(12) UK Patent Application (19) GB (11) 2 023 652 A

(21) Application No **7906240**
(22) Date of filing **22 Feb 1979**
(23) Claims filed **22 Feb 1979**
(30) Priority data
(31) **917833**
(32) **22 Jun 1978**
(33) **United States of America (US)**
(43) Application published
3 Jan 1980
(51) **INT CL^3**
C22C 19/05
(52) Domestic classification
C7A 746 747 748 749
750 781 782 783 78Y
A249 A253 A255 A257
A259 A25Y A260 A263
A266 A280 A28Y A305
A307 A309 A30Y A337
A33Y A340 A349 A35X
A35Y A377 A379 A37Y
A409 A439 A44Y A455
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A525 A527 A53Y A545
A547 A579 A599 A609
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A683 A685 A687 A689
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A699 A69X A70X
(56) Documents cited
None
(58) Field of search
C7A
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(54) Nickel Base Alloys

(57) This invention relates to nickel base alloys consisting of, by weight percent, 57—63 Ni, 7—18 Cr, 10—20 Fe, 4—6 Mo, 1—2 Nb, 0.2—0.8 Si, 0.01—0.05 Zr, 1.0—2.5 Ti, 1.0—2.5 Al, 0.02—0.06 C and 0.002—0.015 B.

The alloys exhibit high weldability long-time structural stability as well as low swelling under nuclear radiation conditions making them especially suitable for use as a duct material and control element cladding for sodium-cooled nuclear reactors.

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SPECIFICATION

Nickel Base Alloys

This invention relates to nickel base alloys.

Nickel-based alloys exhibiting long-time structural stability and low swelling under nuclear radiation conditions are described in co-pending United States Patent Application Serial No. 917,832. Although these alloys contain less nickel and have somewhat poorer physical properties than the alloys of the present invention, they have a much lower neutron cross-section and can be used as fuel cladding or structural elements within the reactor core generally, whereas in-reactor usage of the alloys of this invention is limited to uses such as control element assemblies where low neutron cross-section is not required.

U.S. Patent Specification No. 3,160,500 (Eiselstein) discloses nickel-chromium base alloys having a good combination of mechanical properties over a wide range of temperatures and specifically alloys having a weight percent composition of from 55—62 nickel; 7—11 molybdenum, 3—4.5 columbium, 20—24 chromium, up to 8 tungsten, not more than 0.1 carbon, up to .05 silicon, up to .05 manganese, up to .015 boron, not more than 0.4 of aluminum and titanium, and the balance essentially iron, with the iron content not exceeding about 20% of the alloy. Inconel (Registered Trade Mark) 625 is a commercially available example of such an alloy.

U.S. Patent Specification No. 3,046,108, (Eiselstein) describes a nickel-chromium base alloy having a weight percent composition of about 53 nickel, 19 chromium, 3 molybdenum, 5 niobium, 0.2 silicon, 0.2 manganese, 0.9 titanium, 0.45 aluminum, 0.04 carbon and the balance essentially iron.

While the mechanical properties at high temperatures of the alloys of the aforesaid Eiselstein patents are suitable for many purposes, such alloys are generally difficult to weld and tend to swell when subjected to nuclear radiation.

Accordingly the present invention resides in a nickel base alloy consisting essentially of, by weight percent, 57—63 Ni, 7—18 Cr, 10—20 Fe, 4—6 Mo, 1—2 Nb, 0.2—0.8 Si, 0.01—0.05 Zr, 1.0—2.5 Ti, 1.0—2.5 Al, 0.02—0.06 C and 0.002—0.015 B.

It has thus been found that nickel-based alloys having a combination of high strength, high stability and high weldability can be obtained by the use of certain critical narrow ranges of composition. Especially critical are the concentrations of titanium, niobium, aluminum and molybdenum. Further, certain zirconium and boron concentrations protect the grain boundaries and therefore tend to reduce swelling under nuclear irradiation. Silicon also reduces the swelling from nuclear irradiation and, contrary to the prior art, silicon is preferably used in amounts greater than 1/2%.

The original objective of this work was to produce new solid solution and precipitation hardened nickel-chromium-iron alloys which were stable, low swelling and resistant to in-reactor plastic deformation. Testing indicated that the best commercially available material was Inconel 625 but that swelling under irradiation could be a problem. The alloys of this invention were developed in an effort to reduce swelling. These particular alloys, however, exhibited especially good strength and weldability, and thus are also attractive for non-nuclear applications.

These alloys are high nickel, gamma prime hardened alloys and have improved strength, swelling resistance, structural stability and weldability, as compared to the prior art alloys such as Inconel 625.

The invention will now be illustrated with reference to the following Example:

Example

There is shown in Table I below the composition on which extensive testing was performed.

TABLE I
Alloy Composition (Weight Percent)

Alloy No.	*C*	*Si*	*Ni*	*Cr*	*Fe*	*Mo*	*Nb*	*Al*	*Ti*	*B*	*Zr*
D41	.03	.5	Bal	8	22.5	5	1.5	2	2	.01	.03
D42	.03	.5	Bal	15	15.5	5	1.5	1.5	1.5	.01	.03

These alloys were vacuum induction melted and cast as 100 pound ingots. Following surface conditioning, the alloys were charged into a furnace, heated to 1093°C and then soaked for two hours prior to hot rolling to 2-1/2x2-1/2 inch square billets. Portions of the billets were then hot-rolled into 1/2 inch thick plate.

Samples were then subjected to various treatments. The resulting tensile properties are listed in Table II. The ultimate strength of Inconel 625 is only about 103 ksi at 650°C, and it can be seen that the D42 (with an ultimate strength of over 150ksi at 650°C with treatment #5, for example) is far superior. The highest strengths were realized for treatments #4 and #5. Control over the warm working treatment (treatment #4), was difficult due to the very rapid chilling of the thin sheet upon contact with the rolls, and treatment #5 was therefore chosen for stress rupture tests rather than treatment #4. Treatment #2 was also selected for stress rupture testing and both results are shown in

Table III. It should be noted that the estimated 1000 hour rupture strengths are only estimates and that due to the limited number of tests on alloy D42 (treatment #5) both the 100 hour and 1000 hour rupture strengths should be treated as estimates for this alloy. The 100 hour stress rupture strength of Inconel 625 at 650°C is only about 62, and it can be seen that D42 (e.g. 74 with treatment #5) is significantly better.

TABLE II
Tensile Properties of Alloys D41 and D42

			Alloy D41			*Alloy D42*		
No.	*Treatment*	*Test Temperature (°C)(°C)(K)*	*.2% YS (ksi)*	*UTS (ksi)*	*El. (%)*	*.2% YS (ksi)*	*UTS (ksi)*	*El. (%)*
1	1 hr/1038°C	RT	124.8	187.1	17.0	114.3	176.3	21.5
	+11 hr/800°C	550	120.9	167.1	9.5	106.9	120.3	1.0
	+2 hr/700°C	600	119.4	136.8	1.5	104.9	159.4	10.5
		650	118.2	138.4	2.0	106.2	136.7	6.0
2	1 hr/926°C	RT	160.3	202.6	10.0	153.5	192.7	14.5
	+11 hr/800°C	550	140.4	187.8	6.5	151.6	189.0	5.0
	+2 hr/700°C	600	138.6	176.9	9.0	125.9	169.3	13.0
		650	110.3	147.2	11.0	122.6	152.5	15.0
3	.25 hr/1038°C	RT	116.9	180.6	18.0	109.3	176.0	16.5
	+1 hr/899°C	550	110.5	169.8	7.5	90.0	152.9	23.0
	+8 hr/749°C	600	111.8	148.7	3.0	89.6	148.3	18.0
		650	111.9	135.7	3.0	89.8	135.3	22.0
4	30% warm work							
	(1038°C)	RT	160.0	197.2	12.0	150.0	182.4	13.5
	+11 hr/800°C	550	142.6	185.8	9.5	138.5	176.9	10.0
	+2 hr/700°C	600	140.3	176.6	9.0	136.5	173.1	15.0
		650	122.6	153.1	8.5	127.9	154.6	7.0
5	30% cold work	RT	185.9	216.7	9.0	168.3	198.4	10.0
	+11 hr/800°C	550	159.1	202.6	5.5			
	+2 hr/700°C	600	146.7	188.9	14.0			
		650	122.9	158.9	17.0	125.5	156.4	17.0
6	1 hr/1038°C	RT	230.1	244.0	1.0	212.7	245.3	1.0
	+11 hr/800°C	550	152.8	211.6	3.0	158.8	206.7	1.0
	+2 hr/700°C	600	142.1	191.0	7.0	116.0	178.5	0.5
	+30% cold work	650	96.2	152.2	11.0	89.6	146.0	16.5

TABLE III
Stress Rupture Properties of Alloys D41 and D42

			Rupture Strength	
Alloy	*Treatment*	*Test Temperature (°C)*	*100-hr.*	*Est. 1000-hr.*
D41	1 hr/927°C	650	70	55
	+11 hr/800°C	600	90	73
	+2 hr/700°C (#2)	550	120	105
D42	1 hr/927°C	650	73	62
	+11 hr/800°C	600	97	80
	+2 hr/700°C (#2)	550	138	125
D41	30% cold work	650	75	54
	+11 hr/800°C	600	105	82
	+2 hr/700°C (#5)	550	135	110
D42	30% cold work	650	74	58
	+11 hr/800°C	600	95	72
	+2 hr/700°C (#5)	550	131	115

The room temperature tensile properties following a stability exposure treatment (30% cold work+200 hours at 700°C) are shown in Table IV. It can be seen that the alloys show similar strength and ductility. The microstructures were examined after exposure at 700°C. For alloy D41, a duplex gamma-prime size distribution was developed. Alloy D42 showed a finer gamma prime dispersion. No evidence of any acicular phase was observed in the microstructure of either of these alloys.

TABLE IV

Room Temperature Tensile Properties Following Stability Treatment

Alloy	*Treatment*	*.2% YS (ksi)*	*UTS (ksi)*	*% El.*
D41	30% CW+200 hr/700°C	194.4	225.3	5.0
D42	30% CW+200 hr/700°C	191.1	215.9	7.5

As noted previously, alloys for use in non-nuclear applications or for control assembly applications can be designed having higher nickel ranges than alloys which are designed for nuclear fuel cladding (where neutron absorption is important). While higher nickel alloys such as Inconel 625 could be used in applications where neutron absorption is not important, the alloys of this invention proved to have advantages, and in particular, to have lower swelling, greater strength and, as noted below, better weldability.

Macro-etched micrographs of both D41 and D42 revealed that both alloys produced sound ductile welds. Bend tests revealed, however, that alloy D42 welds were approximately 50% more ductile than those of alloy D41. The advantage of a higher ductility weld, coupled with the fact that D42 relies more heavily on solid solution strengthening than D41, results in alloys in the range of D42 being preferred. The weldability problems common to Inconel 625 have not been encountered with the D42 alloy.

It is felt that the silicon acts as a swelling inhibitor and, especially in nuclear applications, the silicon content is preferably at least 0.5% and indications are that the optimum silicon is greater than 0.5%. It is also believed that the molybdenum content contributes to a Laves phase (which adversely affects strength and increases swelling) and that, especially in reactor applications, the molybdenum content is preferably less than 5%. The zirconium and boron content are thought to be important in the protection of grain boundaries and may reduce swelling in reactor applications. The boron content is preferably not less than 0.01 and the zirconium content is preferably not less than 0.03.

It is felt that the greatly enhanced weldability is due to the lower titanium, niobium and aluminum contents of these alloys. Preferably the titanium content is not greater than 1.5%, the aluminum not greater than 1.5% and the niobium not greater than 1.5%.

Thus, it can be seen that an alloy with a composition by weight of 57—63 nickel, 17—18 chromium, 4—6 molybdenum, 1—2 niobium, 0.2—0.8 silicon, 0.01—0.05 zirconium, 1.0—2.5 titanium, 1.0—2.5 aluminum, 0.02—0.06 carbon, 0.002—0.015 boron, and the balance essentially iron (10—20) has excellent weldability characteristics and is stronger than commercially available alloys such as Inconel 625. In addition, its long-time structural stability due to its low swelling characteristics make it especially adapted for use in control element assemblies and ducting in sodium cooled nuclear reactors.

Claims

1. A nickel base alloy consisting essentially of, by weight percent, 57—63 Ni, 7—18 Cr, 10—20 Fe, 4—6 mo, 1—2 Nb, 0.2—0.8 Si, 0.01—0.05 Zr, 1.0—2.5 Ti, 1.0—2.5 Al, 0.02—0.06 C and 0.002—0.015 B.

2. An alloy according to claim 1, wherein the titanium is not greater than 1.5, the aluminum is not greater than 1.5, and the niobium is not greater than 1.5.

3. An alloy according to claim 2, wherein the silicon is greater than 0.5.

4. An alloy according to claim 1, 2 or 3 wherein the molybdenum is not greater than 5.

5. An alloy according to any of claims 1 to 4, wherein the boron is not less than 0.010, the zirconium is not less than 0.03.

6. Nickel base alloys as claimed in claim 1 and substantially as described herein with particular reference to the foregoing Example.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1980. Published by the Patent Office,
25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.