

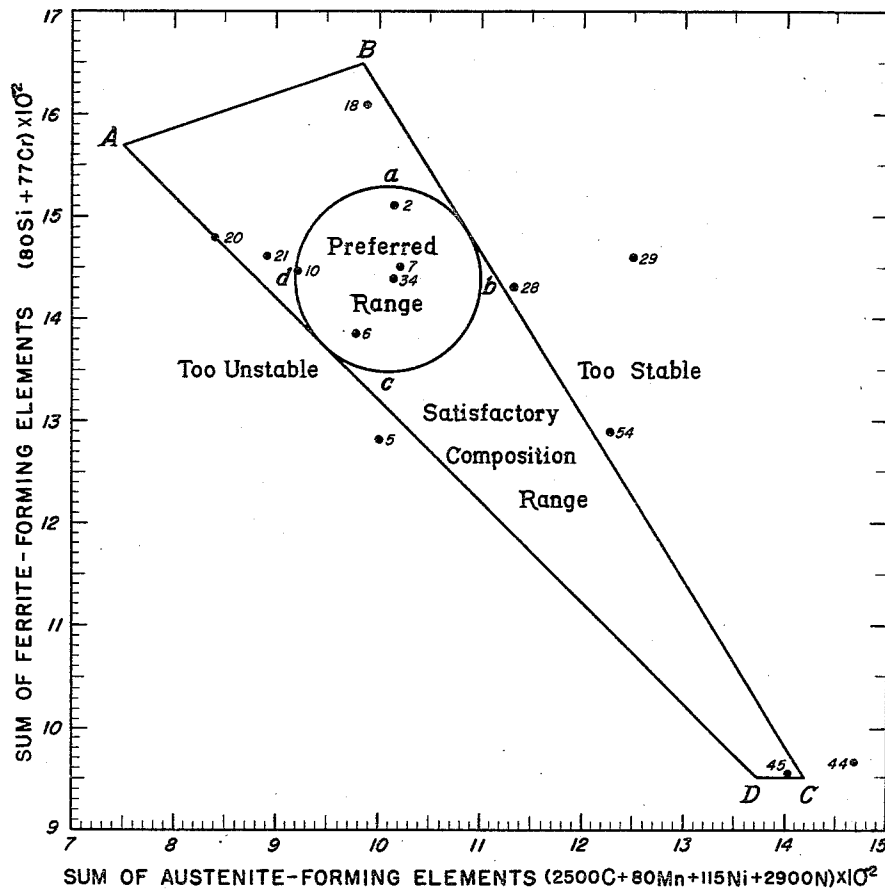
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STAINLESS STEEL AND METHOD OF PRODUCING SAME

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COMPOSITION OF CHROMIUM-NICKEL HEAT HARDENABLE  
STAINLESS STEEL IN TERMS OF THE SUM OF THE  
FERRITE-FORMING ELEMENTS (CHROMIUM AND SILICON)  
VS. THE SUM OF THE AUSTENITE-FORMING ELEMENTS  
(NICKEL, MANGANESE, CARBON, AND NITROGEN.)

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2,820,708

## STAINLESS STEEL AND METHOD OF PRODUCING SAME

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12 Claims. (Cl. 75—128)

My invention relates generally to the austenitic stainless steels, and more especially to an austenitic stainless steel of critical composition which is hardenable by heat-treating methods, to the hardened steel and articles fashioned of the same, and to the method of hardening.

One of the objects of my invention is the provision of a stainless steel which is corrosion-resistant, ductile and readily fabricated as by drawing, forming, punching, bending, and the like, and which may be subsequently hardened and strengthened by heat-treating methods to give high hardness, great strength and substantial toughness, all without necessity for special hardening agents such as aluminum and copper with their attendant difficulties.

Another object is the provision of a simple, practical and reliable method of achieving an austenitic stainless steel and various articles manufactured of the same of desired high physical properties and free of directional effects commonly had in the steels hardened by cold-working methods and which additionally assures hardened steel free of scale, and surface roughening or metal loss resulting from oxidation during heat-treatment as well as free of distortion in treatment.

A further object is the provision of various fabricated stainless steel articles and products, as well as the steel itself, which are hard, tough and strong, with a high ratio of strength to weight, both at room temperature and at temperatures approaching 800° or 900° F.

Other objects of my invention in part will be obvious and in part pointed out during the course of the description which follows.

Accordingly, my invention resides in the combination of elements, composition of ingredients, and in the various operational steps, and the relation of each of the same to one or more of the others; the scope of the application of all of which is set forth in the claims at the end of this specification.

In the single figure of the accompanying drawing I show the composition limits of the steel of my invention and also the limits of the preferred composition.

As conducive to a better understanding of certain features of my invention it may be noted at this point that the stainless steels have found great favor in the arts. They are employed in an almost infinite variety of applications where resistance to corrosion, strength and toughness are required. Such steels generally contain some 10% to 35% chromium with remainder principally iron. There, of course, are present the ingredients carbon, manganese, silicon, phosphorus and sulfur in minor amounts, although substantial amounts of any one or more of these ingredients may be used to achieve known desired properties. So, too, there may be included small amounts of nickel, molybdenum, tungsten, titanium, columbium or other alloying elements for special purposes.

Illustrative of the type of steel noted are the 12% chromium, 17% chromium and 16-2% chromium-nickel grades. Such a steel may be hardened by heating to a temperature of 1850° F. to 1950° F. and quenching either in air, water or oil to effect a direct heat-hardening.

The quench-hardening operation, however, frequently is found to adversely affect the surface condition of the steel and occasionally its shape, as well. Unfortunately, these hardening temperatures are such that there is heavy scaling and metal loss. Moreover, it not infrequently

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happens that there is a tendency toward some distortion of the steel as the result of the high temperatures of heat-treatment.

Perhaps the most popular type of stainless steel is found in the austenitic chromium-nickel grades. Such a steel in addition to chromium in the amount of some 16% to 30% also contains nickel in large amounts, for example 5% to 30%. Other ingredients, of course, such as carbon, manganese, silicon, phosphorus and silicon are present in minor amounts, or in substantial amounts for special purposes if desired. And, here again, molybdenum, tungsten, columbium, titanium and the like may be purposely included in the composition to achieve particular known benefits.

The austenitic chromium-nickel stainless steels, however, are not generally considered to be hardenable by heat-treating methods. The hardness had in sheet, strip, various special shapes, rods and the like is achieved by cold-working methods, that is cold-rolling and cold-drawing, for example.

More recently it has been found that certain of the chromium-nickel stainless steels will respond to a comparatively low temperature heat-hardening treatment when there is included in the composition of the steel some strong carbide-forming element such as columbium or titanium. These ingredients, however, represent special additions which are made at substantial expense. Further, titanium may in some instances detract from the cleanliness of the steel, while columbium is a rare and highly strategic element.

There is a further type of chromium-nickel stainless steel which responds to hardening treatment also at the comparatively low temperatures, this by reason of including in the composition of the steel one or more of aluminum or beryllium or copper. But, here again, the steel requires special addition agents of some expense, beryllium being especially expensive. In many instances it has been found that certain melting hazards are introduced in the production of steels of substantial aluminum content. These steels during teeming are inclined to scum formation on the molten metal stream which makes pouring more difficult.

Accordingly, an object of my invention is the provision of a chromium-nickel stainless steel which does not need added expensive hardening agents and which steel readily lends itself to fabrication into a host of manufactured articles which are subsequently hardened by heat-treatment at comparatively low temperatures to achieve hardness, strength and great strength to weight ratio. A further object is the provision of a method for consistently and reliably achieving the hardened articles.

Referring now more particularly to the practice of my invention, I find that by employing particular amounts of the ingredients chromium and nickel with small amounts of carbon, manganese, silicon and nitrogen, and by further providing a highly critical relationship between the ingredients chromium and silicon on the one hand and the ingredients nickel, manganese, carbon and nitrogen on the other, I produce an austenitic chromium-nickel stainless steel which lends itself to hardening by heat-treatment at a comparatively low temperature.

The steel of my invention is ductile and readily lends itself to working and forming by known fabricating methods such as bending, drawing, stretching, forming and the like. Stainless steel plate, sheet, strip, bars, rods, wire, extrusion shapes and tubes of my stainless steel are worked, formed and otherwise fabricated by known methods into a host of articles of ultimate use. The working and forming, of course, is performed on the various products as they come from the steel mill in the annealed condition, annealing being had in the mill

at some suitable temperature for example 1700° F. to 2200° F. and preferably 1900° F. to 2000° F. And the articles subsequent to fabrication are subjected to heat-treatment at a temperature of some 1200° F. to 1700° F. in order to transform the metal followed by reheating at a temperature of 300° F. to 1150° F. for sufficient time to achieve the desired hardening effect. Actually, I find that best results are had with treatment at a temperature of 700° F. to 900° F., preferably 800° F. to 850° F. The time of treatment ranges from several minutes, say ten minutes, on up to several days' time; in fact, further appreciable hardening may be observed for times of treatment up to 500 hours or more without loss of ductility. In general, I prefer a treatment of at least 10 hours.

Where desired, I make of my steel various castings to desired specification; for example, precision castings such as aircraft fittings. And these are hardened by the combination of transformation and heat-hardening treatments noted.

In the steel and method of my invention a ductile metal is realized thereby permitting a highly desirable degree of workability and formability. Moreover, the worked or formed metal is hardened and strengthened by heat-treatment at such low temperature that there is a complete absence of destructive scaling and, of course, treatment temperature is so low that distortion is avoided.

More specifically, the steel of my invention essentially consists of chromium in the amount of 12.0% to 21.0%, nickel in the amount up to 11.5%, carbon up to .20%, manganese up to 5.0%, silicon up to 2.00%, nitrogen up to .20% and remainder iron. Sulfur and phosphorus, of course, are present in the usual minor amounts, or larger amounts of these two elements may be used where desired. As a further limitation on the composition, however, the several ingredients chromium and silicon bear a particular relation to the ingredients nickel, carbon, manganese and nitrogen. More especially 77 times the percentage of chromium plus 80 times the percentage of silicon representing the sum of the ferrite-forming elements bears a very critical relation to the sum of the austenite-forming elements as defined by 115 times the percent of nickel plus 80 times the percent of manganese plus 2500 times the percent of carbon plus 2900 times the percent of nitrogen. For best understanding, the critical range of composition in terms of these values is given in the drawing. The critical range of my steel is defined by the area A, B, C and D.

A preferred range of composition, a range in which there is had best results in terms of a balance of such

factors as resistance to corrosion, ductility to permit ease of forming and strength and hardness achieved by heat-treatment subsequent to forming, essentially consists of 16% to 19% chromium, 4% to 7% nickel, .05% to .12% carbon, .20% to 4.0% manganese, .20% to 1.0% silicon, .01% to .10% nitrogen, with remainder iron. Here again, of course, it will be understood that the steel may contain the usual impurities such as phosphorus and sulfur in the usual amounts. And as a further limitation in my preferred composition the relationship between the ingredients chromium and silicon on the one hand and the ingredients nickel, carbon, manganese and nitrogen on the other is defined by the area of the circle *a*, *b*, *c* and *d* of the drawing.

The highly critical character of the composition of the steel of my invention readily is apparent from the physical properties of eight specific compositions of my steel as compared with those of six steels of similar general composition but lacking the critical balance between the chromium and silicon contents on the one hand and the sum of the nickel, carbon, manganese and nitrogen contents on the other. The eight steels of my composition, these in the form of thin strip, are represented by the items 18, 21, 2, 10, 7, 34, 6 and 45 of the following table, the composition of the four steels falling outside of my critical range of composition on the high side being indicated as items 29, 28, 54 and 44, and two compositions falling outside on the low side being indicated as items 20 and 5.

TABLE I

Composition analysis of fourteen specific compositions of Cr-Ni stainless steel

| Item No. | C    | Mn  | Si  | Cr    | Ni    | N    | Remarks       |
|----------|------|-----|-----|-------|-------|------|---------------|
| 29-----  | .074 | .79 | .34 | 18.62 | 6.13  | .102 | Too Stable.   |
| 28-----  | .062 | .96 | .33 | 18.24 | 6.14  | .067 | Do.           |
| 54-----  | .067 | .63 | .26 | 16.46 | 7.92  | .034 | Do.           |
| 44-----  | .052 | .78 | .38 | 12.16 | 10.64 | .018 | Do.           |
| 18-----  | .072 | .84 | .67 | 20.22 | 6.16  | .011 | Satisfactory. |
| 21-----  | .036 | .74 | .52 | 18.45 | 6.13  | .013 | Do.           |
| 2-----   | .085 | .48 | .94 | 18.65 | 5.86  | .031 | Do.           |
| 10-----  | .075 | .76 | .65 | 18.12 | 5.60  | .010 | Do.           |
| 7-----   | .070 | .67 | .55 | 18.27 | 6.02  | .035 | Do.           |
| 34-----  | .069 | .89 | .42 | 18.27 | 6.14  | .022 | Do.           |
| 6-----   | .062 | .66 | .50 | 17.48 | 6.00  | .028 | Do.           |
| 45-----  | .056 | .89 | .39 | 12.01 | 9.98  | .016 | Do.           |
| 20-----  | .020 | .72 | .56 | 18.62 | 6.12  | .010 | Too Unstable. |
| 5-----   | .067 | .62 | .60 | 16.13 | 6.05  | .030 | Do.           |

All fourteen of the steels of Table I were annealed at 1950° F. followed by cooling to room temperature, for example 60° F. Report on the mechanical properties of annealed samples is given in Table II, column A, below:

TABLE II

Mechanical properties of the steels of Table I following annealing treatment and annealing plus transformation plus hardening heat treatment

| Item No. | A<br>1,950° F. cool to +60° F.   |                                |                  |                | B<br>A. +1,400° F.—90 min.—cool to<br>-30° F.—+800° F.—50 hrs.—air |                                |                  |                |
|----------|----------------------------------|--------------------------------|------------------|----------------|--------------------------------------------------------------------|--------------------------------|------------------|----------------|
|          | Ult. Tens. Str. X 1,000 p. s. i. | .2% Yld. Str. X 1,000 p. s. i. | Elon. 2" percent | Rock. Hardness | Ult. Tens. Str. X 1,000 p. s. i.                                   | .2% Yld. Str. X 1,000 p. s. i. | Elon. 2" percent | Rock. Hardness |
| 29-----  | 133.7                            | 45.5                           | 66               | B89            | 127.5                                                              | 60.0                           | 51.5             | B97            |
| 28-----  | 141.7                            | 39.3                           | 43               | B87            | 138.5                                                              | 64.6                           | 36.5             | B99            |
| 54-----  | 121.5                            | 30.4                           | 56               | B79            | 120.5                                                              | 44.6                           | 40.5             | B91            |
| 44-----  | 101.2                            | 23.0                           | 54               | B63            | 111.5                                                              | 50.1                           | 26.0             | B92            |
| 18-----  | 124.5                            | 54.3                           | 47               | B94            | 144.0                                                              | 100.3                          | 21.0             | C31            |
| 21-----  | 138.4                            | 40.9                           | 18               | B90            | 174.0                                                              | 168.5                          | 9.5              | C39            |
| 2-----   | 150.2                            | 44.6                           | 40               | B88            | 190.2                                                              | 177.8                          | 12.0             | C42            |
| 10-----  | 171.3                            | 45.4                           | 23               | B93            | 179.5                                                              | 172.0                          | 9.5              | C41            |
| 7-----   | 147.2                            | 40.0                           | 36               | B91            | 171.6                                                              | 155.4                          | 15.5             | C39            |
| 34-----  | 148.5                            | 38.3                           | 31               | B89            | 173.5                                                              | 166.5                          | 12.0             | C40            |
| 6-----   | 157.2                            | 39.5                           | 24               | B89            | 176.5                                                              | 169.2                          | 13.5             | C39            |
| 45-----  | 114.5                            | 24.6                           | 33               | B69            | 138.0                                                              | 96.2                           | 16.0             | C28            |
| 20-----  | 192.2                            | 71.8                           | 10               | C35            |                                                                    |                                |                  |                |
| 5-----   | 139.7                            | 66.3                           | 10               | C24            |                                                                    |                                |                  |                |

The composition of the fourteen steels of Tables I and II expressed in terms of the sum of the ferrite-forming elements (chromium and silicon) versus the sum of the austenite-forming elements (nickel, manganese, carbon and nitrogen) is given in Table III below and graphically presented in the drawing.

TABLE III

Calculated sum of ferrite-forming elements and sum of austenite-forming elements of the fourteen specific compositions of Table I

| Item No. | Ferrite-Formers<br>(77Cr+80Si) X<br>10 <sup>-2</sup> | Austenite-Formers<br>(2500C+80Mn+<br>115Ni+<br>2900N) X 10 <sup>-2</sup> | Remarks       |
|----------|------------------------------------------------------|--------------------------------------------------------------------------|---------------|
| 29.....  | 14.61                                                | 12.49                                                                    | Too Stable.   |
| 28.....  | 14.31                                                | 11.32                                                                    | Do.           |
| 54.....  | 12.89                                                | 12.27                                                                    | Do.           |
| 44.....  | 9.67                                                 | 14.68                                                                    | Do.           |
| 18.....  | 16.10                                                | 9.88                                                                     | Satisfactory. |
| 21.....  | 14.62                                                | 8.92                                                                     | Do.           |
| 2.....   | 15.11                                                | 10.15                                                                    | Do.           |
| 10.....  | 14.47                                                | 9.21                                                                     | Do.           |
| 7.....   | 14.51                                                | 10.22                                                                    | Do.           |
| 34.....  | 14.40                                                | 10.14                                                                    | Do.           |
| 6.....   | 13.86                                                | 9.79                                                                     | Do.           |
| 45.....  | 9.56                                                 | 14.03                                                                    | Do.           |
| 20.....  | 14.79                                                | 8.40                                                                     | Too Unstable. |
| 5.....   | 12.82                                                | 10.00                                                                    | Do.           |

All twelve of the steels reported in Table II, column B reveal some improvement in mechanical properties as a result of the transformation and hardening treatment. Careful comparison, however, of the properties of the hardened steels of column B with the annealed steels of column A shows that there is only a slight increase in the yield strength of the steels of items 29, 28, 54 and 44. This is because these steels are too stable to respond properly to transformation and hardening treatment. And it will be seen by reference to the figure of the drawing that each of these four steels lie outside the composition limits defined by the area A, B, C and D. This further demonstrates the highly critical composition balance of my steel.

The steels of items 18, 21, 2, 10, 7, 34, 6 and 45, all falling within my critical composition range, are seen to respond significantly to the transformation and hardening treatment. In every case the yield strength is increased to at least 90,000 pounds/sq. inch. In the case of steels, items 2, 10, 7, 34 and 6, all of which lie within the preferred range as defined by the circle *a, b, c, d*, the yield strengths are much higher.

The effect of time and temperature of the hardening treatment is shown in Table IV below for the steels designated items 2 and 34 typical analysis.

TABLE IV

Mechanical properties of the steel of items 2 and 34 of Table I when annealed, transformed and hardened, the latter at different times and temperatures of treatment

| Heat Treatment                                        | Ult. Tens.<br>Str. X1,000<br>p. s. i. | 2% Yld.<br>Str. X1,000<br>p. s. i. | Elong. 2"<br>Percent | Rock.<br>Hardness |
|-------------------------------------------------------|---------------------------------------|------------------------------------|----------------------|-------------------|
| Item 2:                                               |                                       |                                    |                      |                   |
| 1,950° F. +1,400° F. cool to 60° +800-90 mins.....    | 156.2                                 | 118.3                              | 18                   | C32.5             |
| 1,950° F. +1,400° F. cool to 60° +800-65 hrs.....     | 185.4                                 | 122.7                              | 17                   | C34.5             |
| 1,950° F. +1,400° F. cool to 60° +850-90 mins.....    | 187.0                                 | 123.1                              | 19                   | C33               |
| 1,950° F. +1,400° F. cool to 60° +900-90 mins.....    | 151.5                                 | 114.2                              | 19                   | C32               |
| 1,950° F. +1,400° F. cool to -60° +800-10 mins.....   | 175.2                                 | 147.0                              | 13                   | C39.5             |
| 1,950° F. +1,400° F. cool to -60° +800-65 hrs.....    | 150.2                                 | 177.8                              | 12                   | C42               |
| 1,950° F. +1,400° F. cool to -60° +900-10 mins.....   | 172.4                                 | 152.3                              | 13                   | C39               |
| 1,950° F. +1,400° F. cool to -60° +1,150-10 mins..... | 142.1                                 | 105.7                              | 16                   | C30               |
| Item 34:                                              |                                       |                                    |                      |                   |
| 1,950° F. +1,400° F. cool to -30° +800-9 mins.....    | 160.8                                 | 140.0                              | 10.0                 | C35.5             |
| 1,950° F. +1,400° F. cool to -30° +800-45 mins.....   | 163.2                                 | 145.5                              | 9.5                  | C36               |
| 1,950° F. +1,400° F. cool to -30° +800-3 hrs.....     | 163.4                                 | 149.7                              | 9.0                  | C35.5             |
| 1,950° F. +1,400° F. cool to -30° +800-15 hrs.....    | 169.3                                 | 158.6                              | 10.0                 | C37.5             |
| 1,950° F. +1,400° F. cool to -30° +800-50 hrs.....    | 173.5                                 | 166.5                              | 12.0                 | C39               |
| 1,950° F. +1,400° F. cool to -30° +800-120 hrs.....   | 183.5                                 | 175.8                              | 11.0                 | C40               |
| 1,950° F. +1,400° F. cool to -30° +800-240 hrs.....   | 188.0                                 | 177.4                              | 11.5                 | C41.5             |
| 1,950° F. +1,400° F. cool to -30° +800-500 hrs.....   | 189.6                                 | 178.8                              | 12.0                 | C41.5             |

From the results given in Table II, column A, it will be noted that the steels designated as items 5 and 20 exhibit considerable hardness immediately upon cooling from the annealing temperature. These steels are much too hard in the annealed condition for satisfactory working and forming operations. The Rockwell hardness figures of C24 and 35 and the low elongation values clearly show that the metal had transformed before reaching room temperature and these steels which, as noted in the drawing, are outside the critical range of composition of the steels of my invention are unsatisfactory. Both steels, although falling within the broad range of the chromium and nickel content of the steel of my invention, fall outside the critical range of composition balance as defined by the area A, B, C and D of the drawing.

Inasmuch as the steels of composition, defined by items 5 and 20, are unsuitable because of excessive hardness upon reaching the customer they need be given no further concern. The mechanical properties of the remaining twelve steels, after being subjected to a transformation treatment, notably reheating to 1400° F. for ninety minutes followed by cooling to -30° F. and then reheating to 800° F. for 50 hours are shown in Table II, column B.

The samples of the steel of item 2 compositions are seen to develop mechanical properties that are virtually the same, whether the ageing treatment is performed at 800°, 850° or 900° F. Some benefit is seen to be had, however, by prolonged treatment. Thus it will be seen that there is a substantial increase in yield strength, ultimate tensile strength, and in hardness for a treatment at 65 hours as compared to one at 90 minutes. Moreover, samples of steel of item 34 reveal substantial increase in ultimate strength, yield strength and hardness with an increase in the length of time of treatment, although as a practical matter it appears that substantial maximum properties are achieved in about 120 hours.

A hardening treatment at a temperature of 1150° F. is not seen to develop the full potential of the properties of my steel as indicated by the physical tests on the final sample of item 2 as given in Table IV above, this temperature of course actually being the top limit of the range of my treatment as more particularly described above.

Strength and hardness are had in the steels of my invention even where the hardening treatment is conducted for only a few minutes at hardening temperature. Best response to short temperature treatments are achieved where the previously transformed steel has been cooled

to low temperatures prior to final heat treatment as revealed by comparison of the two samples under item 2 of Table III above, one cooled to 60° F. from 1400° F. and the other to -60° F., both of which are then finally treated at 800° F. for 65 hours. While the former sample is seen to have a yield strength of 122,700 p. s. i., the latter has developed a strength of 179,000.

Thus, it will be seen that I provide in my invention a chromium-nickel stainless steel of critical composition balance, as well as cast articles of manufacture and converted products such as plate, strip, bars, rods, wire, extrusion shapes and tubes and the like, all of which are soft, ductile and readily lend themselves to a variety of working and other fabricating operations, and which subsequently lend themselves to heat-treatment with comparatively low temperatures to achieve hardness and strength. In the annealed condition the steel and articles of my invention possess a hardness on the order of Rockwell B69 to 94, and a yield strength not exceeding about 60,000 p. s. i. In the hardened condition, however, there is had a hardness of at least Rockwell C28 and a yield strength of at least 90,000 p. s. i. Actually, in the hardened steel and articles of my invention the strength figures approach an ultimate tensile strength of 190,000 p. s. i. and more, and a .2% yield strength of 180,000 p. s. i. There is had a high ratio of strength to weight, a figure comparing favorably or even exceeding that had for the new titanium alloys.

The steel and products of my invention are most practical in that they require no special alloying additions to achieve hardness and are free of the melting and teeming problems encountered with the age-hardening alloys of the prior art. Moreover, although sensitively responding to hardening heat treatment, they are so stable that there is no incidental undesired hardening in the annealed condition. And the transforming and hardening treatments in accordance with my invention are practiced without danger of excessive scaling of the steel subsequent to fabrication. Moreover, the hardened, finished articles are free of the directional properties which commonly are encountered in the various austenitic chromium-nickel stainless steels in which hardening is achieved as a result of cold-working operations.

As many possible embodiments may be made of my invention and as many changes may be made in the illustrative embodiments hereinbefore set forth, it will be understood that all matter described herein or shown in the accompanying drawing is to be interpreted as illustrative and not by way of limitation.

I claim as my invention:

1. In the production of heat-hardened austenitic chromium-nickel stainless steel, the art which comprises providing a steel essentially consisting of chromium 12.0% to 21.0%, nickel up to 11.5%, carbon up to .20%, manganese up to 5.0%, silicon up to 2.00%, nitrogen up to .20%, and remainder substantially all iron, the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; annealing the same at a temperature of about 1700° to 2200° F. and cooling; transforming the same by reheating at a temperature of 1200° to 1700° F. and cooling; and then hardening by reheating to a temperature of 300° to 1150° F.

2. In the production of heat-hardened austenitic chromium-nickel stainless steel, the art which comprises providing a steel essentially consisting of chromium 12.0% to 21.0%, nickel up to 11.5%, carbon up to .20%, manganese up to 5.0%, silicon up to 2.00%, nitrogen up to .20%, and remainder substantially all iron, the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; annealing the same

at a temperature of about 1900° to 2000° F. and cooling; reheating at a temperature of 1200° to 1700° F. and cooling to below room temperature; and then hardening by reheating to a temperature of 300° to 1150° F.

3. In the production of heat-hardened austenitic chromium-nickel stainless steel, the art which comprises providing a steel essentially consisting of chromium 12.0% to 21.0%, nickel up to 11.5%, carbon up to .20%, manganese up to 5.0%, silicon up to 2.00%, nitrogen up to .20%, and remainder substantially all iron, the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C, and D of the accompanying diagram; annealing the same and cooling; transforming the same by reheating and cooling; and then hardening by reheating to a temperature of 800° to 850° F. for a time of a few minutes to several days.

4. In the production of heat-hardened austenitic chromium-nickel stainless steel, the art which comprises providing a steel essentially consisting of chromium 12.0% to 21.0%, nickel up to 11.5%, carbon up to .20%, manganese up to 5.0%, silicon up to 2.00%, nitrogen up to .20%, and remainder substantially all iron, the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; annealing the same and cooling; transforming the same by reheating and cooling; and then hardening by reheating to a temperature of 700° to 900° F. for at least 10 hours.

5. In the production of heat-hardened austenitic chromium-nickel stainless steel, the art which comprises providing a steel essentially consisting of chromium 16% to 19%, nickel 4% to 7%, carbon .05% to .12%, manganese .20% to 4.0%, silicon .20% to 1.0%, nitrogen .01% to .10%, and remainder substantially all iron, with the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; annealing the same and cooling; transforming the same by reheating and cooling; and then hardening the transformed steel by reheating to a temperature of 300° to 1150° F. for a time of a few minutes to several days.

6. In the production of heat-hardened austenitic chromium-nickel stainless steel articles of manufacture, the art which comprises fabricating annealed austenitic chromium-nickel stainless steel plate, sheet, strip, bars, rods, wire, extrusion shapes and tubes, essentially consisting of chromium 12.0% to 21.0%, nickel up to 11.5%, carbon up to .20%, manganese up to 5.0%, silicon up to 2.00%, nitrogen up to .20%, and remainder substantially all iron, the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; transforming the same subsequent to fabrication by heating to a temperature of 1200° to 1700° F. and cooling; and then hardening by reheating to a temperature of 300° to 1150° F.

7. In the production of heat-hardened austenitic chromium-nickel stainless steel articles of manufacture, the art which comprises fabricating annealed austenitic chromium-nickel stainless steel plate, sheet, strip, bars, rods, wire, extrusion shapes and tubes, essentially consisting of chromium 12.0% to 21.0%, nickel up to 11.5%, carbon up to .20%, manganese up to 5.0%, silicon up to 2.00%, nitrogen up to .20%, and remainder substantially all iron, the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; transforming the same subsequent to fabrica-

tion by heating and cooling to below room temperature; and then hardening by reheating to a temperature of 700° to 900° F. for at least 10 hours.

8. In the production of heat-hardened austenitic chromium-nickel stainless steel articles of manufacture, the art which comprises fabricating annealed austenitic chromium-nickel stainless steel plate, sheet, strip, bars, rods, wire, extrusion shapes and tubes essentially consisting of chromium 16% to 19%, nickel 4% to 7%, carbon .05% to .12%, manganese .20% to 4.0%, silicon .20% to 1.0%, nitrogen .01% to .10%, and remainder substantially all iron, the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; transforming the same subsequent to fabrication; and then hardening by reheating to a temperature of 300° to 1150° F. for a time of a few minutes to several days.

9. In the production of heat-hardened austenitic chromium-nickel stainless steel cast articles of manufacture, the art which comprises providing a casting essentially consisting of chromium 12.0% to 21.0%, nickel up to 11.5%, carbon up to .20%, manganese up to 5.0%, silicon up to 2.00%, nitrogen up to .20%, and remainder substantially all iron, the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; annealing the same at a temperature of about 1700° to 2200° F. and cooling; transforming the same by reheating at a temperature of 1200° to 1700° F. and cooling; and then hardening by reheating to a temperature of 300° to 1150° F.

10. Heat-hardened austenitic chromium-nickel stainless steel articles of manufacture essentially consisting of chromium 12.0% to 21.0%, nickel up to 11.5%, carbon up to .20%, manganese up to 5.0%, silicon up to 2.00%, nitrogen up to .20%, and remainder substantially all iron,

the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; said articles subsequent to fabrication having been transformed by heating at a temperature of 1200° to 1700° F. and cooling and then hardened by heat-treating at a temperature of 300° to 1150° F.

11. Heat-hardened austenitic chromium-nickel stainless steel articles of manufacture essentially consisting of chromium 16% to 19%, nickel 4% to 7%, carbon .05% to .12%, manganese .20% to 4.0%, silicon .20% to 1.0%, nitrogen .01% to .10%, and remainder substantially all iron, the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; said articles subsequent to fabrication having been transformed by heating at a temperature of 1200° to 1700° F. and cooling and then hardened by heat-treating at a temperature of 300° to 1150° F.

12. Heat-hardened austenitic chromium-nickel stainless steel cast articles essentially consisting of chromium 12.0% to 21.0%, nickel up to 11.5%, carbon up to .20%, manganese up to 5.0%, silicon up to 2.00%, nitrogen up to .20%, and remainder substantially all iron, the relative amounts of said chromium and silicon on the one hand and nickel, manganese, carbon and nitrogen on the other being substantially in accordance with the area A, B, C and D of the accompanying diagram; said articles having been transformed by heating at a temperature of 1200° to 1700° F. and cooling and then hardened by heat-treating at a temperature of 300° to 1150° F.

#### References Cited in the file of this patent

Transactions: American Society for Metals, vol. 41, 1949, page 1316.

Transactions: American Society for Steel Treating, vol. 19, November 1931, to June 1932, pages 501 to 507.