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PRESSURE VESSEL CODE CONSTRUCTION CAPABILITIES FOR A NICKEL-CHROMIUM-TUNGSTEN-MOLYBDENUM ALLOY

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ABSTRACT

HAYNES® alloy 230 (UNS N06230) has achieved wide usage in a variety of high-temperature aerospace, chemical process industry and industrial heating applications since its introduction in 1981. Combining high elevated temperature strength with excellent metallurgical stability, environment-resistance and relatively straight forward fabrication characteristics, this Ni-Cr-W-Mo alloy was an excellent candidate for ASME Pressure Vessel Code applications. Coverage under case No. 2063 was granted in July, 1989 for both Section I and Section VIII Division 1 construction.

In this paper, the metallurgy of 230™ alloy will be described, and its design strength capabilities contrasted with those for more established code materials. Other important performance capabilities, such as long-term thermal stability, oxidation-resistance, fatigue-resistance, and resistance to other forms of environmental degradation will be discussed. It will be shown that the combined properties of 230 alloy offer some significant advantages over other materials for applications such as expansion bellows, heat-exchangers, valves and other components in the fossil energy, nuclear energy and chemical process industries, among others.

Table I

Nominal Composition of Alloys (Wt. Percent)

Material	Ni	Fe	Co	Cr	Mo	W	Mn	Si	Al	C	Other
HAYNES® alloy 230	Bal	3*	5*	22	2	14	.5	.4	.3	.10	.02 La
INCONEL® alloy 617	Bal	1.5	12.5	22	9	-	.5	.5	1.2	.07	.3 Ti
HASTELLOY® alloy X	Bal	18.5	1.5	22	9	.6	1*	1*	-	.10	
Alloy 625	Bal	5*	1*	22	9	-	.5*	.5*	.4*	.03*	3.6Cb,.4Ti*
800HT®alloy	33	Bal	-	21	-	-	1.5*	1*	-	.08	Al+Ti:.85-1.20
Alloy 600	Bal	7	-	15	-	-	1*	.5*	.4*	.08*	
Type 316	12	Bal	-	16	2	-	2*	1*	-	.08*	

*Maximum

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BACKGROUND METALLURGY

The development of 230 alloy was undertaken to provide a well-balanced, solid-solution- strengthened, high-temperature alloy for a variety of fabricated aerospace, chemical process industry and industrial components. Chief among the alloy design criteria was to avoid optimizing any performance characteristics at the expense of having poor properties in another category. To this end, the short comings of previously developed alloys were very carefully examined to establish pitfalls to be avoided. Comprehensive screening tests, together with advanced alloy design tools, such as using electron vacancy number control concepts to control metallurgical stability were all employed in the conception and eventual development of the material.

The resulting commercial composition for 230 alloy is given in Table I, together with those for other, well-established materials in the ASME Vessel Code. The 230 alloy is a solid-solution- strengthened Ni-Cr-W-Mo alloy which also derives strength from the addition of a moderate amount of carbon. This provides for both primary $(W,Mo)_6C$ type primary carbide formation for grain size control and, importantly, for $(Cr,Ni)_{23}C_6$ type secondary carbide precipitation on mobile dislocations during deformation in service at elevated temperature. Unlike the case with higher carbon alloys, the carbon content in 230 alloy provides significant strengthening, but is low enough to provide for high tensile ductility, and ductility retention in and after service.

The tungsten-rich primary carbides in the alloy are very stable to high temperatures, giving the alloy excellent grain size stability. A typical 2250°F (1232°C) solution heat treatment is employed to solution secondary carbides and produce a grain size in most forms in the range of ASTM 4-7. This treatment was specifically chosen for the production of most products to provide the best balance between creep or stress rupture properties, which are favored by a coarse grain size, and tensile or low cycle fatigue properties, which benefit from a finer grain size. A full solution heat treatment can be achieved at temperatures as low as 2125°F (1163°C) with a correspondingly finer grain size, if optimization of tensile and LCF properties at the expense of creep properties is desirable.

In order to avoid the formation of embrittling or otherwise deleterious phases in the alloy during long-term or short-term thermal exposure, the composition of each heat of material produced is controlled using electron vacancy number, or N_v, concepts. Actual thermal exposures of up to 16,000 hours have been performed, and the results of tensile and impact tests indicate that 230 alloy retains excellent ductility and toughness. Metallographic examination and X-ray diffraction analysis of extracted residues taken from exposed samples reveal that only carbides are present following such exposures. The matrix structure remains single phase, FCC crystal structure.

Environment-resistance for this material derives from its 22% chromium content, and a very careful balancing of the minor elements aluminum, manganese, silicon and lanthanum. These elements optimize the formation of the protective oxide scale on the alloy, which is a nickel-chromium type spinel, and improve its adherence to the alloy surface. This protective scale contributes largely to the basic oxidation-resistance of the alloy, and also to its resistance to other aggressive high-temperature environments.

DESIGN STRESS CAPABILITIES:

The allowable design stresses for 230 alloy, as provided for in ASME Vessel Code case No. 2063, are presented in Table II. Design allowables are relevant to Section I construction up to 1200°F (648°C), and to Section VIII Division 1 construction up to 1650°F (898°C). These values are compared with design stresses for a number of other relevant code-covered materials in Figures 1-3. In all instances (except for alloy 600), the lower values for tensile-limited design stresses from either Section VIII or individual code cases have been used in order to present a fair comparison. Values plotted in the figures are given in Table III (and IIIA for SI units).

Table II

ASME Vessel Code Case No. 2063

Allowable Stresses

For Metal Temperatures Not Exceeding,		Maximum Allowable Stresses *	
°F	°C**	Ksi	MPa**
100	37	27.5	189
200	93	27.5	189
300	149	26.2 (27.5)	180 (189)
400	204	24.7 (27.0)	170 (186)
500	260	23.1 (26.4)	159 (182)
600	315	21.6 (26.0)	148 (179)
650	343	21.1 (25.8)	145 (177)
700	371	21.0 (25.7)	144 (177)
750	398	21.0 (25.7)	144 (177)
800	426	20.9 (25.7)	144 (177)
850	454	20.9 (25.5)	144 (175)
900	482	20.9 (25.4)	144 (175)
950	510	20.9 (25.1)	144 (173)
1000	537	20.8 (24.8)	143 (170)
1050	565	20.8 (24.7)	143 (170)
1100	593	20.8 (21.0)	143 (144)
1150	621	17.4	119
1200	648	14.7	101
1250	676	12.3	84
1300	704	10.1	69
1350	732	8.4	57
1400	760	7.0	48
1450	787	5.7	39
1500	815	4.6	31
1550	843	3.7	25
1600	871	2.8	19
1650	898	2.0	13

* Values in parentheses exceed 67% but do not exceed 90% of governing tensile yield strength properties at these temperatures, and may be used where slightly greater deformation is acceptable. Use of these higher stresses may result in dimensional changes due to permanent strain, and is, therefore, not recommended for flanges or gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

** Converted values are truncated, not rounded up.

As is shown in Figures 1-3, 230 alloy possesses significant design stress advantages over alloy X, 800HT alloy, Type 316 stainless steel and alloy 600 over the entire range of temperatures. Comparison with alloy 625 Grades I and II, and alloy 617, is somewhat complicated by virtue of the variation of the temperature at which design stresses pass from being tensile property limited to being stress rupture property limited for each material. Alloy 625 Grade I (fine grain size) has superior design stresses to 1150°F (621°C), but falls off below 230 alloy at 1200°F (648°C), the limit of coverage. Grade II material of alloy 625 (coarse grain size) has lower design stresses than 230 alloy below 1150°F (621°C), but higher values at temperatures from 1150 to 1450°F (621 to 787°C). At 1500°F (815°C) the limit for alloy 625 Grade II coverage, 230 alloy again has a higher design stress value.

In the case of alloy 617, 230 alloy once again

Table III

Comparison of ASME Vessel Code Section VIII Division 1 Allowable Stresses (Ksi)*

For Metal Temperatures Not Exceeding, °F	230 alloy (1)	Alloy 625 Grade II (2)	Alloy 625 Grade I (4)	Alloy 617 (6)	Alloy X (4)	800HT Alloy (3)	Alloy 600 (4)	Type 316 (5)
1000	20.8	19.6	23.7	15.5	14.3	-	14.5	11.3
1050	20.8	-	23.6	-	14.2	-	10.3	11.2
1100	20.8	19.3	23.4	15.4	14.2	12.9	7.2	11.0
1150	17.4	19.3	21.0	15.4	14.1	10.4	5.8	9.8
1200	14.7	19.3	13.2	15.3	11.3	8.3	5.5	7.4
1250	12.3	14.5	-	13.0	9.3	6.7	-	5.5
1300	10.1	11.7	-	10.0	7.7	5.4	-	4.1
1350	8.4	9.3	-	7.7	6.1	4.3	-	3.1
1400	7.0	7.5	-	6.0	4.8	3.4	-	2.3
1450	5.7	5.8	-	4.6	3.8	2.7	-	1.7
1500	4.6	4.2	-	3.6	3.0	2.2	-	1.3
1550	3.7	-	-	2.8	2.3	1.7	-	-
1600	2.8	-	-	2.2	1.7	1.4	-	-
1650	2.0	-	-	1.8	1.2	1.1	-	-

*Lowest values where two values appear in the Code, except of alloy 600, where highest values (for plate) are given.

Table IIIA

Comparison of ASME Vessel Code Section VIII Division 1 Allowable Stresses (MPa)* **

For Metal Temperatures Not Exceeding, °C**	230 alloy (1)	Alloy 625 Grade II (2)	Alloy 625 Grade I (4)	Alloy 617 (6)	Alloy X (4)	800HT Alloy (3)	Alloy 600 (4)	Type 316 (5)
537	143	135	163	106	98	-	89	77
565	143	-	162	-	97	-	71	77
593	143	133	161	106	97	88	49	75
621	119	133	144	106	97	71	39	67
648	101	133	91	105	77	57	37	51
676	84	99	-	89	64	46	-	33
704	69	80	-	68	53	37	-	28
732	57	64	-	53	42	29	-	21
760	48	51	-	41	33	23	-	15
787	39	39	-	31	26	18	-	11
815	31	28	-	24	20	15	-	8
843	25	-		19	15	11	-	-
871	19	-	-	15	11	9	-	-
898	13	-	-	12	8	7	-	-

* Lowest values where two values appear in the Code, except for alloy 600, where highest values (for plate) are given.

**Converted values are truncated, not rounded up.

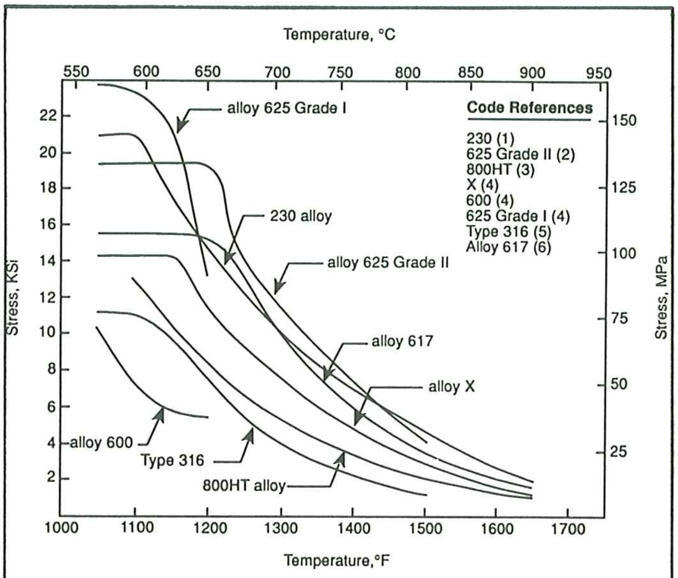

Figure 1: Allowable design stresses from ASME Vessel Code Section VIIII Division I and relevant Code cases. Note: lowest values shown where two valves appear in the Code, except for alloy 600, where highest valves (for plate) are used.

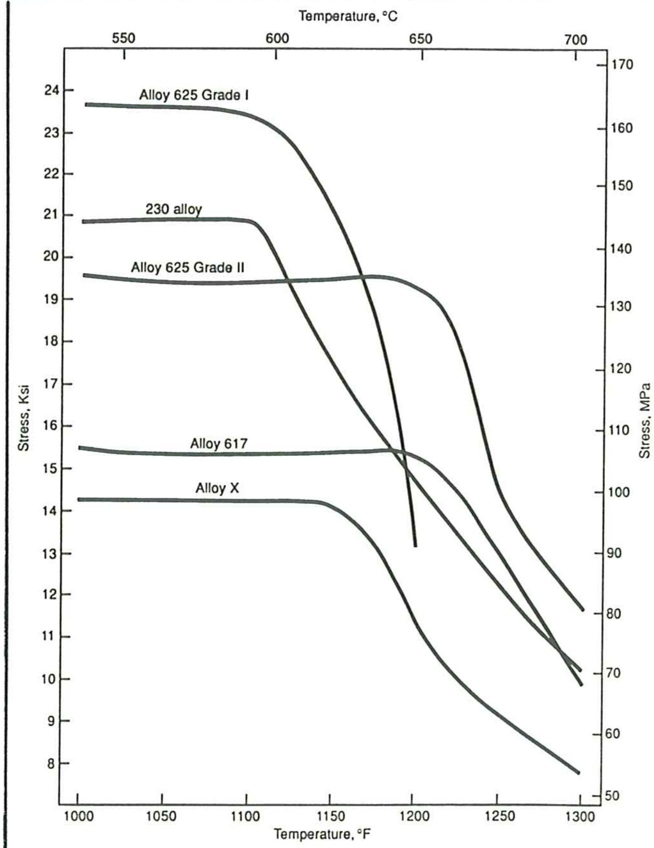

Figure 2: Allowable design stresses from ASME Vessel Code Section VIII Division 1. and relevant code cases. Note: Lowest values shown where two values appear in the code.

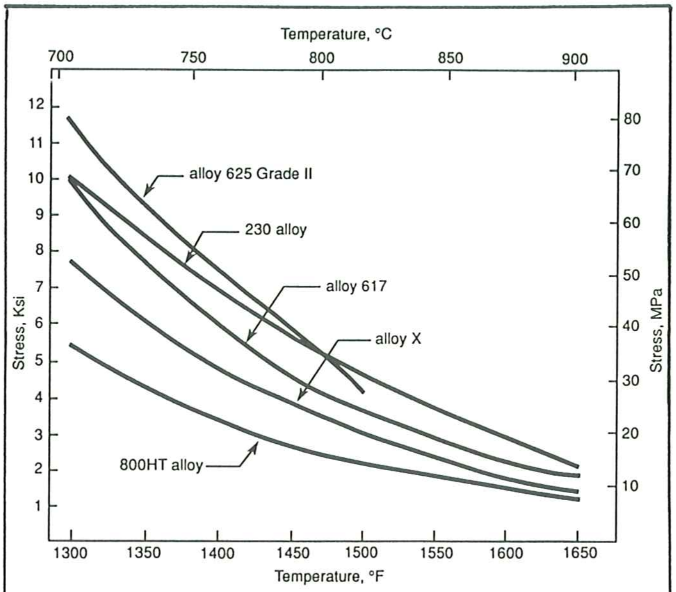

Figure 3: Allowable design stresses from ASME Vessel Code Section VIII Division 1 and relevant Code cases.

has higher design stresses up to 1150°F (621°C). The values for alloy 617 are higher at 1200 and 1250°F (648 and 676°C), but 230 alloy regains superiority from 1300 to 1650°F (704 to 898°C).

The advantages exhibited by alloy 625 Grade II and alloy 617 in the intermediate temperature ranges of 1150 to 1450°F (621 to 787°C) and 1200 to 1250°F (648 to 676°C), respectively, are both attributable in some measure to precipitation strengthening occurring in those ranges during thermal exposure. In the case of alloy 617, $Ni_3(Al,Ti)$ precipitates are involved, which provide moderate strengthening without major loss of ductility (7). In the case of alloy 625 Grade II (and only to a slight lesser extent Grade I), Ni_3Cb intermetallic phase precipitation, which provides the strength increment, will also result in a severe loss of room temperature ductility and impact strength (8, 9). The problem is severe enough to have warranted a warning note in both Section VIII Division 1 for Grade I material (Reference 4, Note No. 13) and in Code case No. 1409-6 for Grade II material (Reference 2, Note No. 1). This subject will be dealt with in the following section on thermal stability.

In view of the design stress advantages inherent with 230 alloy, in many cases it is possible to design construction using thinner gauges. Potential thickness reductions when replacing other materials is illustrated for several temperatures in Figure 4. Looked at another way, it is possible to replace other materials with the same thickness of 230 alloy and increase the operating temperature without a reduction in the design strength. This is shown by the curves in Figure 5, which are plots of the increase in temperature required in order to get equivalence between the 230 alloy design stresses and those for the lower strength alloys at specified operating temperatures.

For alloy X, substituting 230 alloy allows about a 60-90°F (33-50°C) operating temperature increase. For 800HT alloy, the increase is about 130-160°F (72-88°C). The increases possible for alloy 600 and Type 316 stainless steel are about 200-290°F

(111-161°C) and 160-230°F (88-127°C), respectively. These can be quite important when increases in process temperatures to improve productivity, yield, etc. are being considered in relevant industrial applications.

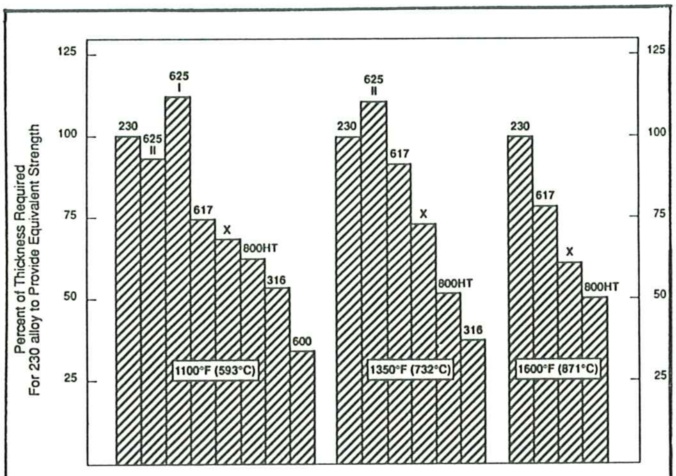

Figure 4: Percent of thickness required for 230 alloy to replace various materials while providing equivalent structural design strength.

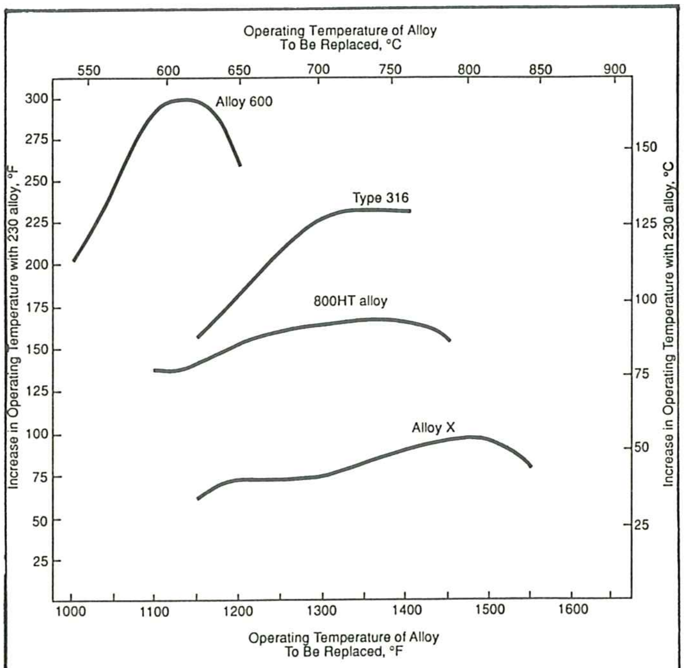

Figure 5: Increase in operating temperature with no reduction in design strength when substituting equal section thickness of 230 alloy.

THERMAL STABILITY:

In any long-term application, retention of alloy ductility during and following service exposure is an important material selection criteria. As mentioned earlier, some high-strength, high-temperature alloys suffer significant loss of both tensile ductility and impact strength at room temperature after being in service at intermediate temperatures, typically in the range of 1200 to 1600°F (648 to 871°C). This is particularly true for alloy 625 and alloy X. Exposures of up to 16,000 hours were conducted by Matthews (9, 10) on both alloys in plate form. The alloy 625 material used was annealed at 1875°F (1023°C), corresponding to Grade I requirements. The alloy X material was standard 2150°F (1176°C) solution-treated.

Results from Matthews' work are shown in Figures 6-8 for tensile elongation at room temperature, and in Table IV for room temperature impact strength (following 8,000 hours exposure). These are compared in the Figures and Table with results obtained for 230 alloy plate samples similarly exposed. The severe loss of both ductility and impact strength for alloy 625 and, to a lesser extent, alloy X are evident; however, 230 alloy exhibited far superior ductility and impact strength retention. As mentioned earlier, only carbide precipitation is observed after 16,000 hours of exposure at these temperatures.

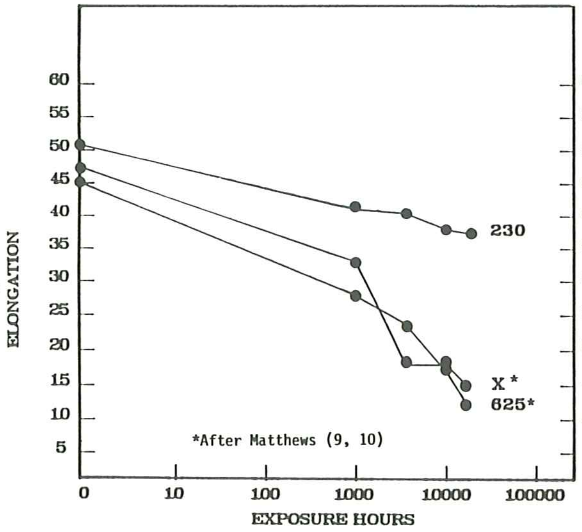

FIGURE 6: RESIDUAL ROOM TEMPERATURE TENSILE DUCTILITY AFTER EXPOSURE AT 1200°F (648°C).

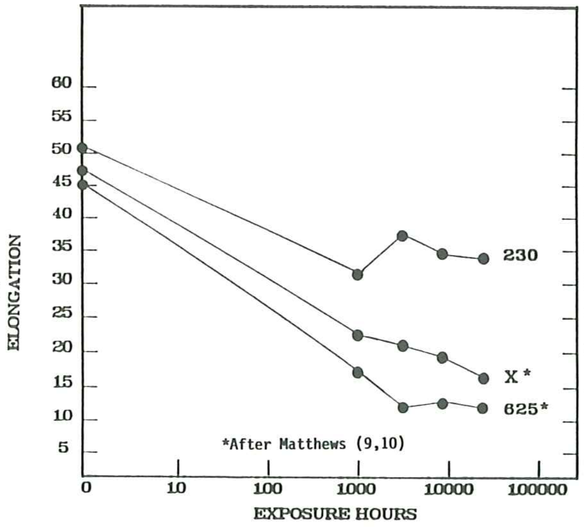

FIGURE 7: RESIDUAL ROOM TEMPERATURE TENSILE DUCTILITY AFTER EXPOSURE AT 1400°F (760°C).

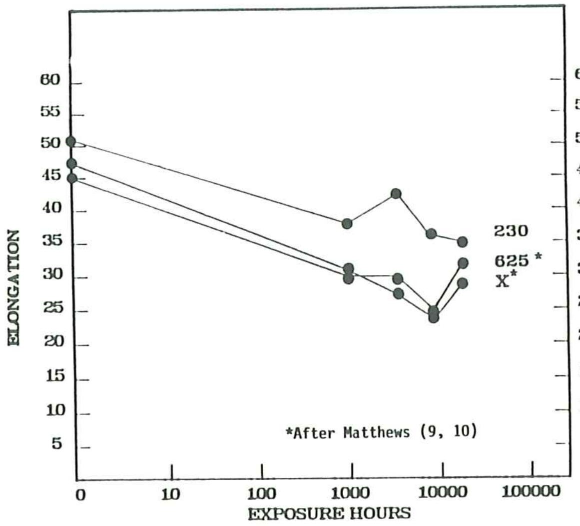

FIGURE 8: RESIDUAL ROOM TEMPERATURE TENSILE DUCTILITY AFTER EXPOSURE AT 1600°F (871°C).

Table IV

Retained Charpy Impact Strength After Exposure

For 8000 Hours*

Material	Room Temperature As-Received Ft-Lbs (Joules)	Room Temperature Impact Strength Ft-Lbs (Joules) After Exposure at Temperature 1200°F (648°C)	1400°F (760°C)	1600°F (871°C)
230 alloy	60 (82)	30 (41)	21 (29)	21 (29)
alloy 625**	81 (110)	5 (7)	5 (7)	15 (20)
alloy X**	54 (72)	15 (20)	8 (11)	15 (20)

*Standard V-Notch Samples. Duplicate tests.

**After Matthews (9, 10)

Alloy X, on the other hand, does suffer from the formation of both sigma and mu phases in the microstructure. In alloy 625, the early-formed, body-centered-tetragonal structure, Ni_3Cb precipitates, which serve to strengthen with only a moderate ductility reduction, overage to form a highly deleterious needle morphology with a corresponding orthorhombic crystal structure. These results have been confirmed by electron microscopy and X-ray analysis of extracted residues in the present study. The effects on ductility in alloy 625 have been substantiated by other investigators (8, 11), who report the loss of ductility to be even worse in Grade II material than in Grade I (8).

OXIDATION-RESISTANCE:

As a consequence of the generally good oxidation-resistance exhibited by all of these materials at temperatures up to 1650°F (898°C), it is not practical to rank alloy performance by means of laboratory tests at or below this temperature. Experience indicates that thousands of hours are required to reach breakaway oxidation, where meaningful rates can be measured. Instead, results reported for 1000 hour cyclic oxidation tests at 1800°F (982°C) by previous investigators (12, 13) are presented in Table V. Data for alloy 800H is given in lieu of 800HT alloy, although the oxidation-resistance is anticipated to be similar for the two materials.

These results are for high-speed (0.3 mach) combustion gas burner rig tests. A mixture of No. 1 and No. 2 fuel oils was burned at 50:1 air:fuel ratio, and exhausted past a rotating carousel of specimens. The specimens were cycled out of the gas stream every 30 minutes, and cooled to less than 500°F (260°C) by air blast. Following the 2,000 cycle exposure, samples were descaled, and evaluated metallographically to assess thinning and internal attack.

An examination of Table V reveals that 230 alloy is far superior to most of the alloys in question, and virtually twice as good as the next-best materials, alloy X and alloy 625. It is difficult to speculate exactly how this translates into behavior in longer-term service at lower temperatures; however, it is reasonable to assume that these results may at least be indicative of relative performance ranking at, say 1600°F (871°C), for 10,000 to 100,000 hour service life.

Table V

Oxidation-Resistance At 1800°F (982°C)

For 1,000 Hour Exposure Under Highly Cyclic Conditions*

Material	Metal Loss Mils	µm	Maximum Metal Affected ** Mils	µm
230 alloy	0.8	20	3.5	89
alloy X	2.7	69	6.4	163
alloy 625	4.9	124	7.6	193
alloy 617	2.7	69	10.7	272
alloy 800H	12.3	312	15.3	389
alloy 600	12.3[a]	312	17.8[a]	452
Type 316	-	-	>>23.0[b]	>>584

*Average of two tests or more

**Metal Loss + Maximum Depth of Internal Penetration

[a] Extrapolated from 917 hours

[b] Completely consumed in 65 Hours

LOW CYCLE FATIGUE PROPERTIES:

In applications involving thermal cycling, and hence the imposition of cyclic strain, low cycle fatigue properties can be very important to the service performance to be expected from the material employed. Data characterizing the full range of alloys at issue here are not readily available. Past experience has shown that it is inadvisable to compare data from varying sources directly, as the sensitivity to the particular test technique and sample preparation used can be significant. Data are available from the same source for the stronger materials, namely 230 alloy, alloy 625 Grade II, alloy X and alloy 617 (14, 15). Since strength is a contributing factor to low cycle fatigue endurance, it may be assumed that the weaker alloys, 800HT alloy, alloy 600 and Type 316 stainless steel, would all exhibit lower properties than these stronger alloys.

Results for strain-controlled low cycle fatigue tests at 800°F (427°C) at two levels of total strain range (TSR) are presented in Figure 9. The materials tested were either plate or bar form, machined to round, smooth-bar samples. Tests were run both as-received, and with a pre-exposure for 1,000 hours at 1400°F (760°C) to simulate service exposure effects upon alloy structure. The exposed samples were machined after exposure to eliminate complicating environmental damage which might have been incurred. In all cases, tests were run fully reversed at a frequency of 20 cycles per minute (0.33 Hz).

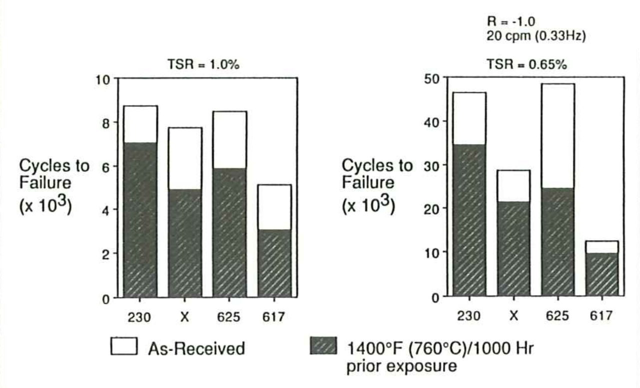

Figure 9: Low Cycle Fatigue lives for alloys at 800°F (427°C) tested at two total strain ranges (TSR) both as-received and following prior exposure at 1400°F (760°C) for 1,000 hours. After Klarstrom (14,15)

An examination of Figure 9 reveals that 230 alloy and alloy 625 Grade II exhibit similar fatigue lives at both levels of TSR in the as-received condition. Alloy X has somewhat less fatigue endurance, particularly at the lower TSR, while alloy 617 is significantly inferior to all of the other materials. It is of interest to note that alloy 617 is normally supplied with a relatively coarse grain size compared with the other materials (typically ASTM 2-4 versus ASTM 4-7 for the others). Grain size is well known to have a major impact upon fatigue properties, and the coarse grain size of alloy 617 may explain its relatively poor performance in these tests; however, the relatively high design stresses for alloy 617 in the creep/stress-rupture controlled temperature range above 1200°F (648°C) are, at least in part, derived from the coarser grain size. So while fatigue endurance might be enhanced by utilizing a finer grain size version of alloy 617, it would likely be at the expense of having lower design stress capability at the higher temperatures.

The pre-exposed sample results shown in Figure 9 reveal that, as expected, alloy 625 Grade II and alloy X are the most adversely affected. The ductility loss for these alloys after 1,000 hours exposure at 1400°F (760°C) is significant in reducing the fatigue endurance. Alloy 617 (16) and 230 alloy, on the other hand, exhibit only moderate ductility reduction as a consequence of the exposure, and, therefore, experience a much less pronounced reduction in fatigue life. With further time at 1400°F (760°C), both alloy 625 and alloy X would be expected to exhibit further degradation in 800°F (427°C) fatigue life from the additional loss in tensile ductility indicated in Figure 7. Both 230 alloy and alloy 617 (16) would not be expected to degrade much more with additional time at the pre-exposure temperature.

Additional results for isothermal, strain-controlled low cycle fatigue tests on 230 alloy, alloy X and alloy 617 are available from Klarstrom (14). Results are presented in Figure 10 for 1600°F (871°C) tests over a range of TSR values. Once again, tests were run fully reversed, at a frequency of 20 cycles per minutes (0.33 Hz), on material as-received. An inspection of the curves shown in Figure 10 reveals that 230 alloy is generally superior to alloy X, and significantly superior to alloy 617.

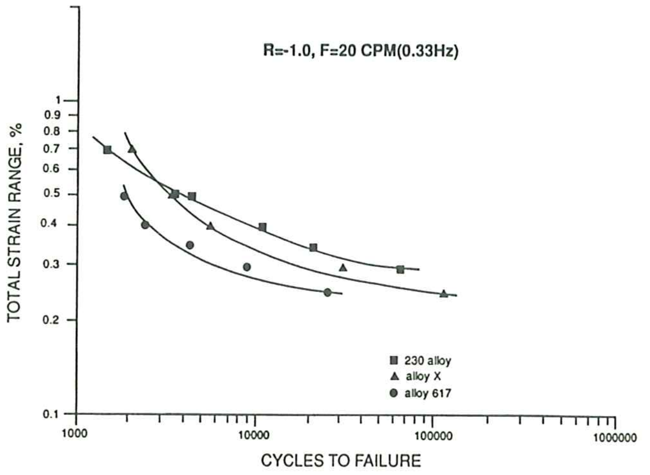

Figure 10: Strain-controlled, Low Cycle Fatigue lives for alloys tests isothermally at 1600°F (871°C). All materials were as-received. After Klarstrom (14, 15).

OTHER FORMS OF ENVIRONMENTAL DEGRADATION:

Tests have been performed to evaluate 230 alloy performance relative to other alloys in resisting aggressive environments at elevated temperature. Results for nitriding-resistance and carburization-resistance have been previously reported (12), and are repeated here with supplementary data for alloy 617 and Type 316 stainless from the same work not reported. Data for nitriding-resistance were generated by exposing samples in 1200°F (648°C) flowing ammonia for 168 hours and measuring the nitrogen absorption per unit area by means of chemical analyses. Results are reported in Table VI. Similar tests were performed to evaluate carburization-resistance by exposing samples to an 1800°F (982°C) mixed gas environment containing Ar-5% H_2-5% CO-5% CH_4 (a_c = 1.0; pO_2 = 10^{-18}) for 55 hours and measuring the carbon absorption per unit area. Results are presented in Table VII. For both nitriding and carburizing tests, alloy 800H results are presented in lieu of 800HT alloy. Differences between the two materials are expected to be negligible for nitriding environments, but may be significant for carburizing environments.

Nitriding test results in Table VI indicate that 230 alloy is superior to all other alloys in the test, including alloy 600, which has been the industry standard for such related service. Results of carburization tests given in Table VII indicate that alloy 800H performs very well, and is a superior choice in this regard to 230 alloy. The 230 alloy results are comparable to alloy X, and both materials are better than the other materials evaluated.

New results have been generated comparing 230 alloy to alloy X and alloy 625 in 1650°F (898°C) hot-corrosion environments. These results were obtained from 1,000 hour exposure in a standard low-velocity burner rig burning No. 2 fuel oil with

Table VI

Nitriding-Resistance at 1200°F (648°C)

in Flowing Ammonia *

Material	Nitrogen Absorption Afer 168 Hours (mg/cm^2)
230 alloy	0.7
alloy 600	0.8
alloy 625	0.8
alloy 617	1.3
alloy X	1.7
alloy 800H	4.3
Type 316	6.9

*Average of two tests or more

Table VII

Carburization-Resistance at 1800°F (982°C)

in Ar-5%H_2-5%CO-5%CH_4*

Material	Carbon Absorption Afer 56 Hours (mg/cm^2)
alloy 800H	1.0
230 alloy	2.5
alloy X	2.5
alloy 600	2.8
alloy 617	5.0
alloy 625	5.3

*Average of two tests or more

0.4% sulfur content, with 5 ppm NaCl injection in the form of artificial sea water. The air:fuel ratio was 30:1. Samples were cycled out of the gas stream once-an-hour and cooled to under 500°F (260°C) by air blast. Damage was determined by metallographic examination of exposed samples after descaling. Results are given in Table VIII, and indicate equivalent performance by all three alloys.

Table VIII

Hot-Corrosion-Resistance at 1650°F (898°C)

in Standard Burner Rig Tests*

Material	Metal Loss Mils	Metal Loss µm	Average Metal Affected** Mils	Average Metal Affected** µm
230 alloy	1.2	30	5.1	130
alloy X	1.8	46	5.2	132
alloy 625	1.6	41	5.5	140

*Average of two tests

**Metal Loss plus average internal penetration

In addition to the above test evaluations, 230 alloy has also been evaluated for resistance to hydrogen embrittlement, chloride stress cracking, cracking in polythionic acid, and aqueous corrosion-resistance in some relevant media. Results are summarized in Table IX, and indicate that 230 alloy is suitable for service in hydrogen, resists chloride and polythionic acid stress cracking, and though not suited for severe aqueous corrosion environments, should provide reasonable performance in some dew point conditions that may arise during process shut downs.

POTENTIAL USE AREAS FOR 230 ALLOY:

In view of its combination of properties, there are many areas where 230 alloy can be used to significant benefit in ASME Vessel Code construction. These include high-temperature expansion bellows; superheated steam process piping and valves; reformer tubes, headers, and pigtails; hydrogen furnace internals (sometimes built to Code though not requiring it); high-temperature pressurized gas heat exchangers; and others.

For high-temperature bellows, the current standard material of construction is alloy 625. Grade I is typically used up to 1200°F (648°C) and Grade II at higher temperatures if Code coverage is required. Many applications are designed or specified to the Code, though not actually requiring Code level performance, In any case, 230 alloy would be a desirable replacement for alloy 625 for service temperatures exceeding about 1150°F (621°C) by virtue of its superior thermal stability and fatigue properties in service. Trial expansion bellows of 230 alloy in a catalytic cracker configuration have been successfully fabricated using standard alloy 625 forming and welding procedures, as previously reported (12).

In superheated steam processes, 230 alloy is under active consideration for 1500°F (815°C) steam relief and process valve bodies and internals. The alloy's high allowable stresses and relatively low expansion characteristics are key factors. Resistance to steam environments has been substantiated in non-Code use at temperatures up to about 1600°F (871°C) in resistance-heated steam generator piping which has been in service approaching four years.

For steam reformer tubes, headers and pigtail pipes, operating at temperatures up to 1650°F (898°C), a common material of construction is alloy 800H or 800HT alloy, though HASTELLOY® alloy S (Ni-16%Cr-15%Mo) has been used for pigtails in some cases. Often built to but not requiring Code coverage, steam reformers can have difficulties with cracking of components associated with the large grain size (typically ASTM 2-4) associated with alloy 800H or 800HT alloy. Replacement with 230 alloy could allow for reduced incidence of such problems and a significant reduction in section thickness required for 800HT alloy construction.

In other areas, potential for 230 alloy application has yet to be established; however, its properties would warrant consideration in many instances.

SUMMARY:

The properties of alloy 230 have been presented in some detail and contrasted with those of other, established ASME Vessel Code Section VIII Division 1 materials of construction. It has been shown that 230 alloy has excellent design stress allowables compared

Table IX

Environment Resistance Data for 230 Alloy in Various Tests

Test For	Test Details	Results
Hydrogen Embrittlement	Ratio of Notched Tensile Strength in Pressurized H_2 to that in air. $K_t = 8.0$; $PH_2 = 5$ Ksi (34MPa): Room Temperature	Ratio = 1.00 No Embrittlement
Chloride Stress Cracking	1008 Hour Exposure in 45% $MgCl_2$ at 309°F (154°C). Standard ASTM G-30 U-bend specimen	No Cracking
Polythionic Acid Cracking	1000 Hour Exposure in 0.1M Solution $Na_2S_2O_3$ at Room Temperature. Standard C ring samples. Samples tested both as-annealed and aged 245 hours at 1150°F (621°C)	No Cracking Annealed or aged.
Corrosion Resistance	Test performed over four 24 hour periods on standard coupons	
	50% HNO_3 at Boiling	Corrosion Rate = 16.7 mpy (0.4 mmpy)
	10% HCl at 150°F (65°C)	Corrosion Rate = 112 mpy (2.8 mmpy)
	20% H_2SO_4 at 150°F (65°C)	Corrosion Rate = 22.4 mpy (0.6 mmpy)

to alloy X, 800HT alloy, alloy 600 and Type 316 stainless steels. Depending upon temperature, alloy 230 may also be superior to or comparable to alloy 625 Grade II, alloy 617 and alloy 625 Grade I. From 1450°F to 1650°F (787°C to 898°C), its allowable stresses are the highest of all of these materials.

It has been shown that 230 alloy possesses excellent thermal stability, fatigue-resistance, oxidation-resistance, and resistance to other aggressive environments. In many, if not all of the categories reviewed, it is superior to most if not all of the alloys considered. In particular, it is a significant improvement over alloy 625 Grade II and alloy X in thermal stability, and over these and alloy 617 in fatigue-resistance.

Applications for 230 alloy include high-temperature expansion bellows, steam process piping and valves, and steam reformer tubes, headers and pigtails, among others. Use of 230 alloy in these and other ASME Vessel Code construction applications is expected to develop with the recent issuance (July 1989) of Code case No. 2063 for Section VIII Division 1 and Section I coverage.

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