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Description

The instant invention relates to nickel-iron-chromium alloys in general and more particularly to a high strength, corrosion resistant alloy having a low work hardenability rate with variable age hardenable characteristics. Tne alloy reduces copper pick-up in fluid streams.

Power plant operators and boiler manufacturers recognized early on that to improve the efficiency of stream generators (both fossil and nuclear), it was useful to adopt regenerative feedwater heating. Essentially, steam is extracted from the steam turbines to preheat the boiler/reactor feedwater before it is introduced into the economizer of a boiler or directly into a steam generatorireactor. The heating of the feedwater occurs in, naturally enough, feedwater heaters. Steam is used to heat the feedwater inside the feedwater heater tubing to impart a portion of the steam's latent heat to the water. Water temperatures from about 100-650°F (37-343°C) and pressures up to 5200 psi (36 MPa) are not uncommon. Moroever, advanced designs are now contemplating pressures up to 7200 psi (49.6 MPa) and 700°F (371°C).

Currently, steels (carbon and stainless) and sometimes nickel-copper alloys (MONEL* nickel-copper alloysi are utiiized in feedwater heaters. Although the feedwater is treated to remove chemicals and other impurities, corrosion of the tubing may still occur.

Free oxygen will attack the steels. Superalloys are often difficult to form into tubes due to their high work hardening rates. High copper-containing materials are generally frowned upon since copper and corrosion products are believed to deposit on boiler tubes and may be carried over into the steam. These undesirable entrained products may enter into the turbines resulting in lower efficiencies. Indeed, operators wish to eliminate all possible copper pick-up in the steam because of fouling and the resulting loss of efficiency of the turbine blades when the copper plates out of the steam. It is also believed that the copper deposits may set up local galvanic cells with the ferrous alloys thereby causing additional corrosion. Operators wish to stay away from nickel-copper alloys which otherwise display better chemical and physical properties than the other alloys. However, the substitution of low carbon or stainless steels for the nickel-copper alloys currently available is not always satisfactory since these materials do not have the requisite corrosion resistance, stress corrosion cracking resistance or strength. This leads to high maintenance costs. Moreover, in the case of carbon steels, undesirably short lifetimes of three to eight years have been reported. Contrast this state of affairs with an expected service life in excess of twenty years. Accordingly, power plant operators are in a quandry: steels corrode: high alloys are costly; and the nickel-copper alloys contain high quantities of copper.

It is apparent that there is a need for a reasonable cost alloy that exhibits corrosion resistance, strength and formability properties suitable for feedwater heaters, chemical and petrochemical installations and other similar applications.

It has been proposed in DE-A-21 35 180 to use a low-carbon chromium-nickel stainless steel containing 0.2 to 4% vanadium together with 0.3 to 4% copper and molybdenum for applications requiring good resistance to stress corrosion cracking.

The present invention provides an austenitic alloy having a low work hardening rate especially suitable for, but not limited to, industrial vessels and particularly for heat exchanger tubing for high temperature, high pressure appiications. The instant alloy combines improved corrosion resistance and the requisite high strength in a system that is of lower cost than the more expensive higher alloys. The alloy displays good stress corrosion cracking resistance and good high temperature corrosion resistance.

According to the invention, an austenitic, age-hardenable nickel-iron-chromium alloy having a combination of high strength, low work-hardening rate, resistance to stress-corrosion cracking and resistance to corrosion by high-temperature deaerated water and by hydrochloric, sulphuric, phosphoric and polythionic acids consists, by weight, of from 24 to 32% nickel, from 15 to 18% chromium, from 1 to 3.5% molybdenum, from 2 to 5.5% copper, from 0.8 to 2.5% titanium, from 0 to 1.5% manganese, from 0 to 1.5% silicon, e.g. less than 0.45% silicon, from 0 to 1% niobium plus tantalum, from 0 to 2% aluminum, from 0 to 0.1% cerium, from 0 to 0.01% boron and from 0 to 0.2% nitrogen, the balance, apart from impurities, being iron.

The term impurities used herein includes residual amounts of calcium added as a processing aid.

The molybdenum content is advantageously from 1 to 3%, and the copper content from 2 to 5%. Preferably the nickel content is from 26 to 29%, the chromium content from 15 to 18%, the molybdenum content not more than 3%, the copper content not more than 5% and the content of niobium plus tantalum not more than 0.4%. In one alloy according to the invention the nickel is about 28%, the chromium about 16%, the molybdenum about 2% and the copper about 4%.

Owing to its low work hardening rate (caused in part by the nickel-chromium combinations) the instant

*A trademark of the Inco family of companies.

alloy easily lends itself to tube fabrication and other cold working operations. The presence of titanium in amounts above about 0.8% renders the alloys increasingly age hardenable, and e.g. about 1.8% titanium may be incorporated for this purpose.

In the alloy of the invention, the incorporation of a measured quantity of titanium can impart an age hardening response of at least 60 ksi (413 MPa) yield strength and 120 ksi (825 MPa) tensile strength in the cold worked and annealed conditions. The titanium raises the work hardening rate of the alloy. Copper, chromium and molybdenum improve the corrosion resistance of the alloy. Aluminum, cerium, boron and calcium assist in the deoxidation of the alloy. Nitrogen serves to boost the ability of the alloy to withstand corrosive attack. The nitrogen raises the strength and increases the work hardening rate of the alloy in the annealed condition.

Table I below sets forth the compositions of a number of heats (Nos. 1-3 and 7-9) of alloys according to the invention within the above composition ranges and also, for purposes of comparison, one alloy (No 4) that is substantially free from copper and molybdenum, one alloy (No. 5) that is substantially free from copper, one alloy (No. 6) that is substantially free from molybdenum and titanium three alloys (Nos. 10-12) having lower titanium contents, and three alloys (Nos. 13-15) having lower nickel contents.

Other alloys used in comparative tests were commercial MONEL alloy 400 (nominal composition: 32.56% copper, 2.40% iron, 1.04% manganese, 0.1% silicon, 0.1% carbon, balance essentially nickel) and 304 stainless steel (nominal composition: 18.09% chromium, 9.18% nickel, 1.77% manganese, 0.73% silicon, 0.24% molybdenum, balance essentially iron).

Some examples will now be given.

TABLE I

Chemical Analysis % Weight

Heat No.	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Nf+Ta	Ce	N
1	0.01	0.93	Bal	0.003	0.36	3.57	28.32	16.24	0.08	1.75	—	0.02	2.08	0.01	0.03	—
2	0.02	0.95	Bal	0.003	0.42	3.42	28.75	15.94	0.08	2.02	—	0.02	2.10	0.01	0.039	—
3	0.04	0.96	Bal	0.003	0.42	3.57	28.59	15.59	0.08	2.30	—	0.02	2.11	0.01	0.038	—
4	0.02	1.00	51.56	0.002	0.43	0.03	28.60	16.29	0.06	1.78	<0.001	<0.01	0.03	0.05	0.046	.005
5	0.03	0.96	50.72	0.002	0.34	<0.01	28.11	15.63	0.07	1.78	—	0.01	1.96	0.02	0.043	.006
6	0.02	0.99	48.84	0.003	0.40	4.07	28.13	15.93	0.04	0.10	—	0.01	0.04	<0.01	0.041	.004
7	0.02	0.98	47.40	0.003	0.40	3.86	27.98	15.92	0.05	0.83	—	<0.01	2.08	0.01	0.036	.004
8	0.02	1.00	46.52	0.001	0.45	3.98	28.05	15.68	0.02	1.79	<0.001	0.01	2.05	0.01	0.026	—
9	0.02	1.02	44.55	0.001	0.45	5.03	28.03	15.69	0.03	1.78	<0.001	0.01	3.02	0.01	0.022	—
10	0.03	0.91	45.72	0.004	0.45	5.03	27.95	15.80	0.02	0.74	<0.001	0.02	3.09	0.01	0.009	—
11	0.03	0.99	47.17	0.002	0.44	4.11	27.88	15.54	0.04	0.76	<0.001	0.01	2.07	0.49	0.030	—
12	0.03	0.95	Bal	0.003	0.42	3.38	27.03	16.52	0.06	0.03	—	—	2.03	—	0.041	—
13	0.02	1.00	Bal	0.001	0.43	3.84	18.24	16.06	0.05	0.06	—	0.01	2.03	<.01	0.029	.12
14	0.03	.95	Bal	0.003	0.38	3.66	12.86	14.76	0.05	0.03	—	0.02	1.92	.01	0.027	0.017
15	0.02	.98	Bal	0.002	0.40	3.63	17.63	15.68	0.06	0.04	—	0.02	2.03	<.01	0.028	0.004

Example 1

Heats 1-3 and 12 (14 kg melts) were vacuum melted and cast to 4 inch (10 cm) diameter ingots. Forged 9/16 inch (1.43 cm) squares plus forged 3/4 × 2 × 12 inch (1.91 × 5.08 × 20.5 cm) flats were made with frequent reheats at 2150°F (1177°C). After overhauling the flats to a uniform thickness, they were hot rolled to 1/4 inch (0.64 cm) at 2150°F. The hot rolled 1/4 inch strip was annealed at 1950°F (1066°C)/one hour water quench and pickled prior to cold rolling. Hardness and tensile tests were taken at various levels of cold work to establish a work hardening response. A low work hardening rate is very desirable in the manufacture of relatively small diameter thin-walled tubing.

Of particular importance is the yield strength at high levels of cold reduction such as 60 to 80% reduction.

Many tube mills produce a large hot-worked tube shell which must be reduced in size during a number of cold working and annealing stages. Experience has shown that alloys which have lower yield strength after high cold reductions may be cold worked to a greater degree without splitting, requiring less annealing stages and lower manufacturing costs.

The instant invention was developed with the attributes of good workability characteristics and ease of processing in mind.

All heats had good malleability. Tensile data on cold rolled strip using increasing amounts of titanium are shown in Tables 2, 3 and 4.

TABLE 2

Effect of Cold Work on Tensile Properties Annealed at 1950°F (1066°C)

Heat No.	Cold Work %	YS MPa	TS MPa	El %	Hard		Aged* Hard	
					Rb/Rc	Ra	Rb,c	Ra
12	0	209.6	516.4	49.5	70b	44.0		
	19.1				97b	59.5	90	56.5
	32.3	738	777	9.5	100b	61.5		
	51.0	781	840	7.0	26c	63.5		
	69.0	844	970	5.5	29c	65.0		

*Aging 732°C/Q1 hour, AC

TABLE 3
Effect of Cold Work on Tensile Properties

Heat/No.		AS ANN	15% CW	20% CW	65% CW	71% CW
1	YS, MPa	248	566	690	929	958
	TS, MPa	552	690	783	1014	1069
	El, %	45	28.5	13.	5.	3.5
	Hard Rb	76.5	96	99	—	—
	Rc		17.	21.	32	32.5
2	YS, MPa	234	576	777	947	1003
	TS, MPa	548	72.5	85.6	1026	1098
	El, %	46.5	25.5	8.	5.	4.
	Hard Rb	74.5	96	103	—	—
	Rc		17	26.	32	33.4
3	YS, MPa	252	591	669	964	958
	TS, MPa	555	743	800	1056	1093
	El, %	45.	25.5	18	5.	3.5
	Hard Rb	77	97	99	—	—
	Rc		19	21	32	33

ANN = annealed
CW = cold worked

TABLE 4
Tensile Properties of Cold Rolled Plus Aging

Heat/No.		AS ANN*	15% CW	20% CW	65% CW	71% CW
1	YS, MPa	758	765	942	1100	1136
	TS, MPa	827	984	1100	1086	1248
	El, %		22.5	17.0	8.0	8.0
	Hard, Rc	25	30	34	39	40
2	YS, MPa	758	870	1045	1163	1182
	TS, MPa	827	1058	1205	1280	1307
	El, %		20	11.0	7.0	8.0
	Hard, Rc	23.5	32.5	38.0	40.	40.
3	YS, MPa	825	874	1018	1214	1220
	TS, MPa	924	1102	1207	1350	1364
	El, %		21.0	15.	9.0	7.0
	Hard. Rc	27	35.	37.	42.	43.5

*All samples aged 732°C/1 h, AC

When titanium was raised to 2.0%, the work hardening rate increased but no change occurred as titanium was raised to 2.3%. The aged tensile test results in Table 4 indicate that 414 MPa yield strength and 827 MPa tensile strength can be accomplished with approximately 1.75% titanium and low level cold working. Indeed, the combination of about 20% cold reduction with a slightly lower titanium content might be optimum for feed-water heaters.

Table 5 shows the strength and ductility characteristics in the annealed and aged conditions.

TABLE 5
Effect of Heat Treatment on Age-Hardenable Alloys (Forged 1.4 cm Squares)

Melt No.	Heat Treatment °C/hr	YS MPa	TS MPa	El %	RA %
1	954/0.33	274	643	46	65.1
	954/0.33 + Age(1)	602	969	27	52.2
	954/0.33 + Age(2)	774	1084	22	34.6
2	954/0.33	276	658	43	65.7
	954/0.33 + Age(1)	584	1043	29	47.2
	954/0.33 + Age(2)	856	1171	21	38.6
3	954/0.33	279	672	41	62.8
	954/0.33 + Age(1)	596	1098	30	48.3
	954/0.33 + Age(2)	927	1244	21	30.9

Age (1) 732°C/1 h.
Age (2) 732°C/8 h FC 56°C/h to 621°C/8 h AC

Example 2

Corrosion tests were conducted on heats 4-12. Corrosion test environments relevant to feedwater heater service and other possible applications were examined.

Table 6 depicts the SCC test results in sodium chloride and sodium hydroxide solutions.

TABLE 6
Stress Corrosion Cracking Test Results —
Maximum Crack Depth (mm) of Duplicate Specimens, One Month Test Period

Alloy/Heat No.	% Cu*	% Mo*	3% NaCl, pH 4 316°C	50% NaOH Boiling	Polythionic Acid 21°C
4	0	0	0	0.05	0
5	0	2.0	0	0.05	0
6	4.0	0	0	0	0
7	3.9	2.1	0	0	0
8	4.0	2.1	0	0	0
9	5.0	3.0	0	0.075	0
10	5.0	3.1	0	0	0
11	4.1	2.0	0	0	0
12	3.4	2.0	—	0.05	—
MONEL alloy 400	32.56	—	0	0	—
Stainless Steel 304	—	0.24	0.38	0.25	3.13

NOTE: In 3% NaCl and 50% NaOH tests, alloy 4, 5, 8, and 9 were annealed and aged at 732°C/1 h, AC (12 aged at 760°C/1 h, AC), all others were tested as annealed.
In the polythionic acid test all materials were tested annealed plus aged at 732°C/1 h, AC.
*Approximate Value

The tests show that the instant alloy is more resistant to SCC (caused by chlorides and sodium hydroxide) than 304 stainless. The relatively high nickel content of the instant alloys provides the increased chloride and caustic cracking resistance.

The test data also indicates very good resistance of the alloys to polythionic acid cracking. This is a common cause of failure of stainless steels and high nickel alloys in petrochemical service. The influence of high titanium content on carbide precipitation is believed to be responsible for good polythionic acid SCC resistance.

Table 7 shows general corrosion test results.

Tables 6 and 7 also demonstrate the resistance of the alloy to environments other than that posed by feedwater heaters. Molybdenum addition of 2-3% greatly improves resistance to hydrochloric acid. Copper additions of 4% or more improved sulfuric acid resistance. The combination of copper and molybdenum appears to improve resistance to phosphoric acid. The instant alloy lends itself to chemical and petrochemical applications.

The design strength of the alloys destined for tubular applications is usually based on the tensile strength of the alloy comprising the apparatus.- In the cold worked plus stress relieved conditions, the instant alloy system will meet the 824 MPa minimum tensile strength usually specified by design engineers. This value, compares favorably with such alloys as Inconel alloy 625 and Incoloy alloy 801. Table 8 compares minimum tubular wall thicknesses between MONEL alloy 400, 304 stainless and the instant alloy for various temperature and pressure conditions. Table 8 was constructed to compare the minimum wall thickness between the listed alloys. The next heavier standard well thickness was used to calculate the weight per meter.

TABLE 7

General Corrosion Test Results —
Average of Duplicates in Annealed Condition (Corrosion Rates in mm/year)

Alloy/ Heat No.	% Cu*	% Mo*	25% HCl 50°C	80% H_2SO_4 60°C	95% H_2SO_4 100°C	85% H_3PO_4 Boiling	50% NaOH Boiling	Deaerated Water 316°C
4	0	0	50	1.32	10.2	>381	0.005	—
5	0	2.0	4.0	0.76	5.61	163	0.01	—
6	4.0	0	37.8	0.25	2.51	164.5	0.0025	—
7	3.9	2.1	3.76	0.05	4.06	1.55	0.005	—
8	4.0	2.0	2.72	0.05	4.04	1.62	0.0025	—
9	5.0	3.0	2.84	0.05	3.61	1.32	0.0025	—
10	5.0	3.1	2.79	0.15	3.22	1.29	0.0025	—
11	4.1	2.1	3.71	0.05	4.88	1.52	0.0025	—
12	3.4	2.0	—	—	—	—	—	0.002
MONEL alloy 400	32.56	—	—	—	—	—	<0.1	0.012
Stainless Steel 304	—	0.24	619	7.6	3.89	>127	>129	0.0015

*Approximate Value

In order to produce objects and, more particularly, tubes which may seamless or welded, the object or tube, made by methods known to those skilled in the art, may be subjected to a stress relieving heat treatment of about 1100 to 1400°F (593-760°C) for an appropriate period of time. The time period is, of course, a function of the temperature selected and the section size.

In particular, the non-age hardenable tubes may be drawn to final size, annealed at about 17OO-2000°F (767-933°C) for a suitable time, straightened, bent into the appropriate shape (if desired), and stress relieved at about 593-760°C up to about three hours. The age-hardenable tubes may be drawn to final size, annealed at about 767-933°C for a suitable time, straightened, aged for about an hour at 593-760°C, bent into the appropriate shape and stress relieved (which also ages the tube) at about 593-760°C for the appropriate time.

TABLE 8
Feedwater Heater Minimum Tube Wall

Tube Alloy	Allowable Stress, MPa	Min. Wall (mm)	Std. Gauge mm	kg/m
(A) 288°C—31 MPa 19 mm OD Avg. Wall				
MONEL alloy 400	145	1.88	2.11	0.992
Type 304 SS	81.4	3.15	3.40	1.64
Type 304 SS (a)	109.6	2.42	2.41	1.0
Low Carbon Steel	81.4	3.15	3.40	1.56
Instant Alloy (b)	179.2	1.54	1.65	0.718
(B) 371°—34.4 MPa 19 mm OD Avg. Wall				
MONEL alloy 400	138.6	2.16	2.41	1.114
Type 304 SS	76.5	3.63	3.76	1.98
Type 304 SS (a)	109.6	3.00	3.05	1.44
Instant Alloy (b)	172.3	1.765	1.83	0.79
(C) 371°C—44.8 MPa 19 mm OD Avg. Wall				
MONEL alloy 400	138.6	2.72	2.77	1.251
Type 304 SS	76.5	4.52	4.57	2.20
Type 304 SS (a)	100.6	3.35	3.40	1.64
Instant Alloy (b)	172.3	2.25	2.41	1.004

(a) These stresses may result in permanent strain.
(b) Age hardenable (i.e. titanium in excess of about 1.8%)

It should be noted that due to the relatively low chromium content, the pitting resistance of the alloy is about the same as stainless 304 and is not recommended for service where superior resistance to localized attack is required. The low chromium lowers resistance to intergranular attack and limits use in highly oxidizing environments such as nitric acid.

A preferred composition for overall strength, corrosion resistance and economy for feedwater heaters is heat 8 (28 Ni - 16 Cr - 4 Cu - 1.8 Ti - 2 Mo - Bal Fe). This composition appears to have the mechanical and corrosion properties necessary for a high pressure material. It also has excellent general corrosion resistance in hydrochloric, sulfuric and phosphoric acids. The good resistance of this composition to polythionic acid attack also indicates potential petrochemical applications.

Claims

1. An austenitic, age-hardenable nickel-iron-chromium alloy having a combination of high strength, low work-hardening rate, resistance to stress-corrosion cracking and resistance to corrosion by high-temperature deaerated water and by hydrochloric, sulphuric, phosphoric and polythionic acids consisting, by weight, of from 24 to 32% nickel, from 15 to 18% chromium, from 1 to 3.5% molybdenum, from 2 to 5.5% copper, from 0.8 to 2.5% titanium, from 0 to 1.5% manganese, from 0 to 1.5% silicon, from 0 to 1% niobium plus tantalum, from 0 to 0.2% aluminum, from 0 to 0.1% cerium, from 0 to 0.01% boron and from o to 0.2% nitrogen, the balance, apart from impurities, being iron.

2. An alloy according to claim 1 wherein the copper content is at least 4%.

3. An alloy according to claim 1 or claim 2 wherein the molybdenum content is from 2 to 3%.

4. An alloy according to any preceding claim wherein the silicon content does not exceed 0.45%.

5. An alloy according to any preceding claim wherein the nickel content is from 26 to 29%, the chromium content is from 15 to 18%, the copper content does not exceed 5%, the molybdenum content does not exceed 3%, and the content of niobium plus tantalum does not exceed 0.4%.

6. An alloy according to claim 5, wherein the nickel content is about 28%, the chromium content is about 16%, the molybdenum content is about 2%, the copper content is about 4%, and the titanium content is about 1.8%.

7. An alloy according to any preceding claim that has been heat-treated at a temperature in the range from 1100 to 1400°F (605 to 760°C) for up to 16 hours.

8. A tube formed from an alloy according to any preceding claim.

9. A heat-exchanger or feed-water heater comprising an alloy according to any of claims 1 to 7 or a tube according to claim 8.

10. The use of an alloy according to any one of claims 1 to 7 for articles or parts exposed in use to polythionic acid.

Patentansprüche

1. Austenitische aushärtbare Nickel-Eisen-Chrom-Legierung mit hoher Festigkeit, geringer Neigung zur Kaltverfestigung, Beständigkeit gegen Spannungsrißkorrosion und entlüftetes Heißwasser, Salz-, Schwefel-, Phosphor- und Polythionsäure aus - in Gewichtsprozent - 24 bis 32% Nickel, 15 bis 18% Chrom, 1 bis 3,5% Molybdän, 2 bis 5,5% Kupfer, 0,8 bis 2,5% Titan, 0 bis 1,5% Mangan, 0 bis 1,5% Silizium, 0 bis 1% Niob und Tantal, 0 bis 0,2% Aluminium, 0 bis 0,1% Cer, 0 bis 0,01% Bor und 0 bis 0,2% Stickstoff, Rest außer Verunreinigungen Eisen.

2. Legierung nach Anspruch 1, deren Kupfergehalt jedoch mindestens 4 % beträgt.

3. Legierung nach Anspruch 1 oder 2, deren Molybdängehalt jedoch 2 bis 3 % beträgt.

4. Legierung nach einem der Ansprüche 1 bis 3, deren Siliziumgehalt jedoch höchstens 0,45 % beträgt.

5. Legierung nach einem der Ansprüche 1 bis 4, die jedoch 26 bis 29 % Nickel, 15 bis 18 % Chrom, höchstens 5 % Kupfer, höchstens 3 % Molybdän und höchstens 0,4 % Niob und Tantal enthält.

6. Legierung nach Anspruch 5, die jedoch etwa 28 % Nickel, etwa 16 % Chrom, etwa 2 % Molybdän, etwa 4 % Kupfer und etwa 1,8 % Titan enthält.

7. Legierung nach einem der Ansprüche 1 bis 6, die jedoch bis 16 Stunden bei 1.100 bis 1.400°F (605 bis 760 ° C) wärmebehandelt worden ist.

8. Rohr aus einer Legierung nach einem der Ansprüche 1 bis 7.

9. Wärmetauscher oder Speisewassererhitzer aus einer Legierung nach einem der Ansprüche 1 bis 7 oder einem Rohr nach Anspruch 8.

10. Verwendung einer Legierung nach den Ansprüchen 1 bis 7 als Werkstoff für Gegenstände, die im Gebrauch Polythionsäure ausgesetzt sind.

Revendications

1. Un alliage austénitique nickel-fer-chrome, susceptible d'être durci par vieillissement, possédant une combinaison d'une résistance mécanique élevée, d'une faible vitesse de durcissement par écrouissage, d'une résistance à la fissuration par corrosion sous tension et d'une résistance à la corrosion par l'eau désaérée à haute température et par les acides chlorhydrique, sulfurique, phosphorique et polythionique, constitué en poids de 24 à 32 % de nickel, de 15 à 18 % de chrome, de 1 à 3,5 % de molybdène, de 2 à 5,5 % de cuivre, de 0,8 à 2,5 % de titane, de 0 à 1,5 % de manganèse, de 0 à 1,5 % de silicium, de 0 à 1 % de niobium et de tantale, de 0 à 0,2 % d'aluminium, de 0 à 0,1 % de cérium, de 0 à 0,1 % de bore et de 0 à 0,2 % d'azote, le reste, à part les impuretés, étant du fer.

2. Alliage selon la revendication 1, dans lequel la teneur en cuivre, est d'au moins 4 %.

3. Alliage selon la revendication 1 ou 2, dans lequel la teneur en molybdène, est de 2 à 3 %.

4. Alliage selon l'une quelconque des revendications précédentes, dans lequel la teneur en silicium, n'est pas supérieure à 0,45 %.

5. Alliage selon l'une quelconque des revendications précédentes, dans lequel la teneur en nickel est de 26 à 29 %, la teneur en chrome est de 15 à 18 %, la teneur en cuivre n'est pas supérieure à 5 %, la teneur en molybdène n'est pas supérieure à 3 %, et la teneur en niobium et en tantale, n'est pas supérieure à 0,4 %.

6. Alliage selon la revendication 5, dans lequel la teneur en nickel est d'environ 28 %, la teneur en chrome d'environ 16 %, la teneur en molybdène d'environ 2 %, la teneur en cuivre d'environ 4 %, et la teneur en titane d'environ 1,8 %.

7. Alliage selon l'une quelconque des revendications précédentes, qui a été traité à chaud à une température de 1100 à 1400 °F (de 605 à 760 °C) pendant jusqu'à 16 heures.

8. Tube formé à partir d'un alliage selon l'une quelconque des revendications précédentes.

9. Echangeur de chaleur ou réchauffeur d'eau d'alimentation, comprenant un alliage selon l'une quelconque des revendications 1 à 7, ou un tube selon la revendication 8.

10. Utilisation d'un alliage selon l'une quelconque des revendications 1 à 7, pour des articles ou des pièces exposées, en cours d'utilisation, à l'acide polythionique.