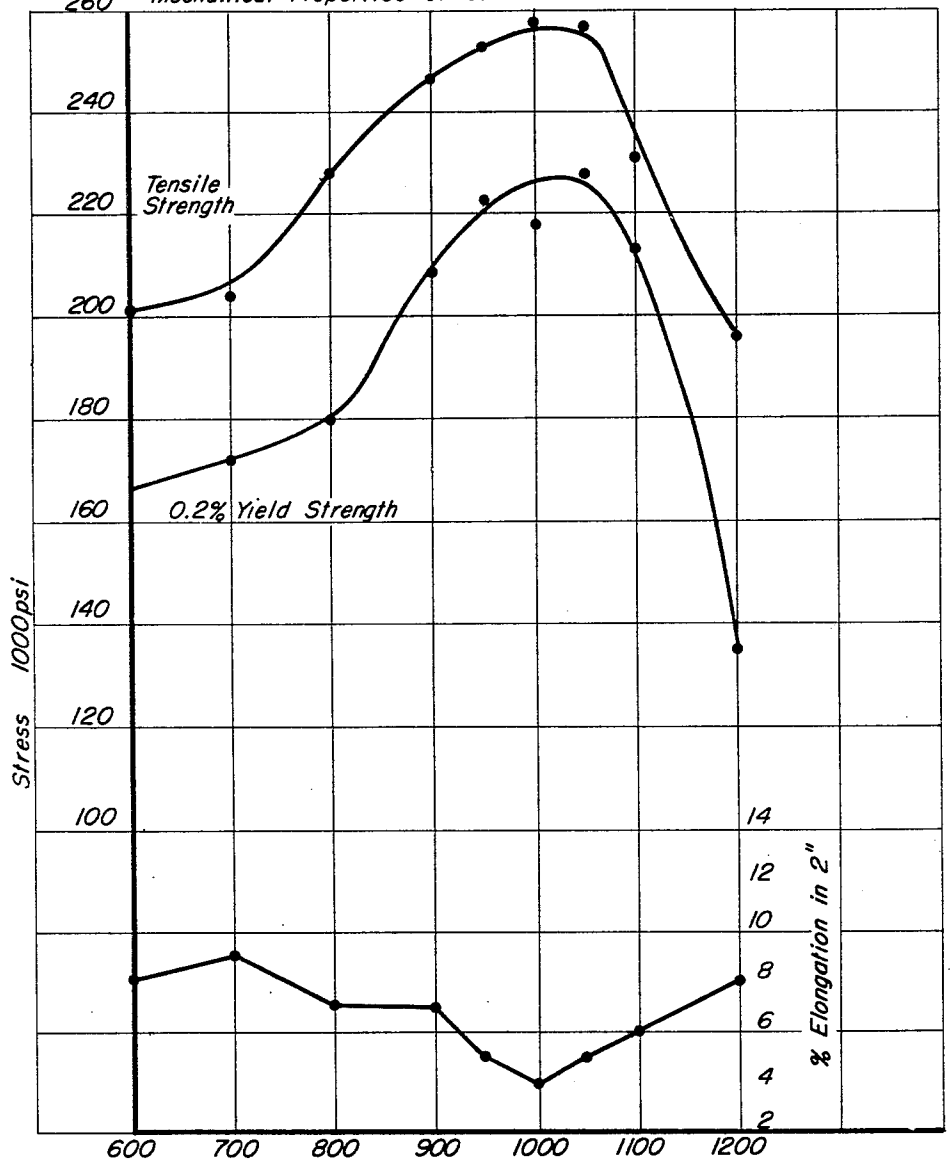
Oct. 6, 1964 D C. PERRY ETAL 3,151,978

HEAT HARDENABLE CHROMIUM-NICKEL-ALUMINUM STEEL

Filed Dec. 30, 1960 3 Sheets-Sheet 1

FIG. 1 *Effect of Hardening Temperature on Room Temperature Mechanical Properties of Cr-Ni-Mo-Al Stainless Steel.*



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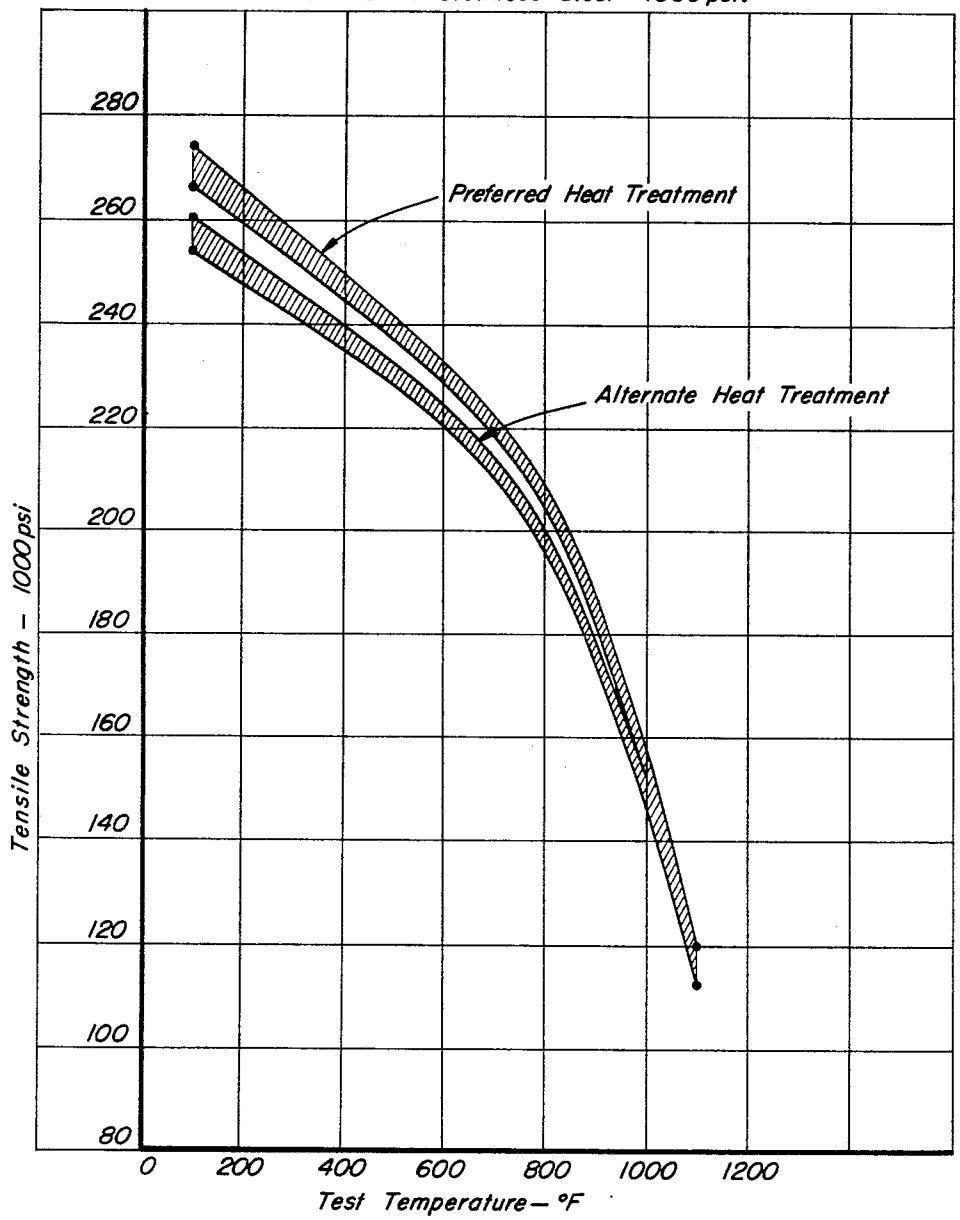
BY

ATTORNEY

HEAT HARDENABLE CHROMIUM-NICKEL-ALUMINUM STEEL

Filed Dec. 30, 1960 3 Sheets-Sheet 2

FIG. 2 *Short Time Elevated Temperature Tensile Strength of Cr-Ni-Mo-Al Stainless Steel - 1000 psi.*



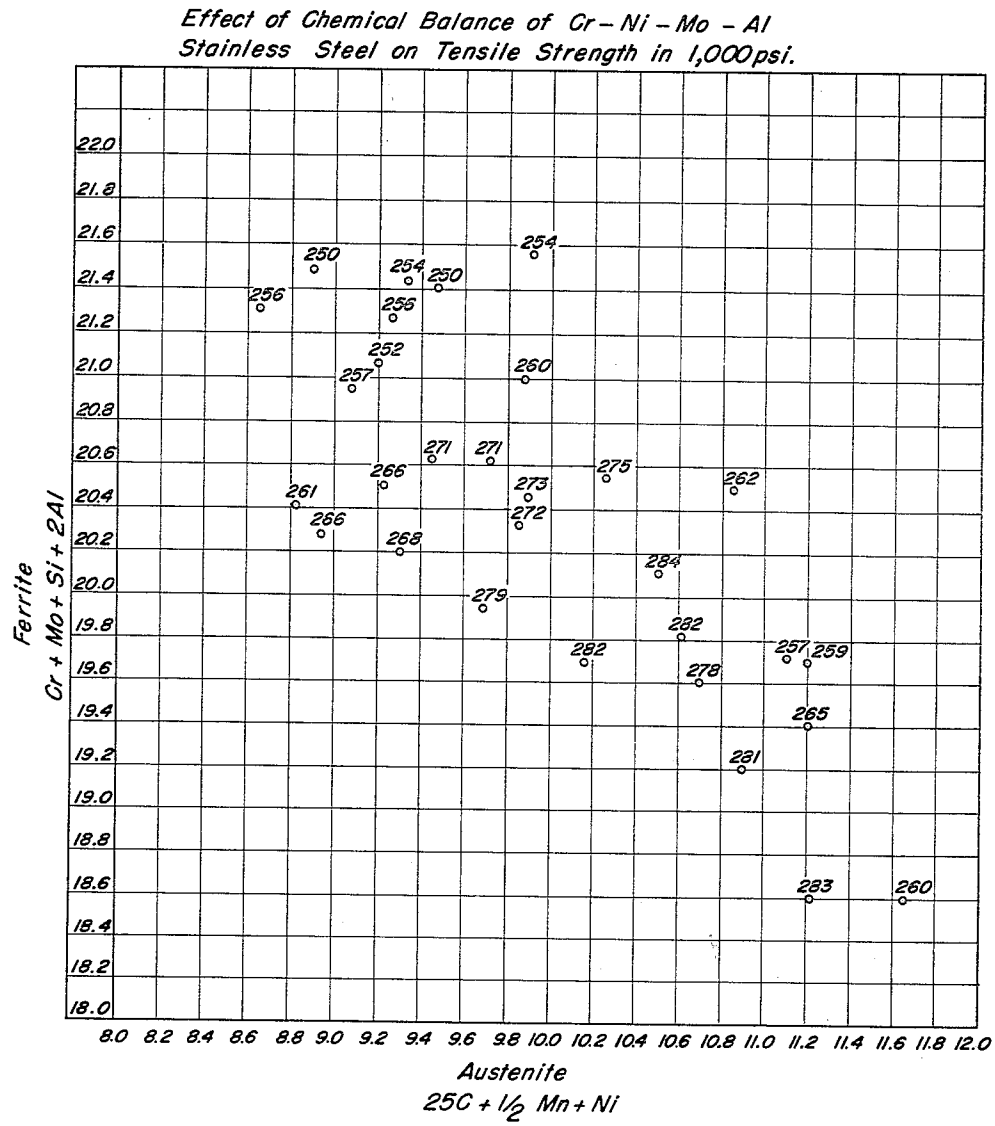
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HEAT HARDENABLE CHROMIUM-NICKEL-ALUMINUM STEEL

Filed Dec. 30, 1960 3 Sheets-Sheet 3

FIG. 3



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HEAT HARDENABLE CHROMIUM-NICKEL-ALUMINUM STEEL

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Filed Dec. 30, 1960, Ser. No. 79,922
14 Claims. (Cl. 75—124)

This application for patent is a continuation-in-part of our copending application Serial No. 842,800, filed September 28, 1959, entitled Heat Hardenable Chromium-Nickel-Aluminum Steel, which in turn is a continuation-in-part of our then copending application Ser. No. 706,471, filed December 31, 1957 and entitled Stainless Steel and Method, now abandonded, and our invention relates to the chromium-nickel steels and more particularly to the heat-hardenable chromium-nickel-aluminum steels and a method of hardening the same, and to the resultant hardened steel.

One of the objects of our invention is the provision of a heat-hardenable chromium-nickel steel which possesses good hot-working properties and yet which readily may be hardened by heat-treating methods to achieve great strength at room temperatures and great strength at high temperatures.

Another object is the provision of a chromium-nickel-aluminum steel which may be converted into plate, sheet, strip, bars, rods, wire, tubes and special shapes through rolling, drawing, piercing and extrusion methods; which steel will not objectionably harden in shipment in winter weather; and which upon receipt by a customer fabricator may be formed and fabricated into a host of articles, which may be hardened either before or after fabrication by heat-treatment.

A further object of our invention is the provision of a simple, direct, reliable and thoroughly practical method of producing heat-hardened chromium-nickel-aluminum steel of great strength.

And another object of our invention is the provision of a heat-hardened chromium-nickel-aluminum stainless steel and various articles and products fashioned of the same with great strength and good surface appearance.

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

Accordingly, our invention consists of 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, and to the combination of composition and operational steps as described herein, the scope of the useful application of which is indicated in the claims at the end of this specification.

In order to gain a better understanding of certain features of our invention it may be noted at this point that although the usual grades of chromium-nickel stainless steel are not considered to be hardenable by heat-treating methods, there are available chromium-nickel stainless steels containing the further ingredients titanium and/or columbium which respond to heat-hardening methods. With a balanced composition of chromium, nickel, titanium and/or columbium together with carbon, there is had a steel possessing substantial hardness in the final heat-hardened state. These steels rely on the carbide-forming

characteristics of the titanium and the columbium, in fact, on the circumstance that both are stronger carbide-formers than is chromium. It is generally known, however, that columbium is an expensive addition and is not readily available. Also it is known that titanium is inclined to produce dirty metal, requiring special steps in the melting operation to produce a quality steel. But with all this, the strength had in the heat-hardened condition leaves much to be desired.

More recently it is to be noted that a series of chromium-nickel-aluminum steels are finding great favor in the art. We refer, for example, to the steels described and claimed in the U.S. Patents 2,505,762; 2,505,763; 2,505,764 and 2,506,558, all of which issued to George N. Goller on May 2, 1950. In the steels of those patents there are employed critical amounts of the ingredients chromium, nickel and aluminum to achieve desired workability in the annealed condition, this in combination with desired hardness and strength in the heat-hardened condition. In the steels of those patents there additionally may be included small amounts of manganese and silicon, sulphur and phosphorus, as well as small amounts of molybdenum, this latter to enhance the corrosion-resistance of the steel. With the balanced composition of the steels of the patents and the special heat-hardening treatment there are achieved ultimate tensile strengths somewhat in excess of 200,000 p.s.i. with 0.2% yield strengths closely approaching the 200,000 p.s.i. figure (see the tables appearing at the foot of col. 6 of the Patents 2,505,763 and 2,505,764). The workability of the steels of the patents in the annealed condition is good, the hardness in the annealed condition being somewhat less than Rockwell B90. Some of these steels, however, require a special stabilizing treatment to prevent an unwanted hardening during shipment in winter weather.

An object of our invention is the provision of a chromium-nickel-aluminum steel possessing good hot-working characteristics and yet which readily may be hardened by simple heat-hardening methods to achieve even greater strength in the heat-hardened condition than the heretofore chromium-nickel-aluminum stainless steels, all without objectionable unwanted hardening in shipment.

In the accompanying drawing illustrating certain features of our invention:

FIG. 1 is a graph illustrating the effect of the hardening temperature on the strength of our steel;

FIG. 2 is a graph illustrating the elevated temperature strength of our steel; and

FIG. 3 is a chart on which there is indicated the strength of our steel as it is affected by the chemical balance of its austenite-forming and ferrite-forming constituents.

In the practice of our invention we find that by closely correlating the ingredients chromium and nickel with the further ingredients aluminum and molybdenum we obtain a steel possessing good hot-working characteristics. The steel is in every sense critical. And we find that by proper heat-treatment from the annealed condition there is achieved great strength and hardness without, however, inadvertently hardening the steel as a result of cold-weather shipment in the annealed condition.

The steel of our invention essentially consists of about 4% to 14.5% chromium, 6% to 12% nickel, 4% to 14% molybdenum, .5% to 2% aluminum, carbon not exceeding

about .20%, and remainder substantially all iron. Ordinarily, the manganese content does not exceed 2% and the silicon content does not exceed 1%. Where desired, however, manganese can be substituted for nickel on the basis of 2 for 1. But in this substitution we find it necessary that there must be at least 3.5% nickel in order to achieve the desired ultimate hardness. The actual nickel content, therefore, is at least 3.5% with the remaining nickel requirement supplied by manganese over and above the 2% manganese commonly present as a maximum, this on a 2 for 1 basis. Thus, for the maximum nickel content of 12%, there may be an actual nickel content of 3.5% with a substituted nickel content of 8.5%, represented by an addition of 17% manganese, with total manganese content, then, of 19% as a maximum.

The ingredient silicon may be substituted for a small portion of the chromium content on a 1 for 1 basis for the purpose of increasing the heat-scale resistance of the steel. The extent of this substitution, however, is limited to replacing no more than 2% of the chromium with silicon which, with the 1% maximum silicon content ordinarily present, gives a total silicon content of 3% as a maximum.

In our steel we find that molybdenum may be replaced by tungsten on a 1 for 1 basis, this up to a total tungsten content of 6%. The molybdenum content and also the tungsten content of our steel may be partially replaced by vanadium on a 1 for 1 basis, this up to a total vanadium content of 2%.

Where desired, we find that boron up to the amount of .010% may be added to improve the hot-workability of the steel, without loss of ductility or undue brittleness in the final heat-hardened condition. And, where desired, there are added titanium and/or zirconium up to 0.10%. Also, where desired, there is added columbium up to 0.50%. The additions of titanium, zirconium and columbium have the effect of tying up the small amount of carbon present in the steel, with the result that the hardness in the annealed condition is lowered significantly and formability correspondingly improved.

Our steel ordinarily, however, consists essentially of 4% to 14.5% chromium, 6% to 12% nickel, 4% to 14% molybdenum, .5% to 2% aluminum, the carbon content not exceeding .20%, manganese up to 2%, silicon up to 1%, phosphorus and sulphur each not exceeding .05%, with remainder iron. One preferred steel analyzes approximately 8% to 14.5% chromium, 6% to 10% nickel, 4% to 8% molybdenum, .5% to 2% aluminum, carbon not exceeding 0.20%, and remainder substantially all iron. This steel is stainless, is readily workable in the annealed condition, and is hardenable by heat-treating methods to great strength.

A preferred range of composition for the stainless steels is about 11.25% to 12.75% chromium, 6.5% to 7.5% nickel, 5.5% to 6.5% molybdenum, .8% to 1.4% aluminum, .06% to .10% carbon, and remainder substantially all iron. In this steel the manganese content is up to 2% as a maximum, the silicon content up to 1% and phosphorus and sulphur each up to .05%. A particular example consists of about 12% chromium, 7% nickel, 6% molybdenum, .8% to 1.4% aluminum, carbon not exceeding about 0.20%, and remainder substantially all iron.

Another preferred composition of stainless steel in accordance with our invention essentially consists of 10.75% to 12.00% chromium, 7.5% to 8.5% nickel, 5.5% to 6.5% molybdenum, .8% to 1.4% aluminum, with carbon up to 0.20%, and remainder substantially all iron. Here again the manganese is up to 2%, the silicon up to 1% and phosphorus and sulphur each up to .05%. A further preferred steel essentially consists of about 10% to 11.5% chromium, 8% to 9.5% nickel, 5% to 7% molybdenum, .5% to 1.5% aluminum, and remainder substantially all iron. Minor amounts of carbon, manganese, silicon, sulphur and phosphorus, of course, are present as noted. A

specific preferred steel analyzes about 11% chromium, 9% nickel, 6% molybdenum, 1% aluminum, and remainder substantially all iron. This steel as well as the further preferred steel noted above, is almost entirely free of delta ferrite, the delta ferrite content being less than about 5% by volume and usually less than 2%. The further preferred steel, and specific preference, is especially suited to the production of bars, billets, forgings, plates and flat-rolled products of heavy section.

In the steels of our invention we preferably maintain chromium on the low side where the molybdenum content is to be on the high side, and conversely, where the molybdenum is to be on the low side, the chromium is maintained on the high side. Thus one of our stainless steels consists essentially of about 13% to 14% chromium, 6.5% to 7.5% nickel, .8% to 1.40% aluminum, about 4% molybdenum, with remainder substantially all iron. Another essentially consists of about 11.25% to 12.75% chromium, 6.5% to 7.5% nickel, .8% to 1.40% aluminum, about 6% molybdenum, and remainder substantially all iron. A further stainless steel essentially consists of 8% to 10% chromium, 8% to 9% nickel, .8% to 1.40% aluminum, about 8% molybdenum, and remainder substantially all iron. More particularly, the steel analyzes about 9% chromium, 9% nickel, 8% molybdenum, .8% to 1.4% aluminum, and remainder substantially all iron.

Some further steels in accordance with our invention essentially consist of 4% to 8% chromium, 7.5% to 12% nickel, 8% to 14% molybdenum, .5% to 2% aluminum, carbon not exceeding 0.20%, and remainder substantially all iron. These steels although not properly considered as stainless steels, are readily workable in the annealed condition and are hardenable by heat-treating methods to great strength. One such steel, more particularly analyzes about 8% chromium, 9% nickel, 10% molybdenum, .8% to 1.4% aluminum, and remainder substantially all iron. Another analyzes about 5% chromium, 12% nickel, 12% molybdenum, .8% to 1.4% aluminum, and remainder substantially all iron.

A further steel, one which is hardenable by a single precipitation-hardening heat-treatment from the annealed or solution-treated condition, essentially consists of 4% to 9% chromium, 6% to 10% nickel, 4% to 8% molybdenum, .5% to 2% aluminum, carbon .10% max., and remainder substantially all iron. In this steel the sum of the chromium and molybdenum contents should be less than 14% in order to prevent the development of delta-ferrite with consequent loss of transverse strength ductility. And for the same reason the nickel content should not be less than 6%.

One preferred single-treatment steel essentially consists of about 5.5% to 6.5% chromium, 8.5% to 9.5% nickel, 5.5% to 6.5% molybdenum, .8% to 1.4% aluminum, carbon .08% max., and remainder substantially all iron. Another analyzes about 4% to 5% chromium, 7.5% to 8.5% nickel, 5.5% to 6.5% molybdenum, .8% to 1.4% aluminum, carbon .08% max., and remainder substantially all iron. A further preferred single-treatment steel analyzes about 7% to 8% chromium, 7.5% to 8.5% nickel, 5.5% to 6.5% molybdenum, .8% to 1.4% aluminum, carbon .08% max., and remainder substantially all iron.

The steels of our invention lend themselves to conversion by known rolling, drawing, piercing and extruding operations, from the ingot and billet into various commercial forms such as plate, sheet, strip, bars, rods, wire, tubes and various special shapes. And we find that they may be shipped to a customer in the annealed condition (annealed, for example 1950° to 2050° F.) without encountering an undesired transformation, even in extreme cold weather.

The steels when received by the customer fabricator readily may be fabricated through known techniques such as bending, punching, machining, and the like, and by

welding, riveting, etc. into a variety of products which subsequently are hardened and strengthened by heat-treatment. Our steels, where desired, may be made into castings which are machined to specification. The heat-treating operation, or one or more of the steps thereof, for both wrought and cast products, may be performed prior to fabrication. In fact, one or more of the conditioning treatment, cold treatment and final hardening may be done at the steel plant prior to shipment when there is little or no drastic shaping required of the fabricator.

The steels of our invention preferably are heat-hardened by first conditioning the annealed steel at a temperature of about 1200° to 1800° F., or even 1000° to 1800° F., and cooling, this to facilitate subsequent hardening treatment. Then cold-treating the steel by holding the same at a temperature of 150° to −320° F., or 150° to −100° F., preferably 60° to −320° F., or more particularly 60° to −100° F. And finally heat-hardening by reheating the steel to a temperature of 800° to 1150° F. or even 700° to 1200° F. Actually, we prefer to condition the annealed steel at a temperature of 1300° to 1650° F., more particularly at 1400° F. The time of treatment usually ranges from about 10 minutes up to an hour or more, preferably about 2 hours at preferred temperature. We find that no particular benefit is had through prolonged conditioning treatment beyond about 2 hours.

While we may cold-treat our steel at a temperature anywhere from 60° to −320° F. for periods of time ranging from 2 hours to 24 hours or more, we preferably refrigerate the steel at a temperature of about −100° F., this for a period of about 8 hours, or −25° F. for 2 hours following the preferred conditioning treatment of 1400° F. for 2 hours.

In hardening the cold-treated steel we preferably employ a temperature of 950° to 1050° F. for a period of about 1 hour. With the conditioning treatment at 1400° F. for 1 hour and cooling followed by refrigeration at −100° F. for 8 hours, we prefer to heat-harden the steel by a treatment at about 1000° F. for a period of 2 hours.

The effect of the conditioning temperature and time on a typical steel of our invention following annealing is given in Tables I(*a*) and I(*b*) below, the analyses of the steel, and two additional examples which will be referred to hereinafter, being given in the former, and the mechanical properties after final heat-treatment following the conditioning treatment being given in the latter.

TABLE I(*a*)

Chemical Analyses of Cr-Ni-Mo-Al *Stainless Steel*

Heat	Grade	C	Mn	Si	Cr	Ni	Mo	Al
R1078 [1]	PH12-7-6 [2]	.080	.61	.59	12.12	7.14	5.82	1.40
R1079	PH12-7-6	.085	.53	.59	11.90	7.20	6.08	1.34
R1080	PH12-7-6	.084	.54	.34	12.32	7.28	6.05	1.34

[1] .004 Boron.
[2] Trademark Armco Steel Corporation.

TABLE I(*b*)

Effect of Conditioning Temperature and Time on Room Temperature Mechanical Properties of the Example R1078 Annealed Steel of Table I(a)

Cond. Temp., ° 10 min.	Conditioning Time=10 mins. 0.2% Y.S., p.s.i.	T.S., p.s.i.	Percent E in 2″	Rc	Conditioning Time=60 mins. 0.2% Y.S., p.s.i.	T.S., p.s.i.	Percent E in 2″	Rc
1,200	221,000	256,000	6	51.5	216,000	250,000	5	51.0
1,300	218,000	253,000	6	51.5	219,000	254,000	6	51.5
1,400	224,000	252,000	4	51.5	227,000	257,000	5	52.5
1,500	223,000	254,000	6	51.0				51.5
1,600	219,000	249,000	7	51.0	220,000	250,000	5	51.0
1,700	215,000	248,000	6	51.0	209,000	215,000	5	51.0
1,800	218,000	249,000	7	50.5	202,000	238,000	5	51.5

From the data presented in Tables I(*a*) and I(*b*) above it will be noted that best results in terms of ultimate tensile strength and .2% yield strength are had where the previously annealed steel is conditioned at a temperature between 1300° and 1600° F., particularly about 1400° F. A treating time of 1 hour, it will be noted, gives somewhat better results than the shorter treating time of 10 minutes.

The effect of the temperature of the cold-treatment and the time of the cold-treatment are illustrated by the data presened in Table I(*c*) below:

TABLE I(*c*)

Effect of Temperature of Cold-Treatment on Room Temperature Mechanical Properties of Steel R1078 of Table I(a) Hardened for 1 Hour at 950° F.

Cond. Temp. in ° F., 10 minutes	Cold Temp. in ° F., 8 hours	0.2% Y.S., p.s.i.	T.S., p.s.i.	Percent E in 2″	Rc
1,550	0	209,000	242,000	6	51.0
	−50	224,000	249,000	7	52.0
	−100	220,500	250,000	6	52.0
1,650	0	208,000	241,000	8	50.0
	−50	215,000	245,000	7	51.0
	−100	215,000	246,000	7	51.0
1,750	0	202,000	236,000	9	51.5
	−50	210,000	241,000	7	50.5
	−100	213,000	242,000	8	51.0

Although the mechanical properties for steels hardened following cold-treatment at −100° F. and −50° F. are about the same, the difference is in favor of the lower temperature treatment. Treatment at either of these temperatures, however, is but slightly better than treatment at 0° F. The −100° F. cold-treatment is preferred. Actually, we find that as a practical matter refrigeration at a temperature of −25° F. is adequate.

While neither the conditioning temperature of our steel nor the temperature of cold-treatment is highly critical, we do find that the temperature of the final hardening treatment is most critical. The critical character of the final hardening heat-treatment in terms of its effect upon the mechanical properties at room temperature is illustrated by the data presented in Table I(*d*) below:

TABLE I(*d*)

Effect of Hardening Temperature on the Room Temperature Mechanical Properties of Conditioned and Cold-Treated Example R1078 of Table I(a)

Hard. Temp. ° F. (1 hr. at temp.)	0.2% Y.S., p.s.i.	T.S., p.s.i.	Percent E in 2″	Rc
600	167,800	201,600	8	42
700	172,300	204,200	9	42
800		228,600	7	47
900	209,400	246,900	7	49
950	224,000	253,100	5	50
1,000	218,600	257,000	4	50
1,050	228,000	256,500	5	51
1,100	213,000	231,600	6	48
1,200	135,700	198,000	8	42

It will be seen from the data of Table I(*d*), particularly the tensile strength and yield strength figures, that best results are achieved where the final hardening treatment is conducted within the critical range of 950° to 1050° F. Within this range tensile strength values in excess of 250,000 p.s.i. are had with yield strength which generally averages in excess of 220,000 p.s.i. The critical natural of the final hardening treatment is forcefully revealed by the curves for tensile strength and yield strength as against the hardening temperature which is given in FIG. 1 of the drawings. These curves support the gen-

eral acceptable range of 800° to 1150° F. with the more critical range of 950° to 1050° F.

While we prefer a hardening heat-treatment consisting of the three steps of conditioning the annealed steel, then cold-treating for a period of time, and finally heat-hardening the same, beneficial results with many of the advantages noted are archieved with other heat-treatments. For example, we find that good results are had by merely cold-treating the steel at a temperature of about —100° F. for 8 hours from previously treating at a temperature of 1750° F., with or without annealing, and then hardening the steel by heat-treatment at a temperature of some 800° to 1150° F. Mechanical properties had at room temperature for a sample of our steel analyzing 13.41% chromium, 7.35% nickel, 4.10% molybdenum, 1.20% aluminum, .095% carbon, .81% manganese, .64% silicon, .012% phosphorus, .020% sulphur, and remainder iron, when cold-treated at —100° F. from a previous treatment at 1750° F. for 10 minutes and then hardened by heat-treatment at temperatures of 750°, 825° and 950° F., are given in Table II below:

TABLE II

Effect of Final Hardening Temperature on Room Temperature Mechanical Properties of Cold-Treated and Heat-Hardened Cr-Ni-Mo-Al *Stainless Steel Strip of .050" Gage*

Condition	0.2% Y.S., p.s.i.	T.S., p.s.i.	Elong. percent in 2"	Rockwell Hardness
Annealed	55,300	145,000	27	RB93.
Hard., 750° F	188,100	216,300	8	RC46.5.
Hard., 825° F	210,400	237,300	9	RC49.5.
Hard., 950° F	233,000	252,500	6	RC51.5.

It will be noted from the data presented in Table II that best results in terms of tensile strengths and yield strengths are had with the higher temperatures of final hardening treatment.

Moreover, it will be noted that the resuts are comparable with the tensile and yield strengths had with the preferred treatment of conditioning, cold-treating and final heat-hardening, as presented in Table I(*d*).

Another heat-treatment which gives some benefits of our invention is one involving conditioning the steel at 1400° F. for 1½ hrs. or more, cooling the same to room temperature (60° F.) within an hour, and then reheating to about 1050° F. for 1½ hours. The mechanical properties had with the sample of our steel analyzing as above, whose properties are given in Table II, are set forth in Table III below:

TABLE III

Mechanical Properties of Conditioned and Heat-Hardened Cr-Ni-Mo-Al *Stainless Steel Strip of .050" Gage*

Condition	0.2% Y.S., p.s.i.	T.S., p.s.i.	Elong. percent in 2"	Rockwell Hardness
Hard. at 1,050° F	215,000	227,400	7	RC48.5.

The superior elevated temperature properties had with our steels, both with the preferred heat-treatment (a conditioning treatment at about 1400° F. for 1 hour, followed by cold-treatment at —100° F. for 8 hours, and hardening by heat-treatment at 1000° F. for 1 hour) and with alternate form of heat-treatment (cold-treatment at —100° F. for 8 hours from the prior treatment at 1750°+final heat-hardening at 1000° F. for 1 hour)

are given in Table IV(*b*) below, the chemical analyses of the several steels being given in Table IV(*a*):

TABLE IV(*a*)

Chemical Analyses of Cr-Ni-Mo-Al *Stainless Steels*

Heat	C	Mn	Si	Cr	Ni	Al	Mo	Chemical Balance Factor	
								Aus.	Fer.
R1415	.083	.62	.64	11.45	7.48	1.13	5.97	9.865	20.32
R1419	.083	.62	.62	11.41	7.51	1.10	6.24	9.895	20.47
R1409	.071	.60	.59	11.29	6.87	1.12	6.17	8.945	20.29
R1407	.070	.58	.53	11.38	7.38	1.15	5.99	9.32	20.20
R1411	.068	.59	.57	11.50	7.45	1.13	6.28	9.445	20.61
R1417	.086	.62	.60	11.36	6.77	1.12	6.29	9.230	20.49

TABLE IV(*b*)

Short Time Elevated Temperature Tensile Properties on Cr-Ni-Mo-Al *Stainless Steel*

(1) ANNEALED+CONDITIONED AT 1400° F. + COLD-TREATED —100° F.+HEAT-HARDENED 1000° F.

Heat	Temp.	0.2— Y.S., p.s.i.	T.S., p.s.i.	Percent E in 2"	Aus.	Fer.
R1415	R. T	248,500	272,400	3	9.865	20.32
	600	193,500	232,000	3		
	900	141,500	182,500	10.5		
	1,000	116,000	151,500	14		
	1,100	85,500	116,000	13		
R1419	R. T	237,100	273,000	2	9.895	20.47
	800	169,500	208,000	6.5		
	900	142,500	183,500	9.5		
	1,000	117,000	153,500	13		
	1,100	85,000	117,000	14		
R1409	R. T	240,000	266,000	5	8.945	20.29
	600	188,000	229,000	2		
	800	164,000	204,500	6		
	1,000	109,000	149,500	14		
	1,050	97,000	135,000	14.5		

(2) ANNEALED+TREATED AT 1,750° F.+ COLD-TREATED —100° F.+HEAT-HARDENED 1,000° F.

R1407	R. T	234,000	259,400	4	9.32	20.20
	600	190,000	233,000	3		
	900	136,500	174,000	10		
	1,000	109,500	147,000	12		
	1,100	85,000	116,000	12		
R1411	R. T	232,300	260,000	3	9.445	20.61
	600	186,500	223,500	3		
	800	157,000	201,000	7		
	900	135,500	176,000	10		
	1,000	114,500	149,000	13		
	1,050	100,000	132,000	17		
R1417	R. T	227,500	255,700	5	9.230	20.49
	600	183,000	221,000	3		
	800	157,500	194,000	7		
	1,000	110,500	145,500	12.5		
	1,100	87,500	112,000	18.0		

It will be seen by simple comparison of the data of Parts (1) and (2) of the Table IV(*b*) that the short time elevated temperature strength of our steel with preferred heat-treatment is significantly superior to the strength had when given the alternate form of heat-treatment. This comparison is illustrated in FIG. 2 of the drawings.

Another preferred treatment for the steels of our invention, following the annealing at 1900° to 2050° F., is a conditioning at 1000° F. to 1200° F. and cooling. Following this, the steel is refrigerated at —30° to —150° F. And then it is hardened by reheating at 700° to 1150° F., especially about 1000° to 1050° F.

Hardening of our steels also is achieved by drastic cold-rolling, or other cold-working, that is, to the extent of at least 25% and preferably about 60% or more, followed by precipitation-hardening heat-treatment. In a steel analyzing about 11% chromium, 8% nickel, 6% molyb-

denum and 1% aluminum, with remainder substantially all iron, excellent mechanical properties are developed where the steel has been cold-reduced by about 60% and then heat-hardened by heating at about 950° to 1050° F. and cooling. The chemical analysis of this steel is given in Table X(*a*) below, with mechanical properties in Table X(*b*):

TABLE X(*a*)

Chemical Analysis of Specific Chromium-Nickel-Aluminum Stainless Steel

Heat	C	Mn	P	S	Si	Cr	Ni	Mo	Al
V421	.07	.44	.012	.017	.43	11.55	8.00	6.00	1.23

Mechanical Properties of Specific Steel of Table X(a)

Heat	Condition [1]	0.2% Y.S., p.s.i.	T.S., p.s.i.	Percent E in 2"	Rockwell Hardness
V421	C	232,500	244,500	3	48.0
V421	CH950	312,500	331,000	3	57.0
V421	CH1000	291,400	322,200	4	56.5
V421	CH1050	288,000	314,000	4	55.5

[1] C=Cold rolled 60%.
CH950=Cold rolled 60% + hardened at 950° F. for 1 hour.
CH1000=Cold rolled 60% + hardened at 1000° F. for 1 hour.
CH1050=Cold rolled 60% + hardened at 1050° F. for 1 hour.

All tests made in longitudinal direction.

The great tensile strength of our cold-rolled and precipitation-hardened steel, this well exceeding 300,000 p.s.i., is to be especially noted, as well as its excellent yield strength, a value approaching 300,000 p.s.i.

The general effect of the chemical balance of our steel, that is, the balance between the austenite-forming ingredients figured at 25×the carbon content+½×the manganese content+the nickel content, as against the ferrite-forming ingredients figured at the sum of the chromium, molybdenum, and silicon contents+twice the aluminum content shows that the greatest strength is achieved where the sum of the austenite-forming ingredients is on the high side and the sum of the ferrite-forming ingredients is on the low side. The mechanical properties for a series of examples of our steel of differing chemical analyses is given in Table V(*b*) below, the analyses of the samples being given in Table V(*a*), this including the samples noted in Table IV(*a*):

TABLE V(*a*)

Chemical Analyses of 12–7–6 Cr-Ni-Mo-Al *Stainless Steels*

Heat	C	Mn	Si	Cr	Ni	Al	Mo	Chemical Balance Factors	
								Aus	Fer.
R1405	.067	.61	.56	11.63	6.84	1.16	5.92	8.82	20.43
R1406	.069	.62	.59	12.55	5.87	1.16	6.03	8.905	21.49
R1407	.070	.58	.53	11.38	7.38	1.15	5.99	9.32	20.20
R1408	.065	.63	.66	12.56	7.39	1.15	5.92	9.33	21.44
R1409	.071	.60	.59	11.29	6.87	1.12	6.17	8.945	20.29
R1410	.064	.62	.60	12.46	6.75	1.03	6.21	8.66	21.33
R1411	.068	.59	.57	11.50	7.45	1.13	6.28	9.445	20.61
R1412	.068	.62	.54	12.44	7.48	1.08	6.28	9.49	21.42
R1413	.079	.58	.56	11.47	6.82	1.06	5.87	9.085	20.97
R1414	.082	.60	.58	12.35	6.85	1.10	5.92	9.20	21.05
R1415	.083	.62	.64	11.45	7.48	1.13	5.97	9.865	20.32
R1416	.083	.63	.63	12.26	7.47	1.08	5.95	9.885	21.00
R1417	.086	.62	.60	11.36	6.77	1.12	6.29	9.230	20.49
R1418	.085	.60	.60	12.30	6.86	1.07	6.24	9.285	21.28
R1419	.083	.62	.62	11.41	7.51	1.10	6.24	9.895	20.47
R1420	.088	.63	.61	12.42	7.40	1.14	6.26	9.915	21.57

TABLE V(*b*)

PH12–7–6 Mechanical Properties of Cr-Ni-Mo-Al *Stainless Steel Conditioned, Refrigerated and Heat-Hardened* [1]

Heat No.	0.2% Y.S., p.s.i.	T.S., p.s.i.	Percent E 2"	Rockwell C Hardness
R1405	234,000	261,000	5	52.0
R1406	221,000	250,700	4	51.5
R1407	245,000	268,500	3	53.0
R1408	225,800	254,800	6	52.0
R1409	240,000	266,000	5	53.0
R1410	224,500	256,000	4	52.0
R1411	240,000	271,000	3	54.0
R1412	217,800	250,000	4	51.5
R1413	228,400	257,500	4	52.5
R1414	226,100	252,700	3	52.5
R1415	248,500	272,400	3	53.0
R1416	235,000	260,000	3	52.0
R1417	238,700	266,300	3	53.0
R1418	224,700	256,000	3	52.0
R1419	237,100	273,000	2	51.0
R1420	220,500	254,000	5	52.0

[1] 1,400° F. for 1 hr.; refrigerate 8 hrs. at −100° F.; harden at 1,000° F. for a hr.

It will be noted from the results given in Tables V(*a*) and V(*b*) that the steels of the high tensile strengths are those in which the sum of the austenite-forming ingredients is high and the sum of the ferrite-forming ingredients is low. This is graphically illustrated in FIG. 3 of the drawing.

A further series of preferred steels according to our invention is given in Table VI(*a*) below, with cold treatment test data, delta ferrite and balance between austenite-forming ingredients and ferrite-forming ingredients given in Table VI(*b*), and with corresponding mechanical properties in hardened condition given in Tables VI(*c*) and VI(*d*).

TABLE VI(*a*)

Chemical Analyses of 11–8–6 Cr-Ni-Mo-Al *Stainless Steels*

Heat No.	C	Mn	Si	Cr	Ni	Mo	Al
R1861	.066	.57	.47	11.27	7.77	5.88	1.15
R1862	.060	.59	.49	11.83	7.72	6.00	1.15
R1879	.071	.57	.48	10.53	8.90	5.79	1.22
R1939	.076	.44	.46	11.26	8.05	5.70	1.16
R1940	.075	.37	.37	11.17	8.60	5.94	1.17
R1941	.076	.44	.39	11.05	8.99	6.00	1.13
R1943	.077	.44	.40	9.76	9.06	6.29	1.09
R1945	.078	.40	.41	11.74	8.11	6.15	1.14
R1944	.077	.47	.41	9.72	9.51	6.23	1.12
R1946	.083	.38	.41	11.78	8.58	6.21	1.03
R2022	.081	.45	.44	11.12	8.47	6.07	.99
R2023	.082	.43	.39	11.08	8.94	6.00	1.13
R2026	.080	.44	.46	10.47	8.99	5.99	1.24
R2043	.080	.49	.38	11.20	8.23	6.02	1.27

TABLE VI(*b*)

Cold Treat Test Data, Delta Ferrite, and Chemical Balance of 11–8–6 Cr-Ni-Mo-Al *Stainless Steels*

Heat No.	Hardness Annealed Rockwell B	Hardness Cold Treat Rockwell B	Percent Delta Ferrite	Chemical Balance	
				Aus.	Fer.
R1861	91	94	10	9.705	19.92
R1862	93	94	10	9.74	20.62
R1879	85	85	4	10.96	19.24
R1939	90	90	8	10.17	19.74
R1940	86	86	5	10.66	19.82
R1941	83	83	4	11.11	19.70
R1943	82	97	2	11.205	18.63
R1944	80	85	0	11.67	18.60
R1945	91	92	12	10.26	20.58
R1946	88	88	10	10.845	20.51
R2022	88	88	5	10.72	19.61
R2023	84	87	3	11.205	19.73
R2026	83	84	1	11.21	19.40
R2043	89	89	10	10.475	20.14

From Table VI(*b*) it is noted that the amount of delta ferrite in our steels is less than 12% by volume (usually less than 10%) and frequently under 5%. The hardness in the annealed condition usually is less than Rockwell B90. And this hardness ordinarily is not increased by treatment at temperatures reached in cold weather shipment (0° F.); the occasional increase is not over 1 or 2 points.

TABLE VI(*c*)

Mechanical Properties of 11–8–6 Cr-Ni-Mo-Al *Stainless Steel Conditioned, Cold-Treated and Heat-Hardened* [1]

Heat No.	0.2% Y.S., p.s.i.	T.S., p.s.i.	Percent E 2"	Rockwell C Hardness
R1861	260,000	279,100	4	54
R1862	248,800	271,000	4	53
R1879	251,800	281,500	4	54.5
R1939	255,600	282,000	4	54
R1940	259,200	282,200	4	54
R1941	229,000	257,400	4	53
R1943	255,000	283,600	6	54.5
R1944	196,100	260,000	4	51.5
R1945	250,000	275,200	5	53.5
R1946	235,000	262,100	6	53
R2022	255,000	278,500	5	54
R2023	231,000	259,000	6	52.5
R2026	232,500	265,600	9	53
R2043	263,600	284,000	4	54.5

[1] Condition 1400° F. for 2 hrs.; refrigerate −25° F. for 2 hrs.; and harden 1000° F. for 2 hrs.

TABLE VI(*d*)

Mechanical Properties of 11–8–6 Cr-Ni-Mo-Al *Stainless Steel Conditioned, Cold-Treated and Heat-Hardened With Furnace Cooling* [1]

Heat No.	0.2% Y.S., p.s.i.	T.S., p.s.i.	Percent E 2"	Rockwell C Hardness
R1861	267,400	290,300	4	55
R1862	247,200	280,200	5	55
R1879	259,000	290,900	3	56
R1939	270,000	290,000	4	55.5
R1940	267,600	289,000	4	55
R1941	241,400	268,600	5	53
R1943	257,000	290,600	6	55
R1944	216,000	265,200	5	53
R1945	266,000	286,600	4	55
R1946	244,100	270,000	3	54.5
R2022	260,000	286,600	4	55.5
R2023	230,200	265,000	7	53
R2026	237,200	273,500	5	54
R2043	269,200	294,000	5	56

[1] Condition 1400° F. for 2 hrs.; refrigerate −25° F. for 2 hrs.; and harden 1000° F. for 2 hrs.; furnace cool to 950° F., hold 3 hrs.; furnace cool to 900° F., hold for 3 hrs.; and air cool.

In general, it is seen from Table VI(*c*) and again from Table VI(*d*) that greatest strength is had in the steels of maximum austenitic content and minimum ferrite content, as given for the steels in Table VI(*a*). Moreover, by comparing Table VI(*c*) with Table V(*b*) it is seen that the steels of the most preferred composition, generally referred to as 11–8–6 Cr-Ni-Mo-Al stainless steel, possess even greater strength than those of the 12–7–6 composition. Also, by comparing the mechanical properties of the steels hardened by the two different methods, it is seen that best results are achieved with the hardening treatment employing the delayed furnace cooling (that is, the treatment of Table VI(*d*)).

As specific example of our steels of the high molybdenum contents, that is 8%, 10% and 12% (the steels respectively analyzing about 8% to 10% chromium, 8.5% to 9.5% nickel, 8% molybdenum, .8% to 1.4% aluminum, and remainder substantially all iron for one group; about 7% to 8% chromium, 9% to 10% nickel, 10% molybdenum, .8% to 1.4% aluminum, and remainder substantially all iron; and 4% to 6% chromium, 10% to 12% nickel, 12% molybdenum, .8% to 1.4% aluminum, and remainder substantially all iron), there are given below several examples for each group in Table VII(*a*), the corresponding mechanical properties being given in Table VII(*b*):

TABLE VII(*a*)

Chemical Analyses of Three Groups of Cr-Ni-Mo-Al *Steels (About 8%, 10% and 12% Molybdenum) With Indication of Chemical Balance*

Heat	C	Mn	Si	Cr	Ni	Mo	Al	Chemical Balance Factors	
								Aus.	Fer.
R2233	.083	.64	.66	9.56	9.43	8.00	1.17	11.825	20.56
R2391	.070	.51	.52	8.89	8.37	7.87	1.14	10.375	19.56
R2392	.073	.54	.58	8.93	8.90	8.03	1.15	10.995	19.84
R2394	.075	.50	.52	8.23	8.40	8.03	1.18	10.525	19.14
R2395	.078	.49	.56	8.36	9.00	8.10	1.20	11.195	19.42
R2237	.070	.67	.73	7.69	9.47	10.00	1.12	11.555	20.66
R2397	.066	.54	.56	7.03	9.38	10.20	1.14	11.30	20.07
R2400	.076	.47	.48	7.85	8.89	10.13	1.16	11.025	20.78
R2243	.080	.67	.82	6.12	9.84	12.30	1.14	12.175	21.54
R2401	.068	.51	.61	4.51	11.86	12.14	1.23	13.815	19.72
R2404	.081	.49	.58	3.72	10.82	11.93	1.13	13.09	18.49

The amount of delta-ferrite for the above steels is less than 12% by volume, and for the second and third groups of steels usually amounts to some 3% to 5% by volume.

TABLE VII(*b*)

Mechanical Properties of the Three Groups of Cr-Ni-Mo-Al *Steels (8%, 10% and 12% Molybdenum) of Table VII(a) as Conditioned, Cold-Treated and Heat-Hardened* [1]

Heat No.	0.2% Y.S., p.s.i.	T.S., p.s.i.	Percent E 2"	Rockwell C Hardness
R2233	199,000	271,500	4	53
R2391	280,000	313,000	2	57
R2392	288,000	315,500	2	57
R2394	271,000	304,200	1	57
R2395	291,000	298,000		58
R2237	274,000	307,000	2	57
R2397	276,000	296,000	1	57
R2400	260,000	287,400	1	56
R2243	290,000	296,500	0.5	60
R2401	296,000	300,000	1	58
R2404	307,000	326,000	1	60

[1] Samples in the form of strip conditioned 1400° F. for 2 hrs.; refrigerated −100° F. for 8 hrs.; hardened 1000° F. for 2 hrs.

Comparable mechanical properties are had where the conditioning treatment is had at 1200° F. for 2 hours. Also where it is had at 1700° F. for some 10 minutes to 2 hours. Actually, in the lower chromium, higher molybdenum grades, it appears that the greatest tensile strength is had with the 1700° F. conditioning treatment followed by the refrigeration at −100° F. and hardening at 1000° F., the tensile strength of the 12% molybdenum grade ranging from some 300,000 to 326,000 p.s.i., although the ductility suffers. In general, therefore, we prefer to condition the steel at 1400° F., with subsequent refrigeration, followed by hardening at about 1000° F.

As further illustration of the practice of our invention, we have had prepared a series of chromium-nickel-aluminum stainless steels, one containing about 6% molybdenum, another about 6% tungsten, a third about 2% molybdenum and 3% tungsten, and a fourth with about 2% molybdenum, 2% tungsten and 1% vanadium. The chemical analyses of these four steels is given in Table

VIII(*a*) below, with mechanical properties in heat-hardened condition in Table VIII(*b*) below:

TABLE VIII(*a*)

Chemical Analyses of 4 Cr-Ni-Al *Heat-Hardenable Stainless Steels*

Heat No.	C	Mn	P	S	Si	Cr	Ni	Mo	Al	W	V
R1079	.085	.53	.010	.010	.59	11.90	7.20	6.08	1.34	------	------
R1197	.10	.47	.011	.010	.44	12.08	7.26	------	1.31	6.44	------
R1207	.11	.45	.009	.011	.37	12.26	7.26	1.78	1.29	3.13	------
R1257	.11	.47	.010	.010	.39	13.17	7.21	1.75	1.33	2.17	.48

TABLE VIII(*b*)

Mechanical Properties of the Steels of Table VIII(a) Following Treatment at 1400° F., Cold-Treating at —100° F. for 8 Hrs. and Heat-Hardening at 1050° F. for 1 Hour

Heat No.	Section	U.T.S., p.s.i.	.2% Y.S., p.s.i.	Percent El.	Rockwell Hardness
R1079	Strip	254,200	236,800	4.0	C51.5.
R1197	Bar	249,100	227,000	9.3	C50.
R1207	---do---	255,700	221,100	10.7	C51.
R1257	---do---	238,600	206,300	10.7	C50.

It will be noted from the Tables VIII(*a*) and VIII(*b*) given above that the ultimate tensile strength of about 250,000 p.s.i. with a yield strength of about 220,000 p.s.i. is had with the steels containing molybdenum and/or tungsten with strengths somewhat less than these figures for the steel containing all three of molybdenum, tungsten and vanadium. The hardness in all cases is Rockwell C50 or better. Certain further benefits are achieved by including in the composition of our steel the ingredients titanium or zirconium up to about 0.10%. This addition improves the weldability, assuring soundness and freedom from pin-holes adjacent the weld. Moreover, on occasion we include up to about 0.50% columbium in our steel for the purpose of improving its toughness.

As specifically illustrative of the single-treatment steels of our invention, reference is made to three examples given in Table IX(*a*) below; with mechanical properties in the annealed condition (1900° F. for ½ hr. and oil-quench) and precipitation-hardened condition (above anneal+1050° F. for 1 hour and air-cool) being given in Table IX(*b*):

TABLE IX(*a*)

Chemical Analyses of 3 Cr-Ni-Al *Hardenable Single-Treatment Steels*

Heat No.	C	Mn	P	S	Si	Cr	Ni	Mo	Al
R2711	.027	.33	.018	.011	.44	4.05	8.08	6.42	1.09
R2707	.037	.39	.020	.029	.19	6.23	9.55	5.73	1.22
R2712	.031	.33	.018	.012	.47	7.60	8.19	6.37	1.11

TABLE IX(*b*)

Mechanical Properties of the Steels of Table IX(a) in Annealed Condition (1900° F.—½ Hr.—Oil-Quench) and in Final Heat-Hardened Condition (Anneal +1050° F.—1 Hr.—Air-Cool)

Heat No.	Condition	U.T.S., p.s.i.	0.2% Y.S., p.s.i.	Percent El. in 2"	Percent Red. Area	Rockwell Hardness
R2711	Annealed	149,000	105,000	9	44	C31.
R2707	---do---	150,000	107,000	9	41	C32.
R2712	---do---	152,000	109,000	8	41	C32.
R2711	Hardened	282,000	248,000	11	38	C53.
R2707	---do---	293,000	252,000	9	35	C54.
R2712	---do---	290,000	251,000	10	36	C54.

While solution-treatment at a temperature of 1900° F. and precipitation-hardening at 1050° F. are employed for the example given above, it will be understood that, where desired, solution-treatment of our single-treatment steel may be conducted at the broader temperature range of 1500° to 2050° F. and quenched in air, oil or water. In this condition the steel is martensitic. And that hardening may be had by treatment at 800° to 1150° F. and cooling.

It will be seen that we provide in our invention a chromium-nickel-aluminum-molybdenum steel of great strength. It is a steel which is readily workable and formable in the annealed condition and yet which is hardened to ultimate tensile strengths of 270,000 p.s.i. and more, with yield strengths of about 240,000 p.s.i. or more.

Note that in the single-treatment steels there are had low hardness and good ductility in the annealed condition in combination with great tensile strength and high yield strength in the heat-hardened condition. Note also that ductility in the hardened condition as reflected by the elongation and reduction in area is good and favorably compare with that of the steel hardened by double-treatment methods. These steels are particularly low in delta-ferrite content, this seldom exceeding 2% by volume, and enjoy good transverse properties, properties which are particularly important where multi-axial stresses are encountered in actual use. The outside casings of missiles, rockets and supersonic aircraft conveniently are fashioned of our steel because of its isotropic characteristics.

Thus it will be seen that we achieve the various objects of our invention hereinbefore set forth, together with many practical advantages in terms of workability and formability in one condition of heat-treatment, and great strengths and hardness in another.

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

We claim as our invention:

1. A chromium-nickel-aluminum steel which is substantially fully austenitic at annealing temperatures and which is hardenable by heat-treatment, said steel consisting essentially of about: 4% to 14.5% chromium, 6% to 12% nickel, .5% to 2% aluminum, 4% to 14% molybdenum, manganese up to 2%, silicon up to 1%, carbon up to .20%, up to about 0.10% of the group consisting of titanium and zirconium, up to about 0.50% columbium, boron up to 0.010%, and remainder substantially all iron, with additional manganese, in excess of said 2%, partially substituted for said nickel on the basis of 2 for 1, the actual nickel content amounting to at least 3.5%, and the total manganese content up to 19%, additional silicon substituted for chromium on the basis of 1 for 1 up to a total silicon content of 3%, tungsten substituted for molybdenum on a 1 for 1 basis up to a total tungsten content of 6%, and vanadium substituted for molybdenum and tungsten on a 1 for 1 basis up to a total vanadium content of 2%.

2. A chromium-nickel-aluminum stainless steel which is hardenable by heat-treatment from a substantially fully austenitic condition, said steel consisting essentially of about: 8% to 14.5% chromium, 6% to 10% nickel,

4% to 8% molybdenum, .5% to 2% aluminum, carbon not exceeding 0.20%, and remainder substantially all iron.

3. A chromium-nickel-aluminum steel which is hardenable by heat-treatment, said steel consisting essentially of about: 4% to 8% chromium, 7.5% to 12% nickel, 8% to 14% molybdenum, .5% to 2% aluminum, carbon not exceeding 0.20%, and remainder substantially all iron.

4. A chromium-nickel-aluminum steel which is substantially fully austenitic at annealing temperatures and which is hardenable by heat-treatment, said steel consisting essentially of about: 4% to 9% chromium, 6% to 10% nickel, 4% to 8% molybdenum, .5% to 2% aluminum, carbon .10% max., and remainder substantially all iron.

5. A chromium-nickel-aluminum steel which is substantially free of delta-ferrite and hardenable by single heat-treatment from the solution-treated condition, said steel consisting essentially of about: 4% to 9% chromium, 6% to 10% nickel, 4% to 8% molybdenum, with the sum of the chromium and molybdenum contents being less than 14%, .5% to 2% aluminum, carbon .10% max., and remainder substantially all iron.

6. A chromium-nickel-aluminum stainless steel which is hardenable by heat-treatment from a substantially fully austenitic condition, said steel consisting essentially of about: 10% to 11.5% chromium, 8% to 9.5% nickel, .5% to 1.5% aluminum, 5% to 7% molybdenum, carbon not exceeding 0.20%, and remainder substantially all iron.

7. A chromium-nickel-aluminum stainless steel which is hardenable by heat-treatment from a substantially fully austenitic condition, said steel consisting essentially of about: 11.25% to 12.75% chromium, 6.5% to 7.5% nickel, .8% to 1.4% aluminum, 5.5% to 6.5% molybdenum, .06% to .10% carbon, and remainder substantially all iron.

8. A chromium-nickel-aluminum stainless steel which is hardenable by heat-treatment from a substantially fully austenitic condition, said steel consisting essentially of about 12% chromium, about 7% nickel, about 6% tungsten, .8% to 1.40% aluminum, carbon not exceeding .20%, and remainder substantially all iron.

9. A chromium-nickel-aluminum stainless steel which is hardenable by heat-treatment from a substantially fully austenitic condition, said steel consisting essentially of about 12% chromium, about 7% nickel, about 2% molybdenum, about 3% tungsten, .8% to 1.40% aluminum, carbon not exceeding .20%, and remainder substantially all iron.

10. A chromium-nickel-aluminum stainless steel which is hardenable by heat-treatment from a substantially fully austenitic condition, said steel consisting essentially of about 12% chromium, about 7% nickel, about 2% molybdenum, about 2% tungsten, about 1% vanadium, .8% to 1.4% aluminum, carbon not exceeding .20%, and remainder substantially all iron.

11. A heat-hardened chromium-nickel-aluminum steel of great strength at room temperatures and at high temperatures substantially free of delta-ferrite and consisting essentially of about: 4% to 14.5% chromium, 6% to 12% nickel, .5% to 2% aluminum, 4% to 14% molybdenum, manganese up to 2%, silicon up to 1%, carbon up to .20%, up to about 0.10% of the group consisting of titanium and zirconium, up to about 0.50% columbium, boron up to 0.010%, and remainder substantially all iron, with additional manganese, in excess of said 2%, substituted for said nickel on the basis of 2 for 1, the actual nickel content amounting to at least 3.5%, and the manganese content up to 19%, additional silicon substituted for chromium on the basis of 1 for 1 up to a total silicon content of 3%, tungsten substituted for molybdenum on a 1 for 1 basis up to a total tungsten content of 6%, and vanadium substituted for molybdenum and tungsten on a 1 for 1 basis up to a total vanadium content of 2%.

12. Chromium-nickel-aluminum cold-worked plate, sheet, strip, bars, rods, wire, shapes and tubes substantially free of delta-ferrite and hardenable by single heat-treatment and consisting essentially of about: 4% to 14.5% chromium, 6% to 12% nickel, .5% to 2% aluminum, 4% to 14% molybdenum, carbon not exceeding .20%, and remainder substantially all iron, in which the extent of cold-reduction amounts to at least 25% reduction in area.

13. Chromium-nickel-aluminum cold-rolled steel sheet and strip which is substantially free of delta-ferrite and hardenable by single heat-treatment, said sheet and strip consisting essentially of about: 4% to 14.5% chromium, 6% to 12% nickel, .5% to 2% aluminum, 4% to 14% molybdenum, carbon not exceeding .20%, and remainder substantially all iron, in which the extent of cold-rolling amounts to at least about 60% reduction in area.

14. Chromium-nickel-aluminum cold-rolled steel sheet and strip which is substantially free of delta-ferrite and hardenable by single heat-treatment, said sheet and strip consisting essentially of about: 11% chromium, 8% nickel, 6% molybdenum, 1% aluminum, and remainder substantially all iron, in which the extent of cold-rolling amounts to at least about 60% reduction in area.

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