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NITROGEN STRENGTHENED Fe-Ni-Cr ALLOY

This invention relates generally to metal alloys containing substantial amounts of iron, nickel and chromium and more particularly to a carefully balanced composition suitable for use in aggressive environments at high temperature.

Many people have attempted to develop alloys exhibiting high mechanical strength, low creep rates and good resistance to corrosion at various temperatures. In United States Patent 3,627,516 Bellot and Hugo report that it was well known to make alloys having mechanical strength and corrosion resistance by including in the alloy about 30% to 35% nickel, 23% to 27% chromium and relatively low carbon, manganese, silicon, phosphorus and sulphur. Mechanical properties of this type of alloy were improved by adding tungsten and molybdenum. Bellot and Hugo further improved this alloy by adding niobium in a range of from 0.20% to 3.0% by weight. Two years later in United States Patent 3,758,294 they taught that high mechanical strength, low creep rate and good corrosion resistance could be obtained in the same type of alloy by including 1.0% to 8.0% niobium, 0.3% to 4.5% tungsten and 0.02% to 0.25% nitrogen by weight.

Both patents teach a carbon content of the alloy in the range 0.05% to 0.85%.

5 Bellot and Hugo appear to have no concern about the hot workability and fabricability of their alloys. It is well known that carbon contents in excess of 0.20% greatly impair hot workability and fabricability. Many of the alloys disclosed by Bellot and Hugo have more than 0.20% carbon. The claims of both their patents require about 0.40% carbon.

10 Because of these high carbon levels such alloys are difficult to hot work, fabricate or repair.

In United States Patent 3,627,516 Bellot and Hugo attempt to avoid the use of expensive alloying elements such as tungsten and molybdenum to improve mechanical properties by adding 0.20% to 3.0% niobium. But in United States Patent 3,758,294 they later find that tungsten is required to achieve high weldability and easy resistance to carburization. Thus, the teaching of Bellot and Hugo is that tungsten although expensive is necessary to achieve high weldability in a corrosion resistant alloy.

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Carbon and tungsten as well as other solid solution strengtheners such as molybdenum are used in alloys of the Ni-Cr-Fe family having generally about 15 to 45% nickel and 15 to 30% chromium to provide strength at high temperatures. The use of substantial amounts of carbon and solid solution strengtheners adversely affect thermal stability,

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reduce resistance to thermal cycling and usually raise the cost of the product excessively.

Precipitation hardening is normally either limited to relatively low temperature strength

5 improvements or has associated thermal stability and fabricability problems. In addition to these strength considerations, prior art alloys of this family have only average corrosion resistance to aggressive high temperature environments such as
10 those containing hydrocarbons, CO, CO₂ and sulphur compounds.

The present invention is a Fe-Ni-Cr alloy having improved mechanical properties and improved hot workability through the addition of a
15 carefully controlled amount of nitrogen and the provision of nitrogen, columbium and carbon within a defined relationship. Preferably, columbium is added to the alloy in order to produce complex carbonitride compound particles which form while the
20 alloy is in service, and promote strengthening. Columbium also increases nitrogen solubility in the alloy, which allows for a higher level of nitrogen to be included in the alloy to yield higher strength. The presence of stronger nitride formers, such as
25 aluminium and zirconium is limited to avoid excessive initial coarse nitride formation during alloy manufacture and consequent loss of strength. Chromium

is present at levels of at least 12% to provide for both adequate oxidation resistance and adequate nitrogen solubility.

5 Accordingly the present invention provides a metal alloy comprised of, in weight percent, 30% to 45% nickel, 12% to 32% chromium, at least one of 0.1% to 2.0% columbium, 0.2% to 4.0% tantalum and 0.05% to 1.0% vanadium, up to 0.20% carbon, 0.05% to 0.50% nitrogen, an addition of titanium up to 0.2% and the
10 balance being iron plus impurities and wherein $(C+N)_F$ is greater than 0.14% and less than 0.29% $(C+N)_F$ being defined as

$$(C+N)_F = C+N - \frac{Cb}{9} - \frac{V}{4.5} - \frac{Ta.}{18} - \frac{Ti.}{3.5}$$

The alloy may also comprise molybdenum and
15 tungsten at a combined weight percent of 2.0 - 12.

In the presence of columbium, vanadium or tantalum in the alloy, a very small amount of titanium will have beneficial strengthening effects (not over 0.20% Ti). Silicon may be added up to 3.0% to optimize oxidation
20 resistance, however, strength drops off markedly over about 1% Si. So two classes of alloy are possible: up to 1% Si has excellent strength and 1%-3% Si has lower strength but better oxidation resistance.

The present alloy is a Fe-Ni-Cr alloy having 30%-45% nickel and 12% to 32% chromium. More particularly the composition should fall within these ranges:

5	Ni	-	30% to 45%
	Cr	-	12% to 32%
	Cb	-	0.10 to 2.0%
			(min. 9 x carbon content)
10	Ti	-	An addition up to 0.20% max
	Si	-	Up to 3% max
	N	-	0.05 to 0.50%
	C	-	0.02 to 0.20%
15	Mn	-	Up to 2.0% max
	Al	-	Up to 1.0% max
	Mo/W	-	Up to 5% max
	B	-	Up to 0.02% max
	Zr	-	Up to 0.2% max
20	Co	-	Up to 5% max
	Y, La, Ce, REM	-	Up to 0.1% max

and the balance iron and typical impurities

The invention also provides a metal alloy comprised of in weight percent 30% to 42% nickel, 20% to 32% chromium, at least one of 0.2% to 1.0% columbium, 0.2% to 4.0% tantalum, and 0.05% to 1.0% vanadium, up to 0.2% carbon, 0.05% to 0.50% nitrogen, an addition of titanium up to 0.2% and the balance being iron plus impurities wherein $(C+N)_F$ is greater than 0.14% and less than 0.29%, $(C+N)_F$ being defined as

$$(C+N)_F = C - \frac{Cb}{9} - \frac{V}{4.5} - \frac{Ta}{18} + N - \frac{Ti}{3.5}$$

The alloy may further include at least one of, up to 1% aluminium, up to 3% silicon, up to 2.0% manganese, up

0.02% boron, up to 0.2% zirconium, up to 5.0% cobalt, up to 2.0% total molybdenum plus tungsten and up to 0.1% total yttrium, lanthanum, cerium and other rare earth metals.

5 In yet another form the alloy may comprise at least one of up 0.5% aluminium, 0.01% to 0.1% titanium, 0.25% to 1.0% silicon, 0.35% to 1.2% manganese, up to 0.015% boron and up to 0.1% total
10 yttrium, lanthanum, cerium and other rare earth metals.

 The nitrogen in the alloy acts as a solid solution strengthener and also precipitates as nitrides in service as a further strengthening mechanism. The prior art involves alloys with
15 generally less than enough nickel to provide a stable austenitic matrix when subjected to long term thermal ageing in service at elevated temperature. Nitrogen acts to stabilize austenitic structure, but if nickel is less than 25%, once nitrides are precipitated
20 during service exposure at greater than 537.8°C (1000°F), the matrix is depleted in nitrogen, and alloys are prone to embrittlement from sigma phase precipitation. To avoid this, our alloys contain at least 30% Ni.

It is known that titanium in the presence of nitrogen in an iron-base alloy will form undesirable, coarse titanium nitride particles. These nitrides form during alloy manufacture and contribute little towards elevated temperature strength in service. The exclusion of titanium from this type of alloy avoids depletion of nitrogen from the solid solution by the manner described, but does not provide optimum strengthening. We have found that in the presence of columbium, vanadium or tantalum in the alloy, a very small amount of titanium will have beneficial strengthening effects as long as there is not more than 0.20% Ti. Consequently, we provide up to 0.20% titanium in our alloy. As those skilled in the art will recognize, columbium, vanadium or tantalum, which have a somewhat greater affinity for carbon than for nitrogen, can be added to this type of alloy to increase nitrogen solubility without depleting the majority of the nitrogen as coarse primary nitride or nitrogen-rich carbonitride particles. In excess of 2.0% columbium is undesirable because of a tendency to form deleterious phases such as Fe_2Cb laves phase or Ni_2Cb orthorhombic phase. For this reason, we prefer to provide a columbium to carbon ratio of at least 9 to 1 but less than 2.0%. Without columbium or an equivalent amount of vanadium or tantalum, the addition of nitrogen would not provide as much

strength. To achieve similar results, half the weight in vanadium or double the weight in tantalum should be used whenever they are substituted for columbium.

5 Silicon may be added up to 3.0% to optimize oxidation resistance. However, strength drops off markedly over about 1% Si. Strong nitride formers, such as aluminium and zirconium, are limited to avoid excessive coarse nitride formation during alloy manufacture, and consequent loss of strength in
10 service. Chromium is present at levels of at least 12% to provide for both adequate oxidation resistance and adequate nitrogen solubility.

EXAMPLE 1

To determine the influence of columbium in
15 this alloy, we prepared an alloy having a nominal composition of 33% Ni, 21% Cr, 0.7% Mn, 0.5% Si, 0.3% Al, plus carbon, nitrogen, titanium and columbium as set forth in Table 1 and the balance iron. These alloys were tested to determine the
20 time required for one percent creep under three temperature and stress conditions. The results of that test are set forth in Table 1.

This data indicates that Ti ties up N in preference to carbon, forming TiN with possibly some
25 Ti (C, N). Cb ties up C in preference to N, so as long as C/Cb ratio stays relatively constant, N is available to form strengthening Cr_2N and CbN

precipitates, or to provide solid solution strengthening. So the strength levels exhibited by alloys C, D and E are nearly the same. Note that adding nitrogen to replace carbon by more than 2:1 without Cb does little to improve strength, as evidenced by alloys A and F versus alloy E. Also, simply adding Cb to alloy containing Ti does not significantly improve strength, as evidenced by comparing alloy G to alloy A. Finally, the alloys with titanium levels at 0.40 and 0.45 performed poorly suggesting that such high titanium levels are detrimental.

Table 1 - Cb vs Ti

Nominal (%): Fe-33%Ni-21%Cr-0.7%Mn-0.5%Si-0.3%Al

5	Alloy	% Other Elements			Time to 1% Creep (Hours for Two Samples)			
		C	N	Ti	(1400°F/13ksi) (1500°F/10ksi) (1600°F/7ksi)			
					760°C/89.62MPa	815.5°C/68.94MPa	871°C/48.26	
	A	.07	.01	.40	.05	1, 1	1, 1	1, 2
	B	.06	.20	.31	.05	4, 5	-	-
	C	.05	.20	.01	.46	12, 18	9, 10	34, 55
	D	.09	.19	.01	1.00	13, 15	7, 8	34, 41
10	E	.02	.19	.01	.26	7, 14	9, 11	32, 32
	F	.01	.19	.01	.05	2, 4	1, 2	8, 10
	G	.08	.04	.45	.48	-	1, 2	2, 5

EXAMPLE 11

The effect of nitrogen and carbon is revealed in tests of several alloys having the same nickel, chromium, manganese, silicon and aluminium content as the iron-base alloys of Example 1 and carbon, nitrogen, titanium and columbium content set forth in Table 2 and Table 2A.

The data in Table 2 demonstrates that strength goes up with increasing (C+N). Greater than 0.14% "free" (C+N) is necessary for good high temperature strength. At a columbium level of 0.20%, a carbon level of 0.05% and a nitrogen content of 0.02% (the minimum values taught by Bellot and Hugo), the "free" (C+N) = 0.05% which is not adequate for good strength. To obtain the needed minimum of 0.14% "free" (C+N) with carbon at 0.05% at least 0.11% nitrogen is required. At a columbium level of 0.50% and carbon level of 0.05%, nitrogen greater than 0.15% is required to obtain "free" (C+N) above 0.14%. If carbon is increased to 0.10% with the same columbium content, then more than 0.10% nitrogen is still required to obtain the desired level of "free" (C+N). Finally, at a third level of columbium of 1.0% we still see a relationship between carbon and nitrogen. With carbon at 0.05%, nitrogen

greater than .20% is required for free (C+N) to be
 above 0.14%. At C = 0.10% then N greater than
 0.15% is required. And, at C = 0.15% then N
 greater than 0.10% is required. Consequently, to
 5 achieve acceptable strength levels (C+N) must be
 greater than $0.14\% + \frac{Cb.}{9}$

Table 2A shows that thermal stability of high
 (C+N) level compositions can be poor. In order to
 maintain adequate stability, "free" (C+N) should
 10 be less than 0.29%. Therefore, (C+N) must be less
 than $0.29\% + \frac{Cb.}{9}$. Thus, the critical ranges of (C+N)

at four levels of Cb are as follows:

	<u>Cb (%)</u>	<u>(C+N) min. (%)</u>	<u>(C+N) max. (%)</u>
	0.25	0.17	0.32
15	0.50	0.20	0.35
	0.75	0.22	0.37
	1.00	0.25	0.40

Table 2

Effect of (C+N) & "Free" (C+N) on Strength

Heat	C	N	Cb	Ti	C+N	Free (C+N)*	Hours to 1% Creep	
							(1600°F/7ksi)	871°C/48.25MPa
5 7984-1	.08	.08	.47	.07	.16	.09	12	
20883	.04	.12	.48	.01	.16	.10	8	
21283	.09	.14	.98	.01	.23	.12	9	
10 7483	.08	.14	.51	.17	.22	.11	19	
5785	.08	.14	.51	.07	.22	.14	25	
5485	.06	.18	.52	.08	.24	.16	33	
8734	.07	.16	.49	.05	.23	.16	40	
8284	.08	.16	.48	.02	.24	.18	35	
15 8884	.09	.27	.51	.07	.36	.28	88	
8984	.09	.40	.50	.05	.49	.42	94	

Table 2A

Effect of (C+N) & "Free" (C+N) on Thermal Stability

Heat	C	N	Cb	Ti	C+N	Free (C+N)*	Exposure at 760°C (1400°F)/1000 Hrs. Residual RT Tensile El (%)
22584	.08	.04	.48	.45	.12	.00	40
7984-2	.05	.07	.48	.20	.12	.01	38
7984-1	.08	.08	.47	.07	.16	.09	34
7483	.08	.14	.51	.17	.22	.11	29
5785	.08	.14	.51	.07	.22	.14	32
5485	.06	.18	.52	.08	.24	.16	32
8784	.07	.16	.49	.05	.23	.16	24
8284	.08	.16	.48	.02	.24	.18	24
8884	.09	.27	.51	.07	.36	.28	25
5885	.08	.29	.49	.08	.37	.29	11
8984	.09	.40	.50	.05	.49	.42	14

$$* \text{ Free (C+N) } = \left[C - \frac{\text{Cb}}{9} \right] + \left[N - \frac{\text{Ti}}{3.5} \right]$$

EXAMPLE 111

The criticality of titanium can be seen from creep data for alloys I, K, L and M which have similar base materials as the other alloys tested. The creep data for those alloys tested at 760°C (1400°F) and 89.62MPa (13 ksi) are shown in Table 3. In that table the alloys are listed in order of increasing titanium content. This data indicates that any titanium is beneficial. However, the data from Table 1 indicates an upper titanium limit of not more than 0.2%.

Table 3 - Ti Criticality

Nominal (%): Fe-33%Ni-21%Cr-0.7%Mn-0.5%Si-0.3%Al-0.005%B

Alloy	% Other Elements			Cb	Average Hours to 1% Creep at 760°C/89.62MPa (1400°F/13ksi) (Hours)
	C	N	Ti		
K	.08	.18	Nil	.49	35
L	.08	.16	.02	.48	47
I	.08	.14	.07	.51	92
M	.08	.14	.17	.51	59

EXAMPLE IV

Silicon is an important component of the alloy. Its influence is shown in Table 4. The data in that table indicates that silicon must be carefully controlled to achieve optimum properties. Low levels of silicon are fine. However, when silicon levels reach and exceed about 2% performance drops sharply. This is apparently caused by silicon nitride which has formed in increasing amounts as the silicon level increases.

Table 4 - Si Criticality

Nominal (%): Fe-33%Ni-21%Cr-0.7%Mn-0.5%Si-0.3%Al-0.005%B

5	Alloy	% Other Elements				Time to 1% Creep (Hours)					
		C	N	Ti	Si	760°C/89.62MPa		871°C/48.62MPa		982°C/17.23MPa	
						1%	R	1%	R	1%	R
10	I	.08	.14	.07	.57	81	951	23	179	43	160
	N	.07	.12	.02	1.40	104	948	27	214	160	402
	O	.08	.15	.06	1.96	61	592	25	321	216	672
10	P	.08	.14	.08	2.41	40	640	10	227		
						3	73	3	58	112	315
						4	79	4	56	206	547
10						4	55	2	47	138	470
						2	49	2	48	137	512

EXAMPLE V

The data shown in Table 5 reveals that the presence of zirconium at 0.02% dramatically reduces creep time. Also, as aluminium content approaches 1.0% it produces a similar result.

Table 5 - Adverse Effects of Al & Zr

Nominal (%): Fe-33%Ni-21%Cr-0.5%Cb-0.7%Mn-005%B

	<u>% Other Elements</u>				<u>Average Hours to 1% Creep at 760°C/89.62MPa (1400°F/13ksi) (Hours)</u>		
	<u>Alloy</u>	<u>C</u>	<u>N</u>	<u>Si</u>			
				<u>Al</u>	<u>Zr</u>		
5	Q	.08	.14	.60	.24	Nil	59
	R	.08	.14	.61	.86	Nil	13
	S	.07	.12	1.40	.28	Nil	49
10	T	.07	.21	1.48	.28	.02	7

Based upon the data from Tables 1 through 5,
we selected alloys 1 and two other alloys, U and
V, and provide creep data in Table 6.

5 Alloys I and V compare favourably to prior
art alloys in mechanical properties as shown in
Tables 7, 8 and 9.

Table 6

Nominal (%): Fe-0.5%C-0.7%Mn-0.5%Si-0.3%Al-0.005%B

5	<u>Alloy</u>	<u>% Other Elements</u>				<u>Time to 1% Creep (Hours)</u>		
		<u>Ni</u>	<u>Cr</u>	<u>C</u>	<u>N</u>	760°C/89.62MPa (1400 [°] F/13ksi)	871°C/48.26MPa (1600 [°] F/7ksi)	982°C/17.23MPa (1800 [°] F/2.5ksi)
	I	34.0	20.8	.08	.14	92	25	83
	U	40.3	20.9	.06	.18	60	33	119
	V	39.8	30.0	.07	.16	77	40	274

Table 7

COMPARATIVE PROPERTIES (Sheet)

Yield Strength MPa (ksi)	Alloy I		Alloy V		800H		253MA		601		310		316	
RT	282.6	(41)	337.8	(49)	241.3	(35)	351.6	(51)	289.5	(42)	220.6	(32)	262.0	(38)
649°C (1,200°F)	179.2	(26)	186.1	(27)	151.7	(22)	165.5	(24)	262.0	(38)	117.2	(17)	144.8	(21)
760°C (1,400°F)	165.5	(24)	193.0	(28)	137.9	(20)	151.7	(22)	268.9	(39)	103.4	(15)	124.1	(18)
871°C (1,600°F)	137.9	(20)	172.3	(25)	89.6	(13)	110.3	(16)	110.3	(16)	82.7	(12)	75.8	(11)
982°C (1,800°F)	75.8	(11)	68.9	(10)	55.1	(8)	-	-	62.0	(9)	41.4	(6)	41.4	(6)
Tensile														
Elongation (%)														
RT	42		45		46		51		47		46		-	
649°C (1,200°F)	42		50		45		48		50		39		-	
760°C (1,400°F)	45		40		62		44		41		73		-	
871°C (1,600°F)	61		35		56		-		55		69		-	
982°C (1,800°F)	56		66		83		-		86		54		-	

Table 8

COMPARATIVE PROPERTIES (Sheet)

Room Temperature Properties After
1,000 Hours at Temperature

5	<u>Exposure Temperature</u>	<u>Alloy I</u>			<u>Alloy V</u>			<u>800H</u>			<u>601</u>			<u>310</u>		
		UTS	YS	EL	UTS	YS	EL	UTS	YS	EL	UTS	YS	EL	UTS	YS	EL
	649°C (1,200°F)	675.6 (98)	282.6 (41)	35	799.7 (116)	392.9 (57)	30	606.7 (88)	262 (38)	38	875.5 (127)	523.9 (76)	31	592.9 (86)	255.1 (37)	41
	760°C (1,400°F)	648 (94)	268.9 (39)	32	834.2 (121)	427.4 (62)	24	572.2 (83)	234.4 (34)	41	730.8 (106)	351.6 (51)	37	689.4 (100)	282.6 (41)	21
	871°C (1,600°F)	620.5 (90)	241.3 (35)	33	744.6 (108)	330.9 (48)	32	537.7 (78)	206.8 (30)	39	627.3 (91)	262.0 (38)	45	579.1 (84)	241.3 (35)	23
	As Annealed	682.5 (99)	282.6 (41)	42	744.6 (108)	337.8 (49)	45	565.3 (82)	248.2 (36)	46	654.9 (95)	289.5 (42)	47	558.4 (81)	220.6 (32)	46

UTS = Ultimate Tensile Strength MPa (ksi)

YS = Yield Strength MPa (ksi)

EL = Elongation %

Table 9

COMPARATIVE PROPERTIES (Sheet)

Stress Rupture Life (Hours)

	<u>ALLOY I</u>	<u>ALLOY V</u>	<u>800H</u>	<u>253MA</u>	<u>501</u>	<u>310</u>	<u>316</u>
760°C/89.6MPa (1,400°F/13 ksi)	949	551	104	110	205	10	95
871°C/48.2MPa (1,600°F/7 ksi)	196	194	88	40	98	5	21

Creep Life (Hours to 1%)

760°C/89.6MPa (1,400°F/13 ksi)	92	77	3	18	46	1	-
871°C/48.2MPa (1,600°F/7 ksi)	25	40	8	10	29	1	-

From the data discussed above, we have found that an alloy comprised of 30 to 45% nickel, 12% to 32% chromium, at least one of 0.1% to 2.0% columbium, 0.2% to 4.0% tantalum and 0.05% to 1.0% vanadium, up to 5 0.20% carbon, 0.05% to 0.50% nitrogen and an addition of titanium with the balance being iron plus impurities has good hot workability and fabricability characteristics provided $(C+N)_F$ is greater than 0.14% and less than 0.29%, where

10
$$(C+N)_F = C+N - \frac{Cb.}{9} - \frac{V}{4.5} - \frac{Ta}{1.8} - \frac{Ti}{3.5}$$

Titanium is added to improve creep resistance. However, not more than 0.20% titanium should be used. Silicon may be added to the alloy up to 3% by weight. Up to 1% silicon has excellent strength while 1% to 3% 15 silicon has lower strength but better oxidation resistance.

Manganese and aluminium may be added basically to enhance environment resistance, but should generally be limited to less than 2.0% and 1.0% respectively.

20 Boron, molybdenum, tungsten and cobalt may be added in moderate amounts to further enhance strength at elevated temperatures. Boron content of up to 0.02% will improve creep strength, but

higher levels will impair weldability markedly. Molybdenum and tungsten will provide additional strength without significant thermal stability debit up to 5%. Higher levels will produce some measurable loss in thermal stability, but can provide significant further strengthening up to a combined content of 12%.

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CLAIMS:

1. A metal alloy comprised of, in weight percent, 30% to 45% nickel, 12% to 32% chromium, at least one of 0.1% to 2.0% columbium, 0.2% to 4.0% tantalum and 0.05% to 1.0% vanadium, up to 0.20% carbon, 0.05% to 0.50% nitrogen, an addition of titanium up to 0.2% and the balance being iron plus impurities and wherein $(C+N)_F$ is greater than 0.14% and less than 0.29% $(C+N)_F$ being defined as $(C+N)_F =$
- 5 $C+N - \frac{Cb}{9} - \frac{V}{4.5} - \frac{Ta.}{18} - \frac{Ti.}{3.5}$
- 10
2. The alloy of claim 1 further including at least one of up to 1% aluminium, 0.01 to 0.2% titanium, up to 3% silicon, up to 2% manganese, up to 5% cobalt, up to 5% total molybdenum and tungsten, up to 0.02%
- 15 boron, up to 0.2% zirconium, and up to 0.1% total yttrium, lanthanum, cerium and other rare earth metals.
3. The alloy of claim 1 containing 30% to 42% nickel, 20% to 32% chromium, one of columbium 0.2% to 1.0%, 0.2% to 4.0% tantalum and 0.05% to
- 20 1.0% vanadium, 0.02% to 0.09% carbon.
4. The alloy of claim 3 further comprising at least one of up to 1% aluminium, up to 3% silicon, up to 2% manganese, up to 0.02% boron, up to 0.2% zirconium, up to 5.0% cobalt, up to
- 25 2.0% total molybdenum plus tungsten and up to 0.1% total yttrium, lanthanum, cerium and other rare earth metals.



5. The alloy of claim 3 comprising molybdenum and tungsten at a combined weight percent in the range of 2.0% to 12%.

5 6. The alloy of claim 3 also comprising at least one of up 0.5% aluminium, 0.01 to 0.1% titanium, 0.25% to 1.0% silicon, 0.35% to 1.2% manganese, up to 0.015% boron and up to 0.1% total yttrium, lanthanum, cerium and other rare earth metals.

10 7. The alloy of claim 3 also comprising from 1.0% to 3.0% silicon.

8. The alloy of claim 1 also comprising molybdenum and tungsten at a combined weight percent in the range of 2.0% to 12%.

15 9. The alloy of claim 1 also comprising from 1.0% to 3.0% silicon.

10. The alloy of claim 1 also comprising from 0.25% to 1.0% silicon.

11. The alloy of claim 1 produced as a casting.
