

(19)



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(11)

EP 1 159 462 B9

(12)

CORRECTED EUROPEAN PATENT SPECIFICATION

Note: Bibliography reflects the latest situation

(15) Correction information:

Corrected version no 1 (W1 B1)
Corrections, see page(s) 10

(51) Int Cl.7: **C22C 38/42**, C22C 38/48,
C21D 1/25

(48) Corrigendum issued on:

16.03.2005 Bulletin 2005/11

(86) International application number:

PCT/US2000/005916

(45) Date of publication and mention
of the grant of the patent:

29.09.2004 Bulletin 2004/40

(87) International publication number:

WO 2000/053821 (14.09.2000 Gazette 2000/37)

(21) Application number: **00913780.3**

(22) Date of filing: **08.03.2000**

(54) **AN ENHANCED MACHINABILITY PRECIPITATION-HARDENABLE STAINLESS STEEL FOR CRITICAL APPLICATIONS**

AUSSCHIEDUNGSHÄTBARER UND ROSTFREIER STAHL MIT VERBESSERTER
VERARBEITBARKEIT FÜR BESONDEREN EINSATZZWECKE

ACIER INOXYDABLE DURCISSABLE PAR PRECIPITATION A USINABILITE AMELIOREE,
DESTINE A ETRE UTILISE DANS DES CONDITIONS EXTREMES

(84) Designated Contracting States:

**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE**

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(30) Priority: **08.03.1999 US 123230 P**

(43) Date of publication of application:

05.12.2001 Bulletin 2001/49

(56) References cited:

EP-A- 0 257 780 EP-A- 0 629 714
EP-A- 0 649 915

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- **PATENT ABSTRACTS OF JAPAN vol. 017, no. 468 (C-1102), 26 August 1993 (1993-08-26) & JP 05 112849 A (NIPPON STEEL CORP), 7 May 1993 (1993-05-07)**
- **PATENT ABSTRACTS OF JAPAN vol. 1998, no. 01, 30 January 1998 (1998-01-30) & JP 09 256041 A (AICHI STEEL WORKS LTD), 30 September 1997 (1997-09-30)**

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Description**FIELD OF THE INVENTION**

[0001] This invention relates to high strength stainless steel alloys and, in particular, to a precipitation-hardenable, martensitic stainless steel alloy having a unique combination of strength, ductility, toughness, and machinability.

BACKGROUND OF THE INVENTION

[0002] Aerospace material specification AMS 5659 describes a 15Cr-5Ni precipitation hardenable, corrosion resistant steel alloy for use in critical aerospace components. AMS 5659 specifies minimum strength and ductility requirements which the alloy must meet after various age-hardening heat treatments. For example, in the H900 condition (heated at about 900F (482C) for 1 hour and then air cooled), a conforming alloy must provide a tensile strength of at least 190 ksi (1310 MPa) in both the longitudinal and transverse directions together with an elongation of at least 10% in the longitudinal direction and at least 6% in the transverse direction. However, products manufactured to meet that specification typically lack the ease of machinability desired by component fabricators.

[0003] As the alloy specified in AMS 5659 continues to be used in many structural components for aerospace applications, a need has arisen for an alloy that meets all of the mechanical requirements of AMS 5659, but which also provides superior machinability. It is generally known to add certain elements such as sulfur, selenium, tellurium, etc. to stainless steel alloys in order to improve their machinability. However, the inclusion of such "free-machining additives", without more, will adversely affect the mechanical properties of the alloy, such as toughness and ductility, to the point where the alloy becomes unsuitable for the critical structural components for which it was designed. EP-A-0 257 780 discloses a 15Cr-5Ni AGG-Hardenable martensitic stainless steel with improved machinability by reducing the carbon plus nitrogen contents below customary levels. However, in so doing the steels of this disclosure sacrifice mechanical toughness. Consequently, a need exists for a precipitation-hardenable martensitic stainless steel having good ductility, toughness, and notch tensile strength to be useful for critical applications and which also provides superior machinability compared with alloy compositions currently utilized for fracture-critical components.

SUMMARY OF THE INVENTION

[0004] The present invention is directed to a precipitation-hardenable martensitic stainless steel which provides mechanical properties (tensile and notch strength, ductility, and toughness) that meet the requirements of AMS 5659 and which also provides significantly better machinability compared to the known grades of 15Cr-5Ni precipitation-hardenable stainless steels. The broad, intermediate, and preferred weight percent compositions of the alloy according to this invention are set forth in the following table.

Weight percent			
Element	Broad	Intermediate	Preferred
C	0.030 max.	0.025 max.	0.010-0.025
Mn	0.51 max.	0.50 max.	0.50 max.
Si	1.00 max.	0.60 max.	0.50 max.
P	0.030 max.	0.030 max.	0.025 max.
S	0.007-0.015	0.007-0.015	0.007-0.013
Cr	14.00-15.32	14.00-15.32	14.25-15.25
Ni	3.50-5.50	3.50-5.50	4.00-5.50
Mo	1.00 max.	0.50 max.	0.50 max.
Cu	2.50-4.50	2.50-4.50	3.00-4.00
Nb+Ta	(5×C)-0.25	(5×C)-0.25	(5×C)-0.20
Al	0.05 max.	0.025 max.	0.025 max.
B	0.010 max.	0.005 max.	0.005 max.
N	0.030 max.	0.025 max.	0.010-0.025
Fe	Bal.	Bal.	Bal.

[0005] The foregoing tabulation is provided as a convenient summary and is not intended thereby to restrict the lower and upper values of the ranges of the individual elements for use in combination with each other, or to restrict the

ranges of the elements for use solely in combination with each other. Thus, one or more of the ranges can be used with one or more of the other ranges for the remaining elements. In addition, a minimum or maximum for an element of a broad, intermediate, or preferred composition can be used with the minimum or maximum for the same element in another preferred or intermediate composition. Here and throughout this specification the term "percent" or the symbol "%" means percent by weight unless otherwise specified.

DETAILED DESCRIPTION OF THE INVENTION

[0006] The interstitial elements carbon and nitrogen are restricted to low levels in this alloy in order to benefit the machinability of the alloy. Therefore, the alloy contains not more than 0.030% each of carbon and nitrogen and preferably not more than 0.025% of each of those elements. Carbon and nitrogen are strong austenite stabilizing elements and limiting them to levels that are too low leads to the formation of undesirable amounts of ferrite in this alloy. Therefore, at least 0.010% each of carbon and nitrogen is preferably present in the alloy.

[0007] This alloy contains a controlled amount of sulfur to benefit the machinability of the alloy without adversely affecting the ductility, toughness, and notch tensile strength of the alloy: To that end, the alloy contains at least 0.007% sulfur. Too much sulfur adversely affects the ductility, toughness, and notch tensile strength of this alloy. Therefore, sulfur is restricted to not more than 0.015% and preferably to not more than 0.013% in this alloy.

[0008] At least 14.00% and preferably at least 14.25% chromium is present in the alloy to provide an adequate level of corrosion resistance. However, when chromium is present in excess of 15.50% the formation of undesirable ferrite results. Therefore, chromium is restricted to not more than 15.32% and preferably to not more than 15.25% in this alloy.

[0009] At least 3.50%, preferably at least 4.00%, nickel is present in the alloy to maintain good toughness and ductility. Nickel also benefits the austenite phase stability of this alloy at the low levels of carbon and nitrogen used in the alloy. The strength capability of the alloy in the aged condition is adversely affected when more than 5.50% nickel is present because of incomplete austenite-to-martensite transformation (i.e., retained austenite) at room temperature. Therefore, this alloy contains not more than 5.50% nickel.

[0010] At least 2.50%, preferably at least 3.00%, copper is present in this alloy as the primary precipitation hardening agent. During the age hardening heat treatment, the alloy achieves substantial strengthening through the precipitation of fine, copper-rich particles from the martensitic matrix. Copper is present in this alloy in amounts ranging from 2.50 to 4.50% to provide the desired precipitation hardening response. Too much copper adversely affects the austenite phase stability of this alloy and can lead to formation of excessive austenite in the alloy after the age hardening heat treatment. Therefore, copper is restricted to not more than 4.50% and preferably to not more than 4.00% in this alloy.

[0011] A small amount of molybdenum is effective to benefit the corrosion resistance and toughness of this alloy. The minimum effective amount can be readily determined by those skilled in the art. Too much molybdenum increases the potential for ferrite formation in this alloy and can adversely affect the alloy's phase stability by promoting retained austenite. Therefore, while this alloy may contain up to 1.00% molybdenum, it preferably contains not more than 0.50% molybdenum.

[0012] A small amount of niobium is present in this alloy primarily as a stabilizing agent against the formation of chromium carbonitrides which are deleterious to corrosion resistance. To that end the alloy contains niobium in an amount equivalent to at least five times the amount of carbon in the alloy ($5 \times \%C$). Too much niobium, particularly at the low carbon and nitrogen levels present in this alloy, causes excessive formation of niobium carbides, niobium nitrides, and/or niobium carbonitrides and adversely affects the good machinability provided by this alloy. Too many niobium carbonitrides also adversely affect the alloy's toughness. Furthermore, excessive niobium results in the formation of an undesirable amount of ferrite in this alloy. Therefore, niobium is restricted to not more than 0.25%, and preferably to not more than 0.20%. Those skilled in the art will recognize that tantalum may be substituted for some of the niobium on a weight percent basis. However, tantalum is preferably restricted to not more than 0.05% in this alloy.

[0013] A small but effective amount of boron may be present in amounts up to 0.010%, preferably up to 0.005%, to benefit the hot workability of this alloy.

[0014] The balance of the alloy composition is iron except for the usual impurities found in commercial grades of precipitation hardening stainless steels intended for similar use or service. For example, aluminum is restricted to not more than 0.05% and preferably to not more than 0.025% in this alloy because aluminum can form aluminum nitrides and aluminum oxides which are detrimental to the good machinability provided by the alloy. Other elements such as manganese, silicon, and phosphorus are also maintained at low levels because they adversely affect the good toughness provided by this alloy. The composition of this alloy is balanced so that the microstructure of the steel undergoes substantially complete transformation from austenite to martensite during cooling from the annealing temperature to room temperature. As described above, the constituent elements are balanced within their respective weight percent ranges such that the alloy contains not more than about 2 volume percent (vol.%) ferrite, preferably not more than about 1 vol% ferrite, in the annealed condition.

[0015] The alloy according to this invention is preferably melted by vacuum induction melting (VIM), but can also be

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arc-melted in air (ARC). The alloy is refined by vacuum arc remelting (VAR) or electroslag remelting (ESR). The alloy may be produced in various product forms including billet, bar, rod, and wire. The alloy may also be used to fabricate a variety of machined, corrosion resistant parts that require high strength and good toughness. Among such end products are valve parts, fittings, fasteners, shafts, gears, combustion engine parts, components for chemical processing equipment and paper mill equipment, and components for aircraft and nuclear reactors.

[0016] The unique combination of properties provided by the alloy according to the present invention will be appreciated better in the light of the following examples.

EXAMPLES

[0017] In order to demonstrate the unique combination of properties provided by the alloy according to the present invention, examples of the alloy were prepared and tested relative to comparative alloys.

Example 1

[0018] Four heats, each weighing approximately 400-pounds (181 by), were vacuum-induction melted and cast as single 7.5" (14.1 cm) square ingots. The chemical analyses of the heats are shown in Table I in weight percent. Heat 1 is an example of the steel according to this invention. Heats A, B, and C are comparative alloys.

TABLE I

Heat No.	Element (weight percent)													
	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Nb	Ta	B	N	Fe
1	.020	.30	.42	.021	.009	14.87	4.72	.10	3.30	.15	<.01	<.0010	.017	Bal.
A	.020	.30	.40	.021	<.001	14.87	4.70	.10	3.30	.15	<.01	<.0010	.017	Bal.
B	.036	.31	.41	.021	<.001	15.11	4.59	.10	3.30	.26	<.01	<.0010	.011	Bal.
C	.035	.30	.41	.021	.009	15.13	4.66	.10	3.31	.26	<.01	<.0010	.017	Bal.

[0019] The ingots were press-forged to 4" (10.2 cm) square billets, cogged to a 2.125" (5.4 cm) diam. round bars, and then hot rolled to 0.6875" (1.7 cm) diam. bar. All the bars were solution annealed by heating them to a temperature of 1040°C, soaking for one hour at that temperature, and then water quenching to room temperature. Further processing consisted of straightening the annealed bars, turning to 0.637" (1.618 cm) diam., restraightening, rough grinding to 0.627" (1.593 cm) diam., and then grinding the bars to a finish diameter of 0.625" (1.588 cm).

[0020] The microstructure and mechanical properties of the bar products were evaluated and compared relative to the requirements of AMS 5659. Table II shows that little or no ferrite was present in the microstructures of the solution-annealed 0.625", (1.59 cm) diam. bars.

TABLE II

(FERRITE CONTENT IN ANNEALED BARS)	
Heat No.	Ferrite Content (Volume Percent)*
1	0.09
A	None Detected
B	None Detected
C	0.08
AMS 5659	2 Maximum

* Measured from tint-etched longitudinal metallographic specimens via image analysis of 100 fields at 1050× screen magnification.

[0021] A comparison of room-temperature smooth tensile properties and hardness of the four alloys in the annealed condition is given in Table III. The data presented in Table III includes the 0.2% offset yield strength (.2% Y.S.) and ultimate tensile strength (UTS) in ksi (MPa), the percent elongation in 4 diameters (% Elong.), the reduction in area

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(% RA), and the Rockwell C hardness (HRC).

TABLE III

(LONGITUDINAL SMOOTH TENSILE PROPERTIES AND HARDNESS OF ANNEALED BARS)					
	Smooth Tensile Properties ⁽¹⁾				
Heat No.	.2% Y.S.	UTS	%Elong.	%RA	HRC ⁽²⁾
1	135.0 (930.8)	149.6 (1031.5)	15.9	70.8	31
A	139.1 (959.1)	149.5 (1030.8)	16.3	77.5	31
B	143.6 (990.1)	155.3 (1070.8)	15.8	73.9	32
C	138.6 (955.6)	154.0 (1061.8)	15.5	70.8	32.5
AMS 5659	—	175 max. (1206.6 max.)	—	—	39.1 max. ⁽³⁾

(1) Average of duplicate specimens.

(2) Average of four measurements taken at midradius location.

(3) Converted from HB scale.

[0022] A comparison of room-temperature smooth tensile properties and hardness was also developed for the alloys in the various aged conditions specified in AMS 5659. Results are presented in Table IV including the 0.2% offset yield strength (.2% Y.S.) and ultimate tensile strength (UTS) in ksi (MPa), the percent elongation in 4 diameters (Elong.), the reduction in area (RA), and the Rockwell C hardness (HRC).

TABLE IV

(LONGITUDINAL SMOOTH TENSILE PROPERTIES AND HARDNESS OF AGED-HARDENED BARS)								
	Smooth Tensile Properties ⁽¹⁾							
Heat No.	Condition ⁽²⁾	.2% YS		UTS		Elong.	RA	HRC ⁽³⁾
1	H900	189.8	(1308.6)	199.0	(1372.1)	14.1	51.4	43
A	"	192.8	(1329.3)	198.6	(1369.3)	14.5	56.6	43
B	"	193.6	(1334.8)	199.7	(1376.9)	14.8	59.6	43
C	"	190.6	(1314.1)	199.3	(1374.1)	14.4	59.7	43
AMS 5659	"	170min. (1172 min)		190min. (1310)		10min.	35min.	41.8-47.1 ⁽⁴⁾
1	H925	178.7	(1232.1)	186.7	(1287.3)	14.4	55.6	41
A	"	178.6	(1231.4)	185.3	(1277.6)	14.5	55.1	41
B	"	179.8	(1239.7)	184.9	(1274.8)	16.4	64.9	41
C	"	177.6	(1224.5)	184.9	(1274.8)	16.7	61.6	41
AMS 5659	"	155min. (1069 min)		170min. (1172 min)		10min.	38min.	40.4-45.7 ⁽⁴⁾
1	H1025	159.6	(1100.4)	163.8	(1129.4)	15.3	62.1	36
A	"	157.8	(1088.0)	162.5	(1120.4)	16.1	63.6	36
B	"	160.5	(1106.5)	164.0	(1130.7)	16.1	65.6	36
C	"	159.6	(1100.4)	163.3	(1125.9)	16.1	65.4	36
AMS 5659	"	145min. (1000 min)		155min. (1069 min)		12min.	45min.	35.5-43.1 ⁽⁴⁾
1	H1150	115.3	(795.0)	139.0	(958.4)	21.3	68.9	30
A	"	115.8	(798.4)	138.6	(955.6)	23.3	73.2	30

(1) Average of duplicate specimens.

(2) Aging cycles are defined as follows: H900: 900F (482°C) / 1 hour/ air cool H925: 925F (496°C) / 4 hours/ air cool H1025: 1025F (552°C) / 4 hours/ air cool H1150: 1150F (621°C) / 4 hours/ air cool

(3) Average of four measurements.

(4) Converted from HB scale.

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TABLE IV (continued)

(LONGITUDINAL SMOOTH TENSILE PROPERTIES AND HARDNESS OF AGED-HARDENED BARS)								
Smooth Tensile Properties ⁽¹⁾								
Heat No.	Condition ⁽²⁾	.2% YS		UTS		Elong.	RA	HRC ⁽³⁾
B	"	113.3	(781.2)	138.2	(952.9)	21.7	71.7	30
C	"	109.6	(755.7)	138.1	(952.2)	21.8	70.2	30
AMS 5659	"	105min. (724 min)		135min. (931 min)		16min.	50min.	28.8-37.9 ⁽⁴⁾

(1) Average of duplicate specimens.

(2) Aging cycles are defined as follows: H900: 900F (482°C) / 1 hour/ air cool H925: 925F (496°C) / 4 hours/ air cool H1025: 1025F (552°C) / 4 hours/ air cool H1150: 1150F (621°C) / 4 hours/ air cool

(3) Average of four measurements.

[0023] The data presented in Tables III and IV show that the hardness and smooth tensile properties of the four alloys are similar and that they all satisfy the requirements of AMS 5659 under the respective heat treating conditions.

[0024] The machinabilities of the annealed 0.625", (1.59 cm) diam. bars of each alloy were tested by employing a Brown and Sharpe Ultramatic (single spindle) Screw Machine. Spindle speed was utilized as the variable test parameter. Three tests were conducted on all four heats at speeds of 95.5 and 104.3 surface feet per minute (SFM). A given trial was terminated for one of two reasons a) part growth exceeding 0.003" (76 µm) as a result of tool wear (Part Growth) or b) at least 400 parts were machined without 0.003" (76 µm) part growth (Discontinued). Catastrophic tool failure, a third reason for test termination, was not experienced in this testing. The screw machine test parameters and results are provided in Table V, including the spindle speed (Spindle Speed) in SFM, the number of parts machined (Total Parts) and the reason for terminating each test (Reason for Test Termination).

TABLE V

(SCREW MACHINE TEST RESULTS FOR ANNEALED BARS)			
Heat No.	Spindle Speed	Total Parts	Reason for Test Termination
1	95.5	400	Discontinued
"	95.5	400	Discontinued
"	95.5	370	Part Growth
"	104.3	240	Part Growth
"	104.3	180	Part Growth
"	104.3	230	Part Growth
A	95.5	110	Part Growth
"	95.5	110	Part Growth
"	95.5	160	Part Growth
"	104.3	90	Part Growth
"	104.3	80	Part Growth
"	104.3	80	Part Growth
B	95.5	40	Part Growth
"	95.5	30	Part Growth
"	95.5	30	Part Growth
"	104.3	30	Part Growth

(1) A rough form tool feed rate of 0.002 ipr (inches per revolution) was utilized for all tests.

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TABLE V (continued)

(SCREW MACHINE TEST RESULTS FOR ANNEALED BARS)			
Heat No.	Spindle Speed	Total Parts	Reason for Test Termination
"	104.3	40	Part Growth
"	104.3	45	Part Growth
C	95.5	90	Part Growth
"	95.5	90	Part Growth
"	95.5	80	Part Growth
"	104.3	50	Part Growth
"	104.3	60	Part Growth
"	104.3	60	Part Growth

[0025] Set forth in Table VI is a summary of the data presented in Table V above, including the number of parts machined at each spindle speed (Parts Machined). The mean and standard deviation values for the comparative alloys are also shown.

TABLE VI

(SCREW MACHINE TEST RESULT SUMMARY ANNEALED BARS)			
Heat No.	Parts Machines at 95.5 SFM	Mean	Standard Deviation
1	>400*, >400*, 370	—	—
A	110, 110, 160	127	28.9
B	40, 30, 30	33	5.8
C	90, 90, 80	87	5.8

* Test discontinued because of runoff.

Heat No.	Parts Machines at 104.3 SFM	Mean	Standard Deviation
1	240, 180, 230	217	32.1
A	90, 80, 80	83	5.8
B	30, 40, 45	38	7.6
C	50,60,60	57	5.8

[0026] When viewed together, the data in Tables II to VI show that Heat 1 provides a significantly better combination of properties relative to Heats A, B, and C, because it provides superior machinability while maintaining the mechanical and microstructural property requirements of AMS 5659.

Example 2

[0027] Four 400 lb. (181 kg) heats were vacuum induction melted and cast as 7½" (19.1 cm) ingots. The chemical analyses of the heats are shown in Table VII in weight percent. Heats 2 and 3 are examples of the steel according to this invention and Heats D and E are comparative alloys.

TABLE VII

Heat No.	Element (weight percent)													
	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Nb	Ta	B	N	Fe
2	.026	.51	.48	.023	.014	15.32	4.28	.12	3.28	.20	<.01	.0011	.018	Bal.

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TABLE VII (continued)

Heat No.	Element (weight percent)													
	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Nb	Ta	B	N	Fe
3	.020	.51	.45	.028	.011	15.28	4.80	.27	3.16	.20	<01	.0020	.013	Bal.
D	.034	.63	.49	.025	.020	15.71	4.29	.12	3.29	.26	<01	.0011	.017	Bal.
E	.020	.52	.45	.026	.018	15.56	4.81	.27	3.16	.22	<01	.0021	.013	Bal.

[0028] Heat 2 was prepared for comparison with Heat D and Heat 3 was prepared for comparison with Heat E. The ingots were press forged to 4" (10.2 cm) square bars as described above in Example 1.

[0029] Set forth in Tables VIIIA and VIIIB are the results of smooth and notch tensile, impact toughness, hardness, and fracture toughness testing of the 4" (10.2 cm) bars of Heats 2, 3, D, and E in the H1150 age-hardened condition. Table VIIIA presents data for longitudinally oriented specimens and Table VIIIB presents data for transversely oriented specimens. The results shown in Tables VIIIA and VIIIB include the .2% offset yield strength (0.2% Y.S.) and ultimate tensile strength (UTS) in ksi (MPa), the percent elongation in 4 diameters (% Elong.), the reduction in area (% RA), the notched tensile strength (NTS) in ksi (MPa), the NTS/UTS ratio (NTS/UTS), the Charpy V-notch impact strength (CVN) in ft-lbs (J), the Rockwell C hardness (HRC), and the fracture toughness (K_{Ic}) in ksi \sqrt{in} (MPa \sqrt{m}).

TABLE VIII A
(LONGITUDINAL MECHANICAL PROPERTIES
OF H1150 AGE-HARDENED BARS)

Heat No.	Smooth Tensile Properties ⁽¹⁾						HRC ⁽⁵⁾	K _Q ⁽⁶⁾
	2% Y.S.	UTS	%Elong.	%RA	NTS ⁽²⁾	NTS/UTS ⁽³⁾		
2	126.0 (868.7)	141.7 (977.0)	20.8	68.6	219.5 (1513.4)			147.2 (161.7)
	127.4 (878.4)	142.2 (980.4)	21.1	68.7	222.2 (1532.0)	1.56	31	145.8 (160.2)
D	117.8 (812.2)	140.9 (971.5)	21.0	66.6	218.7 (1507.9)			123.4 (135.6)
	117.1 (807.4)	140.6 (969.4)	20.9	66.5	217.1 (1496.9)	1.55	31	119.9 (131.7)
3	109.4 (754.3)	136.5 (941.1)	23.4	69.7	212.2 (1463.1)			98.2 (107.9)
	110.5 (761.9)	137.0 (944.6)	23.4	71.5	212.3 (1463.8)	1.55	29	99.1 (108.9)
E	110.0 (758.4)	138.4 (954.2)	22.9	71.5	219.0 (1510.0)			92.3 (101.4)
	111.7 (770.1)	138.5 (954.4)	22.4	71.2	216.6 (1493.4)	1.57	29	90.3 (99.2)
AMS 5659	105 min. (724)	135 min. (931)	16 min.	50 min.			28.8-37.9	

(1) 250" (6.35 mm) diam. gagesmooth tensile specimens.

(2) K_Q = 10 (d=252" (6.4 mm), D=357" (9.07 mm) with root radius of .0010" (0.0254 mm)).

(3) Average NTS/ Average UTS.

(4) Std CVN impact specimens having L-T notch orientation.

(5) Average hardness measured on section of fractured CVN impact specimens.

(6) Std 1-1/2" (38.1 mm) thick compact tension specimens having an L-T slot orientation.

TABLE VIII B
(TRANSVERSE MECHANICAL PROPERTIES
OF H1150 AGE-HARDENED BARS)

Heat No.	Smooth Tensile Properties ⁽¹⁾					NTS/UTS ⁽²⁾	CVN ⁽⁴⁾	HRC ⁽⁵⁾	K _Q ⁽⁶⁾
	2% Y.S.	UTS	%Elong.	%RA	NTS ⁽³⁾				
2	125.1 (862.5)	141.1 (972.9)	17.5	53.7	218.3 (1505.1)		51, 46, 45 (69,62,61)		109.0 (119.8)
D	123.3 (850.1)	140.5 (968.7)	18.7	59.4	220.7 (1521.7)	1.56	Avg. 47 (64)	30	108.0 (118.7)
	120.0 (827.4)	141.1 (972.9)	16.1	42.5	212.6 (1465.8)		39, 39, 27 (53,53,37)		106.3 (116.8)
3	111.9 (771.5)	139.2 (959.8)	19.0	56.7	212.0 (1461.7)	1.51	Avg. 35 (47)	30	89.0 (97.8)
	108.6 (748.8)	136.8 (943.2)	21.1	65.0	210.0 (1447.9)		85, 72, 69 (115,98,94)		96.7 (106.3)
E	108.4 (747.4)	136.0 (937.7)	21.0	66.0	206.9 (1426.5)	1.53	Avg. 75 (102)	29	97.8 (107.5)
	110.3 (760.5)	138.6 (955.6)	19.8	58.9	208.0 (1434.1)		55, 55, 50 (75,75,68)		94.0 (103.3)
AMS 5659	108.7 (749.5)	138.1 (952.2)	19.8	58.2	206.8 (1425.8)	1.50	Avg. 53 (72)	29.5	85.3 (93.7)
	105 min. (724)	135 min. (931)	11 min.	35 min.				28.8-37.9	

(1) 250" (6.35 mm) diam. gage smooth tensile specimens.

(2) K_Q = 10 (d=252(6.4 mm)D=.357"(9.07 mm) with root radius of .0010" (0.0254 mm)).

(3) Average NTS/ Average UTS.

(4) Sid CVN impact specimens having L-T notch orientation.

(5) Average hardness measured on section of fractured CVN impact specimens.

(6) Sid 1-1/2" (38.1mm) thick compact tension specimens having an L-T slot orientation.

[0030] The data in Table VIIIA show that Heats 2 and 3, which are alloys according to the present invention, although providing similar smooth and notch tensile properties and hardness relative to Heats D and E, respectively, provide superior impact toughness and fracture toughness characteristics relative to those alloys. Similar results are demonstrated in Table VIIIB for the transversely oriented specimens, although at somewhat lower levels than the corresponding longitudinal properties. Good impact toughness and fracture toughness are especially important for materials used in critical structural components.

[0031] Considering the data presented in Tables VIIIA and VIIIB, together, they clearly show the superior combination of strength, toughness, ductility, and, machinability provided by the alloy according to the present invention.

Claims

1. A precipitation-hardenable, martensitic stainless steel alloy, comprising, in weight percent,

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C	0.030 max.
Mn	0.51 max.
Si	1.00 max..
P	0.030 max.
S	0.007-0.015
Cr	14.00-15.32
Ni	3.50-5.50
Mo	1.00 max.
Cu	2.50-4.50
Nb+Ta	(5×C)-0.25
Al	0.05 max.
B	0.010 max.
N	0.030 max.

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the balance being Fe and the usual impurities.

2. A precipitation-hardenable, martensitic stainless steel alloy according to claim 1 containing at least 0.010% carbon.

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3. A precipitation-hardenable, martensitic stainless steel alloy according to claim 1 or claim 2 containing not more than 0.013% sulfur.

4. A precipitation-hardenable, martensitic stainless steel alloy according to any one of claims 1 to 3 containing not more than 15.25% chromium.

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5. A precipitation-hardenable, martensitic stainless steel alloy according to any one of claims 1 to 4 containing at least 4.00% nickel.

6. A precipitation-hardenable, martensitic stainless steel alloy according to any one of claims 1 to 5 containing not more than 0.50% molybdenum.

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7. A precipitation-hardenable, martensitic stainless steel alloy according to any one of claims 1 to 6 containing not more than 0.025% nitrogen.

8. A precipitation-hardenable, martensitic stainless steel alloy according to any one of claims 1 to 7 containing not more than 4.00% copper.

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9. A precipitation-hardenable, martensitic stainless steel alloy according to any one of the preceding claims which contains, in weight percent:

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C	0.025 max.
Si	0.50 max.
Al	0.025 max.
B	0.005 max.
N	0.025 max.

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10. A precipitation-hardenable, martensitic stainless steel alloy according to any one of the preceding claims which contains not more than 0.20% niobium-plus-tantalum.

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11. A precipitation-hardenable, martensitic stainless steel alloy according to any one of the preceding claims which contains at least 0.010% nitrogen.

12. A steel article that provides a unique combination of machinability, hardness, strength, ductility, and toughness, in the age-hardened condition, said article being formed of a precipitation-hardenable, martensitic stainless steel alloy according to any one of the preceding claims.

Patentansprüche

1. Ausscheidungshärtbare martensitische Edelstahllegierung, die in Gew.-% Folgendes umfasst:

C	0,030 max.
Mn	0,51 max.
Si	1,00 max.
P	0,030 max.
S	0,007 - 0,015
Cr	14,00 - 15,32
Ni	3,50 - 5,50
Mo	1,00 max.
Cu	2,50 - 4,50
Nb + Ta	(5 x C) - 0,25
Al	0,05 max.
B	0,010 max.
N	0,030 max.

wobei der Rest Fe und die üblichen Verunreinigungen sind.

2. Ausscheidungshärtbare martensitische Edelstahllegierung nach Anspruch 1, die zumindest 0,010 % Kohlenstoff enthält.
3. Ausscheidungshärtbare martensitische Edelstahllegierung nach Anspruch 1 oder Anspruch 2, die nicht mehr als 0,013 % Schwefel enthält.
4. Ausscheidungshärtbare martensitische Edelstahllegierung nach einem der Ansprüche 1 bis 3, die nicht mehr als 15,25 % Chrom enthält.
5. Ausscheidungshärtbare martensitische Edelstahllegierung nach einem der Ansprüche 1 bis 4, die zumindest 4,00 % Nickel enthält.
6. Ausscheidungshärtbare martensitische Edelstahllegierung nach einem der Ansprüche 1 bis 5, die nicht mehr als 0,50 % Molybdän enthält.
7. Ausscheidungshärtbare martensitische Edelstahllegierung nach einem der Ansprüche 1 bis 6, die nicht mehr als 0,025 % Stickstoff enthält.
8. Ausscheidungshärtbare martensitische Edelstahllegierung nach einem der Ansprüche 1 bis 7, die nicht mehr als 4,00 % Kupfer enthält.
9. Ausscheidungshärtbare martensitische Edelstahllegierung nach einem der vorangegangenen Ansprüche, die in Gew.-%

C	0,025 max.
Si	0,50 max.
Al	0,025 max.
B	0,005 max.
N	0,025 max.

enthält.

10. Ausscheidungshärtbare martensitische Edelstahllegierung nach einem der vorangegangenen Ansprüche, die nicht mehr als 0,20 % Niob + Tantal enthält.

11. Ausscheidungshärtbare martensitische Edelstahllegierung nach einem der vorangegangenen Ansprüche, die zumindest 0,010 % Stickstoff enthält.

12. Stahlgegenstand, der im ausgehärteten Zustand eine einzigartige Kombination von Bearbeitbarkeit, Härte, Festigkeit, Duktilität und Tenazität aufweist, wobei der Gegenstand aus einer ausscheidungshärtbaren martensitischen Edelstahllegierung nach einem der vorangegangenen Ansprüche geformt ist.

Revendications

1. Alliage d'acier inoxydable martensitique durcissable par précipitation comprenant, en pour cent en poids,

C	0,030 max.
Mn	0,51 max.
Si	1,00 max.
P	0,030 max.
S	0,007-0,015
Cr	14,00-15,32
Ni	3,50-5,50
Mo	1,00 max.
Cu	2,50-4,50
Nb+Ta	(5xC)-0,25
Al	0,05 max.
B	0,010 max.
N	0,030 max.

le reste étant Fe et les impuretés usuelles.

2. Alliage d'acier inoxydable martensitique durcissable par précipitation selon la revendication 1 contenant au moins 0,010 % de carbone.

3. Alliage d'acier inoxydable martensitique durcissable par précipitation selon la revendication 1 ou la revendication 2 ne contenant pas plus de 0,013 % de soufre.

4. Alliage d'acier inoxydable martensitique durcissable par précipitation selon l'une quelconque des revendications 1 à 3 ne contenant pas plus de 15,25 % de chrome.

5. Alliage d'acier inoxydable martensitique durcissable par précipitation selon l'une quelconque des revendications 1 à 4 contenant au moins 4,00 % de nickel.

6. Alliage d'acier inoxydable martensitique durcissable par précipitation selon l'une quelconque des revendications 1 à 5 ne contenant pas plus de 0,50 % de molybdène.

7. Alliage d'acier inoxydable martensitique durcissable par précipitation selon l'une quelconque des revendications 1 à 6 ne contenant pas plus de 0,025 % d'azote.

8. Alliage d'acier inoxydable martensitique durcissable par précipitation selon l'une quelconque des revendications 1 à 7 ne contenant pas plus de 4,00 % de cuivre.

9. Alliage d'acier inoxydable martensitique durcissable par précipitation selon l'une quelconque des revendications précédentes qui contient, en pour cent en poids:

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C	0,025 max.
Si	0,50 max.
Al	0,025 max.
B	0,005 max.
N	0,025 max.

10. Alliage d'acier inoxydable martensitique durcissable par précipitation selon l'une quelconque des revendications précédentes qui ne contient pas plus de 0,20 % de niobium-plus-tantale.

11. Alliage d'acier inoxydable martensitique durcissable par précipitation selon l'une quelconque des revendications précédentes qui contient au moins 0,010 % d'azote.

12. Article en acier qui offre une combinaison unique d'usinabilité, dureté, résistance mécanique, ductilité et solidité en condition durcie par l'âge, ledit article étant formé d'un alliage d'acier inoxydable martensitique durcissable par précipitation selon l'une quelconque des revendications précédentes.