



US 20140065005A1

(19) **United States**

(12) **Patent Application Publication**
Yoshitake

(10) **Pub. No.: US 2014/0065005 A1**

(43) **Pub. Date: Mar. 6, 2014**

(54) **FERRITIC STAINLESS STEEL WITH
EXCELLENT OXIDATION RESISTANCE,
GOOD HIGH TEMPERATURE STRENGTH,
AND GOOD FORMABILITY**

C22C 38/06 (2006.01)
C22C 38/04 (2006.01)
C22C 38/02 (2006.01)
C22C 38/50 (2006.01)
C22C 38/44 (2006.01)

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(52) **U.S. Cl.**

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CPC *C22C 38/54* (2013.01); *C22C 38/50*
(2013.01); *C22C 38/48* (2013.01); *C22C 38/46*
(2013.01); *C22C 38/44* (2013.01); *C22C 38/42*
(2013.01); *C22C 38/06* (2013.01); *C22C 38/04*
(2013.01); *C22C 38/02* (2013.01); *C22C*
38/004 (2013.01); *C22C 38/001* (2013.01)

(21) Appl. No.: **13/837,500**

USPC **420/42**; 420/60; 420/61

(22) Filed: **Mar. 15, 2013**

Related U.S. Application Data

(60) Provisional application No. 61/695,771, filed on Aug.
31, 2012.

(57)

ABSTRACT

Publication Classification

(51) **Int. Cl.**

C22C 38/54 (2006.01)
C22C 38/48 (2006.01)
C22C 38/46 (2006.01)
C22C 38/00 (2006.01)
C22C 38/42 (2006.01)

Ferritic stainless steels with good oxidation resistance, and good high temperature strength and good formability are produced with Ti addition and low Al content for room temperature formability resulting from equiaxed as-cast grain structures. Columbium (niobium) and copper are added for high temperature strength. Silicon and manganese are added for oxidation resistance. The ferritic stainless steels provide better oxidation resistance than ferritic stainless steels of 18Cr-2Mo and 15Cr—Cb—Ti—Si—Mn. In addition, they are generally less costly to produce than 18Cr-2Mo.

**FERRITIC STAINLESS STEEL WITH
EXCELLENT OXIDATION RESISTANCE,
GOOD HIGH TEMPERATURE STRENGTH,
AND GOOD FORMABILITY**

[0001] This application is a non-provisional patent application claiming priority from provisional application Ser. No. 61/695,771, entitled "Ferritic Stainless Steels with Excellent Oxidation Resistance with Good High Temperature Strength and Good Formability," filed on Aug. 31, 2012. The disclosure of application Ser. No. 61/695,771 is incorporated herein by reference.

BACKGROUND

[0002] It is desirable to produce a ferritic stainless steel with oxidation resistance, high temperature strength, and good formability characteristics. Columbium and copper are added in amounts to provide high temperature strength, and silicon and manganese are added in amounts to provide oxidation resistance. The present ferritic stainless steel provides better oxidation resistance than known stainless steels such as 18Cr-2Mo and 15Cr—Cb—Ti—Si—Mn. In addition, the present ferritic stainless steel is less expensive to manufacture than other stainless steels such as 18Cr-2Mo.

SUMMARY

[0003] The present ferritic stainless steel are produced with titanium additions and low aluminum concentration to provide room temperature formability from equiaxed as-cast grain structures, as disclosed in U.S. Pat. Nos. 6,855,213 and 5,868,875, the complete disclosures of which are each incorporated by reference herein. Columbium and copper are added to the ferritic stainless steel for high temperature strength and silicon and manganese are added to improve oxidation resistance.

**DETAILED DESCRIPTION OF THE PREFERRED
EMBODIMENT**

[0004] The ferritic stainless steel is produced using process conditions known in the art for use in manufacturing ferritic stainless steels, such as the processes described in U.S. Pat. Nos. 6,855,213 and 5,868,875. Columbium and copper are added to the ferritic stainless steel for high temperature strength and silicon and manganese are added to improve oxidation resistance. It can be produced from material having an as-cast structure of fine equiaxed grains.

[0005] A ferrous melt for the ferritic stainless steel is provided in a melting furnace such as an electric arc furnace. This ferrous melt may be formed in the melting furnace from solid iron bearing scrap, carbon steel scrap, stainless steel scrap, solid iron containing materials including iron oxides, iron carbide, direct reduced iron, hot briquetted iron, or the melt may be produced upstream of the melting furnace in a blast furnace or any other iron smelting unit capable of providing a ferrous melt. The ferrous melt then will be refined in the melting furnace or transferred to a refining vessel such as an argon-oxygen-decarburization vessel or a vacuum-oxygen-decarburization vessel, followed by a trim station such as a ladle metallurgy furnace or a wire feed station.

[0006] In some embodiments, the steel is cast from a melt containing sufficient titanium and nitrogen but a controlled amount of aluminum for forming small titanium oxide inclusions to provide the necessary nuclei for forming the as-cast

equiaxed grain structure so that an annealed sheet produced from this steel also has enhanced ridging characteristics.

[0007] In some embodiments, titanium is added to the melt for deoxidation prior to casting. Deoxidation of the melt with titanium forms small titanium oxide inclusions that provide the nuclei that result in an as-cast equiaxed fine grain structure. To minimize formation of alumina inclusions, i.e., aluminum oxide, Al_2O_3 , aluminum may not be added to this refined melt as a deoxidant. In some embodiments, titanium and nitrogen can be present in the melt prior to casting so that the ratio of the product of titanium and nitrogen divided by residual aluminum is at least about 0.14.

[0008] If the steel is to be stabilized, sufficient amount of the titanium beyond that required for deoxidation can be added for combining with carbon and nitrogen in the melt but preferably less than that required for saturation with nitrogen, i.e., in a sub-equilibrium amount, thereby avoiding or at least minimizing precipitation of large titanium nitride inclusions before solidification. The maximum amount of titanium for "sub-equilibrium" is generally illustrated in FIG. 4 of U.S. Pat. No. 4,964,926, the disclosure of which is incorporated herein by reference. In some embodiments, one or more stabilizing elements such as columbium, zirconium, tantalum and vanadium can be added to the melt as well.

[0009] The cast steel is hot processed into a sheet. For this disclosure, the term "sheet" is meant to include continuous strip or cut lengths formed from continuous strip and the term "hot processed" means the as-cast steel will be reheated, if necessary, and then reduced to a predetermined thickness such as by hot rolling. If hot rolled, a steel slab is reheated to 2000° to 2350° F. (1093°-1288° C.), hot rolled using a finishing temperature of 1500-1800° F. (816-982° C.) and coiled at a temperature of 1000-1400° F. (538-760° C.). The hot rolled sheet is also known as the "hot band." In some embodiments, the hot band may be annealed at a peak metal temperature of 1700-2100° F. (926-1149° C.). In some embodiments, the hot band may be descaled and cold reduced at least 40% to a desired final sheet thickness. In other embodiments, the hot band may be descaled and cold reduced at least 50% to a desired final sheet thickness. Thereafter, the cold reduced sheet can be final annealed at a peak metal temperature of 1800-2100° F. (982-1149° C.).

[0010] The ferritic stainless steel can be produced from a hot processed sheet made by a number of methods. The sheet can be produced from slabs formed from ingots or continuous cast slabs of 50-200 mm thickness which are reheated to 2000° to 2350° F. (1093°-1288° C.) followed by hot rolling to provide a starting hot processed sheet of 1-7 mm thickness or the sheet can be hot processed from strip continuously cast into thicknesses of 2-26 mm. The present process is applicable to sheet produced by methods wherein continuous cast slabs or slabs produced from ingots are fed directly to a hot rolling mill with or without significant reheating, or ingots hot reduced into slabs of sufficient temperature to be hot rolled in to sheet with or without further reheating.

[0011] Titanium is used for deoxidation of the ferritic stainless steel melt prior to casting. The amount of titanium in the melt can be 0.30% or less. Unless otherwise expressly stated, all concentrations stated as "%" are percent by weight. In some embodiments, titanium can be present in a sub-equilibrium amount. As used herein, the term "sub-equilibrium" means the amount of titanium is controlled so that the solubility product of the titanium compounds formed are below the saturation level at the steel liquidus temperature thereby

avoiding excessive titanium nitride precipitation in the melt. Excessive nitrogen is not a problem for those manufacturers that refine ferritic stainless steel melts in an argon oxygen decarburization vessel. Nitrogen substantially below 0.010% can be obtained when refining the stainless steel in an argon oxygen decarburization vessel thereby allowing increased amount of titanium to be tolerated and still be at sub-equilibrium.

[0012] To provide the nucleation sites necessary for forming as-cast equiaxed ferrite grains, sufficient time after adding the titanium to the melt should elapse to allow the titanium oxide inclusions to form before casting the melt. If the melt is cast immediately after adding titanium, the as-cast structure of the casting can include larger columnar grains. The amount of time that should elapse can be determined by one of ordinary skill in the art without undue experimentation. Ingots cast in the laboratory less than 5 minutes after adding the titanium to the melt had large as-cast columnar grains even when the product of titanium and nitrogen divided by residual aluminum was at least 0.14.

[0013] Sufficient nitrogen should be present in the steel prior to casting so that the ratio of the product of titanium and nitrogen divided by aluminum is at least about 0.14. In some embodiments, the amount of nitrogen present in the melt is $\leq 0.020\%$.

[0014] Although nitrogen concentrations after melting in an electric arc furnace may be as high as 0.05%, the amount of dissolved N can be reduced during argon gas refining in an argon oxygen decarburization vessel to less than 0.02%. Precipitation of excessive TiN can be avoided by reducing the sub-equilibrium amount of Ti to be added to the melt for any given nitrogen content. Alternatively, the amount of nitrogen in the melt can be reduced in an argon oxygen decarburization vessel for an anticipated amount of Ti contained in the melt.

[0015] Total residual aluminum can be controlled or minimized relative to the amounts of titanium and nitrogen. Minimum amounts of titanium and nitrogen must be present in the melt relative to the aluminum. The ratio of the product of titanium and nitrogen divided by residual aluminum can be at least about 0.14 in some embodiments, and at least 0.23 in other embodiments. To minimize the amounts of titanium and nitrogen required in the melt, the amount of aluminum is $< 0.020\%$ in some embodiments. In other embodiments, the amount of aluminum is $\leq 0.013\%$ and in other embodiments, it is reduced to $\leq 0.010\%$. If aluminum is not purposefully alloyed with the melt during refining or casting such as for deoxidation immediately prior to casting, total aluminum can be controlled or reduced to less than 0.020%. One must be aware that aluminum can be inadvertently added to the melt as an impurity present in an alloy addition of another element, e.g., titanium. Titanium alloys may contain as much as 20% Al which may contribute total Al to the melt. By carefully controlling the refining and casting practices, a melt containing $< 0.020\%$ aluminum can be obtained.

[0016] In addition to using titanium for stabilization, other suitable stabilizing elements may also include columbium, zirconium, tantalum, vanadium or mixtures thereof. In some embodiments, if a second stabilizing element is used in combination with titanium, e.g., columbium or vanadium, this second stabilizing element may be limited to $\leq 0.50\%$ when deep formability is required. Some embodiments include columbium in concentrations of 0.05% or less. Some embodiments include columbium in concentrations of 0.28-0.43%.

Vanadium can be present in amounts less than 0.5%. Some embodiments of the ferritic stainless steels include 0.008-0.098% vanadium.

[0017] Copper improves high temperature strength. The ferritic stainless steels contain 1.0-2.0% copper. Some embodiments include 1.16-1.31% copper.

[0018] Silicon is generally present in the ferritic stainless steels in an amount of 1.0-1.7%. In some embodiments, silicon is present in an amount of 1.27-1.35%. A small amount of silicon generally is present in a ferritic stainless steel to promote formation of the ferrite phase. Silicon also enhances high temperature oxidation resistance and provides high temperature strength. In most embodiments, silicon does not exceed about 1.7% because the steel can become too hard and the elongation can be adversely affected.

[0019] Manganese is present in the ferritic stainless steel in an amount of 0.4-1.5%. In some embodiments, manganese is present in an amount of 0.98-1.00%. Manganese improves oxidation resistance and spalling resistance at high temperatures. Accordingly, some embodiments include manganese in amounts of at least 0.4%. However, manganese is an austenite former and affects the stabilization of the ferrite phase. If the amount of manganese exceeds about 1.5%, the stabilization and formability of the steel can be affected.

[0020] Carbon is present in the ferritic stainless steel in an amount of up to 0.02%. In some embodiments, the carbon content is $\leq 0.02\%$. In still other embodiments, it is 0.0010-0.01%.

[0021] Chromium is present in some embodiments of the ferritic stainless steels in an amount of 15-20%. If chromium is greater than about 25%, the formability of the steel can be reduced.

[0022] In some embodiments, oxygen is present in the steel in an amount < 100 ppm. When a steel melt is prepared sequentially in an argon oxygen decarburization refining vessel and a ladle metallurgy furnace alloying vessel, oxygen in the melt can be within the range of 10-60 ppm thereby providing a very clean steel having small titanium oxide inclusions that aid in forming the nucleation sites responsible for the fine as-cast equiaxed grain structure.

[0023] Sulfur is present in the ferritic stainless steel in an amount of $\leq 0.01\%$.

[0024] Phosphorus can deteriorate formability in hot rolling and can cause pitting. It is present in the ferritic stainless steel in an amount of $\leq 0.05\%$.

[0025] Like manganese, nickel is an austenite former and affects the stabilization of the ferrite phase. Accordingly, in some embodiments, nickel is limited to $\leq 1.0\%$. In some embodiments, nickel is present in amounts of 0.13-0.19%.

[0026] Molybdenum also improves corrosion resistance. Some embodiments include 3.0% or less molybdenum. Some embodiments include 0.03-0.049% molybdenum.

[0027] For some applications, it may be desirable to include boron in the steels of the present invention in an amount of $\leq 0.010\%$. In some embodiments, boron is present in an amount of 0.0001-0.002%. Boron can improve the resistance to secondary work embrittlement of steel so that the steel sheet will be less likely to split during deep drawing applications and multi-step forming applications.

[0028] In some embodiments, the ferritic stainless steels may also include other elements known in the art of steel-making that can be made either as deliberate additions or present as residual elements, i.e., impurities from steelmaking process.

Example 1

[0029] Embodiments of the ferritic stainless steels and comparative reference steels were made in the laboratory with the compositions set forth in Table 1 below.

[0030] The materials identified as “Lab Materials” were processed on laboratory equipment according to the following parameters. Each ingot was reheated to a temperature of 2300° F. (1260° C.). It was hot rolled to a strip thickness of 0.200" (5.08 mm). It was then hot band annealed at a temperature of 1825-1975° C. (996-1079° C.). It was then cold rolled to a thickness of 0.079-0.098" (2.0-2.5 mm). The cold rolled strip was final annealed to a temperature of 1885-1950° F. (1029-1066° C.).

[0031] The materials identified as “Plant Material” were processed on production equipment in the plant according to the following parameters. Each slab was reheated to a temperature of 2273-2296° F. (1245-1258° C.). It was then hot rolled to a strip thickness of 0.200-0.180" (5.08-4.57 mm). The hot rolled strip was then hot band annealed to a temperature of 1950-2000° F. (1066-1083° C.). After cold rolling to 0.079-0.059" (2.0-1.5 mm), the strip was final annealed to a temperature of 1900-2000° F. (1038-1093° C.).

[0032] The materials identified as “Invention” in the remarks are embodiments of the ferritic stainless steels of the present disclosure. The materials identified as “Reference” are not embodiments of the ferritic stainless steels of the present disclosure. In fact, two are well-known prior products: HT #831187 is Type 444 stainless steel and HT #830843 is 15 CrCb stainless steel, which is a product of AK Steel Corporation, West Chester, Ohio.

Example 2

[0033] The oxidation resistance of several of the steel compositions described in Example 1 and Table 1 above was tested at 930° C. for 200 hours in air. The results of the tests are set forth in Table 2 below. The individual compositions are each identified by their respective ID number. The oxidation resistance was evaluated two factors. One was the amount of weight gain, and the other was degree of spalling. For each material, except HT #920097, the reported weight gain value is an average of two tests. For HT #920097, eight samples were tested and the minimum, average, and maximum of these eight tests has been reported.

TABLE 1

Chemical compositions in weight %.																	
ID	Description	Al	B	C	Cb	Cr	Cu	Mn	Mo	N	Ni	P	S	Si	Ti	V	Remarks
V3924	Lab Material	.007	<.0005	.0090	.40	16.70	1.27	1.00	.048	.019	.16	.031	.0016	1.27	.14	.071	Invention
V3925	Lab Material	.009	<.0005	.0054	.43	16.98	1.31	1.00	.049	.012	.16	.033	.0014	1.33	.21	.074	Invention
V3926	Lab Material	.010	<.0005	.0077	.43	16.90	1.28	1.00	.048	.012	.16	.031	.0016	1.31	.25	.080	Invention
V3929	Lab Material	.014	<.0005	.0094	.40	16.56	1.26	.98	.048	.014	.15	.030	.0015	1.28	.17	.073	Invention
V3954	Lab Material	.006	.0020	.014	.30	16.99	1.27	.99	.048	.012	.14	.027	.0016	1.33	.16	.008	Invention
V3955	Lab Material	.010	<.0005	.0085	.28	17.06	1.23	.99	.049	.0082	.14	.028	.0016	1.35	.16	.082	Invention
V3956	Lab Material	.016	<.0005	.0089	.39	16.92	1.23	.99	.048	.0087	.14	.026	.0017	1.32	.17	.078	Invention
V3957	Lab Material	.015	.0017	.0084	.41	16.90	1.28	.99	.048	.0084	.14	.026	.0016	1.32	.17	.075	Invention
V3958	Lab Material	.016	.0017	.0090	.40	16.93	1.24	.99	.048	.0076	.14	.027	.0017	1.32	.16	.078	Invention
V3959	Lab Material	.009	.0020	.0082	.31	17.35	1.27	.99	.049	.0077	.13	.026	.0018	1.31	.15	.078	Invention
V3960	Lab Material	.007	.0007	.0085	.37	17.40	1.27	.99	.048	.0086	.14	.026	.0017	1.33	.16	.078	Invention
V3961	Lab Material	.008	<.0005	.013	.29	16.95	1.28	.99	.048	.011	.14	.025	.0016	1.32	.16	.074	Invention
V3962	Lab Material	.009	.0019	.0093	.30	16.93	1.28	.99	.048	.0082	.14	.026	.0016	1.33	.17	.078	Invention
HT #920097	Plant Material	.010	.0001	.0114	.33	17.01	1.16	.98	.030	.009	.19	.026	.0015	1.30	.18	.098	Invention
V3918	Lab Material	.012	<.0005	.012	.44	16.78	1.28	.28	.048	.010	.16	.031	.0015	.58	.21	.076	Reference
V3920	Lab Material	.012	<.0005	.011	.46	16.88	1.28	.28	.049	.010	.16	.031	.0017	.94	.25	.076	Reference
V3921	Lab Material	.012	<.0005	.0081	.45	16.82	1.28	.28	.049	.010	.16	.030	.0015	1.34	.27	.078	Reference
V3922	Lab Material	.009	<.0005	.0084	.32	16.86	1.28	.28	.048	.010	.16	.030	.0014	1.32	.27	.080	Reference
HT #831187 (444)	Plant Material	.009	.0060	.010	.17	17.58	.09	.35	1.90	.0114	.23	.022	.0005	.44	.20	.066	Reference
HT #830843 (15 Cr-Cb)	Plant Material	.010	.0002	.0086	.37	14.32	.08	1.01	.010	.0077	.14	.022	.0010	1.27	.25	.045	Reference

TABLE 2

Oxidation resistance test results at 930° C. for 200 hours in air.											
	Chemical Composition (weight %)								Weight Gain	Spalling	Remarks
	C	Cb	Cr	Cu	Mn	N	Si	Ti	(mg/cm ²)	(Scale Off)	
V3954	.014	.30	16.99	1.27	.99	.012	1.33	.16	1.34	No	Invention
V3924	.0090	.40	16.70	1.27	1.00	.019	1.27	.14	1.40	No	Invention
V3929	.0094	.40	16.56	1.26	.98	.014	1.28	.17	1.44	No	Invention
V3956	.0089	.39	16.92	1.23	.99	.0087	1.32	.17	1.14	Partial*	Invention
V3955	.0085	.28	17.06	1.23	.99	.0082	1.35	.16	1.15	Partial*	Invention

TABLE 2-continued

Oxidation resistance test results at 930° C. for 200 hours in air.											
	Chemical Composition (weight %)								Weight Gain (mg/cm ²)	Spalling (Scale Off)	Remarks
	C	Cb	Cr	Cu	Mn	N	Si	Ti			
V3961	.013	.29	16.95	1.28	.99	.011	1.32	.16	1.17	Partial*	Invention
V3960	.0085	.37	17.40	1.27	.99	.0086	1.33	.16	1.19	Partial*	Invention
V3958	.0090	.40	16.93	1.24	.99	.0076	1.32	.16	1.20	Partial*	Invention
V3957	.0084	.41	16.90	1.28	.99	.0084	1.32	.17	1.21	Partial*	Invention
V3959	.0082	.31	17.35	1.27	.99	.0077	1.31	.15	1.22	Partial*	Invention
V3962	.0093	.30	16.93	1.28	.99	.0082	1.33	.17	1.37	Partial*	Invention
V3925	.0054	.43	16.98	1.31	1.00	.012	1.33	.21	1.43	Partial*	Invention
V3926	.0077	.43	16.90	1.28	1.00	.012	1.31	.25	1.47	Partial*	Invention
HT #920097	.0114	.33	17.01	1.16	.98	.009	1.30	.18	1.63 Min 1.70 Ave 1.74 Max	No	Invention
V3918	.012	.44	16.78	1.28	.28	.010	.58	.21	-0.14	Severe	Reference
V3920	.011	.46	16.88	1.28	.28	.010	.94	.25	-1.77	Very Severe	Reference
V3922	.0084	.32	16.86	1.28	.28	.010	1.32	.27	-1.98	Very Severe	Reference
V3921	.0081	.45	16.82	1.28	.28	.010	1.34	.27	-2.48	Very Severe	Reference
444	.010	.17	17.58	.09	.35	.0114	.44	.20	0.88	Severe	Reference
15Cr-Cb	.0086	.37	14.32	.08	1.01	.0077	1.27	.25	1.29	Severe	Reference

*"Partial" means that spalling occurred just around the edges of the specimens and a few small spots away from the edges.

Example 3

[0034] The longitudinal high temperature tensile properties of several of the steel compositions of Example 1 were tested according to the procedure of ASTM Standard E21 tensile test. The results of these tests are set forth below:

Example 4

[0035] The longitudinal tensile properties of several of the steel compositions of Example 1 were tested according to the procedure of ASTM Standard E8/E8M test. In addition, the stretch-r values were tested according to the procedure of ASTM Standard E517. Ridging resistance of the composi-

TABLE 3

Longitudinal high temperature tensile properties. (ASTM Standard E21 tensile tests).											
ID	600° C.			700° C.			800° C.			Average	Remarks
	Gauge (mm)	.2% YS (MPa)	UTS (MPa)	Gauge (mm)	.2% YS (MPa)	UTS (MPa)	Gauge (mm)	.2% YS (MPa)	UTS (MPa)	.2% YS at Three Temp.	
V3924	2.03	260	372	2.00	116	126	2.03	37.2	46.9	138	Invention
V3925	2.01	241	391	2.05	151	160	2.01	41.0	50.6	144	Invention
V3926	2.00	265	385	2.03	142	150	2.00	39.3	49.6	149	Invention
V3929	2.01	262	381	2.01	125	135	2.01	37.9	48.9	141	Invention
V3954	2.02	244	348	2.04	135	165	2.03	24.1	35.1	134	Invention
V3955	2.04	239	352	2.05	147	178	2.06	32.0	44.1	139	Invention
V3956	2.05	245	354	2.06	134	150	2.05	40.7	49.3	140	Invention
V3957	2.05	257	376	2.05	100	122	2.06	38.6	50.0	132	Invention
V3958	2.02	246	369	2.04	107	121	2.04	40.0	50.0	131	Invention
V3959	2.03	238	352	2.05	96	120	2.05	34.5	45.8	123	Invention
V3960	2.03	252	370	2.05	102	118	2.05	36.9	49.3	130	Invention
V3961	2.02	244	353	2.03	160	185	2.03	31.0	43.1	145	Invention
V3962	2.03	243	356	2.04	108	126	2.05	34.8	46.2	129	Invention
HT #920097 CL	2.00	247	373	2.00	148	167	2.01	36.6	46.9	144	Invention
#F06626											
HT #920097 CL	2.03	256	373	2.03	144	172	2.02	38.0	47.6	146	Invention
#F06629											
V3918	2.01	245	370	2.02	153	166	2.02	40.0	51.3	146	Reference
V3920	2.02	251	382	1.99	167	195	2.02	38.9	49.6	152	Reference
V3921	2.01	260	383	2.00	137	151	2.00	36.5	47.5	145	Reference
V3922	2.05	247	373	2.03	146	154	2.04	40.3	49.3	144	Reference

tions was also determined on a qualitative scale of 0-6, where 0 is the best and 6 is unacceptable. The results of these tests are set forth below:

TABLE 4

Longitudinal tensile properties (ASTM E8/E8M), stretch r-values, and ridging resistances.								
Lab ID	Longitudinal ASTM Tensile					Stretch r-bar	Ridging (0-6)	Remarks
	Gauge (mm)	.2% YS (MPa)	UTS (MPa)	EL (%)	HRB			
V3926	2.02	475	613	27.5	93.0	1.01	3	Invention
	2.02	476	614	27.7	92.8		2	
V3925	2.02	465	598	27.6	92.4	1.21	2	Invention
	2.02	466	600	28.6	92.0		2	
V3929	2.03	432	563	31.4	89.8	1.37	1	Invention
	2.03	430	563	31.4	89.6		2	
V3924	2.05	451	579	29.9	90.5	1.24	2	Invention
	2.04	452	580	30.0	89.9		1	
V3955	2.01	425	552	31.2	88.0	1.16	1	Invention
	2.02	422	547	30.5	88.2			
V3956	2.01	411	542	31.3	87.7	0.98	1	Invention
	2.02	407	538	30.4	87.5			
V3961	2.05	449	572	29.0	89.8	1.31	1	Invention
	2.04	443	569	29.4	90.0			
V3954	2.04	447	571	28.8	90.4	1.16	1	Invention
	2.04	446	570	29.0	89.6			
V3962	2.07	451	580	28.8	90.5	1.29	1	Invention
	2.07	451	577	30.1	90.0			
V3957	2.01	454	587	27.1	91.6	1.16	1	Invention
	2.01	448	581	28.7	90.8			
V3958	2.05	428	570	27.9	89.2	1.14	1	Invention
	2.05	429	569	29.5	89.1			
V3959	2.07	461	585	28.0	90.9	1.19	1	Invention
	2.07	459	583	28.7	90.2			
V3960	2.06	458	586	29.1	90.5	1.15	1	Invention
	2.06	452	581	28.8	90.7			
V3918	1.99	379	508	33.4	84.9	1.45	1	Reference
	1.99	381	510	33.5	84.8		1	
V3920	2.05	426	556	30.5	89.4	1.13	1	Reference
	2.05	424	555	31.1	89.3		1	
V3921	2.02	477	618	26.9	92.7	1.04	2	Reference
	2.02	474	616	26.5	92.4		3	
V3922	2.04	416	543	33.1	88.4	1.21	1	Reference
	2.03	414	543	32.4	88.2		1	

Example 4

[0036] The longitudinal tensile properties of several of the steel compositions of Example 1 were tested according to the procedure of ASTM Standard E8/E8M test. In addition, the

stretch-r values were tested according to the procedure of ASTM Standard E517. Ridging resistance of the compositions was also determined on a qualitative scale of 0-6, where 0 is the best and 6 is unacceptable. The results of these tests are set forth below:

TABLE 5

Longitudinal tensile properties (ASTM E8/E8M), stretch r-values, and ridging resistances.								
Coil ID Position	Longitudinal ASTM Tensile					Stretch r-bar	Ridging (0-6)	Remarks
	Gauge (mm)	.2% YS (MPa)	UTS (MPa)	EL (%)	HRB			
681730-02	2.01	403	534	33.1	86.3	1.22	0	Invention
Head	2.01	404	535	32.6	86.2		0	
681730-02	1.97	402	532	32.8	86.4	1.24	0	Invention
Tail	1.97	402	532	32.6	86.3		0	
681730-05	2.03	400	530	32.4	86.0	1.37	0	Invention
Head	2.03	398	529	32.7	86.2		0	
681730-05	2.03	404	534	32.7	86.4	1.20	0	Invention
Tail	2.03	404	534	33.8	86.6		0	
681727-02	1.51	405	537	31.8	86.4	1.34	0	Invention
Head	1.51	406	537	31.0	86.4		0	

TABLE 5-continued

Longitudinal tensile properties (ASTM E8/E8M), stretch r-values, and ridging resistances.								
HT #920097								
Longitudinal ASTM Tensile								
Coil ID Position	Gauge (mm)	.2% YS (MPa)	UTS (MPa)	EL (%)	HRB	r-bar	Ridging (0-6)	Remarks
681727-02	1.61	401	530	32.6	86.0	1.31	0	Invention
Tail	1.61	401	530	32.3	86.3		0	
681727-01A	1.53	398	530	31.8	85.8	1.38	0	Invention
Head	1.53	401	532	32.1	86.0		0	
681727-01A	1.56	401	532	31.7	86.2	1.34	0	Invention
Tail	1.56	401	532	32.5	85.9		0	

[0037] It will be understood various modifications may be made to this invention without departing from the spirit and scope of it. Therefore, the limits of this invention should be determined from the appended claims.

What is claimed is:

1. A ferritic stainless steel comprising the following elements by weight percent:

0.020% or less carbon
 0.020% or less nitrogen
 15-20% chromium
 0.30% or less titanium
 0.50% or less columbium
 1.0-2.00% copper

1.0-1.7% silicon
 0.4-1.5% manganese
 0.050% or less phosphorus
 0.01% or less sulfur
 0.020% or less aluminum

2. The ferritic stainless steel of claim 1, further comprising at least one of the following elements by weight percent:

3.0% or less molybdenum
 0.010% or less boron
 0.5% or less vanadium
 1.0% or less nickel

* * * * *