RENE'142: A HIGH STRENGTH, OXIDATION RESISTANT DS TURBINE AIRFOIL ALLOY

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Abstract

Rene'142 is a high strength, nickel base Directionally Solidified (DS) Turbine alloy, which is now operational in commercial and military jet engines. Rene'142 is directionally solidified with columnar grain boundaries; this process is less expensive than the directionally solidified single crystal (no grain boundaries) process, due to easier mold making, faster casting, less expensive inspection and higher yields. Rene'142 has rupture strength equivalent to single crystal Rene'N4, PWA 1480, and CMSX-3.

Rene'142 has excellent resistance to grain boundary cracking during solidification as evidenced by its "A" rating in GE's DS crack susceptibility test which simulates thin-walled turbine airfoils.

Rene'142's high velocity oxidation resistance is outstanding, due primarily to its optimum Ta+Al+Cr content coupled with no titanium addition. At 2150°F - Mach 1 - after 200 hours, the metal surface loss is only 1 mil.

This paper describes Rene'142's development and properties.

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Introduction

Rene'142 is the strongest, nickel base Directionally Solidified (with columnar grains) turbine airfoil alloy operational in commercial and military jet engines. Rene'142 has equivalent longitudinal rupture strength, vastly superior oxidation resistance and lower part costs than Directionally Solidified single crystal (without grains) Rene'N4, PWA 1480, and CMSX-3.

Background

The cost of directionally solidified turbine airfoils cast with grain boundaries (DS) is substantially lower than directionally solidified airfoils cast without grain boundaries (single crystals). DS airfoils are less expensive than single crystals because the process is faster, the yield is higher (less rejectable defects), and the inspection costs are considerably lower (no X-ray diffraction, etc.). Single crystal alloys, however, have recently been developed which are stronger than DS alloys. They can be more "heavily" alloyed and be heat treated at higher temperatures to solution the gamma prime hardener with no or minor incipient melting, due to the elimination of, or reduced levels of low melting grain boundary strengtheners and hafnium in the single crystal alloys.

Rene'142 is an outgrowth of Rene'150, a DS alloy that was invented in the seventies by Wukusick et al (U.S. Patent 4,169,742, alloy DS 392A). Table I lists the Broad Range of the Wukusick et al invention and the DS392A (Rene'150) aim chemistries.

Table I. Alloy Chemistry

Chemistry/ Alloy	Co	Cr	Mo	W	Re	Al	V	Ta	Hf	C	B	Zr
US Patent 4,169,742 (Broad Range)	10-13	3-10	.5-2	3-7	.5-10	5-6	0-2.5	5-7	0.5-2	0.01-.15	.005-.05	0-0.1
US Patent 4,169,742 (DS392A/R150)	12	5	1	5	3	5.5	2.2	6	1.5	0.05	0.015	0.02
Rene'142	12	6.8	1.5	4.9	2.8	6.15	0	6.35	1.5	0.12	0.015	0.02

Weight Percent/Balance Ni

Rene'150 is the forerunner of many of today's directionally solidified airfoil alloys since it contains 3% rhenium for solid solution strengthening; it also does not contain any titanium. Rene'150 has both excellent castability ("A" in the GE crack test, which will be subsequently described) and exceptional longitudinal rupture strength: 100°F greater than conventionally cast Rene'80 or B1900, 65°F over DS Rene'80H and 35°F greater than DS MM 200 and is equivalent to single crystal Rene'N4, PWA 1480, and CMSX-3. Rene'150 also exhibits excellent transverse rupture strength and ductility. Rene'150's bête noire however, is its 2.2% vanadium contact. Although V is a powerful gamma prime strengthener, it is also the cause of the alloy's <u>very poor</u> high velocity (Mach 1) 2075°F oxidation resistance.

Experimental Procedures

The goal of Rene'142 was retainment of Rene'150's excellent rupture strength and castability while vastly improving Rene'150's oxidation resistance. Vanadium was therefore eliminated as a potential alloying element . In order to strengthen the gamma prime (and replace the vanadium) the new alloy needed higher quantities of aluminum and tantalum which when coupled with higher levels of chromium would also improve the alloy's oxidation resistance. The alloy development required the difficult balance of excellent castability, high longitudinal rupture strength, adequate transverse rupture strength and ductility coupled with excellent high velocity oxidation resistance.

The chemistries that were investigated in the development of Rene'142 were first evaluated by utilizing a laboratory crack test that was invented by Wukusick for the development of Rene'150. A 7 lb heat is first vacuum melted into 7/16" diameter rods and the following castability test was then conducted (as described in U.S. Patent 4,169,742):

"The castability test employed a tubular crucible within which was placed a ceramic tube of smaller diameter, the lower one inch of which was slotted. This ceramic tube was held within the outer crucible by appropriate spacers. The alloy to be tested, in the form of a 7/16" diameter rod, was placed within the ceramic tube and the entire assembly was placed within apparatus capable of conducting directional solidification. Upon melting of the alloy charge rod, the molten charge filled the space between the outer tube or crucible and the ceramic tube, solidifying on the ceramic tube during directional solidification. After removal of the ceramic tube with the alloy deposited therein, observations were made and the ratings were selected in accordance with Table II."

Table II. GE DS Castability Test: Ratings

Rating	Criteria
A	No Cracks
B	Minor crack at tip, less than 1/2" long or in starter zone.
C	One major crack, greater than 1/2" long
D	Two or three cracks
E	Several cracks, more than 3 and less than 8
F	Many cracks - most grain boundaries

It should be noted that the resulting wall thickness is ~0.06" inches. It has been shown that this test can accurately predict the castability of thin walled turbine airfoils. An "A" in the test (Table II) correctly predicts the alloy could be cast crack free in thin walled cored airfoils such as the F404 or F110 high pressure turbine blades.

During the Rene'142 development, chemistries which did not result in good castability were eliminated without further testing, while the castable chemistries were then DS cast into 1/4" thick x 2" wide x 4" long slabs. A solution heat treatment temperature study was then conducted on small sections of the slab; the slab was then fully heat treated (solutioned plus ages). Longitudinal and transverse rupture bars were machined and initially tested at 1600°F and 1800°F with a 50-100 hour life aim.

Results: Chemistry Selected, Heat Treatment Studies And Stress Rupture Testing

The combination of an "A" in castability, excellent longitudinal rupture strength coupled with adequate transverse strength and ductility was achieved with the selected Rene'142 chemistry, Table I. It can be seen that Rene'142 has nearly identical Re, Co, W, Hf, B and Zr content to Rene'150 but Rene'142 has 1.8% higher Cr, .65% higher Al, .35% higher Ta, .07% higher C and .5% higher Mo. This chemistry resulted in an alloy with the excellent strength and castability of Rene'150 but with significantly improved oxidation resistance.

A major goal was the development of a heat treatment for Rene'142 which would maximize the longitudinal rupture strength while retaining acceptable transverse strength and ductility (longitudinal ductility is usually excellent in DS and single crystal alloys due to the absence of transverse grain boundaries when testing in the longitudinal direction).As shown in Table III and Figure 1 (test bars were machined from 1/4" thick x 2" wide x 4" long Rene'142 slabs), heat treat B was superior in longitudinal rupture to the lower solution temperature, A; this was due to increased solutioning of γ resulting from the higher solution (2335°F) heat treatment temperature of B compared to A (2300°F). Heat treat B, however, resulted in slightly weaker/less ductile transverse rupture properties than A. Heat treat C added a 2050°F primary age to the B heat treatment; this improved the longitudinal properties even further, but a reduction in the 1600°F transverse life/ductility was realized. The optimum heat treatment in this study, D, utilized a slower cool from the 2050°F primary age cycle; this resulted in an even further improvement in the 1600°F and 1800°F longitudinal life coupled with equal or better 1600°F and 1800°F transverse rupture properties. The 2000°F longitudinal and transverse properties were, however, somewhat reduced.

Table III. R'142 Rupture Tests from 1/4" Thick Slabs with Heat Treatments A to D
(Fast Cools Unless Otherwise Noted)

Test Direction*	Temp/°F	Stress/KSI	Life/Hrs	El/%	RA/%
		A - 2300F/2 Hrs + 1975/4 Hrs + 1650F/4 Hrs			
L	1600	65	319.1	21.5	37.0
L	1600	75	47.5	11.6	27.7
L	1800	35	73.4	16.6	39.4
L	1800	38.5	49.9	18.8	41.6
L	1800	40	38.3	22.3	38.8
L	2000	15	97.0	11.5	45.9
T	1600	65	49.9	1.8	1.3
T	1800	32	87.0	4.0	3.8
T	2000	10	85.5	1.4	0.6
		B - 2335F/2 Hrs + 1975F/4 Hrs + 1650F/4 Hrs			
L	1600	75	113.5	13.0	27.9
L	1800	40	45.9	22.9	51.3
L	2000	15	161.0	13.3	45.9
T	1600	65	50.4	3.5	3.8
T	1800	30	150.1	4.3	3.7
T	1800	32	4.6, 72.2	1.6, 1.5	1.3, 1.3
		C - 2335F/2 Hrs + 2050F/4 Hrs + 1975F/4 Hrs + 1650F/4 Hrs			
L	1600	75	121.4	14.5	28.4
L	1800	40	56.9	21.0	46.2
L	2000	15	293.4	21.4	63.0
T	1600	65	2.0	0.8	0.0
T	1800	32	107.2	2.7	2.5
T	2000	10	72.3	2.0	0.6
		D - 2335F/2 Hrs + 2050F/4 Hrs, One Hour Cool to 1975F + 1975F/4 Hrs + 1650F/4 Hrs			
L	1600	80	99.2, 81.9	13.1, 12.0	25.3, 22.8
L	1800	40	81.7	16.5	42.5
L	1800	30	376.2	21.4	52.2
L	2000	17.5	61.5, 67.6	15.8, 12.8	50.4, 32.0
T	1600	65	27.2, 129.4, 117.3	0.6, 2.3, 2.4	1.2, 2.5, 6.7
T	1800	30	189.1	3.4	5.6
T	1800	32	75.1, 100.4, 159.1	2.4, 2.8, 4.0	2.5, 1.2, 3.1
T	2000	10	22.6	2.5	1.9

* Longitudinal - L, Transverse - T

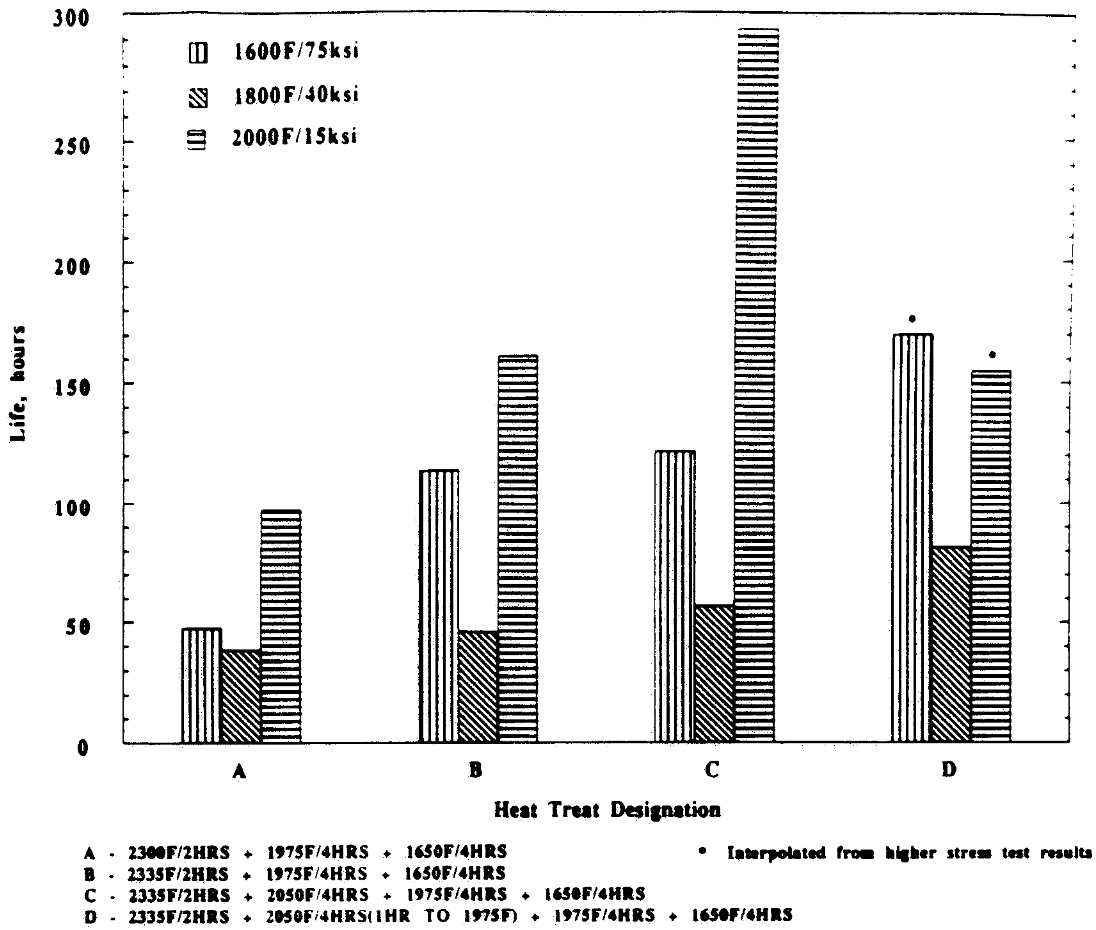

Figure 1. Rene'142 Longitudinal Rupture Test Results: Four Heat Treatment Variations

The D aging heat treatment cycle (2050°F slow cool, 1975°F and 1650°F) was evaluated on specimens machined from CF6-80C HPT blades which had been solution heat treated by the casting suppliers or GE; the Rene'142 specification allows the supplier to develop their particular solution heat treatment which will result in optimum solution of the γ - γ' eutectic and coarse secondary γ' with minimum incipient melting. The selected solution heat treatment (usually ≥2300°F) varies from supplier to supplier; the treatment is dependent on the part, the casting practice utilized (which determines the resulting casting segregation/dendrite arm spacing), the particular furnace utilized and the solution heat treatment heating rate/cycle. Table IV shows the results after rupture testing longitudinal ~.030" thick sheet specimens machined from CF6-80C high pressure turbine (HPT) thin walled airfoils from four suppliers. These lives are excellent; the 1800°F life is ~80% of the expected .160" diameter Rene'142 bar life. Table IV also shows the results of .160" diameter transverse rupture bars which were machined from CF6-80C HPT blade dovetails. These results show that the Rene'142 transverse rupture properties from blades are also acceptable with the supplier or GE solution treatments and the "D" age cycle.

Table IV. Rupture Properties From CF6-80C HP Turbine Blades*

Longitudinal Sheet Specimens from Airfoils
(Four Blades, Four Suppliers)
.028-.030" Thickness (2300F-2320F Solution Heat Treatments by Suppliers)

Temp/°F	Stress/KSI	Life/Hrs	El/%
1800	28	292.6, 318.6	19.6, 15.7
1900	19	255.2, 292.1	9.8, 15.3

Transverse .160" Dia. Bars from Dovetails

Casting Supplier	Solution HT. By	Temp/°F	Stress/KSI	Life/Hrs	El/%	RA/%
1	2335F (Supplier)	1600	60	303.5	2.6	5.5
1	2335F (Supplier)	1600	65	6.7	3.3	1.2
1	2335F (Supplier)	1800	32	145.4	6.1	3.4
2	2335F (Supplier)	1600	65	149.9	1.4	1.9
2	2335F (Supplier)	1800	32	112.0	4.9	1.2
2	2335F (Supplier)	2000	10	83.8	3.6	0.6
3	2335F (GE)	1600	65	178.6	4.0	3.7
3	2335F (GE)	1800	32	159.8	5.4	6.7
3	2325F (GE)	1600	65	70.0, 124.8	5.6, 3.3	15.6, 6.2
3	2325F (GE)	1800	32	185.7, 168.0	5.3, 6.3	6.2, 7.3
3	2300F (Supplier)	1600	65	35.8	1.0	2.5
3	2300F (Supplier)	1800	32	103.3	3.0	2.5
3	2300F (Supplier)	2000	10	175.3	2.3	0.1

* All blades had noted solution heat treatments and 2050F/4 hrs, cool to 1975F in 1 hour +1975F/4 hrs + 1650F/4 hrs aging treatments.

The D heat treat cycle was also evaluated on .160" dia. Rene'142 test bars, machined from 5/16" dia. rods, DS cast and solution heat treated by a casting supplier. These bars were primary aged, machined and thin Codep (aluminide) coated at 1975°F followed by a 1975°F - 15 Min fast cool heat treatment etc at GE. The rupture lives, Table V, were 30 to 130% greater than previously tested Codep coated bars which had been machined from slabs. The longer lives are believed due to the finer dendrite arm spacings (DAS) in the 5/16" dia. cast bars and the resultant improved γ-γ' solutioning. This DAS and improved solutioning is similar to the structure and solutioning found in the airfoils of thin walled turbine blades that are produced by the suppliers.

Table V. Codep Coated R142 Longitudinal Rupture Results

5/16" cast test bars were solutioned, machined to .160" dia., followed by heat treat D ages except the 1975°F cycle was a thin Codep coating + 1975°F/15 Minutes, fast cool.

Temp/°F	Stress/Ksi	Life/Hours	El/%	RA/%
1400	100	582.7	11	17
1800	30	288.7	16	35
1900	20	348.2	21	57
2000	13	399.4	15	46

Results: Alloy Stability

Metallographic examination of failed Rene'142 rupture bars has shown that the alloy is stable; no evidence of sigma or other topologically close-packed (TCP) phases have been seen. Rene'142 blades and slabs that had been exposed (unstressed) at 1400, 1600, 1800 and 2000°F for 1000 hours were also structurally evaluated by S.T. Wlodek of GE Aircraft Engines who concluded that the alloy was "extremely stable" (unpublished results).

Results: Oxidation Tests

Oxidation testing is performed in a burner rig where specimens are mounted in a rotating carousel which cycles to black heat (<1000°F) each hour. A pressurized air delivery system provides gas velocity at the pin hot section which approaches mach 1.0. During prescribed intervals the pins are weighed, measured and photographed.

The poor oxidation resistance of Rene'150 is highlighted in Figure 2, which summarizes testing performed at 2075°F. The excellent oxidation resistance of "first generation" single crystal alloys CMSX-3, PWA 1480 and Rene'N4 is apparent. The magnitude of improvement in oxidation of Rene'142 over these materials can be seen in Figure 3 which summarizes testing performed at 2150°F, an increase of 75°F over the previous data. Here Rene'142 performs better than "second generation" single crystal alloys CMSX-4 and PWA 1484. After 200 hours at 2150°F Rene'142 exhibits only 1 mil surface metal loss.

Studies have been completed on the effects of rare earth additions to the base Rene'142 chemistry. Figure 4 underscores the improvement with yttrium additions of very small amount. The yttrium measurements are taken from the average of three analyses made on the parent casting at the oxidation specimen test section. These additions also result in improved coated test lives when diffusion-type coatings are applied.

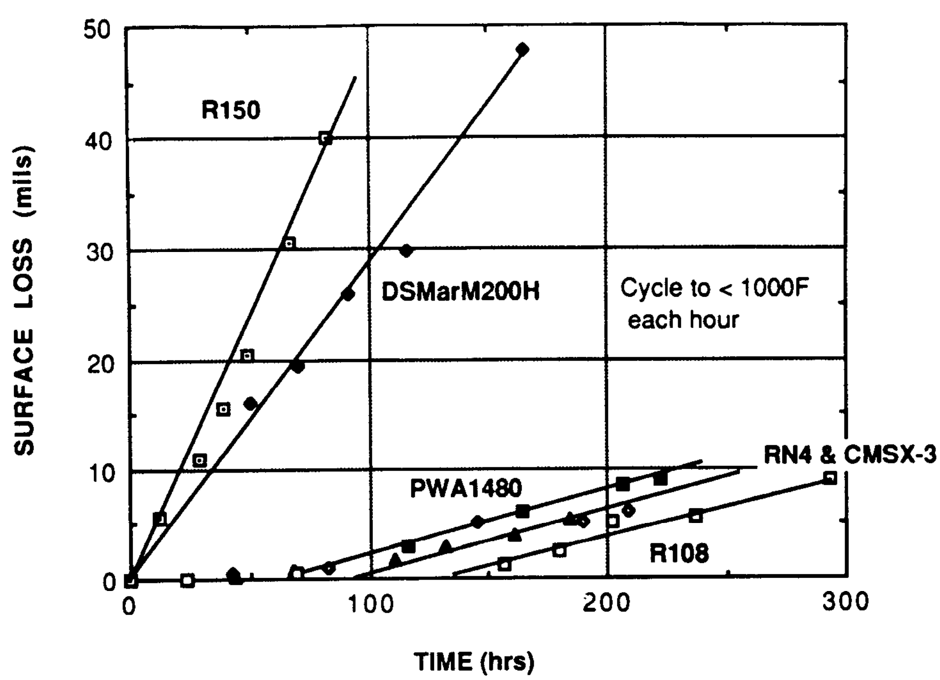

Figure 2. 2075F Mach 1.0 Oxidation

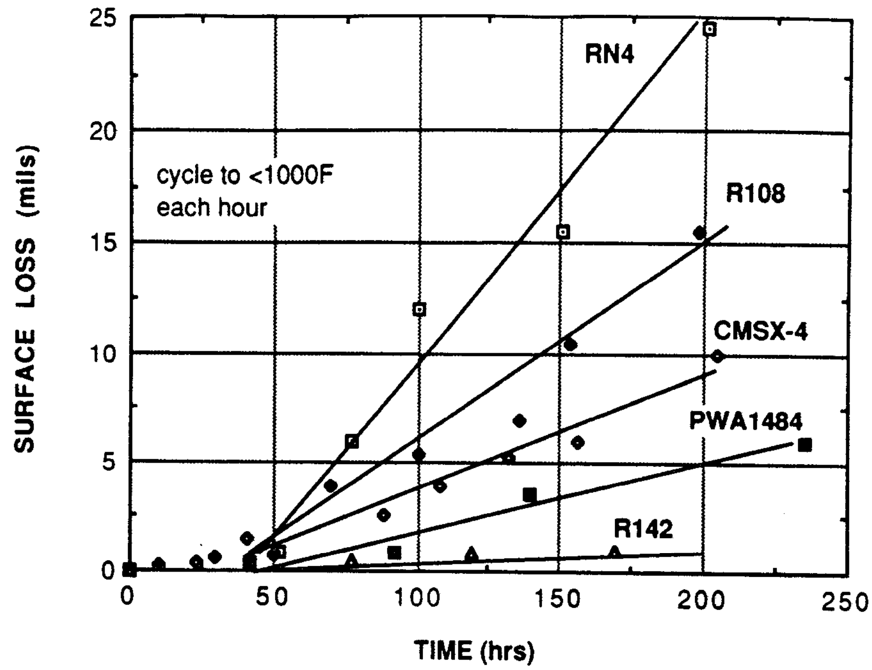

Figure 3. 2150F Mach 1.0 Oxidation

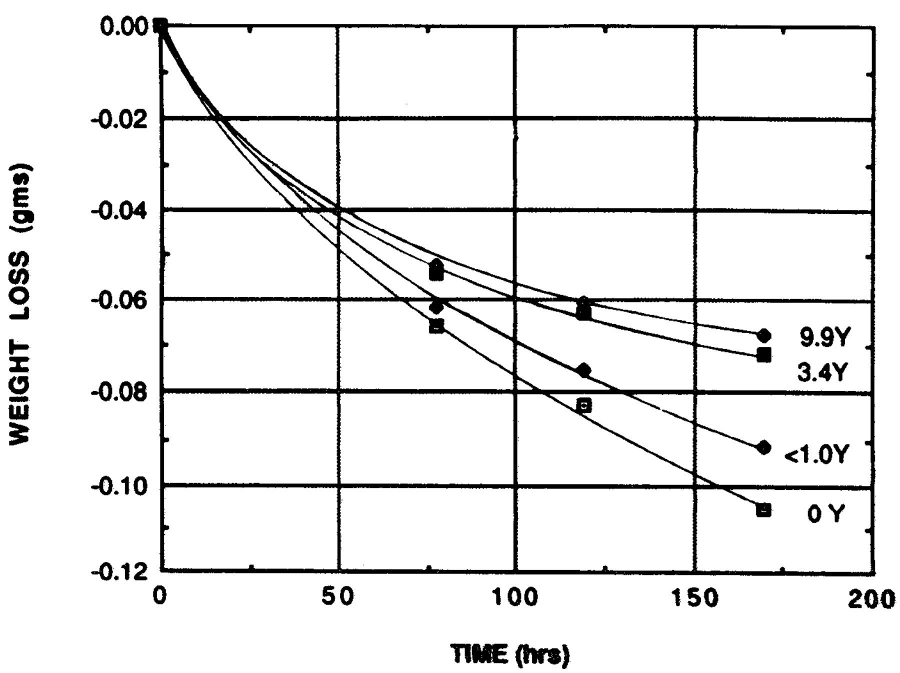

Figure 4. 2150F Mach 1.0 oxidation test results showing the influence of yttrium additions to Rene'142 in retarding oxidation attack, as measured by weight loss.

Summary

This paper describes the development and properties of a DS (with columnar grains) alloy, Rene'142, that has the rupture strength of the first generation of single crystal alloys (Rene'N4, PWA 1480 and CMSX-3) but with vastly superior oxidation resistance and lower part costs.

Acknowledgments

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