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COATINGS FOR AIRCRAFT GAS TURBINE ENGINES AND SPACE SHUTTLE HEAT SHIELDS: A REVIEW OF LEWIS RESEARCH CENTER PROGRAMS

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ABSTRACT

The status of several Lewis Research Center in-house and contractual coating programs is reviewed. This includes the efforts on protecting aircraft gas turbine engine materials from oxidation/corrosion and on protecting refractory metal re-entry heat shields from oxidation.

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SUMMARY

The Lewis Research Center is sponsoring a number of in-house and contractual programs to develop protective coatings for aircraft gas turbine engine components and for Space Shuttle re-entry heat shields. A Lewis duplex protection system for superalloys involving a NiCrAlSi clad, subsequently aluminized, has shown very good oxidation resistance--about a factor of three better than commercial aluminide coatings. The FS-85 alloy has been chosen as the most promising Cb alloy for heat shields, and processing scale-up for full-sized panels has progressed satisfactorily. The coatings for tantalum are definite improvements over existing coatings, but their heat shield potential has yet to be firmly established.

INTRODUCTION

Currently, the major areas of coating research being supported by the Lewis Research Center include the development of protection systems for aircraft gas turbine engine components and for Space Shuttle re-entry heat shields. The gas turbine oriented studies are directed toward providing oxidation/corrosion protection for nickel and cobalt turbine blade and vane alloys with some effort on titanium compressor materials. The Space Shuttle oriented studies are primarily directed toward providing 100 mission protection for columbium and tantalum re-radiative heat shields which are candidates for the Orbiter vehicle. Some studies also involve the evaluation and development of waterproof, high-emittance coatings for fibrous ceramic external insulation heat shields.

The purpose of this paper is to provide an overview of the Lewis in-house and contractual coating program and to highlight some of the areas of progress. The table summarizes the total program, indicates the approximate time span for each effort, and provides a rough estimate of the publication date for major or final reports. The following sections will review the programs listed in the table and will identify the progress being made.

COATINGS FOR AIRCRAFT GAS TURBINE ENGINES

Superalloys

Lewis has supported a continuing effort to characterize, evaluate, and improve the available high temperature protection systems for superalloy turbine components. One growing area of concern involves the influence of such coatings on the increasing number of thin-walled, air-cooled turbine blades and vanes that are being used in advanced engines; a situation where the coating thickness and interdiffusion zone is a significant fraction of the total coating-substrate cross-section. An effort is now underway at GE, West Lynn (NAS3-15557) to quantitatively evaluate the influence of both pack aluminide and CoCrAlY coatings on 0.075, 0.11, and 0.15 cm (0.030, 0.045, and 0.060 in) thick cast sections of Rene 80. The effects of such coatings on the metallurgical stability of the substrate; on the tensile, stress-rupture, thermal and mechanical fatigue, and ballistic impact properties of the composite before and after oxidation and hot corrosion exposure; and on the stress-exposure behavior will be examined. These studies are just beginning since prior effort was directed toward specimen fabrication and coating.

Coating development studies are also progressing. Work on aluminide coating development and evaluation has continued. Under NAS3-14300 (GE, Schenectady), fused salt metalliding is being used to deposit aluminide coatings. Tests to-date indicate that the deposition of only aluminum is more effective than depositing aluminide coatings in which a second element such as Ti is incorporated. Pack cementation variable effects are still being investigated at Lewis to develop a better understanding of the relationship between activator, pack temperature, and time. These studies are supported by an analytical effort which includes comparison of data obtained by electron microprobe (EMP) analysis and ion beam mass spectrometric (IBMS) analysis. As expected, the EMP with a 1 micron beam offers better microanalysis than the IBMS with a 300 micron beam which integrates compositional variations. The IBMS, however, is quite sensitive to light elements as well as heavy elements and supplements EMP coating characterization (1). Both approaches, however, require standards of phases similar to those in the coatings and of known composition before the results can be considered truly quantitative.

The evaluation of promising commercial, developmental, and experimental coatings is continuing at Lewis using the Mach 1 burner rig developed at the Center. These efforts have two purposes. First, there is a definite need to develop readily available, comparative data on the more promising systems. Second, there is a need to develop standard test procedures employing both simple furnace testing and more realistic burner rig exposures. The latest report in this regard (2) has shown that the life of a developmental aluminide coating on B-1900 decreased by a factor of seven in cyclic furnace tests at 1090 °C when the cooling cycle frequency was increased from once each 20 hours to once each hour; raising the exposure temperature by 40 °C from 1050 ° to 1090 °C decreased the 20-hour cyclic life by a factor of ten. At 1090 °C (1 hour cycles) under the more severe Mach 1 burner rig test conditions, the coating on moderate thermal stressed regions of the test specimens degraded about four times as rapidly as in one hour cyclic furnace tests at 1090°C. At the highly thermal stressed leading edges, the coating degraded about 20 times as rapidly as in comparative cyclic furnace tests.

Alternate, improved protection systems are also under development at Lewis. A nickel slurry coating has been developed that is sintered on nickel and cobalt superalloy substrates. The result is a nickel surface layer and enrichment of the superalloy surface in nickel. When this pre-coat is subsequently aluminized, the resulting coating offers improved thermal fatigue resistance for IN-100 and extended protection for WI-52 under Mach 1 burner rig tests as compared to commercial aluminide coatings (3). The improved thermal fatigue resistance may be due to a reversal of the normal compositional gradients in that here enrichment of the surface in nickel rather than surface depletion occurs. Thus, the brittle carbide rich zone which generally forms in the nickel-depleted region at the coating-substrate interface does not develop.

Lewis has also been conducting studies on metallic claddings for superalloys as a way of evaluating, on an idealized basis, the protective ability of highly oxidation resistant metal overlay systems (4,5). These claddings have shown very promising furnace oxidation resistance but specimens tested in the Mach 1 rig showed cladding losses at the leading edges. However, a NiCrAlSi cladding, 0.127 mm thick, subsequently aluminized to a depth of about one-third of the cladding thickness, protected IN-100 for over 800 hours in Mach 1 tests at 1090°C (5). This is the most protective system yet tested at Lewis and is a factor of about three improvement over the best commercial coatings on IN-100 tested to date.

Auxiliary in-house Lewis studies have identified a promising plasma sprayed Ni-Cr system which when subsequently aluminized appears to offer potential for oxidation protection of stainless steel--a material which has potential for use in low-cost engines (6). Also, supporting studies on the degradation of aluminide coatings have identified the presence of a martensitic transformation in the NiAl coating phase after oxidation testing. The implications of this transformation are currently under investigation (7). In addition, furnace oxidation studies on bulk NiAl containing 0, 1, 3, and 10 atomic percent of Ti, Cr, and Si substituted for Al have been conducted at 1100°C. At the 10 percent level, these additions lowered the oxidation resistance of NiAl; the one percent Si may have offered a slight improvement in oxidation resistance (8).

Thoria Dispersion-Strengthened Ni and Ni-Cr Materials

Two contractual efforts to develop diffusion-resistant coatings for dispersion-strengthened Ni and Ni-Cr materials for use above 1150°C are nearly complete. Under NAS3-14312 (Solar) no barrier prevented interdiffusion of FeCrAl claddings and the substrate materials while a tungsten-based slurry barrier limited the inward diffusion of Al from NiCrAl coatings on TD-NiCr at 1260°C. At this temperature, loss of Al by surface oxidation, as well as edge attack, limited the life of such a coating to less than 44 hours in cyclic furnace tests. Within this time period, the mechanical properties of the substrate were generally preserved. Under NAS3-14314 (GE, Evendale) cobalt alloys such as X-40 are being deposited on dispersion-strengthened nickel and nickel-chromium materials and are then aluminized. While tests to date in both programs indicate some progress toward providing extended high temperature oxidation protection for dispersion-strengthened materials, the coating lives do not yet approach the stress-rupture lives at useful stress levels.

Titanium

An exploratory effort is underway at TRW under NAS3-14339 to develop oxidation protection (to 650°C) and hot salt stress corrosion protection (to 480°C) for Ti-6Al-2Sn-4Zr-2Mo with spot checks on the all-beta alloy Ti-13V-11Cr-3Al. Many of the coatings appear to minimize weight change in oxidation testing and some also appear not to degrade the substrate mechanical properties after 100 hours in air at 650°C. The full potential of these coatings containing Al, Si, and additions of Mg, Cr, Ni, Fe, etc. are yet to be established however.

COATINGS FOR SPACE SHUTTLE THERMAL PROTECTION SYSTEMS (TPS)

Columbium

The program at McDonnell-Douglas/Sylvania (NAS3-14307) has examined the oxidation resistance; the mechanical properties before and after simulated re-entry exposure; and the small panel performance under simulated lift-off and re-entry conditions for R512E coated Cb-752, FS-85, and C129Y alloys. All coated alloys showed over 150 cycles of resistance under both external and internal pressure simulation before any evidence of local coating breakdown. Properly coated rib-stiffened panels of FS-85 and Cb-752 survived 100 cycles of stress-pressure-temperature simulation without local coating failure. Some C129Y panels were thinly coated on the highly stressed ribs. While local coating breakdown occurred at 40 cycles under external pressure conditions (35 torr maximum), two such panels survived an additional 47 cycles before structural failure. Under internal pressure conditions (5 torr maximum), local coating breakdown occurred after 70 cycles but no structural failures occurred within 100 cycles. In this program, considerable progress has also been made on process modifications which allow full sized 51 x 51 cm (20" x 20") panels to be uniformly coated.

Based on the above tests, any of the three R512E coated alloys appeared satisfactory for Space Shuttle TPS service. Additional considerations of alloy manufacturing, ease of panel fabrication, and creep strength led to the selection of FS-85 for the final coating program studies. Also, the R512E coating showed slightly more diffusional stability on FS-85 than on the other alloys. (Recent arc test data seem to support this choice of alloy-coating combination).

An advanced "fail-safe" TPS protection system is also being sought. The approach under study involves cladding the solid solution strengthened FS-85 with the more oxidation resistant but weaker B-1 alloy (Cb-15Ti-10Ta-10W-2Hf-2.5Al), and subsequently overcoating with an appropriate fused slurry silicide coating (NAS3-15546 - McDonnell-Douglas/Westinghouse/Sylvania). The program is in its early stages wherein the roll cladding process is being developed to apply B-1 to FS-85 and the feasibility of the approach has yet to be demonstrated.

Tantalum

Two programs are being conducted to improve fused slurry silicide coatings for tantalum alloys in order to better assess their potential for Space Shuttle service (NAS3-14315, Solar/NAS3-14316, Lockheed). The goal of these programs is 100 mission reuse at temperatures in the 1425-1540°C range with a minimum of refurbishment between flights. Several promising coating systems have been identified in both programs for use at 1425°C. For example, the Mn-Ti-Si coating of Lockheed has protected Ta-10W sheet for between 50 and more than 100 simulated re-entry cycles at both 0.1 and 10 torr. At 1540°C, however, 0.1 torr lives were only 5 to 10 cycles and 10 torr lives ranged near 40 cycles. Tensile tests of the Mn-Ti-Si coated Ta-10W after 1425°C exposures indicated a general increase in strength with cycles, but the elongation decreased only slightly from that of the as-received sheet, even after 88 exposure cycles.

TABLE

PROGRAMS ON COATINGS SUPPORTED BY LEWIS RC

Program designation	Program description	Program duration	Estimated date of major/final report
Aeronautics			
NAS3-14300 (G. E.)	Fused salt bath aluminide coatings for IN-100 and TD-NiCr	May '70 - Oct. '71	Jan. '72
NAS 3-14312 (Solar)	Alloyed coatings for TD-materials	June '70 - Aug. '71	CR 120852 Jan. '72
NAS 3-14314 (G. E.)	Enriched aluminide coatings for dispersion strengthened materials	June '70 - June '72	Oct. '72
NAS 3-15557 (G. E.)	Evaluation of coatings on thin-walled super-alloys	June '71 - June '72	Oct. '72
NAS 3-14339 (T.R.W.)	Coatings for titanium	May '71 - Aug. '72	Nov. '72
YOG0603 (Lewis RC)	Evaluation and development of aluminide coatings and metallic claddings for super-alloys	Continuing effort	Several in '72
YOG3704 (Lewis RC)	Advanced coating concepts	Continuing effort	June '72
Space shuttle			
NAS 3-14307 (McD-D/ Sylvania)	Optimization/scale-up of coatings for Cb TPS	June '70 - Sept. '72	Nov. '73
NAS 3-15546 (McD-D/ West./ Sylvania)	Outer skin protection for Cb TPS	May '71 - Sept. '72	Nov. '73
NAS 3-14315 (Solar)	Coatings for TA TPS	June '70 - June '72	Sept. '72
NAS 3-14316 (Lockheed)	Coatings for TA TPS	June '70 - June '72	Sept. '72
YOG3837) (Lewis RC)	Evaluation of contractor coatings and Cb/TA coating improvement	Continuing effort	May '72
YOG5100 (Lewis RC)	Characterization and coatings for RSI	Continuing effort just started	Dec. '72