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AGE HARDENING AUSTENITIC STEEL

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This invention pertains to improvements in austenitic steels, and provides a relatively high carbon, high phosphorus, steel of this type which is age hardenable to a minimum of "C" 32 and up to about "C" 50 Rockwell depending upon the analysis, and which is further characterized by high strength and corrosion resistance at both room and elevated temperatures.

Objects of this invention are: to provide austenitic age hardenable steels which are useful for applications where high strength at room temperature combined with low magnetic permeability are required, as for studs, gears, crankshafts, and so on, in non-magnetic power plants of submarines; for retainer rings on rotors of electric generators; and so forth; also where hardness and resistance to softening at elevated temperatures upward of 1300° F. combined with good resistance to oxidation and corrosion at such temperatures are required, particularly in combustion products of leaded gasoline, as for automotive exhaust valves, valve seats, and similar parts; and finally, where high strength at temperatures upward of 1100° F. is required together with resistance to oxidation at these temperatures, as for steam power plant and gas turbine parts.

Another object of this invention is to provide an austenitic steel which is hardenable to a minimum of "C" 32 Rockwell, or 300 Brinell.

Another object of this invention is to provide an austenitic age hardenable steel which can be hardened to a minimum of "C" 32 Rockwell by use of a solution temperature no higher than 2200° F.

In a co-pending application of one of the present inventors, Serial No. 222,736, filed April 20, 1951, there are disclosed austenitic steels containing: 0.4 to 1.5% carbon; 12 to 30% chromium; 0 to 25% nickel; 0.1 to 25% manganese; the combined nickel and manganese content comprising 8 to 28%; 0 to 5% silicon; balance substantially iron, which are age hardenable to at least "C" 32 Rockwell by a heat treatment consisting of solution treating at about 2300° F. and quenching, and thereupon aging at about 1300° F. An appreciable deterrent to the use of such hardened steel is the very high solution temperature required. Even with modern furnace equipment and design it is not easy to heat treat large quantities of parts at such high temperatures, particularly if the parts are sizeable. Furthermore, the solidus temperature of such steel is not much above 2350° F. Thus the solution temperature is dangerously close to the temperature at which the steel begins to melt, and there is considerable hazard therefore in the handling of such steel at the temperature required for proper solution treatment for the desired hardening.

Now we have discovered that by introducing

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about 0.15 to 0.45% phosphorus into steel of approximately the composition given above, the necessary solution temperature can be lowered appreciably from the undesirably high temperature required for the steel in the absence of this phosphorus content. Depending on the phosphorus content, the necessary solution temperature can be lowered to about 2150° F. with moderate amounts, say about 0.20%, and even to 1950° F. when amounts of about 0.4% phosphorus are used.

We have found that the high hardness of the steel of this invention cannot be obtained merely by the use of phosphorus in the steel, as shown in Table I.

Table I

LOW CARBON AUSTENITIC STEELS WITH PHOSPHORUS

[Solution treated at 2150° F. and 2300° F. and water quenched; aged at 1200°; 1300°; 1400° F. for 16 hours.]

Bar	C	Mn	P	Si	Ni	Cr	N
3915	.05	1.5	.10	.40	11.1	18.0	.26
3918	.05	1.4	.27	.37	11.3	18.8	.21

"C" Rockwell Hardness

	Bar 3915		Bar 3918	
	2,150° F.	2,300° F.	2,150° F.	2,300° F.
As Solution Treated	8	7	6	6
Aged 1,200° F.—16 hours	8	7	8	8
Aged 1,300° F.—16 hours	8	7	20	21
Aged 1,400° F.—16 hours	9	8	19	19

Evidently although some hardening is attainable in low carbon steel containing about 0.27% P, the attainable hardness is considered insufficient for the parts we wish to make from a hardenable austenitic steel. However, when higher carbon is used in the steel along with high phosphorus the desired hardness of over "C" 32 Rockwell can be obtained as shown in Table II.

Table II

EFFECT OF C ON ATTAINABLE HARDNESS IN AUSTENITIC C-Mn-Ni-Cr STEELS CONTAINING PHOSPHORUS

[Specimens solution treated at 2150° F., water quenched, and aged at 1250° F. for 16 hours.]

Bar	C	Mn	P	Si	Ni	Cr	N	"C" Rockwell Hardness	
								As Quenched	After Aging
3965	.24	9.1	.21	.32	2.2	20.3	.20	21	29
3968	.37	9.8	.21	.32	4.0	22.0	.24	23	44
3978	.56	9.0	.21	.90	3.7	20.6	.21	31	45
3900	.20	5.1	.34	.49	3.8	21.6	.21	23	31
3897	.34	4.9	.33	.40	3.8	21.5	.20	22	47
3902	.49	5.1	.36	.53	3.8	21.6	.22	29	49

We therefore, set 0.30% as the low limit for carbon in our steel. The high limit for carbon is established by forgeability and for forgeable steels we generally set the upper limit for carbon at 0.80%. However, for castings we may use as high as 1.5% carbon.

The effect of phosphorus on the attainable hardness of the steel after a solution treatment at 2150° F. and aging at 1250° F. is shown in Table III and Table IV.

steels of the co-pending application it is necessary to solution treat at about 2300° F. in order to develop a hardness of "C" 32 Rockwell or higher in the steel after aging. When a minimum of about 0.15% phosphorus is in the steel, however, adequate hardness may be developed with solution treatments no higher than 2200° F., the higher the phosphorus, the lower the necessary solution temperature. This is illustrated by data in Table V.

Table V

EFFECT OF PHOSPHORUS ON THE SOLUTION TEMPERATURE NECESSARY FOR DEVELOPING ADEQUATE HARDNESS IN C-Mn-Ni-Cr AUSTENITIC STEEL
[Specimens quenched from indicated solution temperature and aged at 1,250° F. for 16 hours.]

Bar	C	Mn	P	Si	Ni	Cr	Mo	N	"C" Rockwell Hardness					
									1,900° F.		2,000° F.		2,150° F.	
									As Quenched	Aged	As Quenched	Aged	As Quenched	Aged
3932	.48	7.8	.15	.40	7.3	22.1	1.8	.06	23	23	21	23	21	32
3716	.65	4.8	.19	.19	3.8	20.6		.07	32	33	32	35	28	43
3975	.36	5.0	.21	.58	3.8	21.4		.22			25	37	22	43
3833	.51	7.5	.23	.47	7.4	22.2	1.8	.05	23	29	23	32	23	40
3897	.34	4.9	.33	.40	3.8	21.5		.20	31	37	28	42	21	47
3907	.35	1.4	.38	.33	9.3	21.1		.26	27	39	27	43	22	47
3934	.53	7.5	.41	.36	7.3	21.5	1.7	.07	27	35	26	38	24	47
3825	.61	1.4	.44	.39	9.8	21.0		.15	26	40	27	41	26	48

Table III

EFFECT OF PHOSPHORUS ON ATTAINABLE HARDNESS OF MEDIUM CARBON AUSTENITIC M1 Ni-Cr STEELS

[Specimens solution treated at 2150° F., water quenched, and aged at 1300° F. for 16 hours.]

Bar	C	Mn	P	Si	Ni	Cr	N	"C" Rockwell Hardness	
								As Quenched	After Aging
3940	.33	3.2	.13	.44	9.4	18.6	.05	14	28
3946	.32	1.5	.13	.37	13.0	19.0	.05	13	26
3949	.45	1.4	.12	.33	13.0	18.7	.06	18	23
3941	.36	3.5	.24	.33	9.4	18.9	.05	15	38
3947	.36	1.4	.24	.22	13.0	18.8	.04	15	35
3950	.49	1.4	.23	.20	13.1	18.8	.05	19	35

Table IV

EFFECT OF PHOSPHORUS ON ATTAINABLE HARDNESS OF HIGH CARBON AUSTENITIC C-Mn-Ni-Cr STEELS

[Specimens solution treated at 2150° F., water quenched, and aged at 1250° F. for 16 hours.]

Bar	C	Mn	P	Si	Ni	Cr	N	"C" Rockwell Hardness	
								As Quenched	After Aging
3821	.61	2.3	.09	.39	9.1	20.9	.04	23	28
3817	.60	4.7	.20	.50	3.8	21.2	.04	29	40
3819	.61	5.0	.41	.41	3.7	20.7	.04	28	43
3825	.61	1.4	.44	.39	9.8	21.0	.15	27	48

We, therefore, set our low limit at about 0.15% phosphorus for securing steel with a hardness after aging of at least "C" 32 Rockwell. With increasing phosphorus, the forgeability of the steel decreases and therefore we set a high limit of about 0.45% phosphorus for wrought material. However, for cast material we may use as much as 1% phosphorus.

As stated earlier, in the high carbon, Mn-Ni-Cr

Furthermore, whereas with the low phosphorus steels of the co-pending application it is necessary to cool rapidly as in a water quench from the solution temperature in order that the desired hardness may be attained in the steel after it is aged, we have found that when phosphorus over about 0.15% is present in the steel, the desired hardness over "C" 32 Rockwell may be attained in the steel after aging even though the cooling rate from the solution temperature is somewhat retarded as in an oil quench, or even air cool of sections under about 1 inch thick. This obviously is of considerable advantage in the heat treatment of large sections which would suffer much less distortion when quenched in oil than when quenched in water.

Although the balance of the composition in addition to carbon and phosphorus is not restricted especially, it is desirable that the austenite forming elements manganese, nickel and nitrogen be present in sufficient amounts to assure a stable austenitic structure in the steel. Manganese may be present within the range of 0.5 to 15% and nickel may be present within the range of 3 to 25%, and the sum of the two within the limits of 9 to 30%. Nitrogen is generally over .03% and may be present up to about 0.40%.

Silicon is always present in the steel for de-oxidation purposes and may be present up to about 3% for improving the resistance of the steel to oxidation at elevated temperatures.

Chromium is generally present in our steel from about 15 to 30% to provide corrosion and oxidation resistance. As the chromium is increased, we generally increase also the sum of manganese and nickel so that the steel will have a stable austenitic structure substantially free of ferrite.

When the steel is to be used under high stress at elevated temperatures we generally include up to about 3% of either one or both of the carbide forming elements molybdenum and tungsten.

Since the steel may be machined in the hard-

ened condition after final heat treatment, we may include sulfur in the steel composition up to about 0.30% to improve machinability.

We may use different proportions of the elements carbon, manganese, phosphorus, silicon, nickel, chromium, molybdenum (or tungsten), and nitrogen in the steel depending on the application. For an application requiring a non-

17 to 25%; nitrogen up to about 0.3%; sulfur up to about 0.3%; balance substantially iron.

For steel to be used for automotive exhaust valves and similar parts, we generally balance the composition with carbon in the middle of the range and manganese in larger amount than nickel, although we may also use a high percentage of nickel as shown in the analysis of Bar 4123 in the table below.

Table VII

PROPERTIES OF STEELS SUITABLE FOR EXHAUST VALVE SERVICE

Bar	C	Mn	P	Si	Ni	Cr	N	"C" Rock. Sol. Treated 2,150° F., Aged 1,300° F., hrs.	Weight Loss in 1 hr., Lead Oxide at 1,675° F., gms./sq. in.
3817-----	.60	4.7	.20	.50	3.8	21.2	.04	41	3.1
3975-----	.36	5.0	.21	.58	3.8	21.0	.17	42	2.8
4116-----	.46	8.2	.25	.79	4.3	21.9	.22	46	2.6
3978-----	.56	9.0	.21	.90	3.7	20.6	.21	46	2.6
4118-----	.44	8.3	.24	1.89	4.3	22.0	.22	46	2.3
4120-----	.45	8.4	.24	2.90	4.3	22.2	.20	46	2.3
4123-----	.53	8.3	.22	.53	15.6	30.0	.39	42	2.4
3820-----	.60	5.0	.42	.35	3.9	20.7	.15	48	3.2

magnetic material with high room temperature strength and good ductility, we generally balance the composition so that the carbon is on the low side of the range and nickel is present in larger amounts than manganese. Data on some compositions suitable for such an application are given in Table VI.

Steels of the foregoing type which are age hardenable to a minimum of "C" 38 Rockwell on solution treating at a temperature no higher than 2200° F., and subsequent aging at about 1300° F., have the following preferred range of analysis: Carbon about 0.4 to 0.7%; phosphorus about 0.15 to 0.45%; manganese about 1 to 12%;

Table VI

MECHANICAL AND PERMEABILITY PROPERTIES OF STEELS FOR NON-MAGNETIC HIGH STRENGTH APPLICATION

Bar	C	Mn	P	Si	Ni	Cr	N
3941-----	.36	3.5	.24	.33	9.4	18.6	.05
3942-----	.34	3.5	.37	.44	9.3	19.0	.04
3944-----	.51	3.5	.25	.38	9.2	18.6	.06
3945-----	.46	3.4	.39	.30	9.3	18.5	.09
3947-----	.36	1.4	.24	.22	13.0	18.8	.04
3948-----	.33	1.4	.37	.30	13.1	19.0	.05
3950-----	.49	1.4	.23	.20	13.1	18.8	.05
3951-----	.47	1.3	.37	.22	13.1	19.1	.14

[Pieces in $\frac{1}{2}$ sq. section solution treated as indicated; aged at 1,300° F. for 16 hours; and machined to tensile, impact, and permeability test pieces.]

Bar	Solution Treatment	"C" Rock. Hard	0.2% Yield, p. s. i.	Tensile Strength, p. s. i.	Elong. in 1.4 in., Percent	Red. Area, Percent	V-Notch Izod, ft.-lbs.	Permea- bility, H=500
3941-----	2,050° F. water----	34	88,000	146,000	27.9	37.5	-----	-----
3941-----	2,150° F. water----	38	116,000	167,000	17.6	26.5	-----	-----
3942-----	1,950° F. water----	36	106,000	155,000	22.2	33.5	14	1.003
3942-----	1,950° F. air-----	35	100,000	152,000	24.4	29.0	13	1.002
3942-----	2,050° F. water----	41	132,000	175,000	15.0	24.5	-----	-----
3944-----	2,050° F. water----	33	88,000	149,000	24.7	33.0	-----	-----
3944-----	2,150° F. water----	42	126,000	177,000	18.4	25.0	-----	-----
3945-----	1,950° F. water----	40	121,000	167,000	18.1	27.0	7	1.003
3945-----	1,950° F. air-----	39	109,000	160,000	20.7	26.0	6	1.003
3947-----	2,150° F. water----	35	105,000	155,000	23.0	33.5	18	1.003
3947-----	2,150° F. air-----	35	107,000	153,000	17.2	29.5	11	1.003
3947-----	2,200° F. water----	39	128,000	171,000	11.5	15.5	-----	-----
3948-----	1,950° F. water----	33	100,000	145,000	22.9	41.5	-----	-----
3948-----	2,050° F. water----	39	124,000	168,000	21.5	35.5	12	1.003
3950-----	2,150° F. water----	36	103,000	155,000	19.4	30.0	12	1.003
3950-----	2,150° F. air-----	36	105,000	155,000	21.0	29.0	8	1.002
3951-----	1,950° F. water----	34	104,000	149,000	18.6	30.5	-----	-----
3951-----	1,950° F. air-----	33	92,000	143,000	22.7	30.0	-----	-----
3951-----	2,050° F. water----	40	125,000	166,000	17.1	28.5	8	1.003

The low permeability steels of the foregoing type having good forging and age hardening characteristics together with high strength, have the following preferred range of analysis: carbon about 0.3 to 0.5%; phosphorus about 0.2 to 0.4%; manganese about 1 to 5%; nickel about 8 to 15%; silicon up to about 1%; chromium about

nickel about 3 to 25%, the sum of manganese and nickel being from about 9 to 30%; chromium from about 20 to 30%; silicon up to about 3%; nitrogen up to about 0.4%; sulfur up to about 0.3%; metal of the group molybdenum and tungsten up to about 3%; balance substantially iron.

For applications where strength at high temperatures for long time service is required, we generally include molybdenum (or tungsten) in the composition as stated above. Some data on steels suitable for high temperature applications such as steam power plant and gas turbine parts are given in Table VIII.

hardness is about 1250°/1300° F. good hardness is developed with aging temperatures as high as 1500° F. Furthermore, steel which has been aged at 1300° F. can be reheated for a short time at temperatures as high as 1700° F. without suffering much loss of hardness. Some data on the resistance of the steels of this inven-

Table VIII

PROPERTIES OF STEEL SUITABLE FOR SERVICE AT 1,200° F. UNDER STRESS

Bar	C	Mn	P	Si	Ni	Cr	Mo
3933-----	.51	7.5	.23	.47	7.4	22.2	1.8
3936-----	.61	7.5	.22	.42	7.3	22.0	1.9
3939-----	.72	7.6	.26	.45	7.3	22.8	1.8
3937-----	.58	7.5	.43	.38	7.5	21.2	1.6

ROOM TEMPERATURE PROPERTIES

Bar	Heat Treatment ¹	"C" Rock. Hard.	0.2% Yield Strength, p. s. i.	Tensile Strength, p. s. i.	Elong. in 1.4 in., percent	Red. Area, percent	V-Notch Izod, ft.-lbs.
3933-----	BB	35	98,000	156,000	18.6	25.0	7
3933-----	BO	32	81,000	141,000	27.1	30.5	15
3936-----	BB	36	96,000	154,000	21.4	23.5	7
3936-----	BO	33	77,000	137,000	26.6	32.5	13
3939-----	BO	33	80,000	140,000	22.6	27.5	-----

STRESS RUPTURE PROPERTIES AT 1,200° F.

Bar	Heat Treatment ¹	Stress, p. s. i.	Rupture Time, Hours	Elongation, Percent in 1.4 in.	Percent Reduction Area
3933-----	BB	56,000	89	11.4	20.0
3933 ² -----	BB	62,000	119	-----	-----
3933-----	BO	56,000	203	5.7	15.0
3936-----	BB	56,000	82	15.4	27.0
3936 ² -----	BB	62,000	196	-----	-----
3936-----	BO	56,000	184	16.3	20.0
3936 ² -----	BO	62,000	197	-----	-----
3939-----	BB	56,000	85	15.4	21.5
3939-----	BO	56,000	96	20.7	27.5
3939 ² -----	BO	62,000	204	-----	-----
3937-----	BO	56,000	527	3.8	8.5

¹ Heat Treatments: BB—2,150° F., water quench; aged 1,500° F.—16 hours. BO—2,150° F., water quench; aged 1,300° F.—16 hours; plus 1,700° F.—2 hours.
² NOTE.—Test piece with 60 degree V-notch, diameter base of notch .252 in. with gage section .357 in. diameter; .005 in. radius base of notch.

A preferred range of analysis for steels of this type is: carbon about 0.45 to 0.7%; phosphorus

tion to softening at high temperatures are shown in Table IX.

Table IX

EFFECT OF HIGH TEMPERATURE HEATING ON HARDNESS OF C-Mn-P-Ni-Cr STEELS
 [Specimens solution treated at 2,150° F., water quenched, and aged as indicated.]

Bar	C	Mn	P	Si	Ni	Cr	Mo	"C" Rockwell Hardness				
								As Q	Aged 1,300° F., 16 hours	Aged 1,400° F., 16 hours	Aged 1,500° F., 16 hours	Aged 1,300° F., 16 hrs., Reheated 1,700° F., 2 hrs.
3933-----	.51	7.5	.23	.47	7.4	22.2	1.8	23	40	35	33	32
3936-----	.61	7.5	.22	.42	7.3	22.0	1.9	24	41	35	34	33
3939-----	.72	7.6	.26	.45	7.3	22.8	1.8	27	41	37	34	33
3934-----	.53	7.5	.41	.36	7.3	21.5	1.7	24	46	42	40	39
3937-----	.58	7.5	.43	.38	7.5	21.2	1.6	25	46	43	38	39

about 0.2 to 0.45%; manganese about 5 to 12%; nickel about 4 to 18%; chromium about 20 to 30%; silicon up to about 3%; metal of the group molybdenum and tungsten, about 1 to 3%; nitrogen up to about 0.4%; sulfur up to about 0.3%; balance substantially iron.

It is of interest that the steels of this invention are quite resistant to overaging. Although the optimum aging temperature for maximum

What we claim is:

1. Age hardenable austenitic steel characterized in being hardenable to a minimum of about "C" 32 Rockwell after solution treatment at a temperature no higher than 2200° F. and subsequent aging at about 1300° F. for about 15 hours, said steel containing about: 0.3 to 1.5% carbon; 0.15 to 1% phosphorus; 0.5 to 15% manganese; 3 to 25% nickel, the sum of nickel and

manganese being about 9 to 30%; 15 to 30% chromium; up to about 3% silicon; up to about 3% of metal selected from the group consisting of molybdenum and tungsten; up to about 0.4% nitrogen; up to about 0.3% sulfur; and the balance iron.

2. A precipitation hardened, austenitic alloy steel, having a hardness of at least "C" 32 Rockwell, said steel having substantially the following composition: 0.3 to 1.5% carbon; 0.15 to 1% phosphorus; 0.5 to 15% manganese; 3 to 25% nickel, the sum of nickel and manganese being about 9 to 30%; 15 to 30% chromium; up to about 3% silicon; up to about 3% of metal selected from the group consisting of molybdenum and tungsten; up to about 0.4% nitrogen; up to about 0.3% sulfur; and the balance iron.

3. A cast article made of precipitation hardened, austenitic alloy steel, having a hardness of at least "C" 32 Rockwell, said steel having substantially the following composition: 0.3 to 1.5% carbon; 0.15 to 1% phosphorus; 0.5 to 15% manganese; 3 to 25% nickel, the sum of nickel and manganese being about 9 to 30%; 15 to 30% chromium; up to about 3% silicon; up to about 3% of metal selected from the group consisting of molybdenum and tungsten; up to about 0.4% nitrogen; up to about 0.3% sulfur; and the balance iron.

4. A forgeable, age hardenable, austenitic steel, characterized in being hardenable to a minimum of "C" 32 Rockwell after solution treating at a temperature no higher than 2200° F. and subsequent aging at about 1300° F. for about 15 hours, said steel having substantially the following composition: 0.3 to 0.7% carbon; 0.15 to 0.45% phosphorus; 0.5 to 15% manganese; 3 to 25% nickel, the sum of nickel and manganese being about 9 to 30%; 15 to 30% chromium; up to about 3% silicon; up to about 3% of metal selected from the group consisting of molybdenum and tungsten; up to about 0.4% nitrogen; up to about 0.3% sulfur; and the balance iron.

5. A forgeable, age hardenable, high strength, low permeability steel, which is age hardenable to a minimum of about "C" 32 Rockwell after solution treating at a temperature no higher than 2200° F. and subsequent aging at about 1300° F. for about 15 hours, said steel having substantially the following composition: 0.3 to 0.5% carbon; 0.2 to 0.4% phosphorus; 1 to 5% manganese; 8 to 15% nickel; 17 to 25% chromium; up to 1% silicon; up to 0.3% nitrogen; up to 0.3% sulfur; balance iron.

6. A precipitation hardened, austenitic alloy steel, having a hardness of at least "C" 32 Rockwell, said steel having substantially the following composition: 0.3 to 0.7% carbon; 0.15 to 0.45% phosphorus; 0.5 to 15% manganese; 3 to 25% nickel, the sum of nickel and manganese being about 9 to 30%; 15 to 30% chromium; up to about 3% silicon; up to about 3% of metal selected from the group consisting of molybdenum and tungsten; up to about 0.4% nitrogen; up to about 0.3% sulfur; and the balance iron.

7. A precipitation hardened, austenitic alloy steel, having a hardness of at least "C" 32 Rockwell, said steel having substantially the following composition: 0.3 to 0.5% carbon; 0.2 to 0.4% phosphorus; 1 to 5% manganese; 8 to 15% nickel; 17 to 25% chromium; up to 1% silicon; up to 0.3% nitrogen; up to 0.3% sulfur; balance iron.

8. A forgeable, age hardenable steel adapted for automotive exhaust valves and similar parts, said steel being hardenable to a minimum of about "C" 38 Rockwell on solution treating at a temperature no higher than 2200° F. and subsequent aging at about 1300° F., and having good corrosion and oxidation resistance at elevated temperatures, said steel having substantially the following composition: 0.4 to 0.7% carbon; 0.15 to 0.45% phosphorus; 1 to 12% manganese; 3 to 25% nickel, the sum of manganese and nickel being about 9 to 30%; 20 to 30% chromium; up to 3% silicon; up to 0.4% nitrogen; up to 0.3% sulfur; up to 3% of metal selected from the group consisting of molybdenum and tungsten, balance iron.

9. An article made of a precipitation hardened alloy steel, having a hardness of at least "C" 38 Rockwell, said steel having substantially the following composition: 0.4 to 0.7% carbon; 0.15 to 0.45% phosphorus; 1 to 12% manganese; 3 to 25% nickel, the sum of manganese and nickel being about 9 to 30%; 20 to 30% chromium; up to 3% silicon; up to 0.4% nitrogen; up to 0.3% sulfur; up to 3% of metal selected from the group consisting of molybdenum and tungsten, balance iron.

10. A forgeable, age hardenable steel, suitable for service under high stress at elevated temperatures upward of 1100° F., said steel being hardenable to a minimum of "C" 32 Rockwell on solution treating at a temperature no higher than 2200° F., and subsequent aging at about 1300° F., said steel having substantially the following composition: 0.45 to 0.7% carbon; 0.2 to 0.45% phosphorus; 5 to 12% manganese; 4 to 18% nickel; 20 to 30% chromium; up to 3% silicon; 1 to 3% of metal selected from the group consisting of molybdenum and tungsten; up to 0.4% nitrogen; up to 0.3% sulfur; balance iron.

11. An article made of a precipitation hardened alloy steel, having a hardness of at least "C" 32 Rockwell, said steel having substantially the following composition: 0.45 to 0.7% carbon; 0.2 to 0.45% phosphorus; 5 to 12% manganese; 4 to 18% nickel; 20 to 30% chromium; up to 3% silicon; 1 to 3% of metal selected from the group consisting of molybdenum and tungsten; up to 0.4% nitrogen; up to 0.3% sulfur; balance iron.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
2,495,731	Jennings	Jan. 31, 1950
2,528,637	Clarke	Nov. 7, 1950