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ALLOY STEEL AND METHOD

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My invention, relating to alloy steels and products fashioned thereof, is closely related to that described in my copending application for patent, Ser. No. 105,878, filed Apr. 27, 1961, and entitled, Stainless Steel Product and Method now U.S. Letters Patent 3,100,729 of Aug. 13, 1963.

One of the objects of my present invention is the provision of a corrosion-resisting alloy steel which possesses good hot-rolling characteristics, and good cold-working and cold-forming properties.

Another object is the provision of an austenitic chrominum-nickel-manganese stainless steel which in the form of sheet, strip, wire and the like lends itself to a variety of cold-forming operations such as bending, pressing and drawing, as well as machining as by cutting, drilling and threading, and moreover is possessed of good welding properties and good corrosion-resisting properties in the as-welded condition and in the annealed condition following welding.

A further object of my invention is the provision of such alloy steel sheet, strip, wire, and the like of good fatigue resistance in combination with good resistance to wear and abrasion and to a method for producing the same.

A still further object is the provision of woven wire belting, especially belting with welded or brazed seam or joint, which is strong, durable, and suited to duty at high speeds over long periods of time.

Other objects of my invention in part will be apparent and in part pointed to in the description which follows.

My invention will be seen to reside in the combination of alloying ingredients and in the relation between the same, in the several operational steps and temperatures of treatment employed and the relation between operational steps and treating temperatures, and in the particular products and articles fashioned of the steel without and with treatment, all as more fully described herein and particularly set out in the claims at the end of this specification.

Now in order to gain a better understanding of certain features of my invention, it may be well to note here that there is a wide variety of alloy steels, particularly including corrosion-resisting and heat-resisting steels, which have gained acceptance in the art. These steels essentially contain chromium in the amount of at least 10%. In many of the grades there is additionally included nickel from incidental percentages on up. And many include manganese. Silicon, too, which commonly is present in corrosion-resisting and heat-resisting steels, may amount to as much as 3% or 4% for special purposes. Carbon is present in amounts up to about 1.5%. Certain of the corrosion-resisting and heat-resisting steels additionally contain special additions of molybdenum, tungsten, cobalt, copper, titanium, columbium and vanadium in small amounts.

The more popular grades of corrosion-resisting chromium-nickel stainless steels are the type 304 (18% to 20% chromium, 8% to 12% nickel, and remainder iron), type 309 (22% to 24% chromium, 12% to 15% nickel, 2% manganese, and remainder iron), the type 310 (24% to 26% chromium, 19% to 22% nickel, 2% manganese, and remainder iron), the type 316 (16% to 18% chromium, 10% to 14% nickel, 2% to 3% molybdenum, and remainder iron), the type 321 (17% to 19% chromium, 9% to 12% nickel, 0.4% titanium, and remainder iron),

and the type 347 (17% to 19% chromium, 9% to 13% nickel, 0.8% columbium, and remainder iron). The more popular grades of chromium-nickel-manganese stainless steels are the type 201 (16% to 18% chromium, 3.5% to 5.5% nickel, 5.5% to 7.5% manganese, and remainder iron) and the type 202 (17% to 19% chromium, 4% to 6% nickel, 7.5% to 10% manganese, and remainder iron).

Many of the steels identified above are possessed of excellent resistance to corrosion in a variety of room temperature applications. Moreover, some are found to have good resistance at elevated temperatures. Many, in the form of plate, sheet, strip, bar, rod, wire and the like lend themselves to a variety of forming operations in the production of a host of articles of ultimate use. Others are lacking in formability. And there are those which weld only with difficulty and suffer in corrosion resistance following a welding operation. None enjoys a full complement of formability, weldability, wear-resistance, corrosion-resistance and fatigue-resistance.

More specifically, in the art of paper-making where there conventionally is employed a Fourdrinier machine with woven wire belting upon which paper pulp is charged for processing and the elimination of moisture, a Grade C Phosphor bronze (92% copper and 8% tin) commonly is used. The corrosion-resisting steels generally are conceded to be unsuitable for this application; they are lacking in fatigue strength. Under the exacting conditions encountered in use, the corrosion-resisting steels deteriorate in a matter of days. And even the Phosphor bronze may only last a matter of weeks or months, this depending, of course, upon the particular duty. For example, in making paperboard, even a Phosphor bronze Fourdrinier wire belt may last only about 7 days. The belting for newsprint may last some 7 to 14 days. For special papers using comparatively slow speeds of operation, the Phosphor bronze belt may last as much as 3 months. The principal causes of belt failure are mechanical wear and mechanical fatigue.

While stainless steel is well adapted to withstand the mechanical wear and corrosive attack encountered in paper-making operations, the life is short as a result of fatigue failure, particularly pointed to in the descriptive portions of my companion application for patent identified above. And the welded or brazed portions of the belting are especially inclined to deterioration.

An object of my present invention, therefore, is the provision of an austenitic chromium-nickel-manganese stainless steel in which there is had a combination of good hot-working properties; good cold-working properties, as in the production of cold-rolled sheet and strip and cold-drawn wire; good cold-forming properties, notably bending, drawing, deep-drawing, upsetting, cutting, threading and the like; good welding properties; and good resistance to corrosive attack after welding, that is, in the as-welded condition and in the annealed condition following welding. A further object is the provision of a method for treating such steel to achieve strip and wire of good corrosion-fatigue resistance, in combination with good welding characteristics and long life under the demanding conditions of Fourdrinier wire belting and other applications where a variety of stresses are encountered under conditions of corrosive attack.

Referring now more particularly to the practice of my invention, I provide an allow steel essentially consisting of the five alloying ingredients chromium, nickel, manganese, silicon and nitrogen, with remainder substantially all iron. The chromium content amounts to 16% to 26%, the nickel amounts to 5.5% to 15%, the manganese also amounts to 5.5% to 15%, the silicon amounts to .1% to 1%, and the nitrogen content amounts to .10% to .60%. Each of these several ingredients is critical in

amount; none may be dispensed with and the percentage ranges of none may not be departed from, all as more fully pointed to hereinafter. In my steel, of course, there is present the further ingredient carbon, this principally as an impurity. The carbon content is maintained at a value not exceeding .06%.

The steel of my invention is conveniently melted in an electric arc furnace. Where desired, of course, the induction furnace may be used. Actually any number of melting techniques may be employed where desired. In general, however, the least expensive melting technique, that is, melting in an electric arc furnace, is employed. Following melting and finishing in the furnace, the furnace is tapped and the metal is teemed into ingot molds of desired size. The resulting ingots are stripped from the molds, reheated and converted into the usual mill products and thence into cold-rolled sheet and strip and into cold-drawn wire. The steel works well in the mill.

The alloy steel of my invention, in broad range or specification, essentially consists of 16% to 26% chromium, 5.5% to 15% nickel, 5.5% to 15% manganese, .1% to 1% silicon, .10% to .60% nitrogen, carbon not exceeding .06%, and remainder substantially all iron. Preferably in this steel the silicon content is in the amount of .4% to 1%, more especially .5% to .8%. And preferably the nitrogen content amounts to .2% to .4%. Carbon preferably is maintained at a value not exceeding .03%. Phosphorus and sulphur, of course, are commonly present. Each of these ingredients, however, is less than about .04% as a maximum.

A preferred steel according to my invention essentially consists of 18% to 22% chromium, 5.5% to 12% nickel, 6% to 11% manganese, .4% to 1% silicon, .2% to .6% nitrogen, with the carbon content not exceeding .06%, and the remainder substantially all iron. There is the further preference of a silicon content of .5% to 1%. So, too, there is the further preference of a nitrogen content of .2% to .4% and a carbon content not exceeding .03%.

A further preferred steel in accordance with the teachings of my invention essentially consists of 18% to 22% chromium, 10% to 12% nickel, 8% to 11% manganese, .4% to 1% silicon, .2% to .6% nitrogen, with the carbon content not exceeding .06%, and with the remainder being substantially all iron. In this preferred steel the silicon content preferably is further limited, this to .5% to 1%. The nitrogen also preferably is in the amount of .2% to .6% and the carbon not exceeding .03%.

The steel of my invention in broad composition range, as well as in preferred composition range, is fully austentic; it is virtually free of delta-ferrite at high temperatures, and the fully austentic condition is retained at room temperatures. While it hardens greatly with drastic cold-reduction, as more fully developed below, the hardening and strengthening as a result of usual fabricating operations such as bending, pressing, drawing, deep-drawing, cutting, trimming, threading, and the like, is limited and not objectionable.

Now, as suggested above, the composition of the steel of my invention is in every sense critical. A chromium content less than 16% results in a loss of corrosion resistance. And where the chromium content exceeds 26%, the composition balance is disturbed; there is a loss of austenite stability and the development of objectionable amounts of delta-ferrite. Hot-workability directly suffers.

In my steel the nickel content and the manganese content both are critical. A nickel content less than the 5.5% figure again results in a loss of austenite stability, and in a brazing or welding operation there is a development of ferrite with resultant loss of impact strength. Moreover, a nickel content less than the prescribed minimum adversely affects the soundness of the weld, the weld being inclined to porosity. And a nickel content exceeding the upper figure of 15% makes the steel much too costly and, of even greater consequence, restricts the solubility of the steel for carbon and increases the susceptibility to objectionable carbide precipitation and loss of corrosion resistance in a heat-affected area adjacent the weld or braze.

The criticality of the manganese content of my steel is in many respects similar to that obtaining with the nickel content. With a manganese content less than the 5.5% figure and particularly with the sum of the manganese and nickel contents less than 11%, the composition balance is disturbed and there is an inclination toward the development of delta-ferrite with consequent loss of hot-workability. Moreover, with a lower manganese content there is insufficient support for the required minimum nitrogen content necessary to my steel. And with a manganese content exceeding 15%, corrosion resistance suffers.

For welding applications the silicon content of my steel is critical. A silicon content of at least .4% is necessary in order to achieve good welding characteristics with the production of sound welds, with freedom from porosity and the entrapment of slag in a variety of welding techniques, at least .5% being preferable for certainty in result. With a silicon content less than .4%, however, the metal is inclined to become dirty, that is, inclined to permit the presence of objectionable quantity of oxide incritical, particularly in that it contributes to the austenitic And with a silicon content exceeding .8%, and certainly where it exceeds 1%, the composition balance of the steel is adversely affected.

The nitrogen content, as suggested above, likewise is critical, particularly in that it contributes to the austenitic structure, increases the yield strength, and aids in the retention of a good yield strength even after tempering treatment, as more particularly pointed to hereinafter. These desired results are not had where the nitrogen content is less than .10%; the full development of all of these properties is best assured with a nitrogen content of at least .2%. A nitrogen content exceeding .6% is not desired; even with the upper limits of chromium and manganese contents, an excess of nitrogen is inclined to gassiness with resultant development of porosity in the metal, particularly in welding.

In my steel the carbon content, too, is critical; carbon is maintained at a figure not exceeding .06% and preferably not exceeding .03%. A carbon content exceeding the .06% figure inclines to the development of an objectionable number of precipitated carbides with the resultant loss of cold-workability, and, of course, a loss of cold-formability, as well. And, additionally, excessive carbon adversely affects the welding and brazing characteristics of my steel as a result of the development of carbide precipitates adjacent the weld or braze.

My steel in the form of cold-rolled sheet and strip, or in the form of cold-drawn wire, is supplied the customer-fabricator usually in the annealed and pickled condition, annealing being had at a temperature of some 1700° to 2000° F., with quenching in air, oil or water. It will be understood, however, that where desired the steel may be supplied in the form of hot-rolled plate, sheet, strip, bars, rods and wire. In the hot-rolled condition it lends itself to a variety of machining operations. And in the cold-rolled condition it lends itself to a variety of cold-forming operations such as bending, pressing, drawing, deep-drawing, upsetting, and the like, as well as the usual machining operations. The steel may be welded or it may be brazed, as desired, in the production of particular articles of use.

Now in the production of woven wire belting for a Fourdrinier paper-making machine, I fashion the warp wires out of the steel of my invention. I subject the steel to the combination of drastic cold-reduction, this without benefit of an intermediate annealing treatment, following by a tempering back. Both the extent of cold-reduction and the temperature of the tempering treatment are critical. As a result of the combination of par-

ticular composition, particular cold-reduction and particular tempering treatment, excellent fatigue strength is had along with wear resistance and corrosion resistance.

The extent of the cold-reduction according to my invention is in excess of 80%. Usually, I prefer a cold-reduction amounting to about 85% on up to as much as 95%. With this cold-reduction there is achieved great hardness and strength; with a cold-reduction exceeding 80% the ultimate tensile strength amounts to at least about 250,000 p.s.i., with a .2% yield strength of at least about 230,000 p.s.i. The grain structure is greatly elongated.

The drastically cold-drawn steel, following the cold-drawing operation, is subjected to a tempering treatment, this at a temperature of at least about 1750° F., and preferably at a temperature of 1750° to 2100° F. A preferred range of tempering treatment is 1900° to 2000° F. The time of treatment, however, is not highly critical; it need be only sufficient to effect recrystallization, but not of sufficient duration to permit undue crystal growth, following recrystallization. The grains are fine and equiaxed, this generally being of a grain size of ASTM 10 to 12. While hardness and strength are sacrificed with the tempering treatment, I nevertheless retain considerable strength and hardness particularly as a result of the high nitrogen content of my steel, the yield strength commonly amounting to some 85,000 to 100,000 p.s.i. And with the substantial yield strength there nevertheless is good fatigue resistance.

As illustrative of the steel and wire of my invention, I give below in Table I*a* the chemical analysis of a specific steel (the Heat #42178) and in Table I*b* the mechanical properties following a cold-reduction of about 90% and a tempering back at about 2000° F.

TABLE I*a*

Heat No.	C	Mn	P	S	Si	Cr	Ni	N	Remainder
42178----	.042	9.36	.023	.006	.10	19.90	6.34	.30	Iron.

The steel of Table I*a* in the form of wire cold-drawn to the extent of about 90% without benefit of intermediate anneal, this to the size of .0093" diameter, is run through a furnace 12 feet long maintained at a temperature of 2000° F. at a speed of about 120 feet per minute.

The ultimate tensile strengths of duplicate samples, following the tempering treatment, the .2% yield strength and the % Elongation in 10" are given below in Table I*b*:

TABLE I*b*

Heat No.	U.T.S., p.s.i.	.2% Y.S., p.s.i.	Percent Elong. in 10"
42178----------	133,000 135,000	81,500 81,500	41.0 46.0

The wire of Tables I*a* and I*b* was subjected to fatigue testing wherein samples of the wire are suspended in vertical position and wrapped once around a cluster of 4 rolls, each 1 inch in diameter, with the diameter of cluster amounting to 4 inches, and wherein each sample is held taut by a weight of 0.4 lb. The cluster is revolved, each complete revolution being taken as one cycle. Five samples of the wire noted had lives of 20,096; 24,052; 23,004; 25,416; and 22,860 cycles before failure. The average life for the wire of Tables I*a* and I*b* thus came to 23,084 cycles. Fatigue life is good, comparing very favorably with the steel and wire of my copending companion application for patent referred to above.

The drastically cold-drawn and tempered steel wire of my invention is woven into wire belting, this serving as the warp wires. The shute wires of the woven belting conveniently are fashioned of the type 302 chromium-nickel stainless steel (17% to 19% chromium, 8% to 10% nickel, and remainder iron) or any one of a number of other grades. The woven belting, made to adequate length is cut and the two ends welded or brazed together in fashioning a belt to required size and specification. In the welding operation, any number of weld rods may be employed, one being of the approximate analysis of the steel of my invention. And in a brazing operation a nickel-gold alloy conveniently is used for greater strength of braze. With either fabricating method the metal reaches substantial temperature (about 1750° F. in brazing and much higher in welding), temperatures which with prior belts are inclined to unduly soften the metal with consequent loss of hardness, strength and resistance to mechanical wear.

In the Fourdrinier wire belting it is the warp wires which are subjected to the reverse bending or flexing as the wire belting passes around the operating rolls. And it is these warp wires which encounter the greatest mechanical friction in the paper-making operation. The belting of my invention is well calculated to withstand the wear, the corrosion and the flexing encountered in actual practical use.

As particularly illustrative of the wire belting made according to the teachings of my invention in which there is employed a welded seam or joint, I give below in Table II the composition of 4 steels according to my preferred invention (Compositions Nos. 4, 5, 6 and 7) and 3 steels (Compositions Nos. 1, 2 and 3) outside of the composition range of the steels of the preferred invention. The quality of the weld had and its strength generally is indicated in the table.

TABLE II—Chemical Composition of Weld and the Quality of the Same

Composition No.	C	Mn	P	S	Si	Cr	Ni	N	Remarks
1 [1]----------	.027	9.55	.019	.010	.14	20.41	6.45	.24	Some porosity in weld deposits.
2 [2]----------	.040	9.77	.021	.008	.05	20.52	6.27	.27	Entrapped slag in weld deposits.
3 [3]----------	.039	9.26	.019	.008	.12	20.14	6.27	.28	Sound welds.
4 [2]----------	.061	10.48	.024	.007	.46	20.59	6.53	.26	Do.
5 [2]----------	.049	9.69	.021	.011	.44	18.93	11.66	.24	Do.
6 [1]----------	.034	6.23	.007	.010	.57	20.28	11.56	.28	Do.
7 [1]----------	.037	9.39	.013	.009	.53	20.11	11.46	.28	Do.

[1] Gas Shielded Metal Arc.
[2] Covered Electrode.
[3] Gas Shielded Tungsten Arc.

It is noted from the data presented in the table set out above that two of the steel welds of low silicon content (Compositions Nos. 1 and 2) are porous and dirty. Those welds are formed by way of a covered electrode or by way of a gas shielded metal arc. Soundness is had in the third low silicon steel (Composition No. 3) when the gas shielded tungsten arc technique is employed.

In the high silicon steel of the present invention soundness is had, irrespective of the method of welding. A sound weld is achieved where that weld is had (Compositions Nos. 4 and 5) even by way of a covered electrode or (Compositions Nos. 6 and 7) by way of a gas shielded metal arc. And it is noted that the desired high-quality weld is had in all four steels of high silicon content even though they are of differing nickel and manganese con-

tents. It is also noted that the four steels are of differing carbon contents. In short, sound welds are achieved in a variety of combinations of carbon, manganese and nickel for about the same level of chromium, silicon and nitrogen. Note that with the lower silicon steels in which these same two welding techniques are employed, objectionable porosity and slag entrapment result.

Thus it will be seen that I provide in my invention an austenitic chromium-nickel-manganese stainless steel of critical silicon and nitrogen contents and critically low carbon content, in which there is had a combination of hot-workability, cold-formability and ease and assurance of good weldability, employing a variety of welding techniques. The steel in the form of sheet, strip, wire, and the like, lends itself to a variety of fabricating operations such as bending, pressing, spinning, drawing, deep-drawing, and the like, as well as cutting, drilling and sawing. The products weld with ease in giving a sound gas-free weld which is clean, strong and resistant to corrosion.

It will be seen that I provide in my invention a steel and method for achieving a combination of tensile strength and resistance to fatigue resulting from flexing or reverse bending. And that I provide strip and wire and woven belting with welded seam suited to prolonged duty under the many severe conditions encountered in actual practical use in paper-making operations.

Since a number of embodiments of my invention will occur to those skilled in the art to which the invention relates and since many variations in the embodiments set out above will also occur to them, it will be understood that the description given above is to be interpreted as illustrative and not as a limitation.

I claim as my invention:

1. In the production of chromium-nickel-manganese stainless steel sheet, strip and wire of good fatigue resistance and strength, the art which comprises providing sheet, strip or wire essentially consisting of about: 16% to 26% chromium, 5.5% to 15% nickel, 5.5% to 15% manganese, .10% to .60% nitrogen, and remainder substantially all iron; cold-reducing the same, without benefit of intermediate anneal, in an amount exceeding about 80%; and then tempering the same at a temperature of at least about 1750° F.

2. In the production of chromium-nickel-manganese stainless steel sheet, strip and wire of good fatigue resistance and strength, and good welding properties, the art which comprises providing sheet, strip, or wire essentially consisting of about: 16% to 26% chromium, 5.5% to 15% nickel, 5.5% to 15% manganese, .4% to 1% silicon, .10% to .60% nitrogen, carbon not exceeding .06%, and remainder substantially all iron; cold-reducing the same, without benefit of intermediate anneal, in an amount exceeding about 85%; and then tempering the same at a temperature of about 1750° to 2100° F.

3. In the production of chromium-nickel-manganese stainless steel sheet, strip and wire of good fatigue resistance and strength and good welding properties, the art which comprises providing sheet, strip or wire essentially consisting of about: 16% to 26% chromium, 5.5% to 15% nickel, 5.5% to 15% manganese, .4% to 1% silicon, .10% to .60% nitrogen, carbon not exceeding .06%, and remainder substantially all iron; cold-reducing the same, without benefit of intermediate anneal, in an amount of about 85% to 95%; and then tempering the same at a temperature of about 1900° to 2100° F.

4. Stainless steel sheet, strip and wire of equiaxed grain structure, at least as fine as ASTM 10, and essentially consisting of 16% to 26% chromium, 5.5% to 15% nickel, 5.5% to 15% manganese, and remainder substantially all iron.

5. Stainless steel sheet, strip and wire of fine equiaxed grain structure, generally ASTM 10–12, and good fatigue resistance and strength after welding, and essentially consisting of 16% to 26% chromium, 5.5% to 15% nickel, 5.5% to 15% manganese, .4% to 1% silicon, .1% to .6% nitrogen, carbon not exceeding .06%, and remainder substantially all iron.

6. Stainless steel sheet, strip and wire of equiaxed grain structure at least as fine as ASTM 10 and having good fatigue resistance and strength after welding, and essentially consisting of 18% to 22% chromium, 5.5% to 12% nickel, 6% to 11% manganese, .4% to 1% silicon, .2% to .4% nitrogen, carbon not exceeding .06%, and remainder substantially all iron.

7. Stainless steel sheet, strip and wire of fine equiaxed grain structure, generally ASTM 10–12, having good fatigue resistance and strength after welding, and essentially consisting of 18% to 22% chromium, 10% to 12% nickel, 8% to 11% manganese, .5% to 1% silicon, .2% to .6% nitrogen, carbon not exceeding .03%, and remainder substantially all iron.

8. A woven wire belt, the warp wires of which are of alloy steel essentially consisting of 16% to 26% chromium, 5.5% to 15% nickel, 5.5% to 15% manganese, .4% to 1% silicon, .10% to .60% nitrogen, carbon not exceeding .06%, and remainder substantially all iron, having equiaxed grain structure at least as fine as ASTM 10, good fatigue resistance and strength.

9. A woven wire belt having a welded or brazed seam therein which belt comprises warp wires of equiaxed grain structure at least as fine as ASTM 10 and essentially consisting of 18% to 22% chromium, 5.5% to 12% nickel, 6% to 11% manganese, .4% to 1% silicon, .2% to .4% nitrogen, carbon not exceeding .06%, and remainder substantially all iron.

10. A woven wire product comprising wire of fine equiaxed grain structure, generally ASTM 10–12, and consisting essentially of 16% to 26% chromium, 5.5% to 15% nickel, 5.5% to 15% manganese, and remainder substantially all iron.

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