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NONFERROUS ALLOYS

1. GENERAL

Two alloys are treated in this section. Cb 132, a solution hardened alloy, and Cb 132M, a dispersion strengthened modification.

These two alloys are characterized as having moderate strength suitable for gas turbine blading. Such key fabricability factors as forgeability, weldability, and coatability are inferior to other candidate moderate strength Cb alloys.

1.01 Commercial Designations

Cb 132, Cb 132M

1.02 Alternate Designations

None.

1.03 Specifications

1.04 Composition

Table 1.04.

1.05 Heat Treatment

1.051 Cb 132. The temperature for 100 percent recrystallization in one hour is 3000F with a resulting grain size of ASTM 4 (2).

1.052 Cb 132M. The temperature for 100 percent recrystallization in one hour is approximately 3200F (3).

1.053 In process annealing temperature is 2500F for both alloys (3)(4).

1.06 Hardness

1.061 Cb 132. Average hardness after a 2760F, 1 hour anneal is 263DPH (4).

1.062 Cb 132M. Hardness of as rolled sheet is 336DPH while sheet heat treated at 3100F, 1 hour is 297DPH (3).

1.07 Forms and Conditions Available

1.071 Both alloys are available in forgings, extrusions, plate and sheet.

1.08 Melting and Casting Practice

1.081 Typical melting and working practice includes double vacuum arc-melting into 6-10 inch ingots (4).

1.082 Closed die forgings of Cb 132M indicate it to be more difficult to forge than Cb 752 or D43. High extrusion temperatures (over 2200F) impair the forgeability (5).

1.09 Special Considerations

1.091 Heating of Cb 132 or Cb 132M to incandescent temperatures in air for short times results in an oxygen contaminated surface. All testing and heat treatments should be in a vacuum better than 10^{-5} torr or when in ultra pure He or A, the specimen should be wrapped in Ta foil.

1.092 Creep testing for periods over 100 hours at 1800F or above must be conducted in a vacuum of 10^{-8} torr or better. A slight change in C level (~100 ppm) will be noticed after 500 hours at 2000F in ultra high vacuum(3).

1.093 Coating of Cb 132M with Ti-Cr-Si has a significant deleterious effect on the room temperature and elevated temperature tensile properties (9)(12).

1.094 Recrystallization heat treatments, 3200F and higher, reduces the room temperature elongation severely (9)(12).

1.0941 Recrystallized Cb 132M specimens when tested in tension failed in the threaded grips at stress levels below the proportional limit due to the extreme notch sensitivity of the recrystallized material (13).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range.

2.012 Phase changes. Cb 132 is strengthened by the solid solution effect of the Ta, W, and Mo. Cb 132M is strengthened by these same elements plus by the dispersion strengthening effect of (Cb, Zr) C and CbC(12).

2.0121 Results from the X-ray diffraction analyses of electrochemically extracted precipitates from Cb 132M, Table 2.0121 (12).

2.013 Thermal conductivity.

2.014 Thermal expansion.

3.0141 Coefficient of linear expansion at low temperature, Figure 2.0141 (6).

2.015 Specific heat.

2.016 Thermal diffusivity.

2.02 Other Physical Properties

2.021 Density, 0.385 lb/cu in (1).

2.022 Electrical properties.

2.0221 Electrical resistivity below 260F, Figure 2.0221.

2.023 Magnetic properties.

2.0231 Temperature dependence of the magnetic susceptibility at low temperatures, Figure 2.0231.

2.024 Emittance.

2.025 Damping capacity.

2.03 Chemical Properties

2.031 Cb 132 being an ungettered alloy (no Zr or Hf addition) will be corroded by alkali liquid metals and is not suitable for alkali liquid metal containment systems (7). The Cb 132M with its 1.5 percent Zr addition is more resistant to liquid metal corrosion and coupled with its high strength is a candidate for turbine components in potassium turbine alternators for Rankine systems (8).

2.032 Both alloys have to be coated (see 4.04) for use in an oxidizing environment.

2.04 Nuclear Properties

Cb
20 Ta
15 W
5 Mo
Zr
C

Cb 132

Cb
20 Ta
15 W
5 Mo
1.5 Zr
0.12 C

Cb 132M

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.02 Mechanical Properties at Room Temperature

3.021 Tension.

3.0211 Room temperature properties of recrystallized Cb 132, Table 3.0211.

3.022 Compression.

3.023 Impact.

3.0231 Impact of coated (V-Cr-Ti)-Si Cb 132M at room temperature (see Table 3.0331).

3.024 Bending.

3.0241 Room temperature bend ductility of Cb 132, Table 3.0241.

3.025 Torsion and shear.

3.026 Bearing.

3.027 Stress concentration.

3.0271 Notch properties (see Table 3.0211).

3.0272 Fracture toughness.

3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures

3.031 Tension.

3.0311 Stress-strain diagrams.

3.0312 Tensile properties of Cb 132 at elevated temperature, Figure 3.0312.

3.0313 Tensile properties of coated and uncoated Cb 132M forgings, Table 3.0313.

3.0314 In 1200F tensile tests, the Cb 132M alloy exhibits superior tensile properties at 1200F with equivalent ductility to other candidate turbine blade alloys (10).

3.0315 Effect of test temperature on elongation and reduction in area for Cb 132, Figure 3.0315.

3.032 Compression.

3.0321 Stress-strain diagrams.

3.033 Impact.

3.0331 Result of impact tests on TNV-7 coated Cb 132M at various temperatures, Table 3.0331.

3.0332 Results of impact test on TRW coated Cb 132M at various temperatures, Table 3.0332.

3.034 Bending.

3.035 Torsion and shear.

3.036 Bearing.

3.037 Stress concentration.

	Cb
20	Ta
15	W
5	Mo
	Zr
	C

Cb132

	Cb
20	Ta
15	W
5	Mo
1.5	Zr
0.12	C

Cb132M

3.0371 Notch properties.

3.0372 Fracture toughness.

3.038 Combined properties.

3.04 Creep and Creep Rupture Properties

3.041 Stress versus time to rupture for Cb 132, Figure 3.041.

3.042 100 hour total creep curves for Cb 132, Figure 3.042.

3.043 Minimum creep rate for Cb 132 heat treated at 3000 F, 1 hour and tested at 2400 F - 9000 psi is 0.00009 in/in/hr. Under these conditions, time to start third stage creep is 50.0 hours (2).

3.044 Creep data for Cb 132M, Table 3.044.

3.045 Cb 132M bar coated with TNV-7 (V-Cr-Ti)-Si when tested at 2200 F and 12.74 ksi had greater than 124 hours life (11).

3.046 Stress rupture life of Cb 132M in various conditions, Table 3.046.

3.05 Fatigue Properties

3.051 Fatigue properties of coated Cb 132M at 1800 F, Table 3.051.

3.052 Results of fatigue tests on TRW Ti-Cr-Si (vacuum) coated Cb 132M alloy in air at 2200 F, Table 3.052.

3.053 The thermal fatigue life of Cb 132M specimens coated by both the TRW Ti-Cr-Si vacuum and slip process was lower than other candidate systems, Cb 129y and D-43 and their coatings, by a significant margin. Cycling was performed by heating in a combusted JP-5 fuel and air mixture and cooling to 200 F - one minute at temperature plus 30 second air blast.

3.06 Elastic properties.

3.061 Poisson's ratio.

3.062 Modulus of elasticity.

3.063 Modulus of rigidity.

4. FABRICATION

4.01 Formability

4.011 General. The as melted ingot is surface prepared by machining and grinding, canned in either a Mo or Fe can and extruded at 2050 F to a 3-6 inch diameter billet. The conditioned billet is process annealed at 2500 F and further cold reduced with appropriate anneals to the desired bar, sheet, or plate. Final recrystallization anneal is carried out in vacuum at 3000-3200 F depending on the alloy (4).

The low ductility of recrystallized sheet (Table 3.0241) places Cb 132 and Cb 132M in the difficult to fabricate category. In the as processed condition, formability should be satisfactory. In such applications, operating use temperature must stay below the recrystallization temperature of 3000 F (2).

4.02 Machining and Grinding

4.03 Welding

4.031 GTA welding of Cb 132 recrystallized 0.030 inch sheet produced severe longitudinal weld shrinkage cracks that propagated into the base metal (2).

4.032 Diffusion bonding studies showed that satisfactory bonds can be obtained at 2200 F between Cb-10Ta-10W-1Zr sheet and Cb 132M plates. Samples bonded at 2200 F showed a smaller degree of carbon migration from the Cb 132M than those bonded at 2400 F. Bonding was facilitated by the use of a vanadium foil intermediate layer acting as an interstitial sink. (10).

4.04 Surface Treatment

4.041 Weight change of coated Cb 132M in an oxidation-erosion test compared to conventional super alloys, Figure 4.041.

4.042 Cb 132 sheet specimens were coated with Sylvania Al-Sn (R-505C) and TRW Ti-Cr-Si and exposed to static and dynamic tests. In the static test, exposure at various temperatures from 1300 to 2700 F in 25 hour intervals, the coating Ti-Cr-Si out-performed the Al-Sn. In the dynamic erosion test (rotated on a spindle at 1750 rpm in a JP-5 fuel air combustion atmosphere), the Sn-Al coating after 100 hours showed severe erosion effects while the Ti-Cr-Si coating looked satisfactory(2).

4.043 Cb 132M coated with TRW Ti-Cr-Si (vacuum) when tested in a combusted JP-5 fuel and air stream in a similar apparatus to that described in 4.042 demonstrated an oxidation-erosion life of 100 hours at 2200 F plus 40 hours at 2400 F. When the coating is applied using the TRW slip process, life is slightly poorer - 60 hours rather than 100 hours at 2200 F (13).

4.0431 Oxidation-erosion life of TRW Ti-Cr-Si (vacuum) coated Cb 132M as a function of temperature, Figure 4.0431.

4.044 Cb 132M tensile specimens coated with the Sylvania Sn-Al (505 F) coating were prestrained at 70 and 1300 F (typical turbine blade root temperatures at stresses up to 67 ksi)(proportional limit is 55 ksi) and then exposed to a 1300 F oxidizing environment for 8 hours. Specimens designed to avoid high stress concentrations showed no visual coating failures. All others failed in a brittle mode due to the notch sensitivity of the recrystallized base metal (13).

4.045 Effect of ballistic impact on oxidation life for Ti-Cr-Si specimens, Table 4.045.

TABLE 1.04

Source	(1)	
Alloy	Cb 132	Cb 132M
Element	Percent	
Tantalum	20	20
Tungsten	15	15
Molybdenum	5	5
Zirconium	-	1.5
Carbon	0.0010	0.1000
Oxygen	0.0200	0.0250
Hydrogen	0.0010	0.0010
Nitrogen	0.0020	0.0100
Columbium	Balance	

TABLE 2.0121

Source	(12)					
Alloy	Cb-20Ta-15W-5Mo-1.5Zr-0.12C					
Form	Forged Bar					
Condition	Extruded		Forged		Forged + 1 hr at 3600 F	
Zr/C Ratio	11:1(a)	21:1(b)	11:1	21:1	11:1	21:1
Phase	Amount of Phase in Specimen					
Cb_2C	appreciable	very little	very little	none	appreciable	some
CbC	major	some	none	none	major	major
(Cb, Zr)C	none	major	major	major	very little	none
ZrO_2	none	none	none	very little	none	very little

(a) 1.1 percent Zr, 0.10 percent C

(b) 1.9 percent Zr, 0.09 percent C

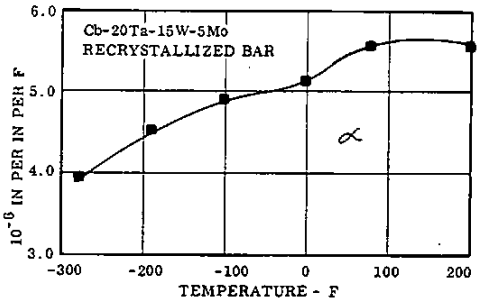

FIG. 2.0141 COEFFICIENT OF LINEAR EXPANSION AT LOW TEMPERATURE. (6)

TABLE 3.0211

Source	(2)
Alloy	Cb-20Ta-15W-5Mo
Form	0.030 inch sheet
Condition	Recrystallized 3000F, 1 hr
Notch	60° K_t = 7.5; 0.500 / .750; Notch Radius = 0.005
Temperature - F	RT
F_{tu} - ksi, (K_t = 1.0)	97
F_{ty} - ksi, (K_t = 1.0)	83
e(1 in)-percent(K_t=1.0)	1
NTS/F_{tu}	1.04

	Cb
20	Ta
15	W
5	Mo
	Zr
	C

Cb132

TABLE 3.0241

Source		(2)			
Alloy		Cb-20Ta-15W-5Mo			
Form		0.030 inch sheet			
Condition		As received, cross rolled		Recrystallized 3000F, 1 hr	
Direction		Parallel	Transverse	Parallel	Transverse
Bend Radius	*1T	Failed(59°)	Failed(65°)	Not Tested	
	5 1/3T	Failed(3°)	Failed (39°)	Failed(0°)	Failed (0°)

* 90 degree V-block with 12 inch per minute ram speed
Single tests for each condition

	Cb
20	Ta
15	W
5	Mo
1.5	Zr
0.12	C

Cb132M

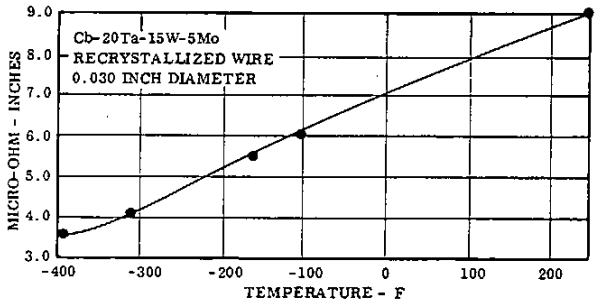

FIG. 2.0221 ELECTRICAL RESISTIVITY BELOW 260F. (6)

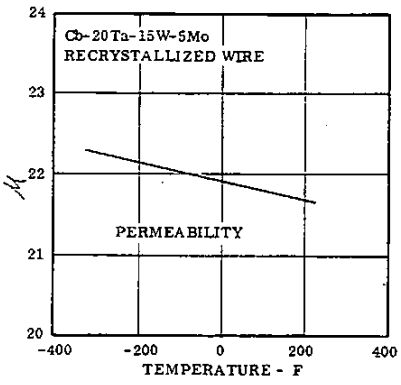

FIG. 2.0231 PERMEABILITY AT SATURATION AS A FUNCTION OF TEMPERATURE. (6)

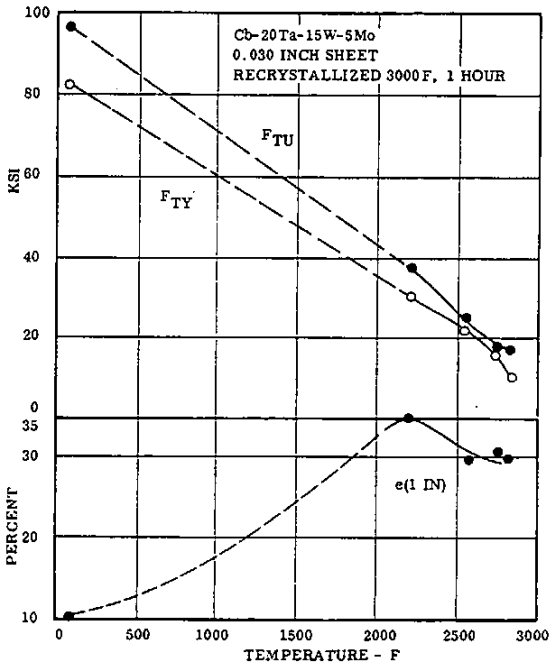

FIG. 3.0312 TENSILE PROPERTIES OF Cb-132 AT ELEVATED TEMPERATURE. (2)

	Cb
20	Ta
15	W
5	Mo
	Zr
	C

Cb132

TABLE 3.0313

Source	(9)(12)					
Alloy	Cb-20Ta-15W-5Mo-1.5Zr-0.1C					
Coating	TRW Ti-Cr-Si					
Condition	Uncoated				Coated	
Temperature-F	RT		2400		RT	2400
Prior Treatment	a	b	a	b	b	b
F_{tu}	131.8	89.2	56.7	58.3	35.6	42.7
F_{ty}	122.1	-	49.2	49.9	-	40.2
e (1 in) -percent	4	0.5	37	20	0	5

(a) As extruded (3400F) material prior to forge-extrude operation.
(b) Heat treated at 3600F, 1 hr after forging to a turbine blade.

TABLE 3.0331

Source	(11)		
Alloy	Cb-20Ta-15W-5Mo-1.5Zr-0.1C		
Form	0.5 inch bar		
Coating	(V-Cr-Ti)-Si (TNV-7)		
Temp - F	RT	1400F	2200F
Impact*, in-lbs	3-16	bent	bent

* Impact at 157 inch-pounds at a velocity of 136 inches per second (miniature Izod test, specimen 0.187 x .187 x 1.5 inch) is the capacity of the equipment.

	Cb
20	Ta
15	W
5	Mo
1.5	Zr
0.12	C

Cb132M

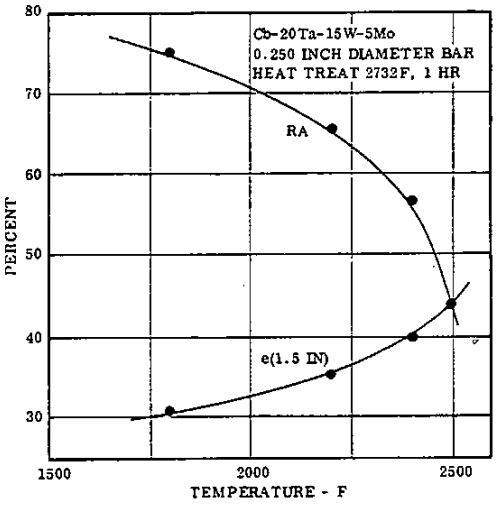

FIG. 3.0315 EFFECT OF TEST TEMPERATURE ON ELONGATION AND REDUCTION OF AREA FOR Cb 132. (4)

TABLE 3.0332

Source	(14)				
Alloy	Cb-20Ta-15W-5Mo-1.5Zr-0.1C				
Form	1.25 inch bar				
Condition	As extruded				
Type Test	Charpy - smooth				
Coating	TRW Ti-Cr-Si (vacuum) pack				
Condition	Uncoated	Coated			
Temperature - F	70	70	1400	1700	2000
IE (ft lb)*	5	0.75	2.25	1.25	4.75

* Average of two tests

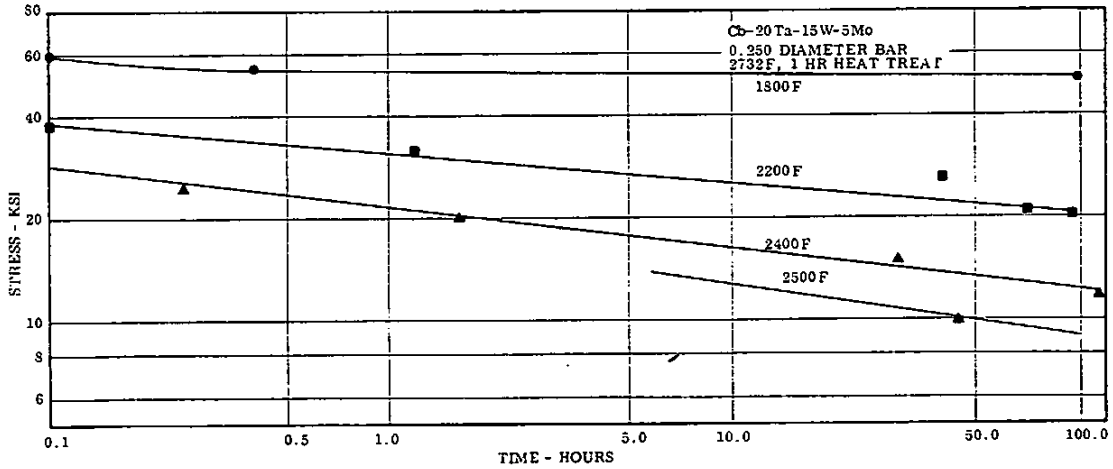

FIG. 3.041 CREEP RUPTURE CURVES AT VARIOUS TEMPERATURES FOR Cb 132. (4)

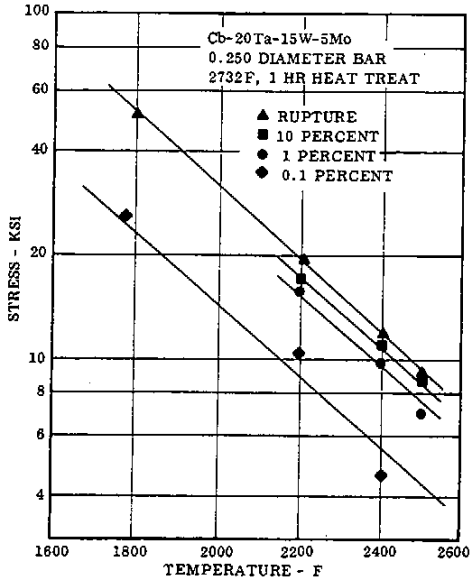

FIG. 3.042 100 HOUR TOTAL CREEP CURVES FOR Cb 132. (4)

TABLE 3.051

Source	(11)				
Alloy	Cb-20Ta-15W-5Mo-1.5Zr-0.1C				
Form	0.5 inch bar				
Condition	Coated with (V-Cr-Ti)-Si (TNV-7)				
Test Temp - F	1800				
F_{max} - ksi	51.0*	49.0	49.5	47.0	48.5
F_{min} - ksi	-	9.8	10.0	9.4	9.7
Cycles to failure	1/4	1760	2100	8470	11,630

*F_{tu}

	Cb
20	Ta
15	W
5	Mo
	Zr
	C

Cb132

TABLE 3.052

Source	(14)		
Alloy	Cb-20Ta-15W-5Mo-1.5Zr-0.1C		
Form	1.25 inch bar		
Condition	As extruded		
Coating	TRW Ti-Cr-Si (vacuum) Pack		
Test Condition	Air, 2200F		
Stress, ksi	50	40	35
Life - cycles	Failure 0.25×10^7	Failure 0.47×10^7	No Failure after 10^7

Note: All tests conducted in reverse bending using a resonant frequency of 600 cycles per second.

	Cb
20	Ta
15	W
5	Mo
1.5	Zr
0.12	C

Cb132M

TABLE 3.044

Source	(3)					
Alloy	Cb-20Ta-15W-5Mo-1.5Zr-0.1C					
Form	0.750 inch Plate					
Condition	Recrystallized 3092F, 1hr					
Temperature - F	2056				2256	
Stress - ksi	20		16.3		7.4	
Creep - percent	0.5	1.0	0.5	1.0	0.5	1.0
- hours	275	495	340	670	250	550
Minimum creep rate in/in /hr	2.0×10^{-5}		1.5×10^{-5}		1.8×10^{-5}	

TABLE 3.046

Source	(12)						
Alloy	Cb-20Ta-15W-5Mo-1.5Zr-0.1C						
Form	Forged Turbine Blade - Air Foil						
Stress, ksi	25						
Temperature - F	2400						
Chemistry	1.1 percent Zr - 0.1 percent C			1.9 percent Zr - 0.09 percent C			
Condition	1	2	3	1	2	3	4
Life - hours	26	1.9	57	12	1	58	20
e(0.5 in) - percent	44	40.5	13	30	39	11	-

1. As extruded
2. Forged.
3. Annealed 3600F, 1 hour
4. Annealed 3600F, 1 hr plus TRW Cr-Ti-Si coating (26,200 psi)

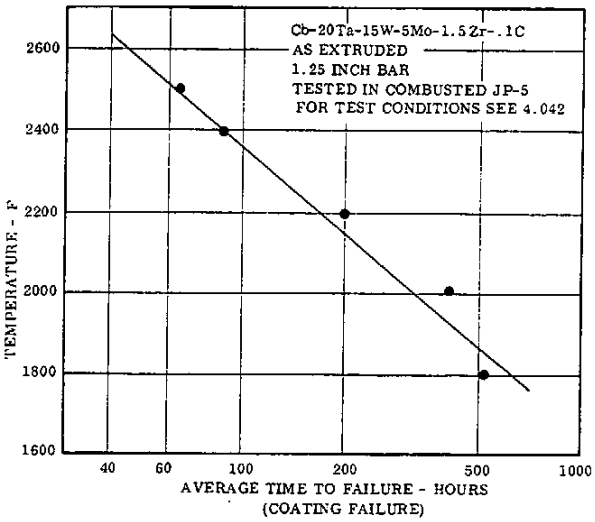

FIG. 4.0431 OXIDATION-EROSION LIFE OF TRW Ti-Cr-Si(VACUUM) COATED Cb 132M AS A FUNCTION OF TEMPERATURE. (14)

	Cb
20	Ta
15	W
5	Mo
	Zr
	C

Cb132

	Cb
20	Ta
15	W
5	Mo
1.5	Zr
0.12	C

Cb132M

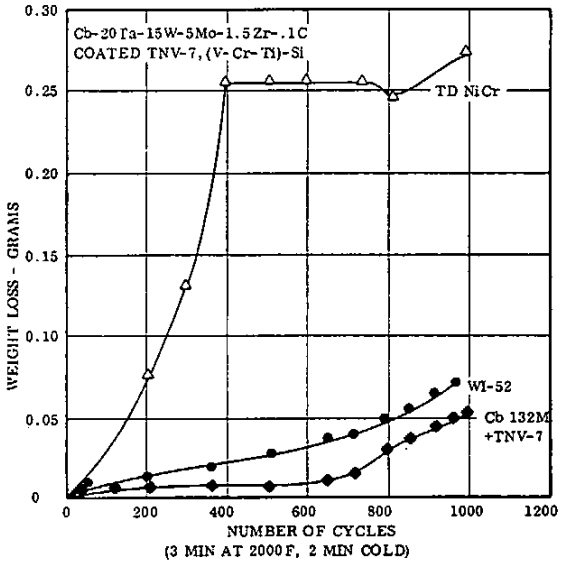

FIG. 4.041 WEIGHT CHANGE OF COATED Cb 132M IN AN OXIDATION EROSION TEST COMPARED TO CONVENTIONAL SUPERALLOYS. (11)

TABLE 4.045

Source	(13)									
Alloy	Cb-20Ta-15W-5Mo-1.5Zr-0.12C									
Form	0.125 x 0.5 x 2.0 inch coupons									
Condition	As extruded from 3400 F at 5:1 ratio									
Coating	TRW Ti-Cr-Si vacuum						TRW Ti-Cr-Si slip			
Specimen Temp - F (at impact)	70		2200			2400	70		2200	
Impact Velocity (a) (ft per sec)	200	500	200	500	900	200	200	500	200	500
Oxidation life at 2200F, after impact hours	(b)	8	(b)	8	5.5	9	5	5	5	5

(a) Weight of steel pellet - 0.75 grams
(b) Fracture

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