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DIVISION SNAP-8
TM 390:64-4-207
DATE 5 February 1964
W.O. 0740-34-2100
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TECHNICAL MEMORANDUM

AUTHOR(S): H. E. Bleil

TITLE: ACCELERATED EROSION TESTING OF CANDIDATE SNAP-8 TURBINE ROTOR AND NOZZLE MATERIALS

ABSTRACT

Materials specimens were exposed to a wet mercury vapor erosion environment. The environment was produced in a boiling condensing, closed pumped loop. Specimens were evaluated for resistance to erosion using weight changes as the criteria. Stellite 6B, a cobalt base alloy, exhibited greater resistance to erosion in the environment than the other materials tested.

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NOTE: This Technical Memorandum is intended as a supplement to TM 390:63-4-137, Selection of Accelerated Mercury Erosion Test Method

APPROVED:
DEPARTMENT HEAD R. S. Carey
R. S. Carey

NOTE: This document is considered preliminary and is subject to revision as analysis progresses and additional data are acquired. The general reader may encounter internal reference not available to him.

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I. INTRODUCTION

The SNAP-8 turbine rotors and nozzles will be exposed to wet mercury vapor at elevated temperatures. The caclulated relative velocity between the turbine blades and the mercury stream ranges from 356 to 400 ft/sec. The relative velocity between the nozzles and the mercury stream ranges from 587 to 631 ft/sec. The mercury quality ranges from 91.5 to 99.5%. The 10,000 hour life required of these components may not be attained unless a material with high resistance to erosion is employed. To provide a basis for the selection of rotor and nozzle materials, a test program was performed.

The selection of an accelerated erosion test method for the testing of candidate SNAP-8 rotor and nozzle materials is described in TM: 390:63-4-137. This method involves the use of the SNAP-8 Low Power Loop operated to provide low quality (85%), high velocity (1000 ft/sec) mercury vapor impinging on pintype materials specimens inserted in the loop. Materials samples were exposed to the accelerated erosion environment to provide data for the final selection of the material to be used for the SNAP-8 rotors and nozzles. This supplement to TM: 390:63-4-137 contains the additional data which was developed as well as a summarization of data previously obtained in evaluating the selected test method.

II. PROCEDURE

Pin-type erosion specimens were inserted in the Low Power Loop two inches downstream from the flow control nozzle as described in TM: 390:63-4-137. Tables I and II present the composition and heat treat condition of the specimens. The weight of each specimen was determined before exposure. After exposure, the specimens were vacuum decontaminated, reweighed, and the volume loss was determined. The volume loss of each specimen was computed to provide a direct comparison of erosion resistance between materials. Table III presents the results of all tests. Figure 1 compares the volume loss of all materials tested.

III. RESULTS AND DISCUSSION

The results indicate that Stellite 6B exhibited the greatest erosion resistance of all materials tested, see Table III, and Figure 1. Initial results with Dynacut Tool Steel heat treated to R_c66 indicated that this material was comparable to Stellite 6B in erosion resistance. This steel exhibited a hardness of R_c66 after tempering at 1100°F. The maximum turbine service temperature of 1150°F will result in further tempering of the material and a reduction in hardness. Samples were prepared using a tempering temperature more indicative of this service temperature. A 1200°F temperature was used. The resultant hardness decreased to R_c62. Erosion of the material heat treated to the softer condition was five times as great as the material in the harder condition and did not approach the resistance of the Stellite 6B. The 18-4-1 tool steel tempered at 1200°F exhibited better erosion resistance than the Dynacut tempered at the same temperature.

These results suggest the possibility of using more than one material in the various stages of the turbine. For example, Dynacut could be used for the last two stages where lower temperatures (889°F and 827°F maximums respectively) are prevalent; and Stellite 6B could be used for the higher temperature first two stages (1238°F and 1038°F maximums respectively), rather than using Stellite 6B throughout. However, changes in design to accomodate differing coefficients of expansion, and possible interchange of wheels in the unit during assembly, weighed against the cost savings which might be possible (approximately $90 materials cost per rotor plus potential savings in machining costs) indicate that the use of a single material of the most erosion resistant material would be most advisable.

SNAP-2 experience after 4300 hours of operation with PH15-7Mo turbine wheels indicate that this material would probably be suitable for the SNAP-2 rotors for 10,000 hours operation. Results of the SNAP-8 Low Power Loop tests indicate that Stellite 6B is approximately seven times as erosion resistant as the PH15-7Mo in the RH 950 condition. Based on the similarity of mercury velocity, and quality in the last stages of the SNAP-2 and the SNAP-8 turbines, Table IV, it is anticipated that less erosion of the Stellite 6B will occur in the SNAP-8 turbine than was experienced on the PH15-7Mo in the SNAP-2 turbine. While the mercury mass flow rate is greater in the SNAP-8 than in the SNAP-2 system, there is also a greater area over which the erosion will probably be distributed. On this basis, it is anticipated that the Stellite rotors and nozzles in the SNAP-8 turbine assembly will probably not be eroded as severely as the PH15-7Mo in the SNAP-2 system, and the liklihood of obtaining 10,000 hour operational life of the 6B rotors from an erosion standpoint is very high.

IV. CONCLUSIONS

1. Stellite 6B exhibits greater resistance to the accelerated mercury erosion environment than any of the other materials tested.

2. The erosion resistance in-service of the SNAP-8 Stellite 6B rotors will probably be as good and probably better than the PH15-7Mo condition RH 950 rotors of the SNAP-2 system which have operated 4300 hours and were predicted by TRW and NASA personnel to be capable of 10,000 hour operation.

V. RECOMMENDATIONS

Stellite 6B material is recommended for use in the SNAP-8 Turbine Assembly rotors and nozzles.

TABLE I

NOMINAL CHEMICAL COMPOSITION OF MATERIALS EXPOSED TO EROSION TEST ENVIRONMENT

	MAJOR ELEMENTS												
MATERIAL	C	Cr	Ni	Mo	Ti	Zr	Cb	Fe	W	Co	V	Cu	Cb+ Ta	Al
Mo Alloy-TZM	.02			Bal	.5	.08								
Mo-$\frac{1}{2}$Ti	.02			Bal	.5									
Cb-752	40PPM*					2.5	Bal		10					
17-4PH	.07*	16.5	4.0					Bal				4.0	.30	
Lapelloy	.30	11.8		2.8				Bal			.25			
AISI 347	.08*	18	10.5				10xc	Bal						
AISI 410	.15*	12.5						Bal						
PH 15-7 Mo	.09*	15.0	7.0	2.5				Bal						1.0
18-4-1 Tool Steel	.75	4.0						Bal	18		1.0			
Dynacut Tool Steel	1.23	3.75		8.7				Bal	1.8	8.2	2.0			
Stellite 6B	1.15	30	1.2	1.5				.8	4.5	Bal				

*Maximum

TABLE II

HEAT TREATMENT OF EROSION SPECIMEN MATERIALS

MATERIAL	HEAT TREATMENT	ROOM TEMPERATURE HARDNESS
TZM	Stress Relieved, 2250°F ½ hour	$28R_C$
Mo-½Ti	Stress Relieved, 2100°F 3/4 hour	$29R_C$
Cb-752	Stress Relieved, 2200°F 1 hour	$84R_B$
17-4PH	900°F 1 hour, Air Cooled	$44R_C$
Lapelloy	2000°F 1 hour, Oil Quench, 1200°F 2 hours	$34R_C$
AISI 347	1950°F, Water Quench	$71R_B$
AISI 410	1550°F, Furnace Cool 50°F/hr. to 1100°F	$95R_B$
PH15-7Mo	1750°F 10 min., Air Cool, -100°F 8 hours, 950°F 1 hour	$48R_C$
18-4-1 Tool Steel	2250°F Oil Quench, 1200°F 1 hour, Air Cool, 1200°F 1 hour	$55R_C$
Dynacut Tool Steel	2200°F, Oil Quench, 1100°F 2 hours, Air Cool, 1100°F 2 hours	$66R_C$
	2200°F, Oil Quench, 1200°F 2 hours, Air Cool, 1200°F 2 hours	$62R_C$
	2200°F, Air Cool, 1200°F 2 hours Air Cool, 1200°F 2 hours	$54R_C$
Stellite 6B	2250°F Rapid Air Cool, 1650°F 4 hours, Furnace Cool to 700°F, Air Cool	$39R_C$

TABLE III

TEST CONDITION AND RESULTS OF MATERIALS SPECIMENS

EXPOSURE TO EROSIVE ENVIRONMENT

MATERIAL	DENSITY (LB/IN^3)	ORIGINAL WT. GMS.	TEST TEMP. °F	EXPOSURE TIME-HRS.	WEIGHT LOSS-GMS	CLACULATED VOLUME LOSS ($IN^3 X 10^5$)
Mo-TZM	.369	9.8613	637	5	.8023	479.0
Mo-$\frac{1}{2}$Ti	.369	10.6385	653	5	.7061	421.6
Mo-$\frac{1}{2}$Ti	.369	9.7699	627	5	.6707	400.1
Cb-752	.326	7.1344	620	3.5	.5867	396.4
17-4PH	.281	7.9403	620	5	.1448	113.5
Lapelloy	.281	7.9118	620	5	.1483	116.3
Lapelloy	.281	7.9022	620	5	.1403	110.0
Lapelloy	.281	8.0322	620	4	.1329	104.2
AISI 347	.286	7.7620	628	5	.1145	88.3
AISI 410	.280	7.7548	629	5	.0749	58.9
PH15-7Mo	.271	7.5480	615	5	.0393	31.25
18-4-1 Tool Steel	.290	8.8753	620	5	.0173	13.14
Dynacut Tool Steel	.284	7.8966	620	5	.0369	28.62
Dynacut Tool Steel	.284	8.0063	620	5	.0216	16.75
Dynacut Tool Steel	.284	8.2336	639	14	.0070	5.42
Dynacut Tool Steel	.284	8.2336	655	5	.0045	3.49
Stellite 6B	.303	8.4745	636	15	.0091	6.61
Stellite 6B	.303	8.4770	625	15	.0088	6.40
Stellite 6B	.303	8.4745	650	5	.0059	4.29
Stellite 6B	.303	8.6966	620	5	.0055	4.00
Stellite 6B	.303	8.4770	637	5	.0046	3.34

TABLE IV

COMPARISON OF SNAP-2 AND SNAP-8 LAST STAGE TURBINE ROTOR CONDITIONS

	SNAP-2	SNAP-8
Inlet Mercury Vapor Velocity (ft./sec.)	794	631
Relative Entrance Velocity of Vapor (ft./sec.)	384	397
Percent Admission (%)	100	100
Mercury Vapor Quality Entering Rotor (%)	91	91.5
Stage Temperature (^{o}F)	620	704
Mercury Flow Rate (#/Hr.)	1242	9210
Rotor Mean Diameter (in.)	2.30	4.75
Blade Height (in.)	.3013	.527

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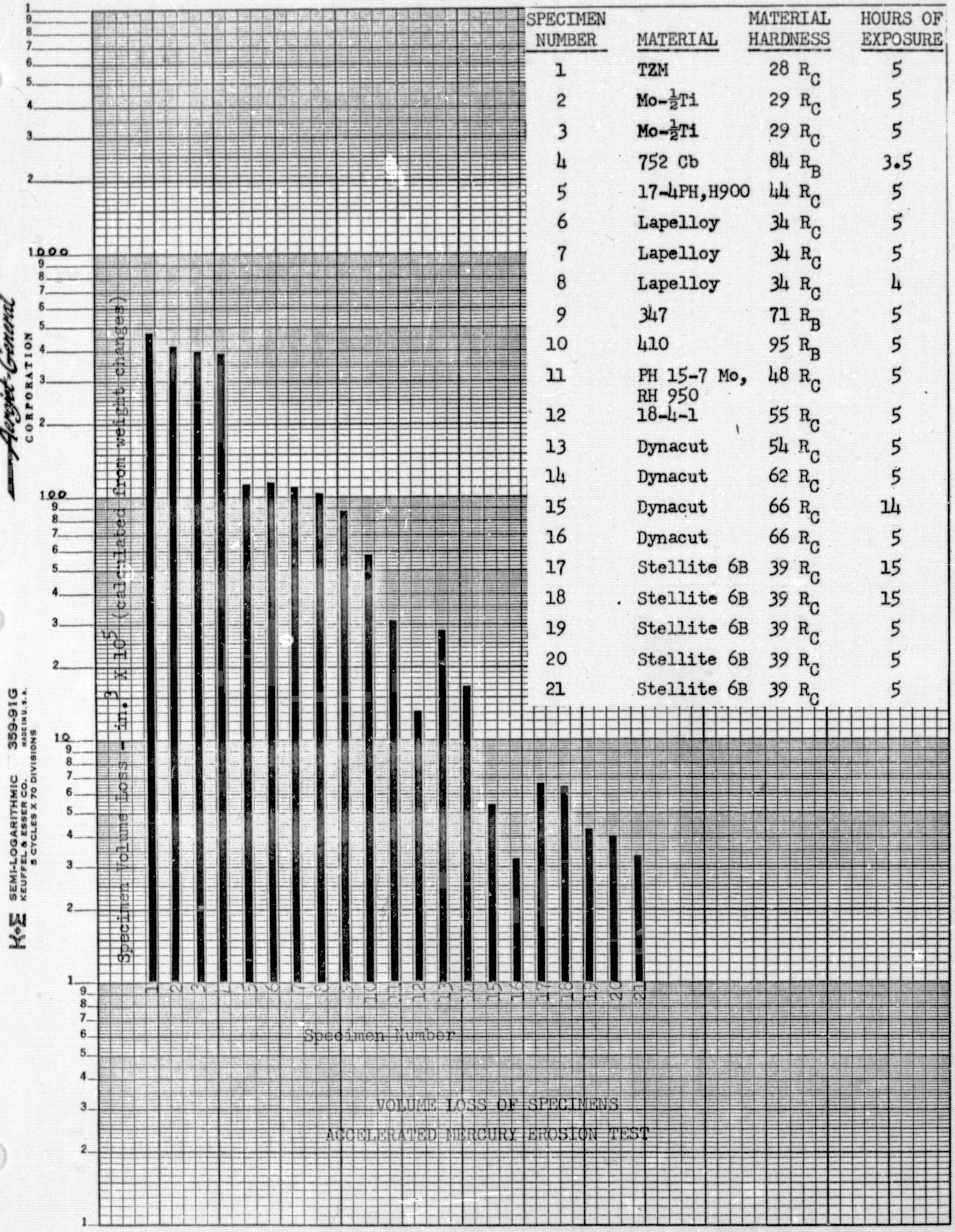

SPECIMEN NUMBER	MATERIAL	MATERIAL HARDNESS	HOURS OF EXPOSURE
1	TZM	28 R_C	5
2	Mo-½Ti	29 R_C	5
3	Mo-½Ti	29 R_C	5
4	752 Cb	84 R_B	3.5
5	17-4PH,H900	44 R_C	5
6	Lapelloy	34 R_C	5
7	Lapelloy	34 R_C	5
8	Lapelloy	34 R_C	4
9	347	71 R_B	5
10	410	95 R_B	5
11	PH 15-7 Mo, RH 950	48 R_C	5
12	18-4-1	55 R_C	5
13	Dynacut	54 R_C	5
14	Dynacut	62 R_C	5
15	Dynacut	66 R_C	14
16	Dynacut	66 R_C	5
17	Stellite 6B	39 R_C	15
18	Stellite 6B	39 R_C	15
19	Stellite 6B	39 R_C	5
20	Stellite 6B	39 R_C	5
21	Stellite 6B	39 R_C	5

VOLUME LOSS OF SPECIMENS

ACCELERATED MERCURY EROSION TEST

Figure 1