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RESEARCH MEMORANDUM

COMPARISON OF NATIONAL BUREAU OF STANDARDS CERAMIC COATINGS L-7C AND A-417 ON TURBINE BLADES IN A TURBOJET ENGINE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
December 22, 1948

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RESEARCH MEMORANDUM

COMPARISON OF NATIONAL BUREAU OF STANDARDS CERAMIC COATINGS L-7C AND A-417 ON TURBINE BLADES IN A TURBOJET ENGINE

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SUMMARY

An Investigation was conducted to determine which of two ceramic coatings L-7C and A-417 developed by the National Bureau of Standards is the more suitable as a protective coating for turbine blades in a turbojet engine. Four cast Vitallium turbine blades, two coated with each of these ceramics, were installed in the turbine wheel of a turbojet engine. Accelerated cyclic life tests were run by subjecting the turbine wheel to 20-minute cycles, consisting of $4\frac{1}{2}$ minutes at idling speed, 15 seconds of acceleration, 15 minutes at rated speed, and 15 seconds of deceleration.

At the end of five cycles, coating L-7C was rough and small ceramic beads and radial-flow lines appeared, indicating that the fusion temperature of the ceramic coating had been exceeded. Ceramic coating A-417 showed no evidence of flow. At the conclusion of 100 cycles, many of the L-7C beads that were formed during the first five cycles had. apparently been thrown off but coating A-417 still showed no evidence of flow. Both coatings flaked off to a alight extent at the tips of the blades but thie flaking was probably the result of dents in the blades caused by foreign particles hitting the blades and by accidental contact with the tail cone during work on the engine. Elongation measurements ehowed that the rate of elongation of the coated blades was within the same range as that of-newly operated uncoated cast Vitallium blades.

The thickness of the coating did not significantly change during the runs.

INTRODUCTION

The development of turbojet engines has created an increasing demand for high-strength materials for high-temperature service.

As a result, interest has been stimulated in the development of ceramics and ceramals for application in critical engine parts. This interest exists because of certain general advantages that ceramics have over metals, such as, higher melting points, lower densities, and more resistance to erosion and corrosion.

The National Bureau of Standards is conducting an extensive program of research and development of high-temperature ceramics and several ceramic coatings have been developed that may prove to be of value as ooatinge for gas-turbine blades.

An investigation was conducted at the NACA Lewis laboratory to determine the erosion resistance and adhesive qualities under actual conditions of engine operation of two of these ceramic coatings as applied to uncooled turbine blades by the National Bureau of Standards. Four cast Vitallium turbine blades, two coated with each of the ceramic coatings, L-7C and A-417, were installed in the turbine wheel of a turbojet engine and subjected to 20-minute cycles consisting of 5 minutes at idle and 15 minutes at rated speed.

Caet Vitallium blades were chosen for this investigation because they were readily available as standard service parts and, although there is no critical problem of corrosion or erosion with these blades, they are suitable bases upon which the ceramic coatings could be applied.

APPARATUS AND METHODS

Composition and application of ceramic coatings. - The National Bureau of Standards applied ceramic coatings to four new standard cast Vitallium I-40 turbine blades, whioh were installed in locations approximately 90° apart (fig. 1). The remainder of the blades in the turbine wheel were uncoated cast Vitallium. Information regarding the application of the coatings is summarized in table I.

The coefficients of thermal expansion were 6.5×10^{-6} per °F from 35° to 900° F, 4.45×10^{-6} per °F from 35° to 900° F, and 8.14×10^{-6} per °F from 70° to 900° F for L-7C, A-417, and cast Vitallium, respectively. a

The surface preparation of the cast Vitallium blades consisted of the complete removal of oil and grease. The coatings were applied with a spray gun. Detailed information on the oompoeition, preparation, and recommended application of the ceramic coatings is given in tables II to V.

Engine operation. -The engine was mounted on a pendulum-type sea-level test stand and was operated with AN-F-32 fuel. Engine speed was measured with a chronometric tachometer. Gas temperature was measured at the exhaust-cone outlet by 14 unshielded chromel-alumel thermocouples equally spaced about the circumference and extending radially 2 inches into the tail cone. The gas temperature at the exhaust-cone outlet was controlled by a variable-area jet nozzle. Turbine-blade elongation was measured by means of a dial indicator in conjunction with a jig fastened to the hub of the turbine wheel.

Cyclic engine-service runs were made with the following sequence of operation, which was designated one cycle:

Total running time		Engine speed (rpm)	Turbine tip speed (ft/sec)	Exhaust-cone temperature (°F)
(min)	(sec)			
4	30	4000±50	288	1100 max.
	15	Acceleration	---------	1450±50
15		11,500±50	829	1240±20
	15	Deceleration	---------	1260 max.

The engine was stopped at the end of each series of five cycles. At the end of the first five cycles and at the end of each series of 25 cycles, the blades were visually inspected and measured for elongation and photographs were taken of the ceramic-coated blades. A mirror was placed in front of the turbine blades in order that the photographs might show both the leading edge and the concave side of the blades. The total engine operating time for the investigation was 33 hours and 20 minutes (100 cycles).

RESULTS AND DISCUSSION

A ceramic-coated blade before installation in the engine is shown in figure 2. The coated blades had no previous running time and the appearance of all four blades was similar. Figure 1 shows the locations of the ceramic-coated blades in the turbine wheel. Blade 1 is shown in figure 3 after five operating cycles. During this first run, coating L-7C became rough and small ceramic beads and radial-flow lines appeared (probably as a result of the starting temperatures, which may have exceeded the 1650° F fusion temperature of the material). Turbine blade 3 had this same appearance. Blade 2 after the first five cycles is shown in figure 4. This A-417 coating, which has a fusion temperature of 1850° F, showed no evidence of flow. The appearance of blade 4 was similar.

Blades'1 and 2 at the end of 100 cycles are shown in figures 5 and 6, respectively. Many of the ceramic beads (coating L-7C), which were formed during the first five cycles, have disappeared but coatfngA-417 shows no evidence of flow. Both coatings flaked off somewhat at the tfp of the blades, but this flaking is probably the result of dents in the blades caused by foreign particles hitting the blades and by accidental contact with the tail cone while it was being removed in order to inspect the turbine wheel. 1030

The average elongation of the ceramic-coated blades was 0.65 percent at the end of 100 cycles. This value is compared with an average elongation of 0.57 percent for newly operated cast Vitallium blades at the end of105 cycles (reference 1). The difference is not considered significant. Comparison of the elongation of the ceramic-coated blades with that of the uncoatedblades in the same wheel was impossible because the uncoated blades were not new at the beginning of the program and rate of elongation changes with operating time.

The National Bureau of Standards measured the coating thicknesses before and after the runs with an estimated accuracy of about ±0.0002 inch. As shown in table I, there was no significant change in the thickness of coating A-417. The L-7C coating showed a measureable increase in the apparent coating thickness, which was caused by the roughness resulting from fusion during the runratherthan by a true increase in thickness.

SUMMARY OF RESULTS

The results of the investigation conducted to determine the suitability of National Bureau of Standards ceramic coatings L-7C and A-417 for turbine blades in a turbojet engine may be summarized as follows:

1, Ceramic coating A-417 showed. no evidence of fusion during loo operating cycles.

2. Ceramic coating L-7C showed evidence of fusion and radial flow, indicating that the 1650° F fusion temperature of the coating is too low for satisfactory service operation in the turbojet engine. At the conclusion of 100 cycles, many of the ceramic beads on coating L-7C, which were formed during the first five cycles, had been thrown off.

3. Both of the ceramic coatings flaked off at the blade tips but this flaking was probably entirely the result of collision with foreign particles and contact with the tail cone during inspection of the turbine wheel.

4. Elongation measurements shoved that the rate of elongation of the coated blades was approximately the same as that of newly operated uncoated cast Vitallium blades.

5. Measurements of the coatings before and after the runs indicated that there was no significant change in thickness.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCE

1. Farmer, J. Elmo, Darmara, F. N., and Poulson, Francis D.: Cyclic Engine Test of Cast Vitallium Turbine Buckets - 1. NACA RM No. E7J23, 1948.

TABLE I - APPLICATION OF CERAMIC COATINGS

Coating	Blade	Number of coats	Firing time (min)	Firing temper-ature (°F)	Average thickness[1]	
					Before run (in.)	After run (in.)
L-7C	1	2	10	1650	0.0013	0.0022
L-7c	3	2	10	1650	.0014	.0026
A-417	2	1	10	1850	.0012	.0019
A-417	4	1	10	1850	.0014	.0011

[1]All thickness measurements were made with National Bureau of Standards electronic thickness gage.

TABLE II - COMPOSITION OF CERAMIC COATINGS

Components	Coating	
	L-7c (parts by wt)	A-417 (parts by wt)
Frit 228R	70	-------------
Frit 331R	-------------	70
Chromic oxide (technical grade)	30	30
Enameling clay	6	6
Water	50	50

TABLE III - RECOMMENDED PREPARATION AND APPLICATION

OF CERAMIC COATINGS

	Coating	
	L-7C	A-417
Recommended milling in 1-gal-jar mill, revolutions	54,000	20,000
Average particle size after milling, mm	0.027	0.027
Recommended specific gravity for spray application	1.56	1.66
Recommended thickness of application, in.	0.0015 - 0.0030	0.0015 - 0.0030
Recommended firing temperature ^{o}F	3.650	1850

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TABLE IV - CALCULATED OXIDE COMPOSITIONS OF

. FRITS 228R AND 331R

	Frit	
	228R (percent by wt)	331R (percent by wt)
Silicon dioxide, SiO_2	51.9	38.0
Titanium dioxide, TiO_2	5.0	---------------
Aluminum oxide, Al_2O_3	5.4	---------------
Boron trioxide, B_2O_3	8.9	6.5
Potassium oxide, K_2O	5.2	---------------
Sodium oxide, Na_2O	13.7	--------NW-I---
Calcium oxide, CaO	----m---w------	4.0
Barium monoxide, BaO	---------------	44.0
Lead monoxide, PbO	5.0	---------------
Beryllium oxide, BeO	---------------	2.5
Zinc oxide, zno	---------------	5.0
Calcium fluoride, CaF_2	2.6	---------------
Cobaltous oxide, coo	1.5	---------------
Nickelous oxide, NiO	.5	---------------
Manganous oxide, MnO_2	.3	---------------

TABLE V - CALCULATED OXIDE COMPOSITIONS OF COATINGS

	Coating	
	L-7c (percent by w-t)	A-417 (percent by wt)
Silicon dioxide, SiO_2	37.5	28.3
Titanium dioxide, TiO_2	3.3	---------------
Aluminum oxide, Al_2O_3	5.5	1.8
chromic oxide, Cr_2O_3	28.6	28.6
Boron trioxide, B_2O_3	6.0	4.3
Potassium oxide, K_2O	3.5	---------------
Sodium oxide, Na_2O	9.1	---------------
Calcium oxide, CaO	---------------	2.7
Barium oxide, Bao	----w-w--w-----	29.3
Lead monoxide, PbO	3.3	---------------
Beryllium oxide, BeO	m---------w----	1.7
Zinc oxide, ZnO	---------------	3.3
Calcium fluoride, CaF_2	1.7	---------------
Cobaltous oxide, CoO	1.0	---------------
Nickelous oxide; NiO	.3	w---------w-a--
- s oxide, MnO_2	.2	-m-w--w--------

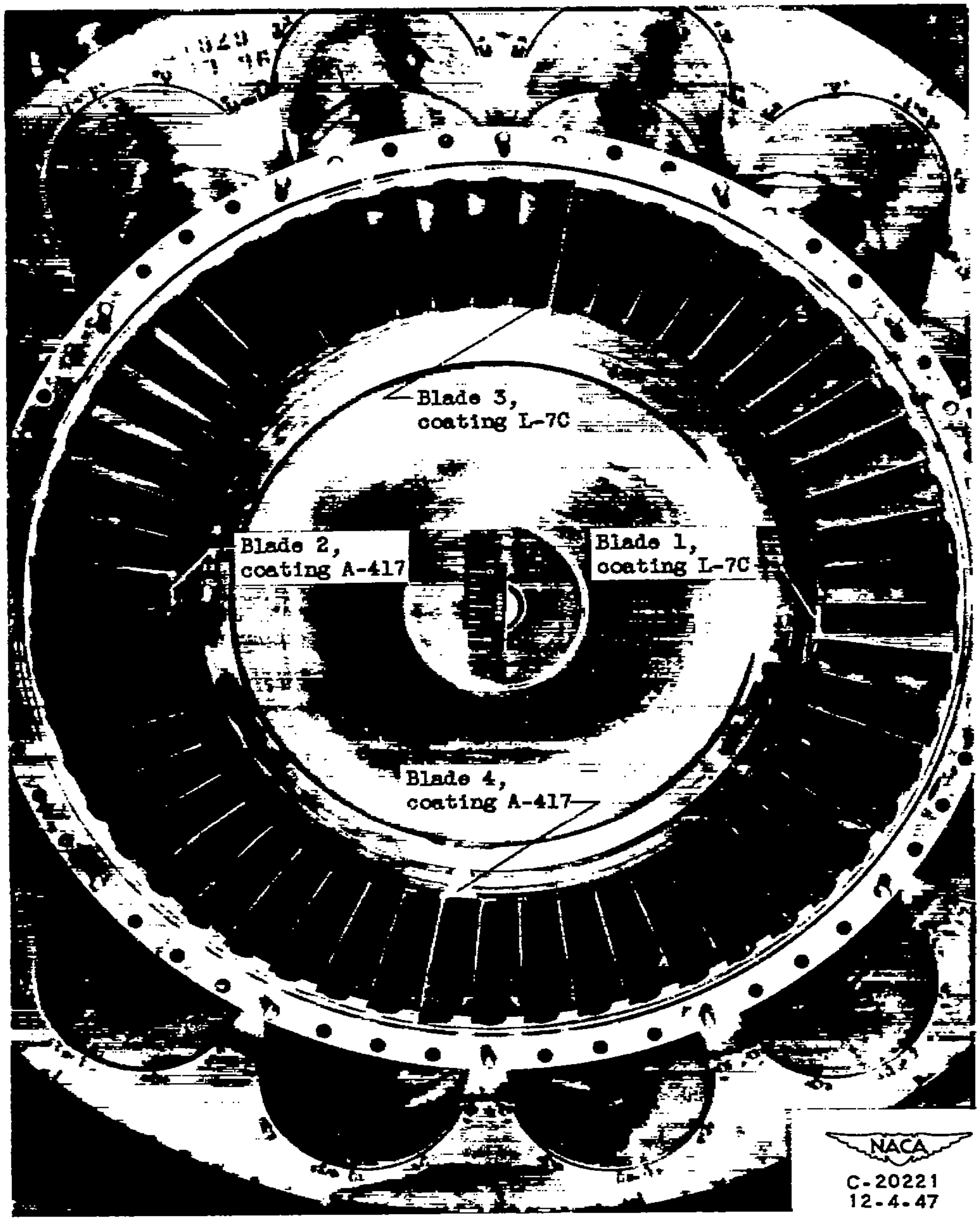
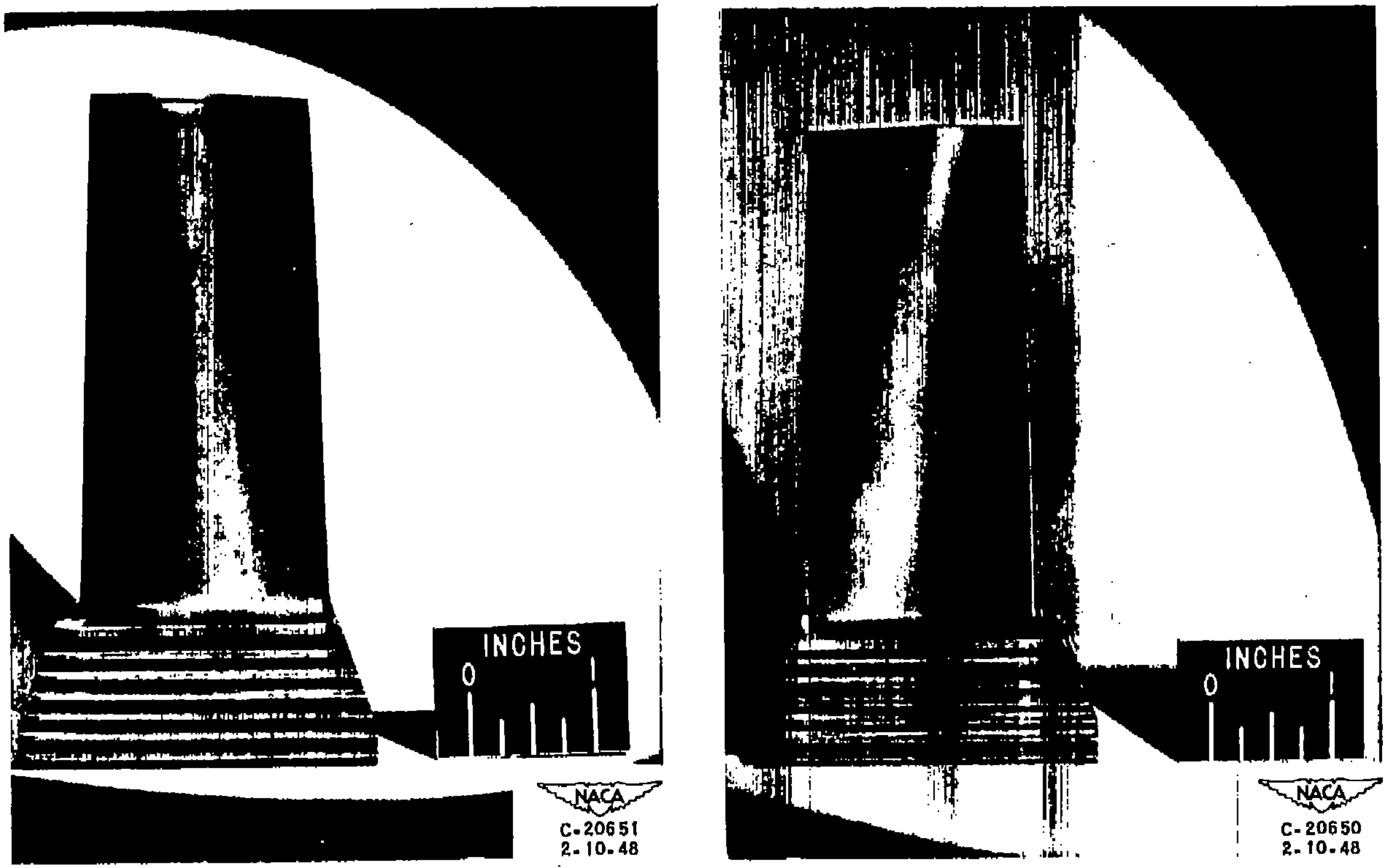


Figure 1. - Ceramic-coated cast Vitallium blades installed in turbine wheel before runs.



(a) Convex side.

(b) Concave side.

Figure 2. - Turbine blade with ceramic coating A-417 before run.

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(a) Leading edge and mirror reflection of concave side.

Figure 3. - Turbine blade 1 after five engine operating cycles (1 hr, 40 min). Ceramic coating L-7C.

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(b) Trailing edge and convex side.

Figure 3. - Concluded. Turbine blade 1 after five engine operating cycles (1 hr, 40 min). Ceramic coating L-7C.

(a) Leading edge and mirror reflection of concave side.

Figure 4. - Turbine blade 2 after five engine operating cycles (1 hr, 40 min). Ceramic coating A-417

(b) Trailing edge and convex side.

Figure 4. - Concluded. Turbine blade 2 after five engine operating cycles (1 hr, 40 min). Ceramic coating A-417.

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(a) Leading edge and mirror reflection of concave side.

Figure 5. - Turbine blade 1 after 100 engine operating cycles (33 hr, 20 min). Ceramic coating L-7C.

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(b) Trailing edge and convex side.

Figure 5. - Concluded. Turbine blade 1 after 100 engine operating cycles (33 hr, 20 min). Ceramic coating L-7C.

(a) Leading edge and mirror reflection of concave side.

Figure 6. - Turbine blade 2 after 100 engine operating cycles (33 hr, 20 min). Ceramic coating A-417.

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(b) Trailing edge and convex side.

Figure 6. - Concluded. Turbine blade 2 after 100 engine operating cycles (33 hr, 20 min). Ceramic coating A-417.