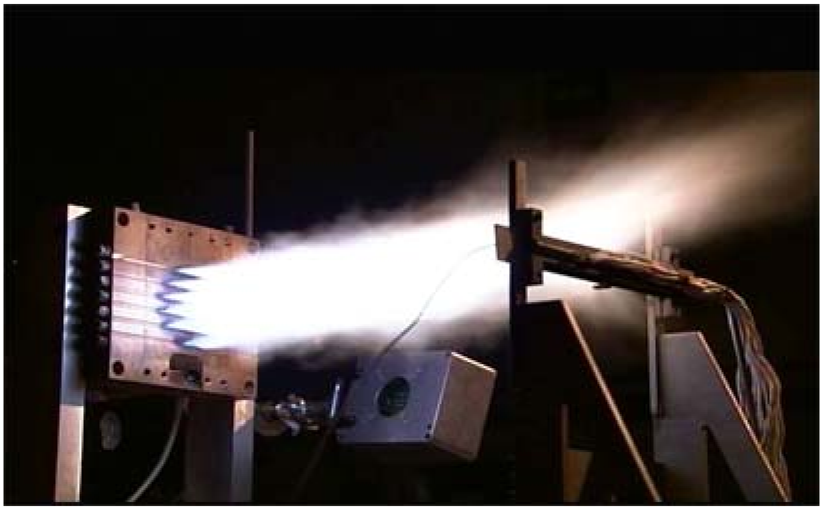
Quick Access Rocket Exhaust Rig Testing of Coated GRCop-84 Sheets Used to Aid Coating Selection for Reusable Launch Vehicles

The design of the next generation of reusable launch vehicles calls for using GRCop-84 copper alloy liners based on a composition[1] invented at the NASA Glenn Research Center: Cu-8(at.%)Cr-4%Nb. Many of the properties of this alloy have been shown to be far superior to those of other conventional copper alloys, such as NARloy-Z (ref. 1). Despite this considerable advantage, it is expected that GRCop-84 will suffer from some type of environmental degradation depending on the type of rocket fuel utilized. In a liquid hydrogen (LH_2), liquid oxygen (LO_2) booster engine, copper alloys undergo repeated cycles of oxidation of the copper matrix and subsequent reduction of the copper oxide, a process termed “blanching” (ref. 2). Blanching results in increased surface roughness and poor heat-transfer capabilities, local hot spots, decreased engine performance, and premature failure of the liner material. This environmental degradation coupled with the effects of thermomechanical stresses, creep, and high thermal gradients can distort the cooling channel severely, ultimately leading to its failure (ref. 3).

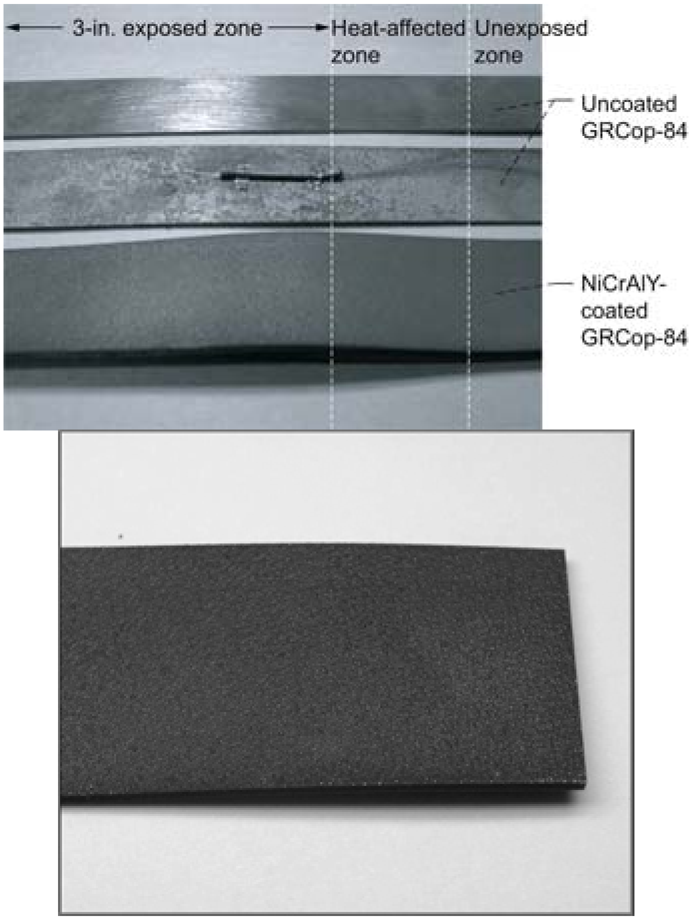
The application of protective coatings on a GRCop-84 substrate can minimize or eliminate many of these problems and extend the operational life of the combustion liner (ref. 3). Such coatings may increase component reliability, shorten depot maintenance turnaround time, and lower operational costs. Therefore, Glenn is actively pursuing the development of advanced overlay coatings technology for GRCop-84 liners. This research effort encompasses the development of technology in four major areas: (1) new metallic coating compositions, (2) application techniques, (3) test methods, and (4) life-prediction design methodology using finite element analysis. This report discusses the results of a specific test method involving the exposures of coated GRCop-84 sheets to a H_2/O_2 combustion flame in Glenn’s Quick Access Rocket Exhaust (QARE) rig.

Both faces of several 1-mm-thick GRCop-84 sheets, having a cross-sectional area of about 305 by 305 mm^2, were vacuum plasma sprayed with the desired coating. The coatings selected for these evaluation studies were Cu-26Cr, NiAl, and NiCrAlY. The sheets were observed to have distorted during the spraying process. Test specimens were machined from these coated sheets, where each specimen was about 305 mm long and 25.4 mm wide. Both coated and uncoated specimens were subjected to an intense H_2/O_2 combustion flame using a mixture ratio of about 6, where the specimens either were cycled between room temperature and approximately 700 °C for 20 cycles or were subjected to a constant flame exposure for a cumulative time of about 10 min (see the following photograph). The specimens were held in a specially designed fixture and subjected to backside air and conductive cooling. Prior to the exposure tests, a superalloy sheet specimen was instrumented with five thermocouples to calibrate the rig. In a typical cycle, the specimen reached a temperature of about 700 °C within 20 sec, whereas the cool down to room temperature occurred in 300 sec.



QARE rig testing of a coated GRCop-84 sheet.

A visual examination of the exposed specimens revealed that uncoated GRCop-84 specimens undergo severe environmental degradation that results in oxide spall and surface roughness (see the preceding photograph). In actual applications, this surface condition is unacceptable because of the reduced heat transfer capability of the liner, associated hot spots, and the potential risk for the liner material to fail. Similarly, specimens coated with Cu-26Cr did not perform well in these tests. These coatings formed blisters, indicating localized failure due to debonding with the substrate. In contrast, specimens coated with NiAl and NiCrAlY performed very well, with no visual distinction between the exposed and unexposed regions of the specimens. For example, the following photograph on the left shows the exposed NiCrAlY-coated specimen, whereas the following photograph on the right shows the unexposed NiCrAlY-coated specimen.



Left: Comparison of NiCrAlY-coated and uncoated GRCop-84 before and after exposure to a H_2/O_2 combustion flame. Right: Unexposed NiCrAlY-coated GRCop-84 sheet.

References

1. Ellis, David L.; and Michal, Gary M.: Mechanical and Thermal Properties of Two Cu-Cr-Nb Alloys and NARloy-Z. NASA CR-198529, 1996.
2. Morgan, Deena B.; and Kobayashi, A.C.: Main Chamber Combustion and Cooling Technology Study; Final Report. NASA CR-184345, 1989.
3. Quentmeyer, R.J.: Experimental Fatigue Life Investigation of Cylindrical Thrust Chambers. NASA TM X-73665, 1977.

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