceptable ductility occurs at the low test temperature of -320°F.

While certain presently preferred embodiments have been shown and described, it is
5 distinctly understood that the invention is not limited thereto but may be otherwise embodied
within the scope of the following claims.

Table 1

Heat #	Ingot #	Cr	Mo	Si	Ni	Mn	C	N	Cu	Al	Ti	Co	Sn	W	V	P	S	Cb
**	min.	16.78	0.20	0.35	4.23	6.41	0.021	0.151	0.42	0.003	0.001	0.057	0.008	0.011	0.066	0.027	0.010	0.006
	ave.	16.95	0.25	0.40	4.24	6.48	0.023	0.157	0.43	0.003	0.001	0.061	0.008	0.012	0.075	0.029	0.010	0.012
	max.	17.19	0.35	0.49	4.26	6.63	0.027	0.160	0.43	0.003	0.002	0.063	0.009	0.013	0.093	0.030	0.011	0.021
RV #1184	A	17.78	0.46	0.36	4.11	6.21	0.020	0.160	0.39	0.002	0.003	0.010	0.003	0.010	0.008	0.002	0.008	0.003
RV #1185	B	17.76	0.46	0.35	4.11	6.20	0.019	0.170	0.39	0.002	0.004	0.010	0.003	0.009	0.007	0.002	0.008	0.029
	C	17.74	0.46	0.35	4.12	6.19	0.027	0.160	0.39	0.002	0.004	0.010	0.003	0.009	0.007	0.002	0.008	0.100
	A	16.91	0.20	0.35	4.22	6.76	0.021	0.168	0.42	0.002	0.003	0.010	0.003	0.008	0.007	0.003	0.0083	0.003
RV #1212	B	16.92	0.20	0.35	4.23	6.78	0.020	0.170	0.42	0.002	0.004	0.010	0.003	0.011	0.007	0.003	0.0081	0.046
	C	16.91	0.20	0.35	4.24	6.75	0.021	0.168	0.42	0.002	0.002	0.010	0.003	0.011	0.007	0.002	0.0091	0.120
	A	16.94	0.26	0.41	4.25	6.69	0.021	0.170	0.43	0.002	0.002	0.010	0.003	0.010	0.007	0.003	0.008	0.078
RV #1212	B	16.91	0.26	0.40	4.25	6.64	0.020	0.170	0.43	0.003	0.003	0.010	0.003	0.009	0.008	0.003	0.008	0.160
	C	16.93	0.26	0.40	4.24	6.60	0.022	0.170	0.43	0.002	0.004	0.010	0.003	0.010	0.007	0.003	0.009	0.210

** Range of chemistries obtained from the three heats of T201LN which were melted in 1994.

Table 2

Sample I.D. #	Cb (Wt %)	Initial Dimensions		Sample Orientation	Hardness (Rb)	Initial Ferrite Reading		Final Ferrite Reading		
		Gage	Width			FN(1)	FN(2)	FN(1)	FN(2)	
1184A	0.003	0.180	0.501	L	86.5	2.3	2.3	18.2	18.5	
		0.179	0.501	"		2.3	2.3	20.5	19.5	
		0.176	0.501	T		1.5	3.9	19.8	16.4	
		0.172	0.502	"		1.8	3.9	19.5	17.5	
1184B	0.029	0.186	0.501	L	90.3	1.5	1.3	13.6	15.7	
		0.186	0.500	"		1.0	1.8	11.3	12.3	
		0.188	0.501	T		92.5	1.8	2.6	17.5	16.7
		0.189	0.501	"		2.8	1.5	18.2	15.1	
1184C	0.100	0.183	0.499	L	90.5	0.0	0.0	9.8	7.4	
		0.183	0.498	"		0.0	0.0	8.7	7.4	
		0.188	0.500	T		95.3	0.0	0.0	8.7	8.5
		0.187	0.500	"		0.0	0.0	8.5	8.5	
1185A	0.003	0.186	0.498	L	95.3	0.0	0.0	11.0	10.5	
		0.185	0.499	"		0.0	0.0	15.1	13.4	
		0.183	0.499	T		90.0	0.5	0.0	11.6	12.6
		0.181	0.499	"		0.0	0.3	14.1	13.1	
1185B	0.046	0.186	0.501	L	88.0	0.0	0.0	10.8	9.5	
		0.187	0.501	"		0.0	0.0	10.0	8.5	
		0.181	0.501	T		94.0	0.0	0.0	11.3	11.3
		0.182	0.501	"		0.0	0.0	11.0	10.5	
1185C	0.120	0.185	0.498	L	94.2	1.3	1.3	14.1	11.3	
		0.186	0.498	"		1.3	1.3	15.4	11.6	
		0.186	0.498	T		96.3	0.8	0.8	15.1	15.4
		0.187	0.497	"		1.0	1.0	13.4	15.4	
1212A	0.078	0.156	0.499	L	94.3	0.0	0.0	12.8	10.5	
		0.157	0.500	"		0.0	0.2	13.9	12.3	
		0.158	0.499	T		0.0	0.0	10.8	11.3	
		0.158	0.500	"		0.0	0.0	12.6	11.5	
1212B	0.160	0.180	0.499	L	97.6	0.0	0.0	10.8	10.3	
		0.181	0.499	"		0.0	0.0	13.6	11.5	
		0.186	0.499	T		0.0	0.0	12.1	13.3	
		0.186	0.499	"		0.0	0.0	12.3	13.1	
1212C	0.210	0.181	0.500	L	97.8	0.0	0.2	16.9	17.2	
		0.178	0.499	"		0.0	0.0	12.3	14.6	
		0.180	0.500	T		0.0	0.0	12.8	10.3	
		0.181	0.499	"		0.0	0.0	12.6	13.9	

Table 2 (continued)

Sample I.D. #	Uniform Deformed Region		Elongation (%)	Grain Size 1 st Anneal	Grain Size 2 nd Anneal	Strain Hardening Exp.		Strength (p.s.i.)	
	Width	Gage				n(1)	n(2)	Yield (0.2%)	Ultimate
1184A	0.421	0.148	55	7.5		0.23	0.43	57100	105200
	0.420	0.148	53			0.23	0.43	57500	103900
	0.417	0.146	53	7.5	7.0	0.24	0.44	51100	104500
	0.423	0.143	54		7.5	0.24	0.44	48500	103800
1184B	0.423	0.155	54	6.5		0.24	0.44	49400	103200
	0.423	0.153	54			0.24	0.42	49900	102000
	0.420	0.154	54	7.0	6.5	0.24	0.40	48800	103800
	0.417	0.155	54		7.0	0.24	0.38	48200	102700
1184C	0.422	0.154	50	10.0		0.23	0.39	58500	108200
	0.428	0.153	51			0.24	0.39	56400	108200
	0.422	0.158	50	9.5	9.5	0.23	0.39	53600	109400
	0.424	0.158	50		9.5	0.23	0.39	55000	109300
1185A	0.415	0.153	57	6.5		0.26	0.45	49100	101300
	0.415	0.154	57			0.26	0.46	47900	103000
	0.417	0.153	55	6.5	6.0	0.26	0.46	46100	103300
	0.415	0.152	55		6.0	0.25	0.46	47500	102800
1185B	0.422	0.151	54	6.5		0.26	0.46	45700	98600
	0.418	0.150	54			0.26	0.44	44900	96500
	0.418	0.152	55	6.0	6.5	0.26	0.45	47800	103900
	0.420	0.152	55		6.5	0.26	0.44	48600	103300
1185C	0.423	0.151	51	9.0		0.23	0.38	54700	104500
	0.424	0.153	52			0.24	0.39	55100	105700
	0.423	0.156	50	8.5	10.0	0.24	0.40	50800	108600
	0.420	0.154	52		9.5	0.23	0.40	56100	109200
1212A	0.425	0.133	52	8.5		0.24	0.41	55200	108400
	0.420	0.133	52			0.24	0.43	54700	108400
	0.417	0.130	52	8.0	8.5	0.25	0.42	54200	109200
	0.418	0.130	51		8.0	0.24	0.41	54400	109600
1212B	0.420	0.153	51	10.0		0.23	0.38	57900	110300
	0.417	0.148	51			0.23	0.39	58600	112100
	0.415	0.153	50	10.0	9.5	0.23	0.39	57900	113400
	0.422	0.157	49		10.0	0.23	0.39	58700	113100
1212C	0.420	0.152	50	10.0		0.23	0.41	58500	113400
	0.420	0.148	50			0.24	0.38	57300	112600
	0.425	0.150	46	10.0	10.0	0.24	0.39	56400	112000
	0.421	0.151	47		10.0	0.24	0.39	57100	112400

Table 3

Sample I.D. #	Cb (wt %)	Testing Temp (°F)	Annealed @ 1950°F for 6 min. (TAT)			Reannealed @ 1950°F for 6 min. (TAT)		
			Impact Energy (ft-lbs)	% Shear	Lateral Expansion (in)	Impact Energy (ft-lbs)	% Shear	Lateral Expansion (in)
1184A	0.003	-320	21.0	10	0.023	28.5	10	0.026
1184A	0.003	-320	18.5	10	0.018	23.0	10	0.034
1184A	0.003	-320	24.0	15	0.021	16.0	5	0.021
1184B	0.029	-320	42.0	20	0.025	27.5	10	0.038
1184B	0.029	-320	22.5	15	0.024	26.0	10	0.037
1184B	0.029	-320	40.0	15	0.033	27.0	10	0.041
1184C	0.100	-320	24.0	10	0.018	13.5	5	0.020
1184C	0.100	-320	20.0	5	0.020	13.0	5	0.013
1184C	0.100	-320	19.0	5	0.021	13.0	5	0.016
1185A	0.003	-320	24.0	10	0.014	26.0	5	0.035
1185A	0.003	-320	30.0	10	0.021	25.0	5	0.041
1185A	0.003	-320	24.0	15	0.016	25.0	5	0.028
1185B	0.046	-320	30.0	10	0.034	32.0	10	0.035
1185B	0.046	-320	28.5	10	0.032	27.0	10	0.024
1185B	0.046	-320	26.0	10	0.023	24.0	5	0.029
1185C	0.120	-320	17.0	5	0.013	17.5	5	0.019
1185C	0.120	-320	15.0	5	0.018	14.0	5	0.019
1185C	0.120	-320	16.0	5	0.016	14.0	5	0.018
1212A	0.078	-320	14.0	5	0.013	19.0	5	0.020
1212A	0.078	-320	19.0	5	0.011	14.0	5	0.020
1212A	0.078	-320				25.0	5	0.022
1212B	0.160	-320	11.5	5	0.016	13.0	5	0.020
1212B	0.160	-320	15.0	5	0.017	12.0	5	0.019
1212B	0.160	-320				13.0	5	0.015
1212C	0.210	-320	11.5	5	0.011	11.0	5	0.012
1212C	0.210	-320	14.0	5	0.010	11.5	5	0.015
1212C	0.210	-320				11.0	5	0.013
1184A	0.003	-50	38.0	80	0.044	46.0	60	0.051
1184A	0.003	-50	42.5	75	0.059	44.0	55	0.044
1184A	0.003	-50						
1184B	0.029	-50	47.5	85	0.057	45.0	60	0.055
1184B	0.029	-50	51.5	90	0.058	53.0	50	0.054
1184B	0.029	-50						
1184C	0.100	-50	38.0	60	0.043	42.0	45	0.048
1184C	0.100	-50	38.5	65	0.032	42.0	55	0.059
1184C	0.100	-50						
1185A	0.003	-50	41.0	60	0.040	46.0	35	0.041
1185A	0.003	-50	38.5	65	0.055	46.0	35	0.054
1185A	0.003	-50						
1185B	0.046	-50	43.0	65	0.051	50.0	50	0.054
1185B	0.046	-50	44.0	75	0.038	52.0	50	0.049

Table 3 (continued)

Sample I.D. #	Cb (wt %)	Testing Temp (°F)	Annealed @ 1950°F for 6 min. (TAT)			Reannealed @ 1950°F for 6 min. (TAT)		
			Impact Energy (ft-lbs)	% Shear	Lateral Expansion (in)	Impact Energy (ft-lbs)	% Shear	Lateral Expansion (in)
1185B	0.046	-50						
1185C	0.120	-50	36.5	70	0.039	39.5	55	0.051
1185C	0.120	-50	39.0	80	0.044	40.0	45	0.043
1212A	0.078	-50	33.5	75	0.025	32.0	60	0.047
1212A	0.078	-50	31.5	70	0.026	33.5	65	0.049
1212A	0.078	-50						
1212B	0.160	-50	36.5	70	0.037	36.0	50	0.040
1212B	0.160	-50	34.0	80	0.040	37.0	50	0.047
1212B	0.160	-50						
1212C	0.210	-50	34.0	50	0.025	34.0	40	0.044
1212C	0.210	-50	30.5	50	0.025	32.0	40	0.046
1212C	0.210	-50						
1184A	0.003	70	42.5	90	0.053	41.0	70	0.052
1184A	0.003	70	42.0	95	0.056	42.0	75	
1184A	0.003	70				40.0	60	0.055
1184B	0.029	70	48.0	95	0.064	51.0	85	0.059
1184B	0.029	70	48.5	90	0.058	46.0	75	
1184B	0.029	70				50.0	75	0.059
1184C	0.100	70	39.5	80	0.055	42.5	55	0.047
1184C	0.100	70	40.0	85	0.053	44.0	65	
1184C	0.100	70				41.5	55	0.044
1185A	0.003	70	41.0	90	0.047	45.0	50	0.058
1185A	0.003	70	41.5	90	0.061	44.5	55	
1185A	0.003	70				44.0	50	0.049
1185B	0.046	70	45.5	95	0.051	50.0	60	0.054
1185B	0.046	70	45.0	90	0.056	51.0	60	
1185B	0.046	70				49.5	50	0.053
1185C	0.120	70	45.0	95	0.056	42.5	55	0.060
1185C	0.120	70	41.5	85	0.059	45.0	60	
1185C	0.120	70				42.0	50	0.051
1212A	0.078	70	29.5	95	0.052	34.0	65	0.047
1212A	0.078	70	28.0	90	0.050	34.0	65	
1212A	0.078	70				31.5	65	0.051
1212B	0.160	70	32.0	90	0.044	39.0	50	0.047
1212B	0.160	70	32.0	90	0.046	37.0	50	
1212B	0.160	70				36.0	60	0.042
1212C	0.210	70	30.0	80	0.043	34.0	50	0.046
1212C	0.210	70	30.0	85	0.047	34.0	45	
1212C	0.210	70				32.0	55	0.036

What is claimed:

1. An austenitic stainless steel, the austenitic stainless steel having a chemical composition of the 201 series and comprising, in weight percent, greater than 0.003% columbium.
2. The austenitic stainless steel of claim 1, wherein said columbium is present in an amount of at least 0.06%
3. The austenitic stainless steel of claim 2, wherein said columbium is present in an amount of at least 0.10%
4. The austenitic stainless steel of claim 1, wherein said columbium is present in an amount not greater than 0.21%.
5. The austenitic stainless steel of claim 1, comprising 0.06% carbon max. and 0.10% columbium.
6. The austenitic stainless steel of claim 1, comprising, in weight percent, 0.15 carbon max., 5.4 to 7.5 manganese, up to 1.0 silicon, 16.0 to 18.0 chromium, 3.5 to 5.5 nickel, 0.25 nitrogen max., and greater than 0.003% columbium.
7. The austenitic stainless steel of claim 6, wherein said columbium is present in an amount of at least 0.06%
8. The austenitic stainless steel of claim 6, further comprising, in weight percent, 0.060 phosphorous max. and 0.030 sulfur max.

9. An austenitic stainless steel comprising, in weight percent, 0.03% carbon max., 6.4 to 7.5% manganese, up to 1.0% silicon, 16 to 17.5% chromium, 4.0 to 5.0% nickel, up to 1.0% copper, 0.13 to 0.20% nitrogen, and greater than 0.003% columbium.

10. The austenitic stainless steel of claim 9, wherein said columbium is present in an amount of at least 0.06%.

11. The austenitic stainless steel of claim 9, wherein said columbium is present in an amount of at least 0.075%.

12. The austenitic stainless steel of claim 9, wherein said columbium is present in an amount not greater than 0.21%.

13. The austenitic stainless steel of claim 9, consisting essentially of, in weight percent, 0.03% carbon max., 6.4 to 7.5% manganese, up to 1.0% silicon, 16 to 17.5% chromium, 4.0 to 5.0% nickel, up to 1.0% copper, 0.13 to 0.20% nitrogen, greater than 0.003% columbium, and the balance iron.

14. The austenitic stainless steel of claim 9, characterized by at least 100,000 psi tensile strength and at least 50,000 psi yield strength at room temperature.

15. The austenitic stainless steel of claim 14, further characterized by an ASTM grain size of 6 or higher.

16. In an austenitic stainless steel of the 201 series, the improvement comprising including in the steel greater than 0.003% columbium.

17. The improvement of claim 16, wherein the steel comprises, in weight percent, 0.15 carbon max., 5.4 to 7.5 manganese, up to 1.0 silicon, 16.0 to 18.0 chromium, 3.5 to 5.5 nickel, and 0.25 nitrogen max.

18. In an austenitic stainless steel comprising, in weight percent, 0.03% carbon max., 6.4 to 7.5% manganese, up to 1.0% silicon, 16 to 17.5% chromium, 4.0 to 5.0% nickel, up to 1.0% copper, and 0.13 to 0.20% nitrogen, the improvement comprising including in the steel greater than 0.003% columbium

19. An article of manufacture comprising an austenitic stainless steel, said steel having a chemical composition of the 201 series and comprising, in weight percent, greater than 0.003% columbium.

20. The article of manufacture of claim 19, wherein said austenitic stainless steel comprises columbium in an amount of at least 0.06%.

21. The article of manufacture of claim 19, wherein the article of manufacture is selected from the group consisting of a plate, a tank, and a pressure vessel.

22. The article of manufacture of claim 19, wherein said austenitic stainless steel comprises, in weight percent, 0.03% carbon max., 6.4 to 7.5% manganese, up to 1.0% silicon, 16 to 17.5% chromium, 4.0 to 5.0% nickel, up to 1.0% copper, 0.13 to 0.20% nitrogen, and greater than 0.003% columbium.

23. The article of manufacture of claim 22, wherein said austenitic stainless steel is characterized by at least 100,000 psi tensile strength and at least 50,000 psi yield strength at room temperature.

24. A method for providing a high strength stainless steel, the method comprising preparing a heat comprising, in weight percent, 0.15 carbon max., 5.4 to 7.5 manganese, up to 1.0 silicon, 16.0 to 18.0 chromium, 3.5 to 5.5 nickel, 0.25 nitrogen max., and greater than 0.003% columbium.

25. The method of claim 24, wherein the heat comprises columbium in an amount of at least 0.06%

26. The method of claim 24, wherein the heat comprises, in weight percent 0.03% carbon max., 6.4 to 7.5% manganese, up to 1.0% silicon, 16 to 17.5% chromium, 4.0 to 5.0% nickel, up to 1.0% copper, 0.13 to 0.20% nitrogen, and greater than 0.003% columbium.

27. A method for providing an article of manufacture comprising a high strength stainless steel, the method comprising processing at least a portion of an alloy comprising, in weight percent, 0.15 carbon max., 5.4 to 7.5 manganese, up to 1.0 silicon, 16.0 to 18.0 chromium, 3.5 to 5.5 nickel, 0.25 nitrogen max., and greater than 0.003% columbium.

28. The method of claim 27, wherein the alloy includes columbium in an amount of at least 0.06%

29. The method of claim 27, wherein the alloy comprises, in weight percent, 0.03% carbon max., 6.4 to 7.5% manganese, up to 1.0% silicon, 16 to 17.5% chromium, 4.0 to 5.0% nickel, up to 1.0% copper, 0.13 to 0.20% nitrogen, and greater than 0.003% columbium.

30. The method of claim 27, wherein the act of processing comprises hot rolling at least a portion of the alloy at less than 2200° F in a reducing atmosphere.

31. The method of claim 27, wherein the act of processing comprises hot rolling the least a portion of the alloy at approximately 2150° F in a reducing atmosphere.

32. The method of claim 30, further comprising annealing at least a portion of the alloy at approximately 1950° F.

33. The method of claim 27, wherein the article of manufacture is a plate.

34. An austenitic stainless steel alloy comprising, in weight percent, 0.03% carbon max., 6.4 to 7.5% manganese, up to 1.0% silicon, 16 to 17.5% chromium, 4.0 to 5.0% nickel, up to 1.0% copper, 0.13 to 0.20% nitrogen, and at least 0.06% columbium, the alloy characterized by at least 100,000 psi tensile strength and at least 50,000 psi yield strength at room temperature.

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FIG. 1

RV #1184	AveFN= 10.8	AveFN= 10.9	AveFN= 11.7
INGOT A	INGOT B	INGOT C	INGOT C
10.5 11.0 10.3 10.5 9.0	10.3 10.8 10.5 10.3 9.2	10.3 11.0 11.8 11.0 9.8	10.3 11.0 11.8 11.0 9.8
10.8 11.8 11.6 11.6 9.0	11.6 12.6 11.6 11.8 10.0	11.6 12.6 11.8 13.4 11.6	11.6 12.6 11.8 13.4 11.6
10.5 11.8 12.1 11.6 10.8	11.3 12.3 11.8 12.1 10.5	11.3 12.8 13.6 12.1 11.8	11.3 12.8 13.6 12.1 11.8
9.8 11.6 11.0 12.1 10.8	11.3 11.6 11.6 11.6 9.8	11.3 12.6 12.6 12.6 11.6	11.3 12.6 12.6 12.6 11.6
8.5 9.2 11.3 11.3 10.3	10.0 10.5 11.0 10.3 9.0	10.3 11.6 12.1 10.5 10.5	10.3 11.6 12.1 10.5 10.5

RV #1185	AveFN= 4.3	AveFN= 4.6	AveFN= 5.1
INGOT A	INGOT B	INGOT C	INGOT C
3.1 4.4 4.6 4.6 3.9	4.6 4.9 4.6 4.1 3.6	4.4 5.4 5.6 5.1 4.4	4.4 5.4 5.6 5.1 4.4
4.1 4.9 4.9 4.9 4.6	5.1 5.4 5.4 5.1 3.9	4.4 5.9 5.1 5.6 5.1	4.4 5.9 5.1 5.6 5.1
4.4 5.1 4.6 5.1 4.9	4.9 5.1 4.6 5.1 3.9	5.1 5.4 5.4 5.6 5.1	5.1 5.4 5.4 5.6 5.1
3.6 4.9 4.6 4.6 3.9	4.1 5.1 5.4 5.1 4.4	4.6 5.4 5.6 5.4 5.4	4.6 5.4 5.6 5.4 5.4
2.8 4.4 4.1 4.1 2.6	3.6 4.4 3.9 4.1 4.1	4.1 4.6 4.9 5.4 4.6	4.1 4.6 4.9 5.4 4.6

RV #1212	AveFN= 5.3	AveFN= 5.2	AveFN= 5.3
INGOT A	INGOT B	INGOT C	INGOT C
3.8 5.4 5.6 5.1 3.8	4.6 5.1 4.6 4.6 4.6	4.4 5.1 5.1 4.1 4.4	4.4 5.1 5.1 4.1 4.4
4.6 6.4 6.2 6.2 4.6	5.1 6.4 6.2 5.9 4.9	4.9 5.6 6.7 5.9 5.4	4.9 5.6 6.7 5.9 5.4
5.4 5.9 5.1 6.2 5.6	4.9 6.4 5.1 6.4 4.6	5.4 5.9 6.2 6.2 5.6	5.4 5.9 6.2 6.2 5.6
5.1 5.9 5.6 6.2 5.4	4.1 5.9 5.9 5.9 4.9	5.1 6.4 6.4 5.9 4.9	5.1 6.4 6.4 5.9 4.9
4.1 5.1 6.2 5.4 4.4	3.6 4.9 5.6 4.9 4.4	4.9 5.1 4.9 4.4 4.1	4.9 5.1 4.9 4.4 4.1

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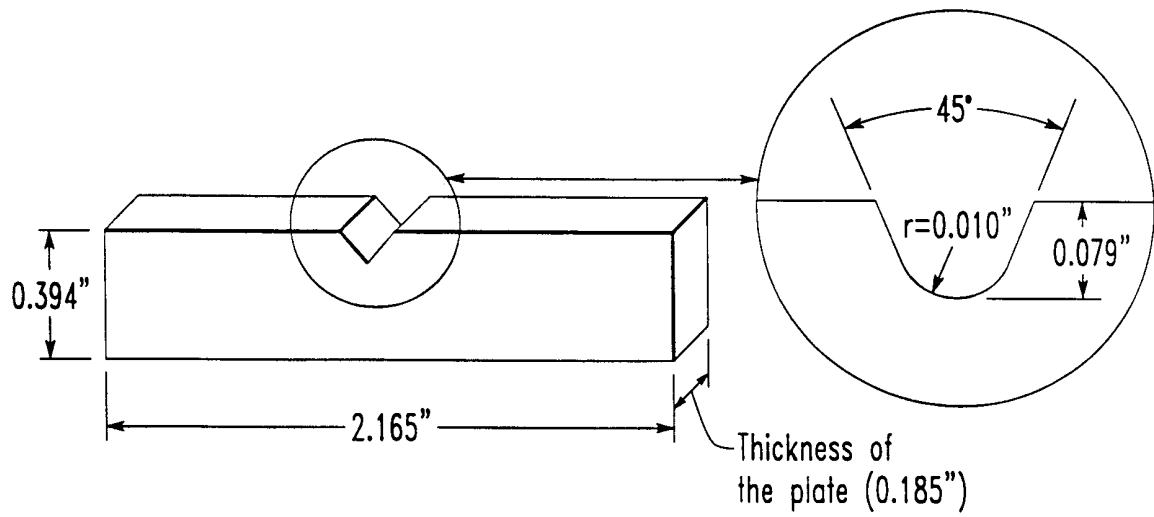
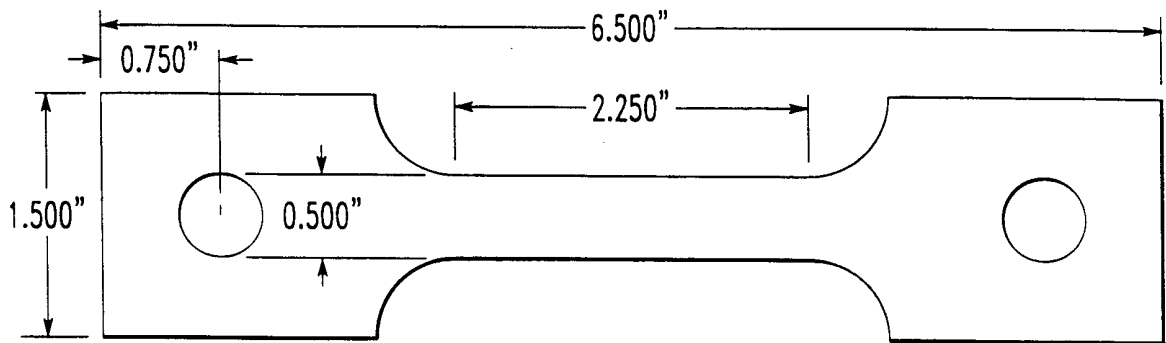


FIG.2

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FIG.3

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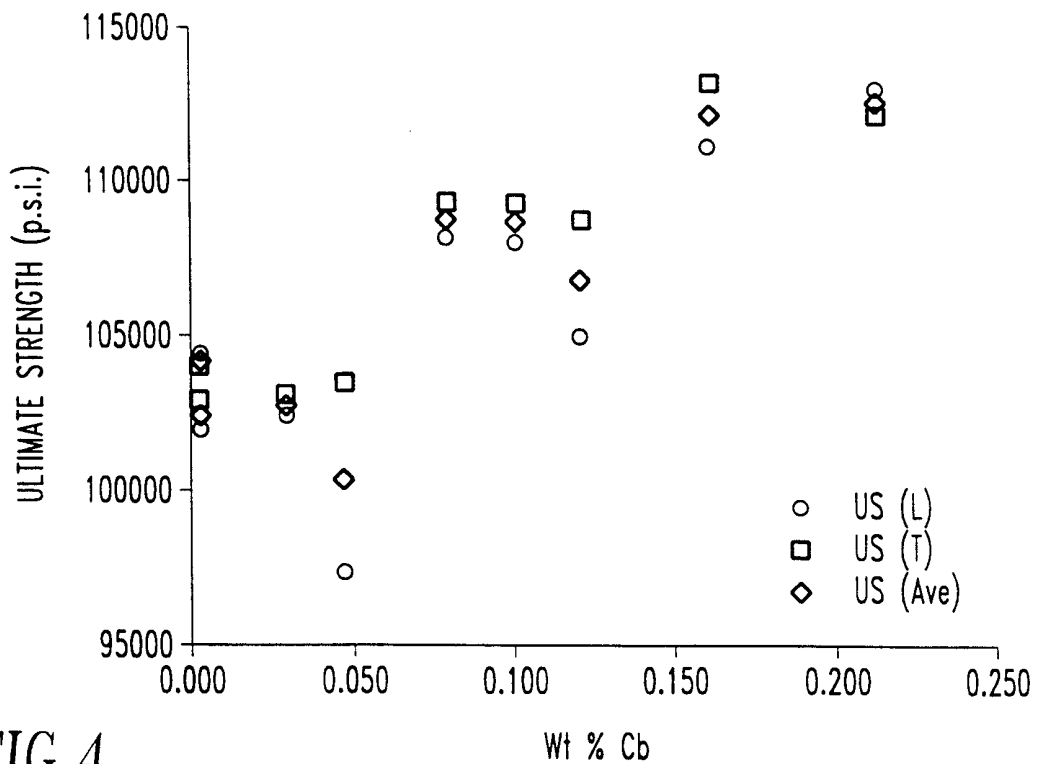
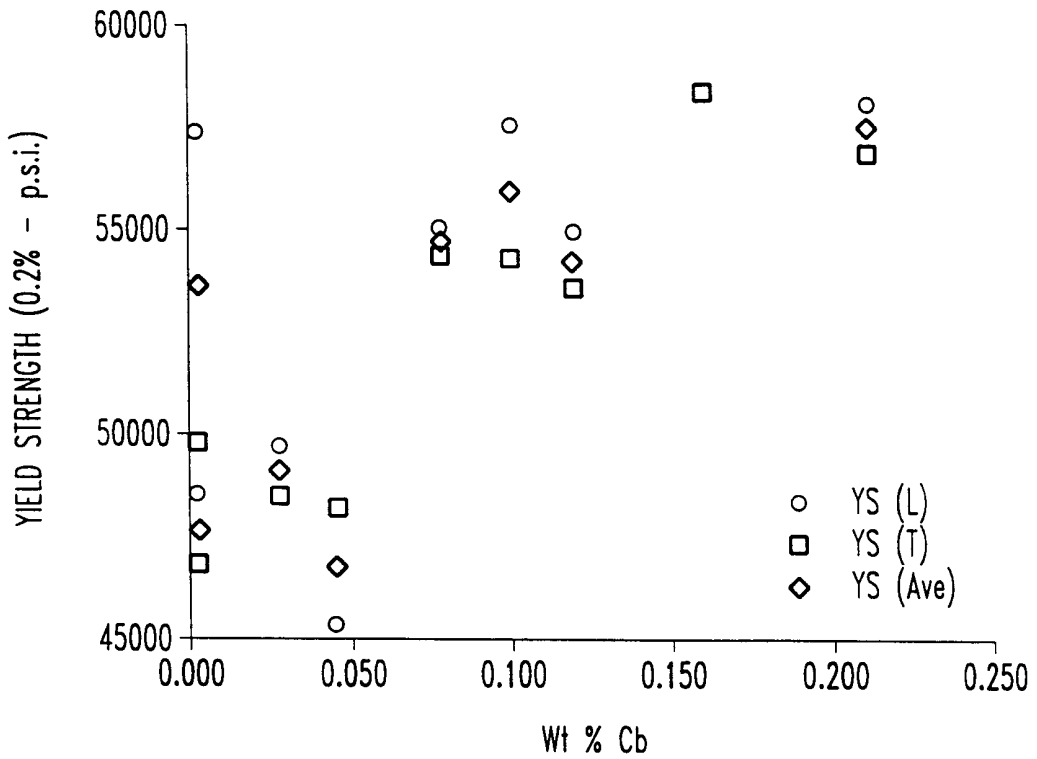


FIG.4

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FIG.5

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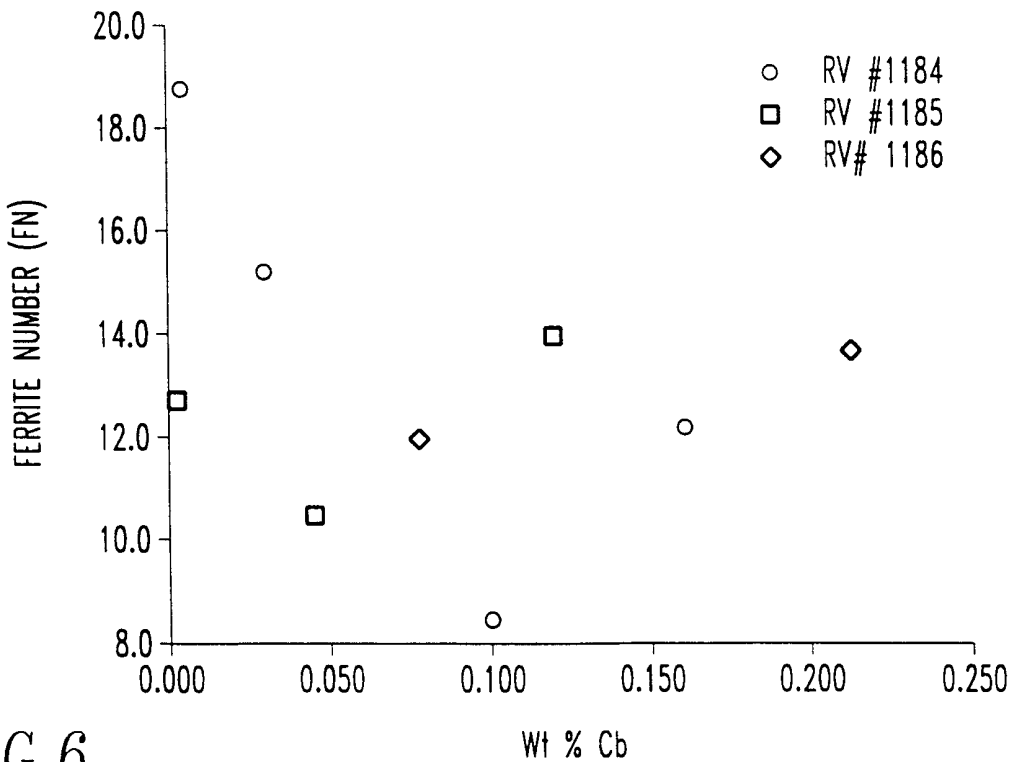
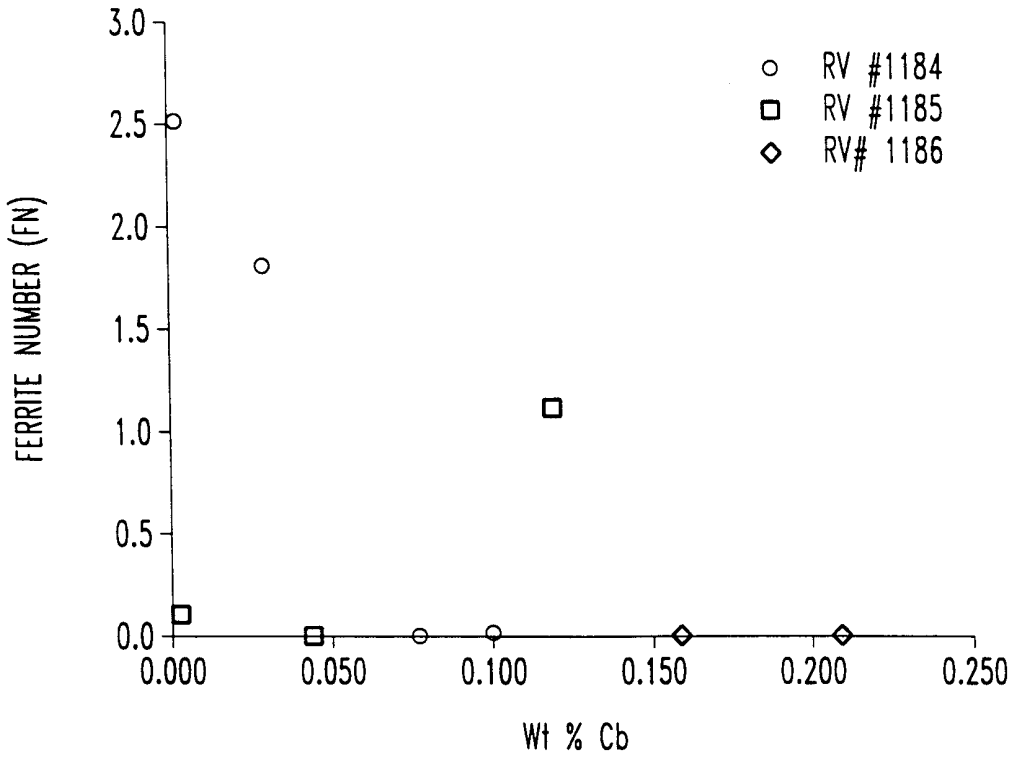


FIG.6

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FIG. 7

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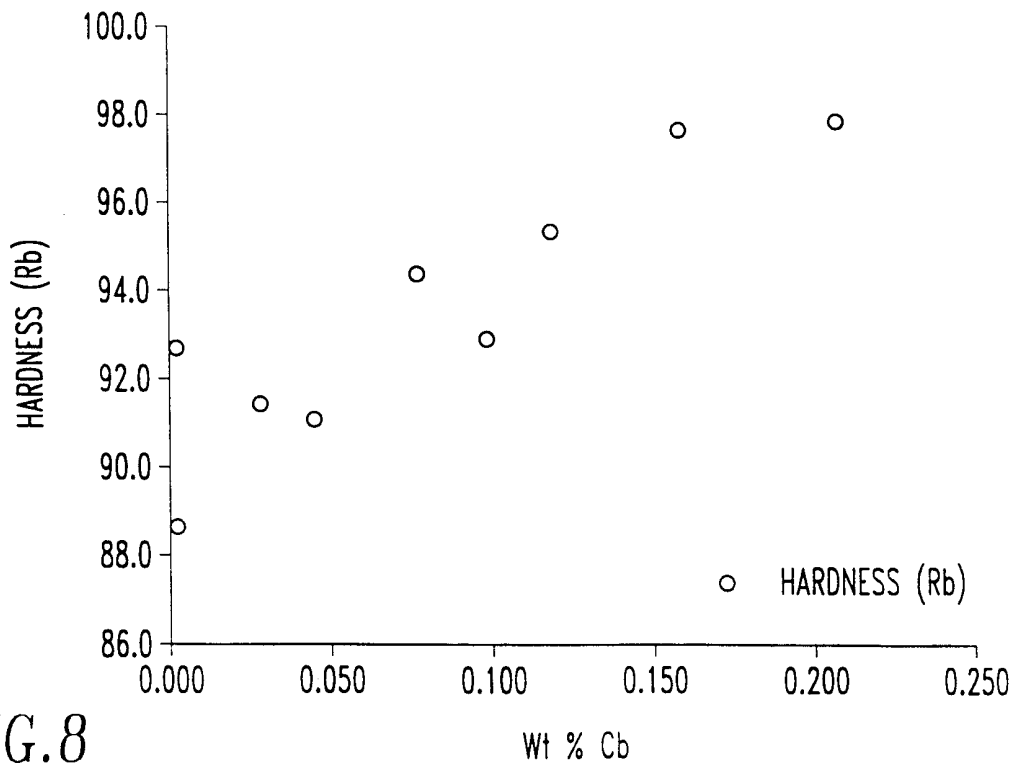
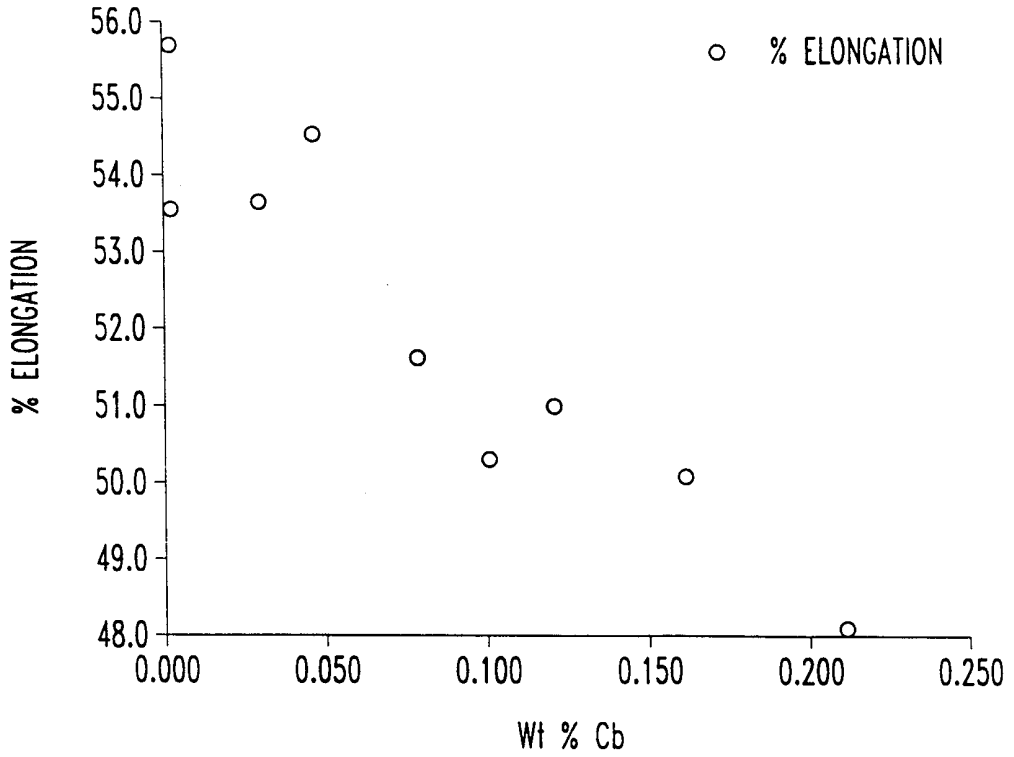


FIG. 8

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FIG. 9

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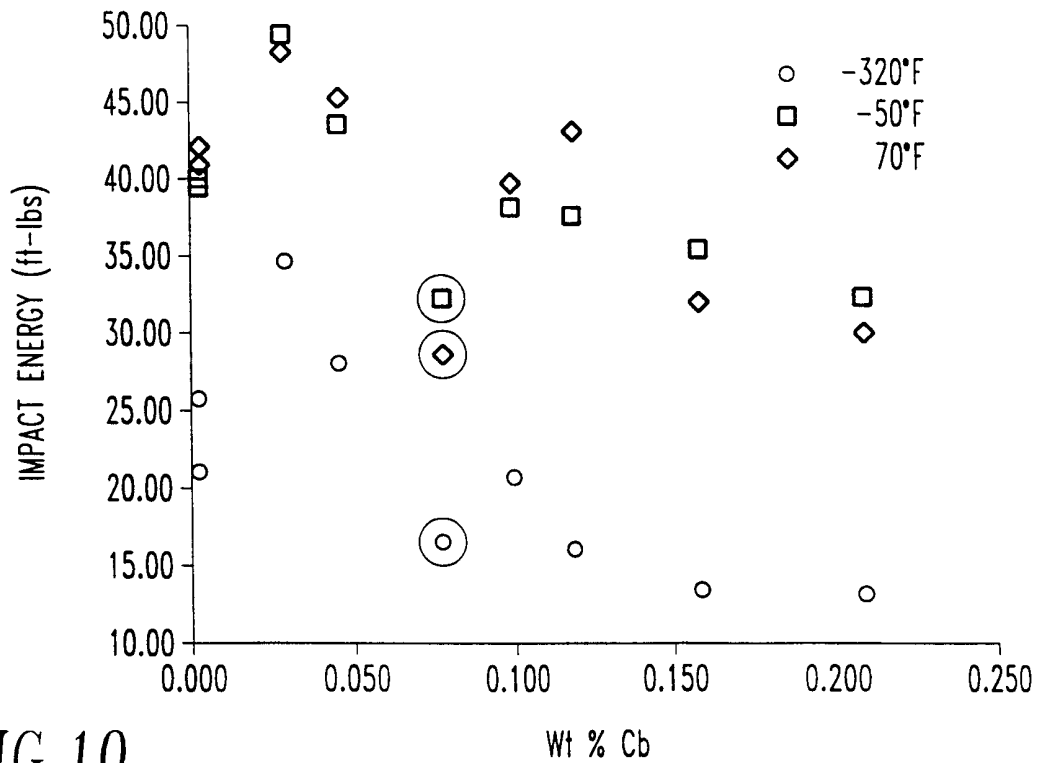
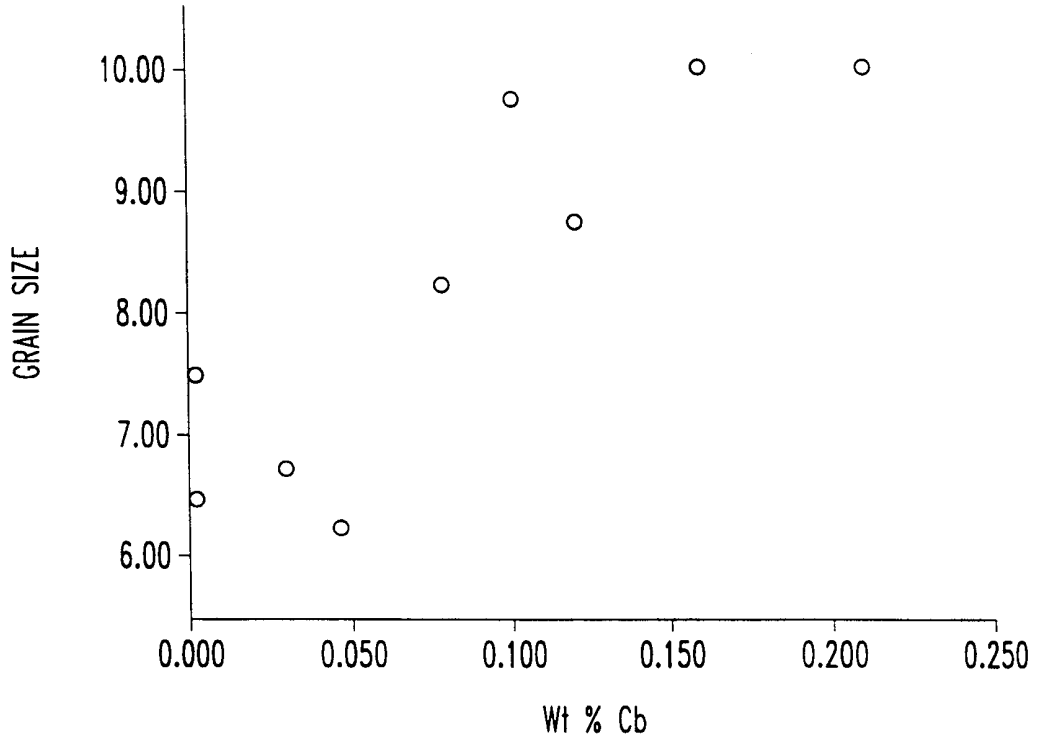


FIG. 10

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FIG. 11

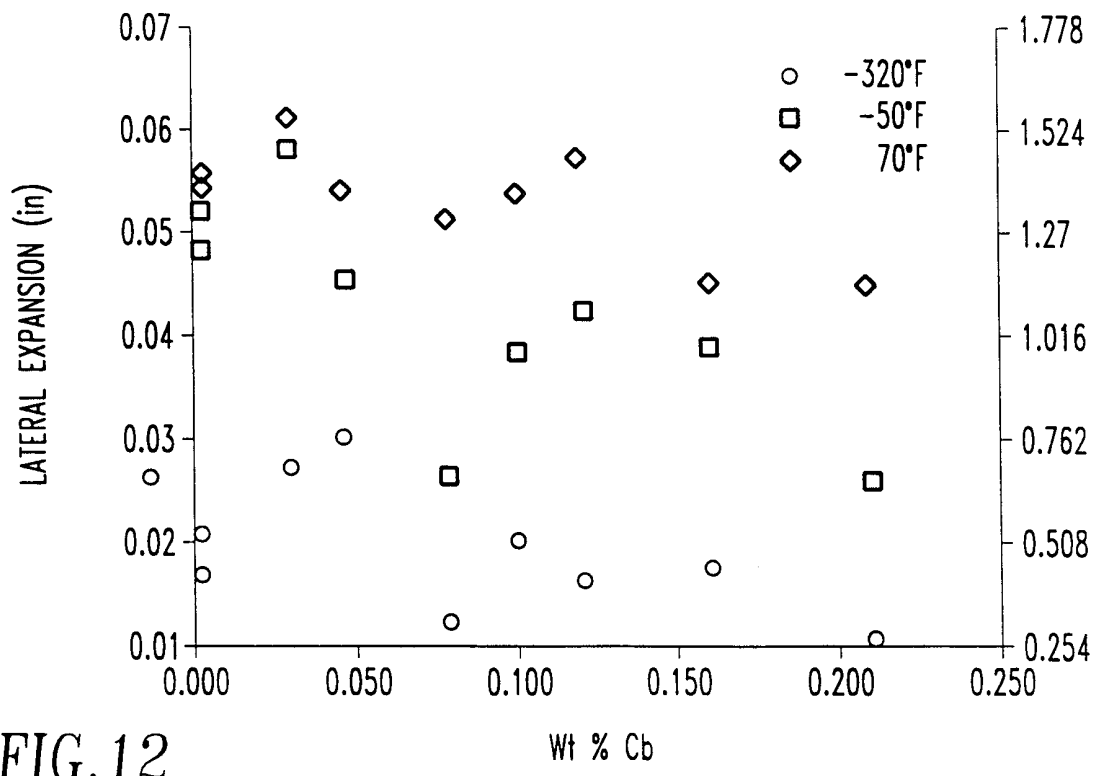
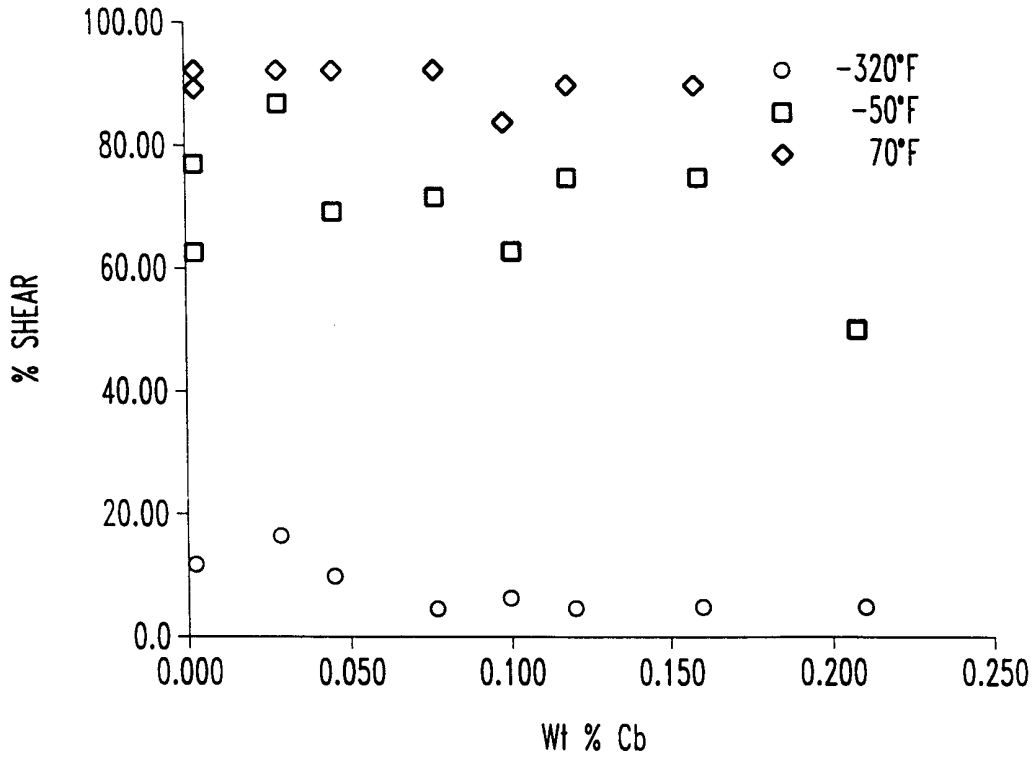


FIG. 12

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/27602

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C22C38/58

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 C22C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 096, no. 001, 31 January 1996 & JP 07 233444 A (NIPPON STEEL CORP), 5 September 1995 see abstract; example 17 ---	1-34
X	PATENT ABSTRACTS OF JAPAN vol. 006, no. 139 (C-116), 28 July 1982 & JP 57 063666 A (NISSHIN STEEL CO LTD), 17 April 1982 see abstract; examples SUS201,B ---	1-32
X	PATENT ABSTRACTS OF JAPAN vol. 018, no. 097 (C-1167), 17 February 1994 & JP 05 295486 A (NIPPON STEEL CORP), 9 November 1993 see abstract; example 13 ---	1-32
-/--		

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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- "&" document member of the same patent family

Date of the actual completion of the international search

29 March 1999

Date of mailing of the international search report

08/04/1999

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Authorized officer

Ashley, G

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/27602

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4 568 387 A (ZIEMIANSKI JOHN P) 4 February 1986 cited in the application see abstract ---	1-32
Y	EP 0 573 335 A (AUBERT & DUVAL SA) 8 December 1993 see page 3, line 4 - line 6 ---	1-32
A	PATENT ABSTRACTS OF JAPAN vol. 012, no. 387 (C-536), 14 October 1988 & JP 63 134627 A (KOBE STEEL LTD), 7 June 1988 see abstract ---	
A	PATENT ABSTRACTS OF JAPAN vol. 096, no. 004, 30 April 1996 & JP 07 314178 A (NIPPON STEEL CORP), 5 December 1995 see abstract -----	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No PCT/US 98/27602

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4568387 A	04-02-1986	CA 1238801 A	05-07-1988
		EP 0171868 A	19-02-1986
		JP 1626907 C	28-11-1991
		JP 2050980 B	06-11-1990
		JP 61019767 A	28-01-1986
EP 0573335 A	08-12-1993	FR 2691982 A	10-12-1993
		AT 149212 T	15-03-1997
		DE 69308234 D	03-04-1997
		DE 69308234 T	12-06-1997
		DE 573335 T	21-04-1994
		DK 573335 T	17-03-1997
		ES 2048128 T	16-03-1994
		GR 94300003 T	28-02-1994
		GR 3022903 T	30-06-1997