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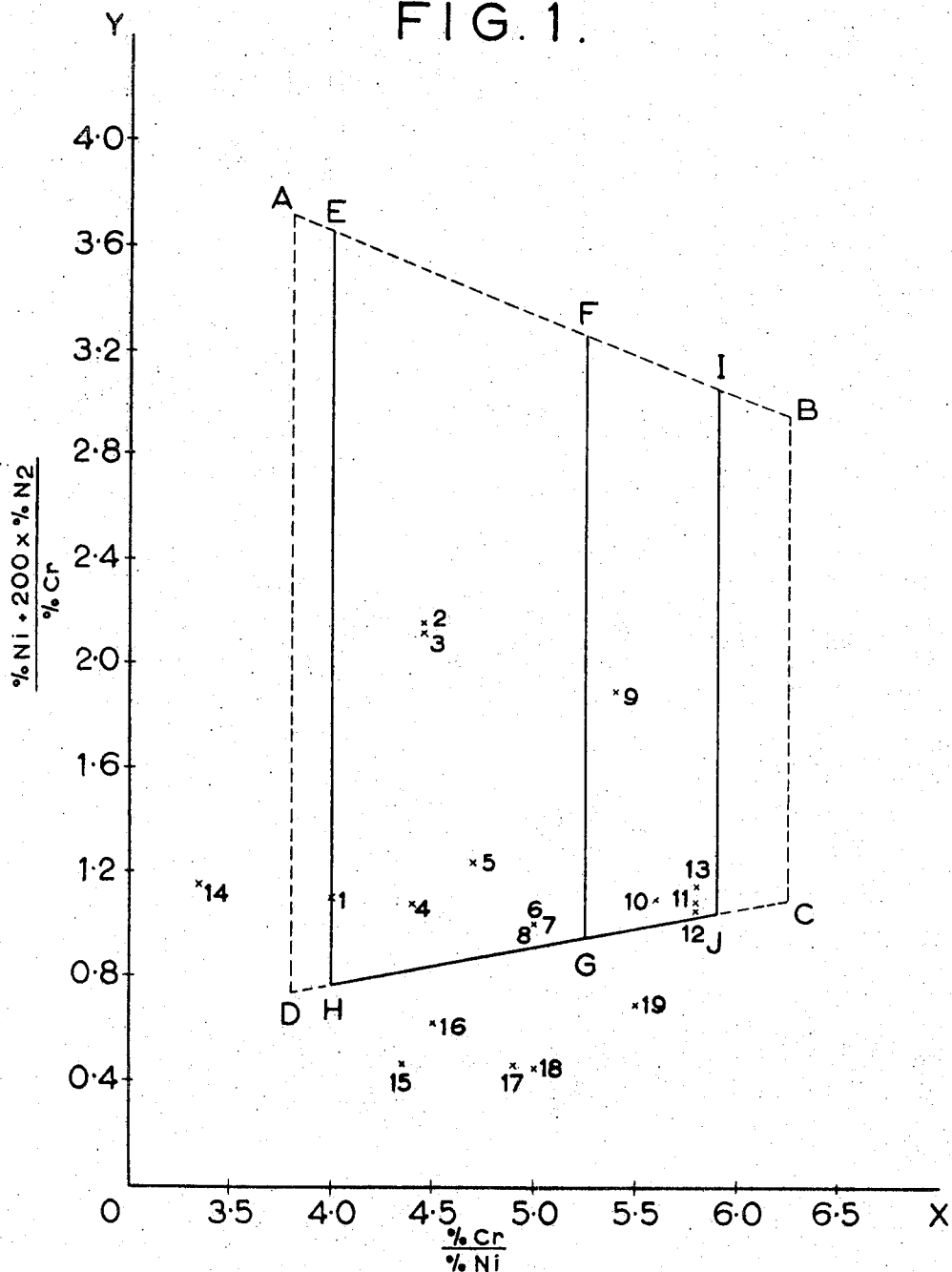
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STAINLESS STEELS

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2 Sheets-Sheet 1

FIG. 1.



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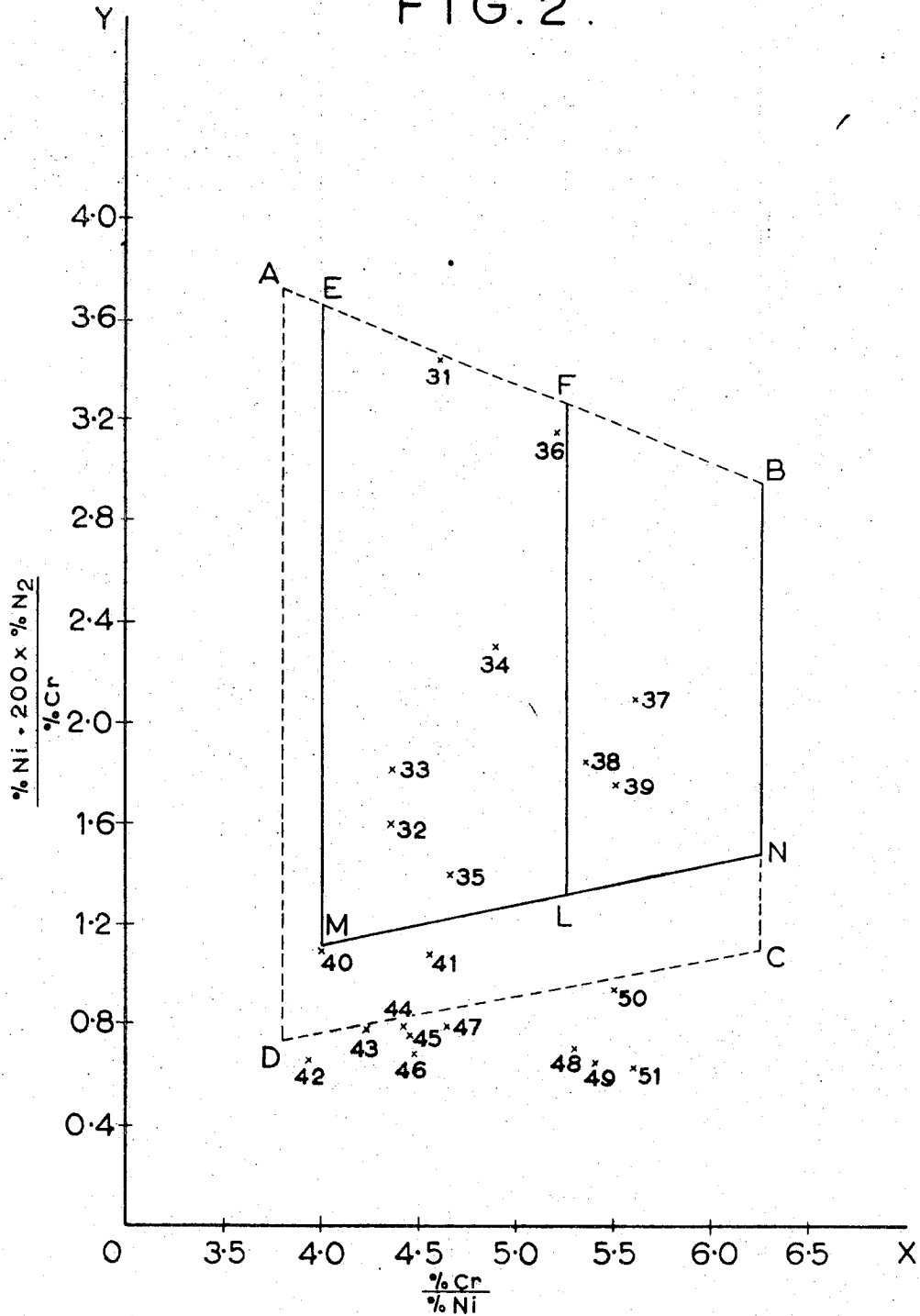
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STAINLESS STEELS

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2 Sheets-Sheet 2

FIG. 2.



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1

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STAINLESS STEELS

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7 Claims

ABSTRACT OF THE DISCLOSURE

A corrosion resistant and wear resistant high strength ferritic-austenitic steel consisting of:

	Percent
Chromium -----	23.0-30.0
Nickel -----	4.0-7.0
Molybdenum -----	1.0-5.0
Copper -----	1.0-4.0
Silicon -----	0.2-2.0
Manganese -----	0.2-4.0
Carbon -----	0.01-0.1
Nitrogen -----	0.06-0.4
Iron (excepting unavoidable impurities) -----	Balance

and wherein the chromium and nickel and nitrogen contents satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 3.8-6.25\%$$

$$(ii) \quad \frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 0.74-3.72\%$$

and wherein when the said formulae are plotted on a graph with Formula i plotted against the X axis and Formula ii plotted against the Y axis, the values of the two formulae taken together fall within that area of the graph bounded by four straight lines extending between points A, B, C and D of the graph respectively having the following co-ordinates:

	X	Y
A-----	3.8	3.72
B-----	6.25	2.96
C-----	6.25	1.1
D-----	3.8	0.74

Stainless steels are usually defined as steels containing substantial proportions of chromium with or without substantial amounts of nickel which render the steels resistant to corrosion in many media. The best known steels in this category are those containing nominally 18% chromium, 10% nickel and small proportions of silicon, manganese and carbon. Such alloys are substantially austenitic steels although they may contain some ferrite depending on the ratio of chromium to nickel. They are, however, highly resistant to corrosion but in general their strength is low and they are not amenable to hardening or strengthening by heat-treatment.

Many attempts have been made to produce stainless steels which could be strengthened or hardened by heat-treatment and the most successful alloys in this category are the so-called martensitic transformation stainless steels which contain in the region of 14-18% chromium and 3-8% nickel, together with other alloying constituents such as silicon, manganese and carbon. Such stainless steels require a rather complicated heat-treatment in order to

2

achieve the high strengths and hardnesses obtainable and although an excellent combination of mechanical properties can be achieved, the corrosion resistance is usually inferior to that of the non-hardenable austenitic steels referred to above.

The object of this invention was to develop a stainless steel possessing a corrosion resistance superior to that of the non-hardenable austenitic stainless steels referred to above, but which was capable of being heat-treated to give hardnesses and tensile strengths comparable with those of the martensitic transformation stainless steels described above.

Such a combination of properties, hitherto unknown in stainless steels, is most desirable for the production of equipment for the chemical industry, and dairy industry, the marine industry, and in fact all applications where a high corrosion resistance, combined with high strength and high resistance to galling and abrasion and erosion, are desirable.

The austenitic stainless steels containing nominally 18% chromium and 10% nickel are well known for their excellent corrosion resistance to a wide variety of corrosive environments, but due to their comparatively low strength and low hardness they are quite unsuitable for the type of applications referred to above.

By increasing the chromium content to about 25% and reducing the nickel content to about 5%, a much harder and stronger alloy, possessing an austenitic/ferritic structure is produced. However, this alloy possesses many undesirable characteristics compared with the austenitic stainless steels, the most serious being

(1) Very poor resistance to corrosion under certain conditions,

(2) Although the tensile strength is much higher, the ductility and notch impact value can be very low and finished products may be very brittle,

(3) Welding of finished products can result in very brittle welds,

(4) Propensity to hot cracking during either casting or subsequent heat-treatment.

It has now been shown that the poor corrosion resistance of this 25% chromium, 5% nickel alloy, can be vastly improved by the addition of molybdenum and copper as shown by the following Examples a and b.

Example a

Samples of an alloy containing 26.3% chromium and 5.15% nickel and weighing 15.5 grammes each when immersed respectively in 30% H₂SO₄ and 70% H₂SO₄ at 60° C. completely dissolved in 20 hours.

Example b

Samples of an alloy of the following composition:

	Percent
Chromium -----	25.5
Nickel -----	5.2
Molybdenum -----	2.1
Copper -----	3.5
Silicon -----	1.6
Manganese -----	1.1
Carbon -----	0.06
Balance, substantially all iron.	

weighing approximately 20 grammes, when tested under similar conditions showed excellent resistance to corrosion as follows.

Weight loss in 24 hours:

30% H₂SO₄ at 60° C.—Nil

70% H₂SO₄ at 60° C.—0.16 gramme

However, with this alloy containing copper and molybdenum, although it possessed a vastly improved resistance to corrosion, nevertheless, the ductility of test pieces was unpredictable and could be very low when measured by the elongation of a tensile test specimen or by impact test (Izod or Charpy "V" notch test). In the case of a casting hot cracking is liable to occur during casting or heat-treatment. It was also found that this alloy was sensitive to cracking during welding when tested in accordance with the weld test described in ASTM Specification No. B369-61T.

We have now found that these undesirable characteristics possessed by this alloy can be completely eliminated by the introduction of a substantial percentage of nitrogen, which can readily be introduced into the alloy by means of high nitrogen ferrochromium master alloy.

This invention therefore comprehends alloys falling within the following range of composition:

	Percent
Chromium -----	23-30
Nickel -----	4.0-7.0
Molybdenum -----	1.0-5.0
Copper -----	1.0-4.0
Silicon -----	0.2-2
Manganese -----	0.2-4.0
Carbon -----	0.01-0.1
Nitrogen -----	0.06-0.40

However, in order to ensure that the aforementioned beneficial effects of nitrogen are reliably and consistently achieved, it is necessary to balance the elements chromium, nickel and nitrogen, so that they satisfy the following formulae:

Formula *i*

$$\frac{\text{Chromium (percent)}}{\text{Nickel (percent)}} = 3.8-6.25$$

Formula *ii*

$$\frac{\text{Nickel (percent)} + 200 \times \text{nitrogen (percent)}}{\text{Chromium (percent)}} = 0.74-3.72$$

Indeed it is a further essential feature of the present invention that the composition of the alloy must be so selected, that when plotted in accordance with the accompanying graphs, FIG. 1 or 2, where Formula *i* is plotted on the X axis of the graph and Formula *ii* on the Y axis, the values of the two Formulae *i* and *ii* taken together fall within the area bounded by four straight lines extend-

ing between points A, B, C and D of the graph respectively having the following co-ordinates:

	X	Y
A-----	3.8	3.72
B-----	6.25	2.96
C-----	6.25	1.1
D-----	3.8	0.74

The stainless steel alloy composition having the constituents controlled as specified above is suitable for utilization either for high quality castings or for production in wrought form. However, in order to ensure that the most satisfactory alloys are produced for various utilizations, further control of the composition, within the broad range above specified, may be effected as set out below and the various alloys discussed may be conveniently summarized under the following headings:

(1) Alloys having a nitrogen content of 0.06% to 0.40% according to a first preferred range of composition, suitable for high quality casting and which have excellent ductility as measured by elongation or impact test (Examples 1 to 8 of Table A).

(2) Alloys having a nitrogen content of 0.06% to 0.40% according to a second preferred range of composition, suitable for high quality casting, and which have notable qualities of strength and hardness (Examples 9 to 13 of Table B).

(3) Alloys having a nitrogen content of 0.10% to 0.40% according to a third preferred range of composition, and suitable for production in wrought form and which have excellent ductility as measured by elongation or impact test (Examples 31 to 36 of Table D).

(4) Alloys having a nitrogen content of 0.10% to 0.40% according to a fourth preferred range of composition and which have notable qualities of strength and hardness (Examples 37 to 39 of Table E).

The alloys of Tables A, B and C were cast, then solution treated at 1120° C. then oil quenched and then precipitation hardened for four hours at the various temperatures given in the tables.

The alloys of Tables D, E, F and G were cast into billets, then hot rolled at 900°-1200° C. into bars, followed by a single stage heat-treatment for four hours at the various temperatures given in the tables.

These various alloy compositions together with methods of production will be discussed in greater detail below.

Alloy in cast form

Alloys according to this invention are suitable for production as high quality castings which are not susceptible to hot tearing during casting or quench cracking during heat-treatment and they are readily weldable without cracking when tested in accordance with the weld test specified in ASTM specification No. B369-61T.

Tensile tests carried out also confirm this since the specimens tested exhibited a much higher elongation value than those which did not intentionally contain nitrogen; see Examples *c* and *d* of Table I.

TABLE I.—EXAMPLE C

[Nitrogen not intentionally added (or present in quantities of less than 0.06%)]

	Chemical composition, percent							Condition	0.1% proof stress, T/sq.in.	Tensile strength, T/sq.in.	Elongation, percent
	Cr	Ni	Mo	Cu	Si	Mn	C				
Example:											
C-----	24.9	5.7	2.51	3.29	1.31	0.82	0.06	As cast-----	37.25	48.75	3.0
C-----	24.9	5.7	2.51	3.29	1.31	0.82	0.06	Heat-treated--	47.5	62.0	8.5

EXAMPLE D.—NITROGEN INTENTIONALLY ADDED

	Chemical Composition, percent								Condition	0.1% proof stress T/sq.in.	Tensile strength T/sq.in.	Elonga- tion, percent
	Cr	Ni	Mo	Cu	Si	Mn	C	N ₂				
Example:												
D-----	25.1	5.7	2.44	3.18	1.24	1.61	0.05	0.13	As cast-----	29.4	52.5	22.0
D-----	25.1	5.7	2.44	3.18	1.24	1.61	0.05	0.13	Heat treated--	45.5	63.75	20.0

A first preferred alloy suitable for production as a high quality casing has a composition in which the chromium, nickel and nitrogen contents satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 4.0-5.25$$

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(ii)

$$\frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 0.77-3.65$$

provided that when these two formulae are plotted in accordance with FIG. 1 their values fall within the area bounded by straight lines joining the points E, F, G and H of the graph, FIG. 1, respectively having the following co-ordinates:

	X	Y
E.....	4.0	3.65
F.....	5.25	3.27
G.....	5.25	0.95
H.....	4.0	0.77

Castings produced in accordance with this first preferred range will, after heat-treatment referred to below, possess a 0.5% yield stress of at least 40 tons/sq. in. combined with excellent ductility as measured by the elongation value on tensile test or the notch impact value as measured by the Izod or Charpy "V" notch test. Such castings can be readily welded, produce high quality welds and, in general, the corrosion resistance and resistance to stress corrosion is far superior to that of the austenitic stainless steels referred to earlier.

Typical examples of alloys falling within this first preferred range together with the heat-treatment applied after casting and the mechanical properties obtained are shown in Table A.

Alloys having a ratio of chromium to nickel of between 4:1 and 5.25:1 in which the chromium, nickel, molybdenum and copper contents are similar to those referred to in this specification, are not unknown, but unless such alloys are produced with a nitrogen content of 0.06% to 0.40% as provided for according to this invention and with the nickel, chromium and nitrogen contents balanced so that the values of Formulae I and II fall within the area bounded by the lines joining points E, F, G and H of the graph, FIG. 1, such known alloys possess the undesirable characteristics referred to earlier in this specification.

What is more, published information indicates that such known alloys have always been heat-treated as follows: Heat to 1120° C. and quench in a suitable medium, e.g. oil or water, followed by precipitation hardening for 3-4 hours at 450-480° C.

This heat-treatments results in such known alloys possessing good tensile properties but the notch impact value as measured by the Izod test or the "V" notch Charpy test is very low (see Examples 16-18 of Table C). Moreover, such known alloys are prone to quench cracking during heat-treatment while the alloys of Table A are not subject to this disadvantage if heat-treated as described below.

A second preferred composition suitable for production as a high quality casting has a composition in which the chromium, nickel and nitrogen contents are controlled to satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 5.25-5.9$$

(ii)

$$\frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 0.95-3.26$$

but the balance of nickel, chromium and nitrogen contents must be such that when Formulae I and II are plotted on FIG. 1 their values fall within the area bounded by the straight lines joining the points F, I, J

6

and G of the graph of FIG. 1 respectively having the following co-ordinates:

	X	Y
F.....	5.25	3.27
I.....	5.9	3.06
J.....	5.9	1.05
G.....	5.25	0.95

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10 Castings produced from alloy compositions in accordance with this second preferred range possess an excellent combination of properties as will be seen from Examples 9-13 in Table B and it will be noted that producing the alloy according to this second preferred range 15 confers a high strength, in excess of 45 tons per square inch (0.5% proof stress) and has an extremely beneficial effect on the tensile properties of the alloy and in particular on the elongation value.

Alloys which fall within Formula I but not Formula II 20 in which do not contain sufficient nitrogen are extremely brittle as determined by the elongation value on tensile test as shown in Example 19 in Table C.

As will be further seen from Table B, castings according to this second preferred range when subjected to heat- 25 treatment in accordance with this specification possess a hardness value of not less than 300 Brinell Hardness Number with high yield stress, tensile strength and good ductility, combined with excellent corrosion resistance and, in spite of the increased strength and hardness due 30 to the higher chromium content and method of heat-treatment, the additional nitrogen ensures that they are not susceptible to hot tearing during casting, or quench cracking during heat-treatment.

With further reference to this second preferred range 35 of alloy composition according to this invention as intended for casting, with high ratios of chromium to nickel it is particularly important to increase the nitrogen content so that the value of Formula II falls above the line GJ on the graph, FIG. 1. As seen in Example 19 the 40 chromium nickel ratio is 5.5 and satisfies Formula I but the nitrogen content is only 0.07 thereby producing a value for Formula II which is lower than that specified above with the result that the ductility as measured by elongation and notch impact values, is very poor.

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Production of alloy in cast form

As stated above the alloy according to this invention is particularly suitable for production as a high quality 50 casting.

The alloy is first melted by any of the well-known steel melting techniques provided that all necessary precautions are taken to ensure that the melt contains the required proportion of nitrogen as specified above.

After being cast in a sand mould the alloy is heat-treated as follows:

(a) Solution treatment by heating to a temperature of between 1050° C. and 1200° C. followed by quenching in oil or water.

(b) This is followed by precipitation hardening in the temperature range of 480° to 560° C. usually for from 3-5 hours and preferably for four hours at 500° C.

It will be noted that Examples 10 to 13 of Table B indicate that higher impact values can be achieved by 65 modifying the precipitation hardening temperature with alloys having chromium/nickel ratios in excess of 5.25. However, this particular response to modification of the precipitation hardening temperature is not found with alloys which are otherwise similar except that their nitrogen content is below that specified above (again see 70 Example 19 of Table C).

However as Examples 9-13 show the improvement in ductility conferred by heat-treatment at higher temperatures is accompanied by some reduction in hardness and 75 strength.

Alloy in wrought form

The invention also confers notable advantages when the alloy is utilized for the production of high quality wrought products in which case the nitrogen content should be controlled to between 0.1% and 0.4%.

Table G contains examples of wrought alloy steels in which nitrogen is not intentionally added or is present in amounts of less than 0.1%.

It will be noted that in all of the Examples 42 to 51 the Izod Impact Values are low and in most cases are well below 10 ft. lbs.

Tables D, E and F show wrought alloy steels according to this invention, these alloys having a composition as follows:

	Percent
Chromium -----	23.0-30.0
Nickel -----	4.0-7.0
Molybdenum -----	1.0-5.0
Copper -----	1.0-4.0
Silicon -----	0.2-2.0
Manganese -----	0.2-4.0
Carbon -----	0.01-0.1
Nitrogen -----	0.10-0.4
Iron (excepting unavoidable impurities) -----	Balance

and wherein the chromium, nickel and nitrogen contents satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 3.8-6.25$$

$$(ii) \quad \frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 0.74-3.72$$

and wherein when the said formulae are plotted on the accompanying graph FIG. 2 with Formula I plotted against the X axis and Formula II plotted against the Y axis, the values of the two formulae taken together fall within that area of the graph bounded by four straight lines extending between points A, B, C and D of the graph respectively having the following coordinates:

	X	Y
A-----	3.8	3.72
B-----	6.25	2.96
C-----	6.25	1.1
D-----	3.8	0.74

In a third preferred range of alloy composition according to this invention, nickel chromium and nitrogen contents are adjusted to satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 4.0-5.25$$

$$(ii) \quad \frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 1.12-3.66$$

and wherein the chromium, nickel and nitrogen contents are controlled such that when the said formulae are plotted on the accompanying graph, FIG. 2, the values of the two formulae taken together fall within that area of the graph bounded by four straight lines extending between points E, F, L and M respectively having the following co-ordinates:

	X	Y
E-----	4.0	3.66
F-----	5.25	3.27
L-----	5.25	1.32
M-----	4.0	1.12

It will be noted that the alloys of Examples 30-36 of Table D have significantly improved Izod or Charpy Impact Values as compared with the examples given in Table G. It will further be noted that the significant dif-

ference between the two tables is that the alloys of Table D have a nitrogen content ranging from 0.15 to 0.39 whereas in the alloys of Table G the nitrogen content ranges from 0.05 to 0.08.

5 The alloys of Table D also present a useful improvement in ductility measured by elongation as compared with the alloys of Table G.

In the alloys of Examples 40 and 41 of Table F, the nitrogen content is 0.1 and 0.11 respectively and the improvement in the Izod or Charpy Impact Values is maintained but is less marked.

10 Example 36 of Table D and Example 41 of Table F show how the Izod Impact Values can be significantly increased by heat-treatment at 525° C. for four hours. No corresponding increase is encountered with the alloys of Examples 43 and 47 of Table G while in Example 46 although some improvement was obtained by heat-treating this alloy, the Izod Value was still of low order.

In a fourth preferred range of alloy composition according to the invention and intended for production in wrought form, the chromium, nickel and nitrogen contents are adjusted to satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 5.25-6.25$$

$$(ii) \quad \frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 1.32-3.27$$

30 and the chromium, nickel and nitrogen contents are controlled such that when the said formulae are plotted on the accompanying graph FIG. 2, with Formula I plotted against the X axis and Formula II plotted against the Y axis, the values of the two formulae taken together fall within that area of the graph bounded by four straight lines extending between points F, B, N and L on the graph respectively having the following co-ordinates:

	X	Y
F-----	5.25	3.27
B-----	6.25	2.96
N-----	6.25	1.48
L-----	5.25	1.32

40 Examples of alloys according to this fourth preferred range are given in Table E, where it will be noted that the alloys of Examples 37 to 39 have an excellent combination of properties, together with hardness values exceeding 300 Brinell Hardness Number. These alloys have chromium/nickel ratios (Formula I) exceeding 5.25 and are, therefore, to be compared with Examples 48 to 51 of Table G and in this respect it will be noted that the alloys of Examples 37 to 39 possess greater ductility than the alloys of Examples 48 to 51. However, a more significant advantage lies with the excellent combination of proof stress and ductility obtained with the alloys of Examples 37 to 39. These alloys respond to heat-treatment and as shown with reference to Example 39 the ductility as measured by the Izod Impact Value is considerably enhanced by heat-treatment for four hours at 525° C. at the expense of some reduction in hardness and strength which is not practically significant.

Methods of producing alloy for wrought products

55 The alloy described may be melted by any of the well-known steel melting techniques, although it should be melted in electric furnaces, e.g. arc furnace, or induction furnace, in air or under inert atmosphere. The alloy may also be melted in vacuum, either in induction furnace or by the consumable arc process, but in this case all necessary steps should be taken to ensure that the alloy contains the necessary proportion of nitrogen.

60 Having thus produced an alloy according to the invention, it may be cast into ingots by any conventional method, or alternatively, billets of any desired section may be produced by continuous casting.

We have found that ingots or billets thus produced are readily hot workable by all conventional methods, i.e. forging, rolling or extrusion over a wide temperature range from 900° C. to 1200° C. which is an additional improvement over the fully austenitic stainless steels which have a more restricted hot working temperature range and are rather susceptible to cracking during such hot working.

An excellent combination of properties can be achieved without resorting to any subsequent heat-treatment since in the hot worked condition the tensile properties will fall within the following range:

0.5% proof stress—35–50 tons/sq. in.
Tensile strength—55–65 tons/sq. in.
Elongation—20–50%
Brinell Hardness—260–300

combined with excellent corrosion resistance.

But if these products are required to possess particularly high strength or hardness values, they may be subjected to a single stage heat-treatment (precipitation hardening) consisting of heating within the temperature range 400° C. to 600° C. after which they will possess mechanical properties and hardness values:

0.5% proof stress—45–60 tons/sq. in.
Tensile strength—60–80 tons/sq. in.
Elongation—15–40%
Izod Impact Value—15–70 ft. lbs.
Brinell Hardness—270–350

Alternatively, after hot working by forging, pressing, rolling, extrusion or any other method, the wrought product may then be solution heat-treated by heating to a temperature in the range 1050° C. to 1200° C. followed by quenching in water, oil or cooling rapidly in air.

Being in a solution treated condition, the material is now susceptible to precipitation hardening which consists of re-heating the product to within the temperature range 400° C. to 600° C. after which the tensile properties and hardness will be as follows:

0.5% proof stress—45–60 tons/sq. in.
Tensile strength—60–80 tons/sq. in.
Elongation—15–40%
Izod Impact Value—15–70 ft. lbs.
Brinell Hardness—270–350

The hot rolled product which may be in the form of hot rolled sheet, strip or rod, having been subjected to solution treatment or having been rapidly air cooled from a hot working operation, may then be cold worked to a considerable extent either by rolling, drawing or other conventional cold working method.

Such cold worked products will possess tensile properties of which the following range are typical:

0.5% proof stress—70 tons/sq. in.
Tensile strength—74 tons/sq. in.
Elongation—12%
Redn. in area—40%

but these properties may be further increased by subjecting the cold worked product to a precipitation hardening treatment within the range 350° C. to 550° C. following which the following properties can be achieved:

0.5% proof stress—80 tons/sq. in.
Tensile strength—87 tons/sq. in.
Elongation—12%
Redn. in area—42%

The high chromium content combined with a comparatively low nickel content of the alloys provided according to this invention, ensures a slightly lower density than most previous austenitic stainless steels and Nickel alloys and this combined with a high modulus of elasticity and high proof stress, results in an alloy possessing a high specific modulus and specific proof stress. The alloy is, therefore, suited to all applications demanding a high strength to weight ratio combined with a high specific modulus and excellent resistance to corrosion and stress corrosion.

In spite of the comparatively high content of ferrite in this alloy, the magnetic permeability of the finished product will be in the region of 3–4 and consequently it is suitable for many so-called nonmagnetic applications demanding a high strength material.

TABLE A.—CASTINGS

	Chemical composition, percent								Percent Cr, Ni	Percent Ni plus 200X percent N ₂ , Cr	Heat treatment, O.Q.=oil quenched, ¹ ° C. at—	0.5% proof stress, T./sq. in.	Tensile strength, T./sq. in.	Elongation, percent	Izod impact value, ft. lbs.
	Cr	Ni	Mo	Cu	Si	Mn	C	N ₂							
Example:															
1.....	24.0	6.0	2.78	3.29	1.21	1.33	0.05	0.10	4.0	1.1	500	38.0	60.0	33.0	28
2.....	25.9	5.8	2.6	3.6	1.29	1.21	0.05	0.25	4.45	2.16	475	47.0	64.0	28.0	17
											500	43.0	59.0	28.0	48
											525	41.0	58.5	32.0	59
3.....	25.2	5.65	2.24	3.72	1.28	2.37	0.06	0.24	4.45	2.12	475	46.0	63.0	29.0	22
											500	43.0	60.0	31.0	59
											525	40.0	58.0	37.0	60
4.....	25.1	5.7	2.44	3.18	1.24	1.61	0.05	0.10	4.4	1.08	475	46.0	62.5	23.0	-----
											475	47.0	64.0	20.0	12
5.....	25.5	5.4	2.37	3.5	1.2	1.15	0.06	0.13	4.7	1.23	500	47.0	62.0	26.0	43
											525	44.0	57.0	22.0	46
											475	43.0	61.0	26.0	46
6.....	24.7	4.9	2.2	3.4	1.4	3.0	0.07	0.10	5.0	1.0	500	42.0	61.0	26.0	56
											525	40.0	54.0	35.0	62
											475	48.0	62.0	26.0	16
7.....	25.2	5.1	1.9	3.29	1.64	1.1	0.04	0.10	5.0	1.0	500	46.0	59.0	30.0	45
											550	41.0	55.0	28.0	32
											475	44.0	57.0	19.0	15
8.....	25.0	4.9	2.3	0.6	1.5	1.2	0.06	0.10	5.0	1.0	500	46.0	55.0	20.0	25
											525	44.0	53.0	23.0	30

¹ 1,120° C. O.Q. plus 4 hours.

TABLE B.—CASTINGS

	Chemical composition, percent								Percent Cr, Ni	Percent Ni plus 200X percent N ₂ , Cr	Heat treat- ment, O.Q.= oil quenched, ¹ ° C. at—	0.5% proof stress, t./sq.in.	Tensile strength, t./sq.in.	Elonga- tion, percent	Izod impact value, ft. lbs.	B.H.N.
	Cr	Ni	Mo	Cu	Si	Mn	C	N ₂								
Example:																
9-----	28.6	5.3	2.18	3.18	1.24	1.09	0.04	0.25	5.4	1.9	475 500 525	57.0 48.0 48.0	73.0 64.0 60.0	15.0 25.0 26.0	----- ----- -----	341 311 293
10-----	25.8	4.6	1.9	3.18	1.15	1.18	0.06	0.12	5.6	1.1	475 500 525	51.0 48.0 46.0	65.0 61.0 58.0	17.0 19.0 25.0	6 13 28	317 302 285
11-----	28.3	4.9	2.0	3.0	1.6	2.84	0.05	0.13	5.8	1.09	475 500 525	59.0 51.0 50.0	73.0 65.0 61.0	8.0 19.0 18.0	5 7 15	331 317 302
12-----	26.8	4.6	1.97	3.05	1.17	1.21	0.05	0.12	5.8	1.06	475 500 525	56.0 50.0 47.0	70.0 62.5 59.0	20.0 16.0 19.0	5 8 15	321 307 290
13-----	26.7	4.6	1.97	3.05	1.17	1.21	0.05	0.13	5.8	1.14	475 500 525	56.0 50.0 47.0	70.0 62.5 59.0	16.0 16.0 19.0	5 8 14	317 302 293

TABLE C.—CASTINGS

	Chemical composition, percent								Percent Cr, Ni	Percent Ni plus 200X N ₂ , Cr	Heat treat- ment, O.Q.= oil quenched, ¹ ° C. at—	0.5% proof stress, t./sq. in.	Tensile strength, t./sq. in.	Elonga- tion percent	Izod impact value, ft. lbs.
	Cr	Ni	Mo	Cu	Si	Mn	C	N ₂							
Example:															
14-----	23.0	6.8	2.3	3.9	1.3	1.09	0.03	0.10	3.35	1.15	500	35.0	56.0	36.0	-----
15-----	24.9	5.7	2.5	3.29	1.31	0.82	0.06	0.03	4.35	0.468	475	48.0	63.0	10.0	-----
16-----	24.9	5.5	2.5	3.29	1.3	0.0	0.04	0.05	4.5	0.62	475 500 525	38.0 39.0 39.0	60.0 56.5 53.6	7.0 15.0 18.0	5 10 15
17-----	23.5	4.75	2.2	0.2	1.3	1.1	0.08	0.03	4.9	0.46	475 500 525	41.0 42.0 40.0	54.0 51.0 47.0	18.0 18.0 21.0	11 11 22
18-----	23.6	4.75	1.9	4.0	1.3	1.09	0.08	0.03	5.0	0.45	500 525	48.0 47.0	61.0 57.0	18.0 20.0	8 22
19-----	27.0	4.9	2.2	3.0	1.0	1.0	0.04	0.07	5.5	0.7	475 500 525	----- 52.0 51.0	37.5 61.0 60.0	Nil 4.0 5.0	1, 2, 1 3, 4, 4 4, 4, 6

¹ 1,120° C.O.Q. plus 4 hours.

TABLE D.—HOT ROLLED BARS

	Chemical composition, percent								Percent Cr, Ni	Ni+200XN ₂ , percent Cr	Heat-treat- ment, ¹ ° C.	0.5% proof stress, t./sq. in.	Tensile strength, t./sq. in.	Elonga- tion percent	Izod impact value, ft. lbs.
	Cr	Ni	Mo	Cu	Si	Mn	C	N ₂							
Example:															
31-----	23.9	5.2	2.2	1.5	.45	1.09	.07	0.39	4.6	3.45	500	52.4	66.8	36.0	59, 71, 82
32-----	24.8	5.7	2.48	1.75	.52	1.30	.08	0.17	4.35	1.6	500	53.0	65.0	26.0	37, 39, 39
33-----	25.2	5.8	1.98	2.31	.33	1.12	.05	0.20	4.35	1.82	500	53.9	64.8	30.0	34, 44, 36
34-----	25.4	5.2	2.30	1.67	.52	1.48	.07	0.27	4.89	2.3	500	48.0	64.0	30.0	67, 79, 84
35-----	25.5	5.5	2.85	2.08	.75	1.79	.08	0.15	4.65	1.4	475 500 525	54.4 53.2 49.4	66.0 63.2 60.8	28.0 33.0 30.0	59, 59, 57 41, 46, 44 60, 60, 57
36-----	26.0	5.0	2.58	1.98	.61	1.18	.06	0.38	5.2	3.12	475 500 525	56.3 54.1 51.2	68.6 67.2 64.8	30.0 37.0 32.0	19, 21, 23 40, 49, 52 63, 66, 69

¹ 4 hours at.

TABLE E.—HOT ROLLED BARS

	Chemical composition, percent								Percent Cr, Ni	Ni plus 200XN ₂ , percent Cr	Heat-treat- ment, ¹ ° C. at—	0.5% proof stress, t./sq. in.	Tensile strength, t./sq. in.	Elonga- tion, percent	Izod impact value, ft. lbs.	B.H.N.
	Cr	Ni	Mo	Cu	Si	Mn	C	N ₂								
Example:																
37-----	26.7	4.8	2.12	2.08	.49	1.21	.06	0.26	5.6	2.1	500	66.0	75.0	26.0	7, 8, 9	321
38-----	27.8	5.2	2.40	1.98	.39	1.33	.05	0.23	5.35	1.85	500	67.0	75.2	24.0	7, 8, 10	331
39-----	26.3	4.8	2.37	1.75	.56	1.52	0.10	0.21	5.5	1.76	475 500 525	56.8 54.9 51.0	68.2 66.9 63.6	30.0 31.0 30.0	9, 10, 10 12, 15, 19 43, 53, 55	311 302 295

¹ 4 hours.

TABLE F.—HOT ROLLED BARS

	Chemical composition, percent								Percent Cr, Ni	Ni plus 200XN ₂ , percent Cr	Heat-treat- ment, ¹ ° C. at—	0.5% proof stress, t./sq. in.	Tensile strength, t./sq. in.	Elonga- tion, percent	Izod impact value, ft. lbs.	B.H.N.
	Cr	Ni	Mo	Cu	Si	Mn	C	N ₂								
Example:																
40-----	24.1	6.0	2.20	1.65	.52	1.15	.08	0.10	4.0	1.1	500	49.1	60.3	30.0	18, 19, 20	-----
41-----	25.1	5.5	2.37	1.75	.33	.88	0.10	0.11	4.55	1.08	475 500 525	58.4 57.9 50.4	68.5 65.9 58.4	28.0 22.0 24.0	8, 9, 10 14, 14, 16 36, 37, 35	----- ----- -----

¹ 4 hours.

TABLE G.—HOT ROLLED BARS

	Chemical composition, percent								Percent Cr, Ni	Percent Ni plus 200 X percent N ₂ , Cr	Heat-treat- ment ¹ , ° C. at—	0.5% proof stress, t./sq. in.	Tensile strength, t./sq. in.	Elonga- tion, percent	Izod impact value, ft./lbs
	Cr	Ni	Mo	Cu	Si	Mn	C	N ₂							
Example:															
42-----	23.8	6.05	2.32	1.86	0.49	1.30	0.05	0.07	3.94	0.67	500 475 500 525 475 500 525	58.5	65.5	22.0	6, 6, 6
43-----	25.5	6.05	2.64	1.86	0.96	1.91	0.08	0.07	4.22	0.78		65.9	75.2	18.0	4, 4, 6
												58.4	66.9	20.0	4, 6, 7
											57.4	65.9	20.0	6, 7, 8	
44-----	24.9	5.65	2.64	2.19	0.55	1.21	0.05	0.07	4.42	0.79	475	60.8	69.0	21.0	3, 4, 4
											500	56.3	64.8	20.0	5, 6, 7
											525	50.6	57.4	22.0	11, 13, 14
45-----	25.7	5.8	2.64	2.19	0.75	1.79	0.08	10.7	4.45	0.77	475	67.0	74.7	18.0	5, 2, 2
											500	62.2	70.7	22.0	2, 4, 4
											525	57.1	65.6	20.0	7, 6, 6
46-----	24.6	5.5	2.48	1.98	0.47	1.21	0.06	0.056	4.47	0.68	500	57.2	65.5	21.0	4, 4, 5
47-----	28.0	6.05	2.12	1.86	0.59	1.30	0.04	0.08	4.65	0.79	500	66.5	73.0	23.0	3, 4, 4
48-----	25.4	4.8	1.97	1.98	0.51	1.15	0.06	0.065	5.3	0.71	500	58.0	65.0	22.0	4, 5, 6
49-----	26.9	4.8	2.32	2.19	0.39	1.2	0.08	0.06	5.4	0.65	500	53.8	63.0	28.0	5, 6, 7
50-----	26.4	4.8	2.10	2.19	0.37	1.21	0.07	0.10	5.5	0.95	500	50.0	60.32	17.0	8, 7, 6
51-----	26.9	4.8	2.30	1.75	0.43	1.30	0.08	0.06	5.6	0.63	500	59.2	72.2	18.0	2, 2, 3

¹ 4 hours.

We claim:

1. A corrosion resistant and wear resistant high strength ferritic-austenitic steel consisting of:

	Percent
Chromium	23.0–30.0
Nickel	4.0–7.0
Molybdenum	1.0–5.0
Copper	1.0–4.0
Silicon	0.2–2.0
Manganese	0.2–4.0
Carbon	0.01–0.1
Nitrogen	0.06–0.4
Iron (excepting unavoidable impurities)	Balance

and wherein the chromium and nickel and nitrogen contents satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 3.8-6.25$$

$$(ii) \quad \frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 0.74-3.72$$

and wherein when the said formulae are plotted on the accompanying graph, FIG. 1 or 2, with Formula *i* plotted against the Y axis, and formula *ii* plotted against the Y axis, the values of the two formulae taken together fall within that area of the graph bounded by four straight lines extending between points A, B, C and D of the graph respectively having the following coordinates:

	X	Y
A.....	3.8	3.72
B.....	6.25	2.96
C.....	6.25	1.1
D.....	3.8	0.74

2. A corrosion resistant ferritic-austenitic high strength steel capable of being cast and hardened by heat-treatment to produce in the casting 0.5% yield strength of at least 40 tons per square inch and consisting of:

	Percent
Chromium	23.0–30
Nickel	4.0–7.0
Molybdenum	1.0–5.0
Copper	1.0–4.0
Silicon	0.2–2.0
Manganese	0.2–4.0
Carbon	0.01–0.1
Nitrogen	0.06–0.4
Iron (excepting unavoidable impurities)	Balance

and wherein the chromium, nickel and nitrogen contents satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 4.0-5.25$$

(ii)

$$\frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 0.77-3.65$$

and wherein when the said formulae are plotted on the accompanying graph FIG. 1, with Formula *i* plotted against the X axis and Formula *ii* plotted against the Y axis, the values of the two formulae taken together fall within that area of the graph bounded by four straight lines extending between points E, F, G and H on the graph respectively having the following coordinates:

	X	Y
E.....	4.0	3.65
F.....	5.25	3.27
G.....	5.25	0.95
H.....	4.0	0.77

3. A corrosion resistant and wear resistant high strength ferritic-austenitic steel capable of being cast and hardened by heat-treatment to produce in the casting a 0.5% yield strength of at least 45 tons per square inch and consisting of:

	Percent
Chromium	23.0–30.0
Nickel	4.0–7.0
Molybdenum	1.0–5.0
Copper	1.0–4.0
Silicon	0.2–2.0
Manganese	0.2–4.0
Carbon	0.01–0.1
Nitrogen	0.08–0.4
Iron (excepting unavoidable impurities)	Balance

and wherein the chromium, nickel and nitrogen contents satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 5.25-5.9$$

(ii)

$$\frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 0.95-3.26$$

and wherein when the said formulae are plotted on the accompanying graph FIG. 1, with Formula *i* plotted against the X axis and Formula *ii* plotted against the Y axis, the values for the two formulae taken together fall within that area of the graph bounded by four straight lines extending between points F, I, J and G of the graph respectively having the following co-ordinates:

	X	Y
F.....	5.25	3.27
I.....	5.9	3.06
J.....	5.9	1.05
G.....	5.25	0.95

4. A corrosion resistant and wear resistant high strength ferritic-austenitic steel capable of being cast and hardened

by heat-treatment to at least 300 Brinell and consisting of:

	Percent
Chromium -----	23.0-30.0
Nickel -----	4.0-7.0
Molybdenum -----	1.0-5.0
Copper -----	1.0-4.0
Silicon -----	0.2-2.0
Manganese -----	0.2-4.0
Carbon -----	0.01-0.1
Nitrogen -----	0.08-0.4
Iron (excepting unavoidable impurities) -----	Balance

and wherein the chromium, nickel and nitrogen contents satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 5.25-5.9$$

$$(ii) \quad \frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 0.95-3.26$$

and wherein when the said formulae are plotted on the accompanying graph with Formula *i* plotted against the X ordinate and Formula *ii* plotted against the Y ordinate, the values of the two formulae taken together fall within that area of the graph bounded by four straight lines extending between points F, I, J and G of the graph respectively having the following coordinates:

	X	Y
F -----	5.25	3.27
I -----	5.9	3.66
J -----	5.9	1.05
G -----	5.25	0.95

5. A corrosion resistant and wear resistant high strength ferritic-austenitic steel consisting of:

	Percent
Chromium -----	23.0-30.0
Nickel -----	4.0-7.0
Molybdenum -----	1.0-5.0
Copper -----	1.0-4.0
Silicon -----	0.2-2.0
Manganese -----	0.2-4.0
Carbon -----	0.01-0.1
Nitrogen -----	0.10-0.40
Iron (excepting unavoidable impurities) -----	Balance

and wherein the chromium and nickel and nitrogen contents satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 4.0-5.25$$

$$(ii) \quad \frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 1.12-3.66$$

and wherein when the said formulae are plotted on the accompanying graph, FIG. 2, with Formula *i* plotted against the X axis and Formula *ii* plotted against the Y axis, the values of the two formulae taken together fall within that area of the graph bounded by four straight lines extending between points E, F, L and M of the graph respectively having the following coordinates:

	X	Y
E -----	4.0	3.66
F -----	5.25	3.27
L -----	5.25	1.32
M -----	4.0	1.12

6. A corrosion resistant and wear resistant high strength ferritic-austenitic steel consisting of:

	Percent
Chromium -----	23.0-30
Nickel -----	4.0-7.0
Molybdenum -----	1.0-5.0
Copper -----	1.0-4.0
Silicon -----	0.2-2.0
Manganese -----	0.2-4.0
Carbon -----	0.01-0.1
Nitrogen -----	0.10-0.40
Iron (excepting unavoidable impurities) -----	Balance

and wherein the chromium, nickel and nitrogen contents satisfy the following formulae:

$$(i) \quad \frac{\text{Chromium content}}{\text{Nickel content}} = 5.25-6.25$$

$$(ii) \quad \frac{\text{Nickel content} + 200 \times \text{nitrogen content}}{\text{Chromium content}} = 1.32-3.27$$

and wherein when the said formulae are plotted on the accompanying graph, FIG. 2, with Formula *i* plotted against the X axis and Formula *ii* plotted against the Y axis, the values of the two formulae taken together fall within that area of the graph bounded by four straight lines extending between points F, B, N and L on the graph respectively having the following co-ordinates:

	X	Y
F -----	5.25	3.27
B -----	6.25	2.96
N -----	6.25	1.48
L -----	5.25	1.32

7. A corrosion resistant and wear resistant high strength ferritic-austenitic steel consisting of:

	Percent
Chromium -----	23.0-30.0
Nickel -----	4.0-7.0
Molybdenum -----	1.0-5.0
Copper -----	1.0-4.0
Silicon -----	0.2-2.0
Manganese -----	0.2-4.0
Carbon -----	0.01-0.1
Nitrogen -----	0.06-0.4
Iron (excepting unavoidable impurities) -----	Balance

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