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Ornitz et al.

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[54] **AUSTENITIC STAINLESS STEEL**

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[73] Assignee: **Crucible Inc.,** Pittsburgh, Pa.

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[21] Appl. No.: **234,305**

[52] U.S. Cl. .... **75/128 F,** 75/128 N
[51] Int. Cl. **C22c 39/28**
[58] Field of Search .... 75/128 N, 128 C

[56] **References Cited**

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Attorney—Clair X. Mullen, Jr.

[57] **ABSTRACT**

An austenitic stainless steel and a thermal reactor constructed therefrom consisting essentially of, in weight percent, carbon 0.15 max., manganese 3.0 max., phosphorus 0.04 max., sulfur 0.04 max., silicon 1.0 max., nickel 22 to 32, chromium 20 to 30, nitrogen 0.10 max., boron 0.01 max., and the balance iron.

3 Claims, 4 Drawing Figures

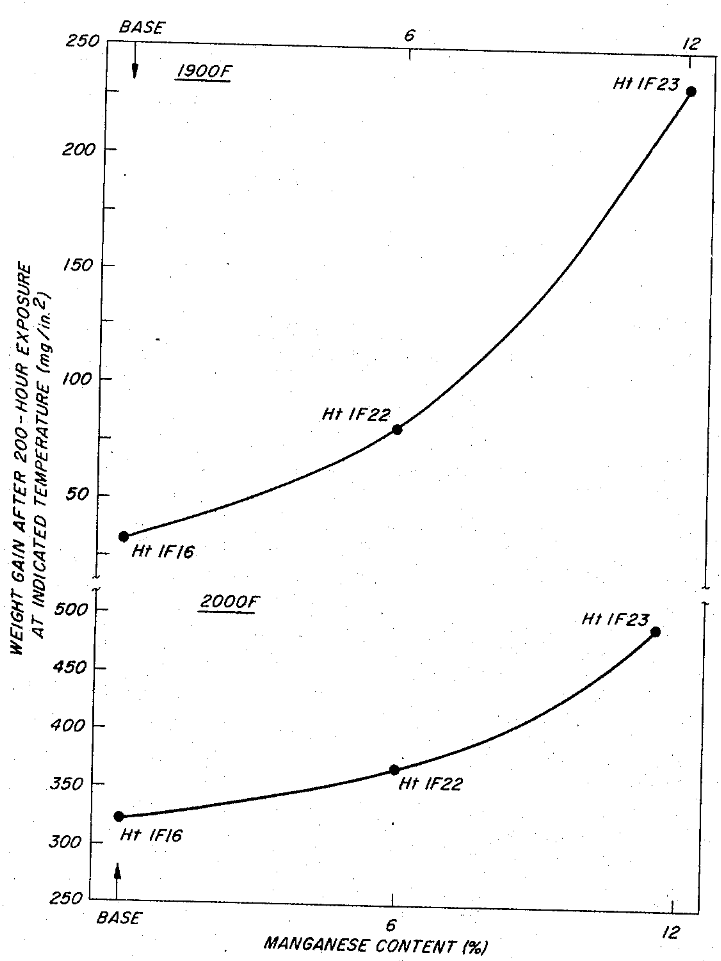


FIG. 1

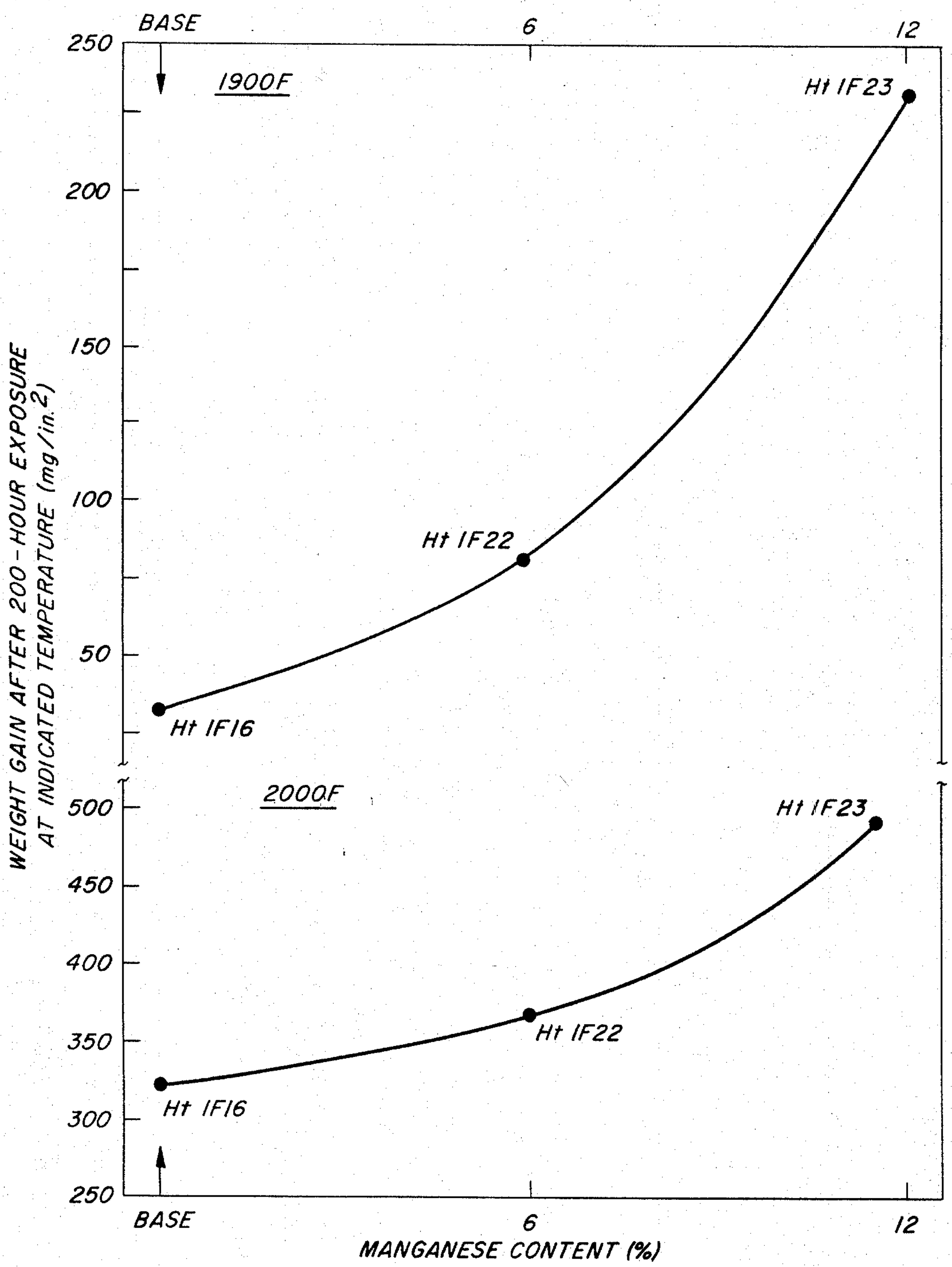
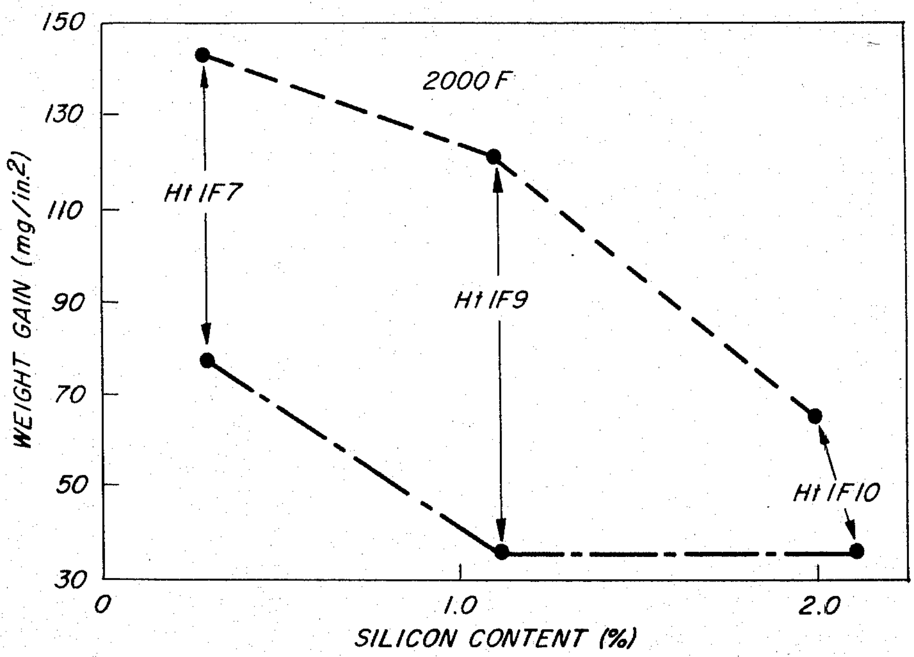

BASE
6
12
250
200
150
100
50
1900F
Ht IF23
Ht IF22
Ht IF16
2000F
500
450
400
350
300
250
Ht IF23
Ht IF22
Ht IF16
BASE
6
12
WEIGHT GAIN AFTER 200-HOUR EXPOSURE AT INDICATED TEMPERATURE (mg/in.2)
MANGANESE CONTENT (%)

FIG. 2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130
110
90
70
50
30
WEIGHT GAIN (mg/in.2)
2000 F
Ht IF7
Ht IF9
Ht IF10
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1.0
2.0
SILICON CONTENT (%)

FIG. 3

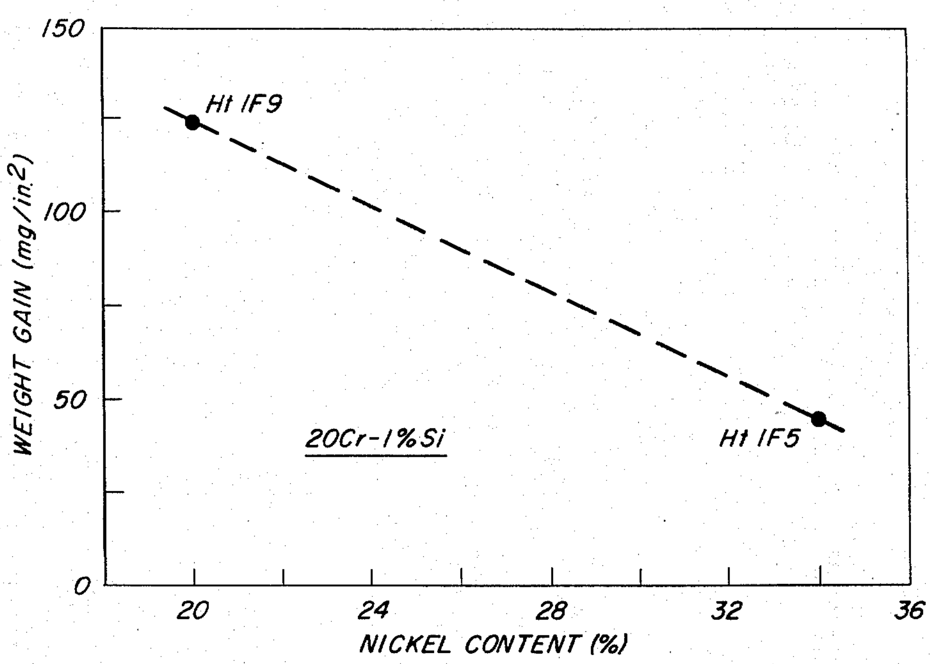
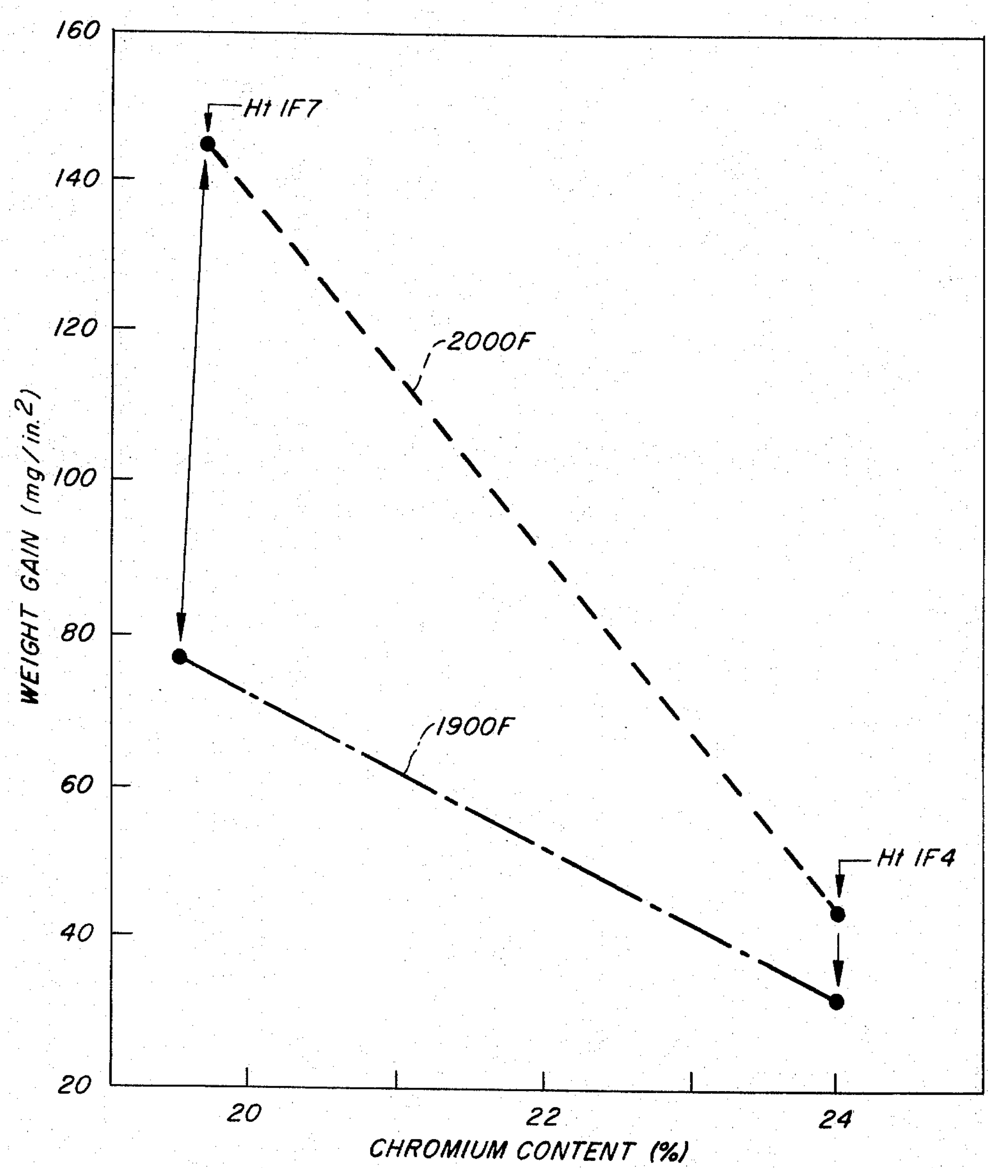

150
100
50
0
WEIGHT GAIN (mg/in.2)
Ht IF9
Ht IF5
20Cr-1%Si
20
24
28
32
36
NICKEL CONTENT (%)

FIG. 4


160
140
120
100
80
60
40
20
WEIGHT GAIN (mg/in.2)
Ht IF7
2000F
1900F
Ht IF4
20
22
24
CHROMIUM CONTENT (%)

AUSTENITIC STAINLESS STEEL

In view of recent efforts with respect to pollution abatement various steps have been taken to reduce the emissions, particularly of unburnt hydrocarbons from the exhaust of motor vehicles. For this purpose it is known to use a thermal reactor which is essentially an afterburner in that unburnt components of the exhaust gases such as hydrocarbons and carbon monoxide are further oxidized in the afterburner to nontoxic gas, e.g. CO_2. This further combustion takes place in the thermal reactor which is a separate combustion chamber outside the engine of the vehicle. In order to achieve satisfactory oxidation of the unburnt hydrocarbons and the like it is necessary that the reactor operate at temperatures on the order of 1,500° to 1,900° F. Typically, AISI Type 330 has been used for the purpose but in view of the high nickel content, e.g. 35 percent nickel, the material costs for the reactor are extremely high. Alternately AISI Type 310 has been proposed but it does not have sufficient resistance to distortion during high temperature service.

stainless steel having chromium and nickel within the ranges of 20 to 30 percent and 22 to 32 percent, respectively, with a boron additive of up to 0.01 percent, while controlling manganese and silicon. More specifically, the desired result is achieved by an alloy within the ranges set forth on Table I.

TABLE I

Element	Broad Range	Preferred Range	Typical
Carbon	0.15 max.	0.08 max.	0.05
Manganese	3.00 max.	2.00 max.	1.70
Phosphorus	0.04 max.	0.04 max.	0.030
Sulfur	0.04 max.	0.04 max.	0.015
Silicon	1.0 max.	0.7 max.	0.50
Nickel	22/32	24/30	25.0
Chromium	20/30	23/28	25.0
Nitrogen	0.10 max.	0.08 max.	0.05
Boron	0.01 max.	0.001/0.005	0.002
Iron	Bal.	Bal.	Bal.

Table II lists alloy compositions melted and tested in establishing the above composition limits.

TABLE II

COMPOSITIONS OF EXPERIMENTAL ALLOYS

Alloy Identification	C	Mn	P	S	Si	Ni	Cr	N	B	Remarks
25—25	0.05	1.38	0.034	0.014	0.53	23.84	24.58	0.08	0.002	—
T-330	0.04	1.68	0.011	0.015	1.14	34.90	19.00	0.05	0.002	—
T-310	0.05	1.52	0.020	0.012	0.31	19.52	24.59	0.05	0.001	—
1F16	0.069	1.05	—	—	1.11	14.24	20.04	0.06	0.002	also 1.10 Al
1F22	0.077	6.02	—	—	1.17	14.30	19.38	0.06	0.002	also 1.70 Al
1F23	0.075	11.39	—	—	1.09	14.30	18.47	0.06	0.002	also 1.70 Al
1F7	0.066	1.18	—	—	0.31	19.65	19.74	0.07	—	—
1F9	0.067	1.15	—	—	1.06	19.90	19.89	0.06	—	—
1F10	0.064	1.15	—	—	2.09	19.90	19.81	0.07	—	—
1F5	0.059	1.08	—	—	0.81	33.80	19.24	0.06	—	—
1F4	0.066	1.01	—	—	0.56	23.98	19.68	0.07	—	—
1H64	0.090	6.24	—	—	2.22	13.73	24.58	0.39	—	—
1H65	0.093	6.17	—	—	2.16	13.67	24.48	0.39	0.002	—

It is accordingly a primary object of the present invention to provide an austenitic stainless steel particularly adapted for use in the manufacture of thermal reactors having good resistance to deformation at high temperature, as characterized by good creep resistance, oxiation resistance, weldability, all of which are achieved with a relatively low nickel content.

These and other objects of the invention as well as a complete understanding thereof may be obtained from the following description, specific examples and drawings, in which:

FIG. 1 is a graph showing the effect of manganese on the oxidation resistance of alloys of the type of the present invention;

FIG. 2 is a graph showing the effect of silicon with respect to oxidation resistance;

FIG. 3 is a graph showing the effect of nickel with respect to thermal expansion; and

FIG. 4 is a graph showing the effect of chromium on oxidation resistance at high temperatures.

Broadly in the practice of the invention the above-stated object is achieved by providing an austenitic

As pointed out hereinabove for use in the manufacture of thermal reactors it is critical that the alloy be characterized by a resistance to distortion at high temperature. As may be seen from Table III Alloy 25—25 is more resistant to creep than conventional Types 330 and 310. Comparative creep results for these alloys are given in Table III resulting from testing at 1,700° F in 100-hour discontinued tests at a 2,000 psi stress level.

TABLE III

Alloy	Creep Extension (%) at Indicated Stress*	
	3000 psi	3500 psi
25–25	3.8, 2.7, 3.0	9.6, 9.4
T–310	8.8, 10.8, f(92)	f(95), f(99)
T–330	7.7, f(70), f(93)	14.0, f(92), f(96)

*Individual test results, numbers indicate percent elongation in 100-hr. discontinued tests. The letter f indicates creep failure and the number in parenthesis denotes time of failure (hrs.).

To determine oxidation resistance the alloys of Table IV were tested at 2,000° F to determine weight gain at various degrees of high temperature exposure.

TABLE IV

CYCLIC OXIDATION TESTS*

Alloy	Weight Gain (mg/in.^{2}) After Indicated Time (Hours) at 2000°F				
	100	200	300	400	500
25-25	24	28	34	42	46
T-330	33	46	60	75	87
T-310	24	31	39	43	60

*Cyclic oxidation tests conducted as follows:
Test specimens were placed in porcelain crucible and weighed. The crucible containing the specimens was then placed in an air furnace. The test cycle consisted of heating in still air at the desired temperature for 20 hours and then air cooling to room temperature. Crucibles containing the specimens were reweighed and, since all oxide that formed was collected in the crucibles, a net weight gain was recorded. The test cycle was repeated until the desired total exposure time was attained.

As may be seen from the results reported in Table IV the Alloy 25—25 in accordance with the present invention exhibited better oxidation resistance than did the conventional alloys.

To determine weldability Alloy 25—25, in accordance with the invention, was subjected to TIG welding at speeds of up to 100 inches per minute; with the alloy in accordance with the invention crack-free welds were produced over a wide range of welding conditions and heat inputs. In contrast AISI Type 330 exhibited significant weld cracking under identical conditions.

TABLE V

ROOM TEMPERATURE TENSILE PROPERTIES

	UTS (ksi)	0.2% YS (ksi)	Elongation % in 2 inches
Crucible 25—25	89.0	39.6	40.0
T-310	87.1	39.1	45.0
T-330	83.4	40.9	40.0

ELEVATED TEMPERATURE (1800°F) PROPERTIES

	UTS (ksi)	0.2% YS (ksi)	Elongation % in 2 inches
Crucible 25—25	9.8	6.3	52.0
T-310	8.7	6.0	57.5
T-330	9.1	6.8	52.0

The results as reported in Table V show the superior room and elevated temperature tensile properties of Alloy 25—25 in accordance with the present invention in comparison with conventional Types 310 and 330.

To achieve the results as reported above with respect to the desired combination of properties it is necessary that the alloying elements be closely controlled. Specifically carbon must be kept low to avoid sensitization in welding and in cooling after annealing. Accordingly carbon must be restricted to 0.08 percent max. in the preferred composition. Although manganese is a useful addition for deoxidation purposes it may be seen from FIG. 1 that manganese contents above about 2 or 3 percent decreased oxidation resistance during cyclic tests at 1,900° and 2,000° F for 200 hours.

Phosphorus and sulfur each should be maintained below about 0.04 percent to ensure good resistance to

weld cracking. Also silicon is significant for improving oxidation resistance at high temperatures as may be seen from FIG. 2 showing steels having 20 percent chromium and 20 percent nickel containing varying silicon contents and tested at 1,900° and 2,000° F for 200 hours. Although silicon is significant for this purpose it has been found that if silicon is above 0.7 or 1 percent the susceptibility of the alloy to weld cracking increases. Specifically, the 25—25 alloy of Table I, but containing 1.19 percent silicon, consistently showed longitudinal weld cracking after TIG welding; whereas, Alloy 25—25 of Table I containing 0.53 percent silicon was immune to cracking during identical welding operations.

Nickel is a critical addition for high temperature (creep) strengths and is preferred within the range of 24 to 30 percent; higher or lower nickel levels than claimed result in lower creep strength. Also, as shown in FIG. 3, nickel has a strong effect on the oxidation resistance at high temperature and for this purpose also is preferred within the range of 24 to 30 percent. Chromium is also important for high temperature strength and, as shown in FIG. 4, is critical for oxidation resistance and also for resistance to corrosion in the intended exhaust gas environment within the range of 22 to 28 percent. FIG. 4 reports cyclic tests at 1,900° and 2,000° F for 200 hours. If, however, chromium is above about 30 percent it will undly embrittle the alloy, aside from increasing the cost thereof.

TABLE VI

Heat No.	Boron Content (%)	Creep Extension (%) after 100 hours at 1700°F at 2000 psi
1H64	nil	4.12
1H65	0.002	2.50

With respect to boron, the addition to the alloy of the invention promotes good creep resistance as indicated for tests on modified Type 309 tested at 1,700° F, the results of which are reported in Table VI. On the other hand, boron contents above about 0.005 percent and 0.01 percent are detrimental to sensitization resistance and hot workability.

We claim:

1. An austenitic stainless steel characterized by resistance to distortion at high temperature, and resistance to oxidation and scaling consisting essentially, in weight percent, of carbon 0.08 max., manganese 2.0 max., phosphorus 0.04 max., sulfur 0.04 max., silicon 0.7 max., nickel 24 to 30, chromium 23 to 28, nitrogen 0.08 max., boron 0.001 to 0.005 and the balance iron.

2. An austenitic stainless steel characterized by resistance to distortion at high temperature, and resistance to oxidation and scaling consisting essentially, in weight percent, of carbon 0.05, manganese 1.70, phosphorus 0.030, sulfur 0.015, silicon 0.50, nickel 25.0, chromium 25.0, nitrogen 0.05, boron 0.002 and the balance iron.

3. A thermal reactor made from the stainless steel of claim **1.**

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