

[54] **HIGHLY CASTABLE, WELDABLE,
OXIDATION RESISTANT ALLOYS**

[75] Inventors: **Robin Mackay Forbes Jones,**
Suffern, N. Y.; **Walter Adrian**
Petersen, Ridgewood, N.J.

[73] Assignee: **The International Nickel Co., Inc.,**
New York, N.Y.

[22] Filed: **Dec. 13, 1974**

[21] Appl. No.: **532,330**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 384,799, Aug. 2,
1973, abandoned.

[52] U.S. Cl. **29/196.1; 75/122; 75/128 A;**
75/128 C; 75/128 F; 75/128 W;
75/134 F; 75/171

[51] Int. Cl.² **B23P 3/00; C22C 19/05;**
C22C 38/44; C22C 38/54

[58] Field of Search **75/134 F, 122, 171, 128 A,**
75/128 C, 128 F, 128 W; 29/196.1

[56]

References Cited

UNITED STATES PATENTS

2,938,786	5/1960	Johnson	75/171
3,758,296	9/1973	Johnson	75/122

Primary Examiner—L. Dewayne Rutledge

Assistant Examiner—Arthur J. Steiner

Attorney, Agent, or Firm—Ewan C. MacQueen;
Raymond J. Kenny

[57]

ABSTRACT

Special highly castable and weldable heat resistant alloys containing nickel, manganese, silicon, chromium, carbon, iron, boron and molybdenum afford high temperature oxidation resistance and characteristics which render the alloys particularly suitable for the casting of thin section components for use at elevated temperatures under oxidizing conditions.

11 Claims, No Drawings

HIGHLY CASTABLE, WELDABLE, OXIDATION RESISTANT ALLOYS

The present invention is a continuation-in-part of application Ser. No. 384,799 filed Aug. 2, 1973, now abandoned, and relates to heat-resistant alloys having excellent castability and weldability and high temperature oxidation resistance.

It is well known that many industrial processes and applications require heat resistant components of intricate design. To produce such components, the alloy should be highly castable; however, to be commercially useful in respect of any number of applications, the alloy must also be capable of offering good weldability characteristics to permit, for example, fabrication of the components into larger, more complex units and, more importantly, for the joining of the components to other parts of an assembly.

One application requiring alloys having both high castability and weldability is static components in vehicular turbines, e.g., shrouds and the dome and plenum chambers. These components are commonly manufactured by special casting techniques and/or sheet fabrication, extremely expensive procedures adding greatly to cost. In this connection and desirably, such components should be capable of being cast in conventional sand molds, and, in particular, in thin section sand molds. And, more importantly, the component should be weldable since this allows the component to be assembled to the other parts of the vehicular turbine. Additionally, welding also allows for the fabrication of several small components into one large unit and for repairing of casting defects or even service damage.

But bringing these two properties, castability and weldability, together in one heat-resistant alloy, particularly of the nickel-base type, is beset with difficulty since one property is often achieved at the expense of the other. To explain, weldable heat resistant alloys and, in particular, heat-resistant nickel alloys containing high amounts of chromium, are known to have relatively poor casting properties, forming folds, cold shuts and misruns, especially when cast into thin sections. Attempts to improve casting properties have invariably led to a decrease in weldability. However, improved castability properties have been recently achieved through the judicious use of both silicon and boron in at least nickel-containing stainless steels. However, weldability was such that brazing was recommended. Now, as is well known in the art, silicon and boron are considered to be among the most detrimental performers in terms of weldability considerations with regard to high nickel, chromium-containing alloys. Notwithstanding this and as will be demonstrated herein, these constituents, we have found, can be used to their advantage but while simultaneously achieving outstanding weldability.

We have now discovered a new alloy providing a new combination of characteristics, especially excellent castability and weldability, notwithstanding the presence of relatively high amounts of the normally weld-cracking promoters, silicon and boron, and this has been accomplished while obtaining good oxidation resistance and other properties at high temperature.

It is an object of the invention to provide an alloy having a combination of characteristics including ex-

cellent castability and weldability and resistance to oxidation at high temperatures.

Another object of the invention is to provide oxidation-resistant cast alloy products and articles, including products and articles for use as static components in vehicular turbines.

Other objects and advantages will become apparent from the following description.

Generally speaking, the present invention is directed to an alloy containing (by weight) up to about 1.4 percent carbon, up to about 8.5 percent molybdenum, the carbon and molybdenum being specially correlated as detailed herein, from about 1.5 to about 4 percent silicon, up to about 4.5 percent manganese, from about 16 to about 30 percent chromium, up to about 50 percent iron, from about 0.1 to about 1 percent boron, and the balance essentially nickel, in an amount preferably at least about 35 percent, the nickel being further correlated such that for molybdenum-free alloys or those containing less than about 2 percent molybdenum, the nickel content should be maintained below about 49 percent and preferably less than about 45 percent. As will be understood by those skilled in the art, the use of the expression "balance essentially" in referring to the nickel content of the alloys does not exclude the presence of other elements commonly present as incidental constituents and impurities.

Carbon has been found to contribute to the elevated temperature strength of the alloy and molybdenum to contribute to the stress-rupture strength and ductility of the alloy; however, both elements have a detrimental effect on weldability. In order to weld the alloy, carbon and molybdenum must be correlated according to the following relationship:

$$\%Mo + 6(\%C) < 8.5,$$

wherein %Mo and %C are in terms of weight percent. Alloys with a calculated carbon and molybdenum level above about 8.5 exhibit heat-affected-zone cracking and cannot be welded. Alloys which exhibit heat-affected-zone cracking may be weldable under certain conditions, e.g., thin, unrestrained sections, special welding techniques, etc., but are not considered to be within the purview of this invention. Alloys in accordance with the foregoing relationship, however, are weldable and, as will be appreciated by those skilled in the art, alloys exhibiting only weld cracking may be welded using special filler wires. It is preferred, however, that matching filler wires be employed. It has been found that molybdenum and carbon correlated according to the following relationship:

$$5.4 < \%Mo + 6(\%C) < 8.5,$$

will result in alloys having these preferred welding characteristics. In striving for an optimum combination of properties, e.g., stress-rupture strength, weldability, etc., it is preferred that molybdenum in accordance with the foregoing relationships be present in the alloy in amounts of at least about 3 percent, and advantageously, about 6 percent.

Silicon and boron are essential for their beneficial effect on castability. Silicon and boron reduce the melting point of the alloy improving fluidity and also alter the chemical composition of the oxide film on the surface of the molten metal minimizing the formation of casting defects such as folds. Silicon and boron also contribute to the oxidation resistance of the alloy.

However, the exact mechanism which will explain the theoretical considerations as to why the alloy is weldable, given the high levels of silicon and boron, is not presently at hand.

While alloys containing silicon above about 1 percent may be welded, the castability of the alloy requires that the level of silicon be at least about 1.5 percent and preferably 2 to 2.5 percent. Alloys with silicon levels above about 4 percent are extremely brittle and an upper limit of about 3.5 percent is preferred.

The level of boron in the alloy is dependent on the carbon and molybdenum content. For alloys without molybdenum, boron levels below about 0.1 percent and above about 0.5 percent are deemed to have a detrimental effect on weldability. An upper level of about 0.4 percent is preferred. Alloys containing molybdenum and which have carbon levels below about 0.05 percent, are weldable at boron levels from about 0.1 to about 1 percent and greater. It is expected though that at the higher boron levels, the ductility of the alloy would be unsatisfactory and an upper level of about 0.5 percent boron is considered more useful. For castability however, it is preferred that the alloys contain boron in an amount of at least 0.2 percent and, advantageously, about 0.3 percent.

Nickel contributes to the elevated temperature oxidation resistance of the alloy and suppresses the embrittling sigma-forming tendencies of silicon, manganese and chromium. While the nickel content might be extended down to say, 20 percent, given the chemistry of the other constituents, such alloys tend to be brittle in the as-cast condition and also exhibit severe cracking in the weld heat-affected-zone. In any case it is most preferred that the nickel level not fall below 30 percent and it is of marked benefit that the nickel be about 35 percent or more. The upper limit for nickel is dependent on its effect on weldability and for molybdenum-free alloys or those containing less than about 2 percent molybdenum, the nickel content should be maintained below about 49 percent and preferably less than about 45 percent. Alloys containing molybdenum above this level, however, may contain nickel in amounts up to about 65 percent, but preferably, about 55 percent.

Chromium is essential in the alloy for oxidation resistance and should be maintained at levels of at least about 16 percent and preferably from about 19 to about 24 percent. Also, at the lower limit for chromium, weldability was found to be detrimentally affected in that the weldment was susceptible to weld and heat-affected-zone cracking. Chromium may be present in amounts up to about 30 percent. At levels above about 30 percent, it is suspected that a deleterious intermetallic compound, sigma phase, would form, thereby embrittling the alloy.

Iron in amounts up to about 50 percent, but most advantageously at least 10 percent, e.g., 15 percent, can be incorporated in the alloy without materially affecting the properties. Alloys containing less than about 10 percent iron in the thicker sections, e.g., one-half inch or more, tend to be susceptible to heat-affected-zone cracking during the welding operation. This range of iron contents also enables use of less expensive raw materials, e.g., ferrochrome instead of electrolytic chromium, thereby resulting in a significant cost savings.

Manganese contributes to castability and also counteracts the detrimental effect of sulfur. Manganese above about 4.5 percent has a detrimental effect on

weldability however, and a level from about 0.2 to about 0.8 percent for alloys containing molybdenum and from about 0.5 to about 3 percent for alloys without molybdenum is preferred.

Solid solution strengtheners such as columbium may also be incorporated in the alloy to improve elevated temperature properties; columbium at levels up to about 2.2 percent has been found to produce beneficial effects in this regard. Columbium, however, appears to have a detrimental effect on the ductility and any benefit to strength must be offset by the decrease in the ductility of the alloy. Aluminum or other suitable deoxidation elements may be added to the alloy; it is expected though that the castability of the alloy would deteriorate if the aluminum content exceeded about 0.5 percent. Consistent with good steelmaking practice, other additives, such as desulfurizing agents and the like, may also be added to the melt. The phosphorus and sulfur levels may have an influence on hot-tearing resistance and weldability and should be maintained at levels less than about 0.04 percent. However, copper adversely affects weldability. It is an unnecessary constituent but if present should be less than about 2 percent and preferably should not exceed 1 percent.

In accordance with the invention, preferred alloys contemplated herein contain (by weight) from about 0.005 to about 0.04 or 0.05 percent carbon, from about 5 to about 8 percent molybdenum, from about 2 to about 4 percent silicon, from about 0.2 to about 0.8 percent manganese, from about 19 to about 24 percent chromium, up to about 30 percent and particularly from 10 or 15 to 30 percent, iron, from about 0.1 to about 0.5 percent boron, and the balance essentially nickel.

Other preferred alloys in accordance with the invention contemplated herein contain (by weight) from about 0.8 to about 1.2 percent carbon, from about 2.5 to about 3.5 percent silicon, from about 0.5 to about 3.0 percent manganese, from about 19 to about 23 percent chromium, from about 30 to about 47 percent iron, from about 0.2 to about 0.4 percent boron, and the balance essentially nickel.

For the purpose of giving those skilled in the art a better understanding of the invention, the following examples are given:

EXAMPLE I

Table I sets forth the compositions of Alloys 1 through 16 which are examples of alloys within the invention and Alloys A through E which are outside the invention. The series of alloys was air-induction melted using a magnesia crucible. Electrolytic nickel, electrolytic manganese and Armco iron were charged into the furnace and heated to 2,850°F. Molybdenum pellets were then added followed by silicon-manganese (18 percent silicon, 62 percent manganese, balance iron), electrolytic chromium (Alloy No. 1 was prepared using ferro-chromium containing about 70 percent chromium), boron in the form of ferro-boron or nickel-boron (23 percent and 18 percent boron, respectively), electrolytic manganese and metallic silicon. Columbium, in the form of columbium pellets was also added to Alloy No. 5. The melts were then deoxidized with 0.1 percent aluminum and poured at 2,650°F. into green sand Chinese Puzzle pattern molds and green sand single keel block rectangular plate molds having the dimensions: (1) $\frac{3}{8}$ inch $\times$ $1\frac{3}{4}$ inches $\times$ $12\frac{1}{2}$ inches,

(2) ½ inch × 2 inches × 12 inches and (3) 1 inch × 3 inches × 12 inches. The castings were then shaken from the molds, sandblasted and examined visually for defects, such as folds.

It should be noted that the Chinese Puzzle pattern molds are designed to test castability characteristics such as the ability of a molten metal to run through the passages of a complex mold with abrupt changes in flow direction that are conducive to turbulence, and comprise a number of partially adjoining rectangular cavities of about three-sixteenths inch thickness. The Chinese Puzzle pattern demands more of a melt than simply the capability to remain fluid over the course of a long run, such as in a fluidity spiral, but requires many

as evidenced by the Chinese Puzzle castings which were filled completely without evidence of folds or cold-shuts. In contrast, Alloy B, which is similar in composition to a well known commercial alloy, had unsatisfactory castability under the same conditions in that numerous folds and poor definition at the corners resulted.

Test specimens of Alloys 1, 2, 5 and B were machined from the castings (Mold Nos. 1 and 2) and tested at room and elevated temperatures for mechanical properties using a standard testing procedures. As can be seen from the results shown hereinbelow in Table II, the alloys of the invention exhibit satisfactory tensile properties in both the as-cast and heat treated

15

TABLE I

Compositions of Cast Alloys, Weight Percent											
Alloy No.	C %	Si %	Mn %	Ni %	Cr %	Mo %	Fe %	B %	Al %	Other	
1	0.040	3.5	0.5	Bal.	23.9	6.0	30.15	0.35	0.087		
2	0.014	3.1	0.27	Bal.	23.9	6.1	19.3	0.30	0.09		
3	0.017	3.2	0.27	Bal.	24.1	6.0	19.3	0.32	0.11		
4	0.55	2.8	0.57	Bal.	20.3	3.0	19.0	0.31	—		
5	0.02	2.05	N.A.	Bal.	20.8	7.9	0.089	0.27	0.080	2.2 Cb	
6	0.017	2.6	0.53	Bal.	21.9	3.0	19.0	0.31	—		
7	0.010	2.8	0.57	Bal.	21.9	1.0	19.0	0.31	—		
8	0.015	2.9	1.85	Bal.	20.9	6.2	19.9	0.30	—		
9	0.011	2.9	4.3	Bal.	20.7	6.3	19.6	0.30	—		
10	0.028	2.9	0.6	Bal.	21.2	6.2	19.9	0.90	—		
11	0.024	2.8	0.23	Bal.	20.5	6.3	18.5	0.18	—	0.9 Cu	
12	0.022	3.2	0.25	Bal.	21.9	6.3	18.5	0.38	0.12		
13	0.017	3.2	0.22	Bal.	21.0	6.0	15.0	0.25	0.085		
14	0.010	3.2	0.26	Bal.	22.6	6.0	18.9	0.31	0.11		
15	0.015	3.1	0.22	Bal.	20.5	6.0	5.2	0.28	0.060		
16	0.019	3.2	0.22	Bal.	20.5	6.0	9.2	0.35	0.070		
A	0.55	3.0	0.48	Bal.	20.0	7.0	19.0	0.31	—		
B	0.005	1.2	0.29	Bal.	22.9	9.2	18.9	N.A.	0.09		
C	0.013	2.8	0.23	Bal.	20.5	6.3	18.4	0.20	0.10	1.9 Cu	
D	0.011	3.3	0.23	Bal.	20.5	6.1	19.0	0.38	0.073	3.9 Cu	
E	0.015	3.3	0.23	Bal.	20.5	6.1	19.4	0.40	0.077	5.9 Cu	

N.A. = Not Added.

sharp changes in flow direction with the flow meeting and merging with itself, filling of many corners and flow through and filling of large thin flat surfaces, e.g., 1½ inches square by 3/16 inch thick.

The alloys of the invention had excellent castability

condition and, although the room temperature ductility is lower than that of Alloy B, the ductility is deemed sufficient for many applications as contemplated herein. The relatively low ductility of Alloy 5 can probably be attributed to the 2.2 percent columbium content of the alloy, as discussed hereinabove.

TABLE II

Tensile Properties of Cast Alloys							
Alloy No.	Condition	Mold No.	Test Temp., °F.	Yield Strength psi	Tensile Strength psi	Elong., %	R.A., %
1	As Cast + 1 hr. at 2200°F., AC	2	70	37,400	77,100	18.0	26.0
2	As Cast	2	70	39,800	85,800	15.0	17.0
				39,800	78,800	11.0	14.0
2	As Cast	2	70	38,300	83,500	16.6	22.0
				40,200	83,900	16.5	13.0
5	As Cast	2	70	46,900	72,700	4.0	7.0
				46,300	75,000	5.0	5.5
5	As Cast + 1 hr. at 2200°F., AC	2	70	44,100	85,000	10.0	13.0
				44,900	92,600	15.0	17.5
5	As Cast	2	1200	32,100	70,900	13.0	12.0
5	As Cast	2	1400	31,600	67,600	19.0	15.0
5	As Cast	2	1600	29,900	64,600	30.0	37.5
B	As Cast	2	70	35,300	72,500	38.0	39.0
				36,000	74,700	40.0	34.5
B	As Cast	2	70	36,300	68,900	32.5	35.0
				38,300	80,600	45.5	51.0

15.0

AC = Air Cooled
R.A. = Reduction of Area

The oxidation resistance of the alloys were compared with commercial alloys by cyclically testing specimens in an air-5 percent water atmosphere at 1,000°F., using a 24 hour cycle period. The air-water mixture was flowing at 250 cc/min. over the specimens, which were machined from the castings to a size of 0.3 inch diameter × 0.75 inch long. At the end of each test period, the specimens were removed to cool in air. The specimens were then lightly descaled to remove the oxide formed and the weight change of the specimens was measured. Descaling of all the test specimens was done with an S. S. White precision abrasive cleaning unit using 50 micron alumina propelled by dry CO₂. A total of 500 hours exposure was employed. The 500 hour exposure weight change results shown hereinbelow in Table III evidence the excellent oxidation resistance of the alloys of the invention as compared with commercial composition Alloy B and commercially obtained alloys Type 310 stainless Steel and HK-40.

TABLE III

Results of Oxidation Tests		
Alloy No.	Condition	Weight Change (Descaled) mg/cm ²
1	As Cast	-7.31
		-8.04
2	As Cast	-8.59
		-9.14
	As Cast + 1 hr. at 2200°F., AC	-8.72
		-8.71
B	As Cast	-6.73
		-6.87
	As Cast + 1 hr. at 2200°F., AC	-6.44
		-6.58
Type 310 SS	Wrought	-11.7
HK-40	As Cast	-9.76

To test the weldability of the alloys of the invention, comparative tests were performed by using a Bead-on-Plate test, by welding ½ inch butt joints and by welding 1 inch butt joints. As is known, the Bead-on-Plate test is primarily a screening test, the butt-weld being an actual welded joint which shows the ability of the metal to be welded.

affected-zone cracking and Alloys D and E exhibited severe weld and heat-affected-zone cracking. Alloy A violates the above-described carbon-molybdenum relationship. Alloy 8 had very slight heat-affected-zone cracking in one test specimen but the other specimen showed none, indicating, as will be appreciated by those skilled in the art, a satisfactory base plate material. Alloys 6 and 7, which are below the required value of the carbon-molybdenum weldability relationship, exhibited severe weld cracking, indicating the need for a special filler metal, e.g., a filler made from Alloy 3. The same applies to Alloy 9, an alloy relatively high in manganese, i.e., 4.3 percent, and which exhibited severe weld cracking.

Alloys D and E which are outside of the invention and contained 3.9 and 5.9 percent copper, respectively, exhibited severe weld and heat-affected-zone cracking. This is in contrast to the freedom from weld and heat-affected-zone cracking in the bead-on-plate test exhibited by Alloy No. 11 which contained 0.9 percent copper and by Alloy C which contained 1.9 percent copper.

With regard to butt-weld tests, restrained ½-inch thick butt-welds were prepared in the various base-plate compositions as described in Table V by manual gas-tungsten arc welding. The base plate was prepared with a 60° V-bevel edge preparation, 3/32-inch root face and 1/16-inch root space. Direct-current-straight-polarity was used with an amperage between about 180 and 220 and a voltage of about 16 volts. Argon shielding at a rate of about 25 cubic feet per hour and manual welding at a rate of approximately 2 to 2.5-inch/min. were employed. Approximately 8 to 10 passes were needed to fill these joints. After welding, ½-inch wide transverse slices (containing base plate, heat-affected-zone and weld deposit approximately 50 to about 75 percent weld deposit) were cut from the weldment. Approximately eight slices from each weld were ground, polished, etched with Lepito's reagent and examined for defects at 10X. The compositions of the filler metals used are given hereinbelow in Table IV, and the base plate and filler metal data in Table V.

TABLE IV

Compositions of Filler Metals									
Filler Metal (Alloy No.)	C %	Si %	Mn %	Ni %	Cr %	Mo %	Fe %	B %	Other
I	0.007	0.32	0.26	Bal.	21.8	6.0	19.4	0.13	
II	0.007	0.30	0.29	Bal.	22.6	6.0	19.1	0.29	
III	0.031	0.28	0.22	Bal.	21.0	6.1	19.7	0.23	
17	0.023	2.90	0.31	Bal.	21.6	6.2	18.5	0.35	
F*	0.05	0.40	0.3	61.0	21.5	9.0	4.0	—	Cb+Ta 3.6
G*	0.10	0.50	0.50	Bal.	22.0	9.0	18.5	—	W 0.6

*A Commercial Filler Metal

The Bead-on-Plate tests were performed on the cast pieces by grinding the surface and welding a single bead with an automatic gas tungsten arc welding machine using argon shielding, 250 amperes, 11 volts, direct-current-straight-polarity and a travel speed of 16 inches per minute. No filler metal was used in the as-welded bead. The weld beads were examined for cracking under a microscope at 10X. Alloys 1 through 15 (within the invention) exhibited no heat-affected-zone cracking, whereas Alloy A exhibited severe heat-

TABLE V

½-inch Butt Joints		
Weld No.	Alloy No.	Filler Metal (Alloy No.)
1	4	D
2	6	D
3	7	D
4	3	3
5	3	11

TABLE V-Continued

½-inch Butt Joints		
Weld No.	Alloy No.	Filler Metal (Alloy No.)
6	1	I
7	2	G
8	2	F
9	11	II
10	C	II

The ½-inch joint, No. 9 in Table V, in Alloy No. 11 containing 0.9 percent copper made with the special composition filler No. II was found to be entirely free from weld and heat-affected cracking. However, a similar weld, No. 10, in the 1.9 percent copper Alloy C, showed heat-affected-zone cracking. These results, together with the results of the Bead-on-Plate tests, show that the alloys of this invention can tolerate a small copper addition such as that resulting from the use of copper-containing scrap in the preparation of the charge and that large additions of copper must be avoided in order to retain the desirable weldability characteristic.

All the other ½-inch welds were satisfactory and exhibited freedom from heat-affected-zone and weld cracking, except Alloys 2, 4 and 7 which had very slight weld cracking, less than about one crack per section. As will be appreciated by those skilled in the art, this amount of weld cracking is not considered detrimental and meets the requirements as set forth in Military Specification MIL-E-21562B(SHIPS). The results also indicate the ability of the alloy to be welded with both matching and non-matching filler wires.

In order to further demonstrate the weldability of the alloys of this invention, butt-welds were prepared in 1-inch thick plates prepared from No. 3 rectangular plate mold castings having a single U-groove joint preparation. This preparation consisted of a 15° bevel blended to a 3/32-inch root face by a ¼-inch radius. Two plates with such edge preparation were separated by 1/16-inch and clamped to a 3-inch thick cast iron platen for welding tests. Gas tungsten-arc welding was used manually at a travel speed of about 2 to about 2.5-inch/min., about 16 volts, about 180 to 200 amperes direct-current-straight-polarity and argon shielding at about 25 cubic feet per hour. Also, gas metal-arc welding was used automatically at a travel speed of about 10 inches per minute, about 33 volts, about 300 amperes direct-current-reverse-polarity, with 0.062-inch diameter wire and argon shielding at about 40 cubic feet per hour. After welding, transverse slices were prepared and examined as previously described for the ½-inch welds.

TABLE VI

1-inch Butt Joints			
Weld No.	Alloy No.	Filler Metal (Alloy No.)	Process
11	12	17	Gas Tungsten Arc
12	13	III	Gas Tungsten Arc
13	14	I	Gas Metal-Arc
14	15	III	Gas Tungsten Arc
15	16	III	Gas Tungsten Arc

The 1-inch thick weld No. 11 was prepared with the manual gas tungsten-arc process using filler wire of the same composition as the alloy of this invention, e.g., matching composition filler wire. This wire was prepared by casting ¼-inch dia. rods which were centerless ground to 5/32-inch dia., a suitable form for gas tungsten-arc welding. The joint required 17 passes for completion. A total of 13 polished and etched transverse faces were examined at 10X and found to be entirely free from weld and heat-affected-zone cracking.

A similar 1-inch thick gas tungsten-arc weld, No. 12 in Table VI, was prepared with a special composition wrought filler wire, identified as III, in base plate 13 containing 15.0 percent iron. This joint was completed in 21 passes and transverse slices were entirely free from weld and heat-affected-zone cracking.

A third 1-inch thick weld, No. 13 in Table VI, was prepared with the special wrought filler composition, I, using the gas metal-arc welding process. This 8-pass weld in Alloy 14 was entirely free from weld and heat-affected-zone cracking. It is generally known in the Welding Industry that the automatic gas metal-arc process provides conditions significantly more severe than those imposed by the manual gas tungsten-arc welding process and accordingly, further support is provided for the exceptional weldability of the alloy of this invention.

Weld Nos. 14 and 15 in Table VI were 1-inch thick butt-joints in base alloys 15 and 16 which contained 5.2 percent and 9.2 percent iron, respectively. Both joints were completed in 21 passes using the manual gas tungsten-arc welding process. Microscopic examination of transverse slices, cut from these welds, showed the presence of cracks within the heat-affected zone of both. This behavior is distinctly different from the behavior shown previously for weld Nos. 11, 12 and 13 of this invention. As previously mentioned herein, alloy with less than about 10 percent iron tend to exhibit susceptibility to cracking in the heat-affected zone in thick sections. It is most beneficial that the alloys of this invention contain more than 10 percent iron to minimize susceptibility to heat-affected-zone cracking.

To test the stress-rupture properties of the alloys, the transverse slices from the butt welds described hereinabove were machined into test bars containing weld metal, heat-affected zone and base metal (approximately 50 percent to about 75 percent weld deposit). The stress-rupture properties were then measured at 1,600°F. using standard testing procedures. The results shown hereinbelow in Table VII reflect the excellent stress-rupture properties of the alloys of the invention and show that sound welds are produced without degrading the base metal properties.

A comparison of welds 2 and 3 in Alloys 6 and 7 demonstrate the beneficial effect of molybdenum on the stress-rupture life of the alloy. Alloys 6 and 7 are comparable in composition except for the molybdenum contents which are 3 percent and 1 percent, respectively.

TABLE VII

Stress-Rupture Properties of Welds							
Weld No.	Base Alloy No.	Filler Metal Alloy No.	Stress psi	Life hrs.	Elong., % (1")	R.A., %	Fracture Location
4	3	3	10,000	23.1	30.0	52.5	Base
			8,000	139.9	20.0	51.7	Base
			6,000	496.6	7.0	2.5	Weld
5	3	11	8,000	56.5	26.0	54.3	Base
			6,000	692.5	24.0	53.0	Base
			10,000	21.0	26.0	61.5	Base
8	2	F	8,000	106.0	23.0	61.0	Base
			6,000	378.3	29.0	52.8	Base
			10,000	10.7	19.0	47.3	Base
1	4	D	8,000	66.2	18.0	25.5	Base
			6,000	317.6	8.0	17.0	Base
			10,000	52.1	12.0	29.0	Base
2	6	D	8,000	154.3	8.0	24.4	Base
			6,000	456+			
			8,000	17.6	21.0	37.8	Base
3	7	D	6,000	48.5	18.0	40.3	Base
			10,000	13.6	21.0	58.6	Base
			8,000	75.7	11.0	35.3	Base
13	14	I	6,000	835.7	11.0	19.0	Base

EXAMPLE II

Table VIII sets forth the compositions of Alloys 18 through 29, alloys within the invention, and Alloys H through R, alloys outside the invention, having been prepared and cast following the procedures described in Example I except that molybdenum was not added to the melts. Alloy 25 was not cast into molds 1, 2 and 3 but was cast into a similar mold (double keel) having the dimensions 1 inch $\times$ 1½ inches $\times$ 7½ inches (Mold No. 4).

The alloys of the invention had excellent castability as evidenced by the Chinese Puzzle castings which were filled completely without evidence of folds or cold shuts. In contrast, a commercial composition HU Alloy having the nominal composition (in weight percent) 0.45 percent carbon, 1.6 percent manganese, 1.6 percent silicon, 20.7 percent chromium, 38.8 percent nickel, balance iron exhibited folds when poured at the same temperature and, when the pouring temperature was increased to eliminate the folds, other defects such as hot tears and solidification shrinkage appeared.

TABLE VIII

Compositions of Cast Alloys, Weight Percent								
Alloy No.	C %	Si %	Mn %	Ni %	Cr %	B %	Al %	Fe %
18	0.95	3.17	2.09	39.7	19.5	0.27	0.055	Bal.
19	0.97	2.8	2.15	39.7	21.5	0.34	0.040	Bal.
20	0.98	3.02	0.74	38.5	20.1	0.32	0.086	Bal.
21	0.9	2.76	2.28	40.5	20.0	0.13	0.01	Bal.
22	0.91	2.90	1.86	38.8	20.1	0.14	0.063	Bal.
23	0.90	3.07	1.48	39.9	19.4	0.3	0.08	Bal.
24	0.80	1.99	2.32	39.9	20.4	0.14	0.04	Bal.
25	0.98	2.77	2.34	39.7	21.3	0.24	0.13	Bal.
26	1.03	2.90	1.90	41.9	18.6	0.29	0.11	Bal.
27	1.08	3.20	1.80	29.5	21.1	0.24	0.005	Bal.
28	1.01	3.10	1.39	38.5	19.6	0.28	0.12	Bal.
29	1.00	3.12	1.00	38.4	20.0	0.32	0.11	Bal.
H	1.50	3.10	1.90	39.7	20.7	0.26	0.005	Bal.
I	1.08	3.00	4.60	39.7	20.6	0.27	0.005	Bal.
J	0.97	2.97	2.36	40.4	20.5	0.53	0.10	Bal.
K	1.05	2.90	2.00	49.0	19.8	0.26	0.005	Bal.
L	1.10	2.90	1.90	38.8	15.7	0.24	0.005	Bal.
M	1.09	0.93	1.80	39.8	20.6	0.27	0.039	Bal.
N	1.12	3.20	1.80	19.9	21.1	0.26	0.005	Bal.
O	0.87	2.90	1.80	39.1	19.7	N.A.	0.068	Bal.

TABLE VIII-Continued

Compositions of Cast Alloys, Weight Percent								
Alloy No.	C %	Si %	Mn %	Ni %	Cr %	B %	Al %	Fe %
P	0.46	1.1	1.2	20.8	27.4	N.A.	N.A.	Bal.
Q	0.70	3.10	1.80	39.7	20.7	0.24	0.005	Bal.
R	1.04	4.10	1.90	40.0	20.1	0.26	0.005	Bal.

N.A. = Not Added

Test specimens of Alloys 18 and 20 were machined from the castings (Mold Nos. 1 and 2 described hereinabove in Example I) and tested at room and elevated temperatures for mechanical properties using standard testing procedures. Alloy 25 was welded with a matching composition filler wire as a ½-inch butt-weld by manual gas tungsten-arc welding as described hereinabove in Example I. Tensile specimens were machined from the transverse slices of the weldment and contained base plate, heat-affected-zone and weld deposit (about 50 to about 75 percent weld deposit). For comparison purposes also shown hereinbelow in Table IX are tensile values of commercial alloy (HU) obtained from the American Casting Institute Data Sheet for Heat Resistant Type HU, issued March 1957.

TABLE IX

Tensile Properties of Cast Alloys							
Alloy No.	Condition	Mold No.	Test Temp., °F.	Yield Strength psi	Tensile Strength psi	Elong., %	R.A., %10
20	As-Cast		70	48,000	78,000	3.5	3.5
	As-Cast		70	46,600	73,100	2.0	1.5
18	As-Cast		1200	30,000	49,800	2.0	4.0
	As-Cast		1400	23,300	42,200	11.0	14.5
40	As-Cast		1600	12,600	22,900	20.0	28.0
	As-Cast		1800	7,700	13,200	16.0	37.0
25	As-Welded		70	54,900	63,900	1.0	1.0*
	As-Welded		1600	14,800	22,100	19.0	16.5
**	As-Cast	—	70	40,000	70,000	9.0	—
	As-Cast	—	1600	—	20,000	16.0	—
	As-Cast	—	1800	6,200	10,000	28.0	—

*Failure outside of weld in base plate

**Commercial alloy HU

Oxidation tests were also conducted in respect of versions of the molybdenum-free alloys of Table VIII as well as a few comparative alloys. The procedures were identical to those described hereinbelow. Specimens were either machined from the castings (as-cast) or from ½-inch butt-welds (as-welded). The as-welded specimens included the base-plate, heat-affected zone and weld deposit (approximately 50 to about 75 percent weld deposit). The results are given in Table X.

As can be seen from the data, the alloys of the invention exhibit excellent oxidation-resistance in both the as-cast and as-welded conditions as compared to commercial alloys. The relatively low oxidation-resistance of Alloy 24 can be attributed to the silicon content which is below the preferred range of the alloy, i.e., 2.5 percent. Alloy O demonstrates the effect of not including boron in the alloy as this alloy has a relatively low oxidation resistance.

TABLE X

Results of Oxidation Tests		
Alloy No.	Condition	Descaled Weight Change mg/cm ²
18	As-Cast	-5.95
		-5.46
19	As-Welded	-7.04
24	As-Cast	-18.10
		-25.72
26	As-Welded	-8.42
27	As-Welded	-6.50
28	As-Welded	-5.79
29	As-Welded	-4.77
0	As-Cast	-18.38
		-18.28
P	As-Cast	-9.76
(1)	Wrought and Annealed	-5.21
(2)	Wrought and Annealed	-11.7

(1) = commercially obtained Hastelloy X

(2) = commercially obtained Type 310 S.S.

To determine weldability behavior, the alloys in Table VIII were tested using the Bead-on-Plate test and several by welding a ½-inch butt-welded joint, as described hereinabove in Example I.

As to the Bead-on-Plate tests, none of the preferred alloys exhibited heat-affected-zone cracking. Alloys H through M, which are outside the invention, showed both severe heat-affected-zone and weld cracking and are thus unsatisfactory as base plate materials. Alloy O did not exhibit any heat-affected-zone cracking but exhibited severe weld cracking. Alloys Q and R exhibited weld and heat-affected-zone cracking and this is attributable to a carbon content below the preferred level and a silicon content above the preferred level, respectively.

The ½-inch butt-weld joints were made from Alloys 19, 22, and 23 and Alloy N with matching filler wires. None of the joints exhibited weld cracking; however, Alloy N, which is outside the invention, exhibited severe heat-affected-zone cracking. This may be attributed to the low nickel content of 19.9 percent.

To test the stress-rupture properties of the alloys of the invention, specimens of Alloys 19 and 23 were machined and tested (in the as-cast condition) at 1,600°F. The results as shown hereinbelow in Table XI indicate the excellent stress-rupture properties of the cast alloy. The stress-rupture life of Alloy 19 at the 8,000 psi stress level is low probably due to a casting defect and should not be regarded as representative of the alloy's stress-rupture property.

Transverse slices of a ½-inch butt-weld of Alloy 22 (prepared as described hereinabove) was also tested and, as can be seen from the results, exhibits excellent stress-rupture properties. The weld was prepared using the procedures described hereinabove and the filler wire, identified as I in Table IV, contained 21.8 percent chromium, 19.4 percent iron, 6.0 percent molybdenum, 0.13 percent boron and the balance essentially nickel.

TABLE XI

Stress-Rupture Properties					
Alloy No.	Stress psi	Elong., %	R.A., %	Rupture Life, hours	
19	10,000	24.0	26.3	6.1	
	8,000	8.5	8.5	5.0	
	6,000	7.0	7.0	88.6	
	3,000	6.0	7.3	824.0	
22	6,000	8.0	12.5	308.2	
	5,000	7.0	15.4	725.3	
23	10,000	11.0	18.1	9.3	
	8,000	23.0	19.2	57.3	
	6,000	16.0	21.7	203.8	

The alloys of the invention are especially useful in high temperature oxidizing atmosphere applications. They may be employed in many other applications, including high temperature applications where resistance to corrosion and good creep and rupture properties are required. The alloys are particularly useful as static components in vehicular turbines.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

We claim:

1. A highly castable and weldable heat resistant alloy affording high temperature oxidation resistance consisting essentially of (by weight) up to about 1.4 percent carbon, less than 8.5 percent molybdenum, the carbon and molybdenum being specially correlated according to the following relationship:

$$\%Mo + 6(\%C) < 8.5$$

from about 1.5 to about 4 percent silicon, up to about 4.5 percent manganese, from about 16 to about 30 percent chromium, up to about 50 percent iron, from about 0.1 to about 1 percent boron for alloys containing molybdenum and from about 0.1 to about 0.5 percent for alloys without molybdenum, and the balance, in an amount of at least about 35 percent, essentially nickel, the nickel being further correlated such that for alloys not containing molybdenum, the nickel content does not exceed about 49 percent.

2. An alloy in accordance with claim 1 wherein the carbon and molybdenum are correlated according to the following relationship:

$$5.4 < \%Mo + 6(\%C) < 8.5$$

3. An alloy in accordance with claim 1 containing from about 0.005 to about 0.05 percent carbon, from about 5 to about 8 percent molybdenum, from about 2 to about 4 percent silicon, from about 0.2 to about 0.8 percent manganese, from about 19 to about 24 percent chromium, up to about 30 percent iron and from about 0.1 to about 0.5 percent boron.

4. An alloy in accordance with claim 3 wherein the carbon and molybdenum are correlated according to the following relationship:

$$5.4 < \%Mo + 6(\%C) < 8.5$$

5. An alloy in accordance with claim 1 containing at least about 10 percent iron.

15

6. An alloy in accordance with claim 1 containing at least about 15 percent iron.

7. An alloy in accordance with claim 1 containing from about 0.005 to about 0.05 percent carbon, from about 5 to about 8 percent molybdenum, from about 2 to about 4 percent silicon, from about 0.2 to about 0.8 percent manganese, from about 19 to about 24 percent chromium, from about 10 to about 30 percent iron and from about 0.1 to about 0.5 percent boron.

8. An alloy in accordance with claim 1 containing from about 0.005 to about 0.05 percent carbon, from about 5 to about 8 percent molybdenum, from about 2 to about 4 percent silicon, from about 0.2 to about 0.8 percent manganese, from about 19 to about 24 percent chromium, from about 15 to about 25 percent iron and

16

from about 0.1 to about 0.5 percent boron.

9. An alloy in accordance with claim 1 containing from about 0.8 to about 1.2 percent carbon, from about 2.5 to about 3.5 percent silicon, from about 0.5 to about 3.0 percent manganese, from about 19 to about 23 percent chromium, from about 30 to about 47 percent iron, and from about 0.2 to about 0.4 percent boron.

10. An alloy in accordance with claim 9 containing less than about 45 percent iron.

11. As a new article of manufacture, a welded assembly of the alloy as set forth in claim 1, exhibiting freedom from cracking in sections of 1/2-inch and greater thicknesses.

* * * * *

20

25

30

35

40

45

50

55

60

65

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,892,541

DATED : July 1, 1975

INVENTOR(S) : Robin Mackay Forbes Jones and Walter Adrian Petersen

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 8, for "to" read -- or --.

line 63, for "insteaad" read -- instead --.

Col. 5, last column of Table II (R.A.%), bottom line,
omit "15.0".

Col. 12, last column of Table IX, for "R.A. % 10" read
-- R.A. % --.

Signed and Sealed this

sixteenth Day of September 1975

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks