DESIGNED EXPERIMENT IN ANTI-OXIDATION SYSTEMS FOR CARBON-CARBON COMPOSITES

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Introduction

Anti-oxidation protection of non-friction surfaces is a critical component in the design of carbon/carbon composite friction materials for aircraft brakes. As these friction materials routinely operate at temperatures well above critical limits for carbon oxidation, some type of effective system is required. Traditionally, relatively inexpensive, phosphoric acid-based systems have been used in aircraft friction applications and, in general, results have been excellent. In parallel, testing of these systems has typically been confined to relatively mild conditions (540-650°C). Recent aircraft programs have pushed the performance envelope in a number of ways, in particular, the use of higher normal energies with resulting higher temperatures in routine service, and exposure of carbon materials to salt-water environments which enhance oxidation. Additionally, carbon brake equipped aircraft are now frequently being used in short-haul, quick turnaround service environments. The reduced cooling period between landings results in higher average brake temperatures and, more importantly, higher peak temperatures than are typically seen on long-haul aircraft. Conventional wisdom in this area has assumed that further improvements in oxidation resistance would require the use of combined barrier/deactivator coatings similar to those used on structural carbon/carbons (e.g. Space Shuttle.) Such systems are expensive and typically require long cycle times. Additionally, questions have arisen concerning their durability through the thousands of thermal cycles seen on typical aircraft braking systems.

The current study was undertaken with four primary objectives, 1) maximize the performance of current protection systems, 2) define the relative effects of various parameters on system performance; 3) generate sufficient data to be statistically significant, and 4) establish direction for further investigation and process improvement.

Experimental Overview

A standard three-factor, three-level, Taguchi design was used, utilizing an "L27" array (Ref. 1.) Such an array results in a full factorial experiment, with no confounding of main factor effects with the effects of factor interactions. A fourth two-level factor was added, resulting in essentially two separate experiments. Factor descriptions are as follows:

Factor I: Carbon/carbon friction material type.

Level 1: CARBENIX® 2300 (Random fiber/resin/CVD)
Level 2: CARBENIX® 2400 (Random fiber/resin/CVD)
Level 3: CARBENIX® 4000 (Non-woven fiber/CVD)

Factor II: Penetrant Type

Level 1: P-13 (Phosphoric acid based deactivator)
Level 2: P-13S (Surfactant Modified P-13)
Level 3: 865-19-1 (Experimental, high borate)

Factor III: Coating Process

Level 1: Standard Process
Level 2: Multiple Coatings
Level 3: Process A

Factor IV: Penetrant Cure Temperature

Level 1: 700°C
Level 2: 900°C

A total of 270 penetrant treated coupons were prepared, yielding a total of five coupons per factor combination. In addition, thirty blank coupons (10 from each material type) were included for reference purposes. The total population was randomized into 15 groups of 20 coupons. Each group was subsequently randomized to provide racking order in the oxidation furnace.

Sample description : Round, machined oxidation coupon (1.930" Ø, .230" thickness), cut directly from full scale carbon/carbon discs (no anti-oxidation treatment.) Typical mass was 19-20 grams.

Sample preparation: Samples were cleaned ultrasonically with acetone, and dried to constant weight, then saturation coated and cured per the experimental design. Samples were weighed before and after coating to evaluate penetrant pickup.

Test procedure: Samples were oxidzed under constant airflow (2 scf/hr), for four (4) hours @ 816°C (1500°F). Weight loss due to oxidation was measured to .0001 g.

Results

Typical main factor effects are shown in Figures 1-3. In order to evaluate the robustness of various factors, standard deviations are shown along with mean oxidative weight loss values. In addition to the factors illustrated, the enhanced coating process was shown to be superior to the standard process, in that oxidative weight loss was reduced by more than one-third. Analysis was done on all first order interactions. Noteworthy among these were the interactions between coating process and material type, and between cure temperature and penetrant type.

Analysis and Discussion

While the differences in oxidation of the various materials is of general interest, the differences due to processing have obvious applications. Significant improvement is possible with only a minor change in cure temperature. (This in agreement with published information on the subject. Ref. 2.) In addition to measuring the weight losses due to oxidation, total penetrant retention through the coating and curing processes was also measured for all samples. While there is considerable scatter in the data there is an obvious trend toward reduced oxidative weight loss and reduced variation in weight loss with increased penetrant retention. One would conclude then that oxidation resistance is a function of not only base materials and penetrant type, but also is highly dependent on the process used to apply the anti-oxidant treatment.

References

1. Ross, P. J. "Taguchi Techniques for Quality Engineering," McGraw-Hill, New York, 1988

2. Buckley, J. and Edie, D., eds. "Carbon-Carbon Materials and Composites," Noyes Publications, Park Ridge, NJ, 1993.

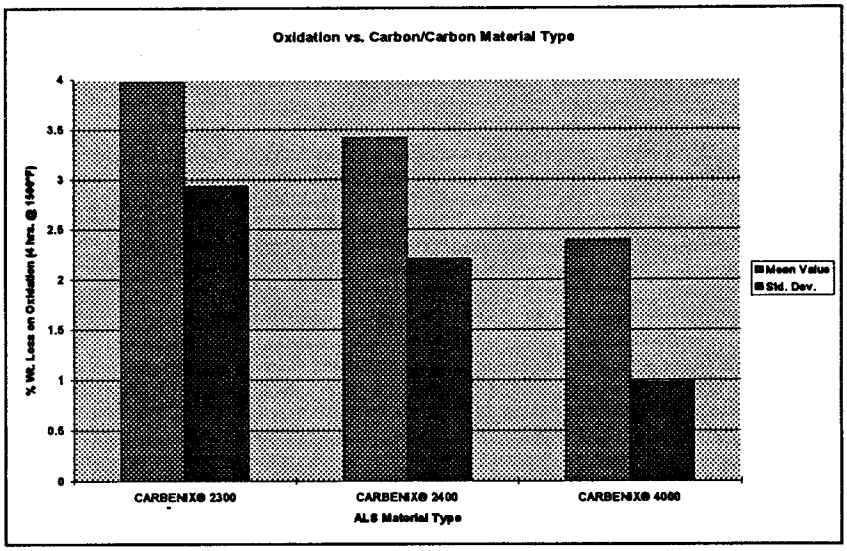

Figure 1

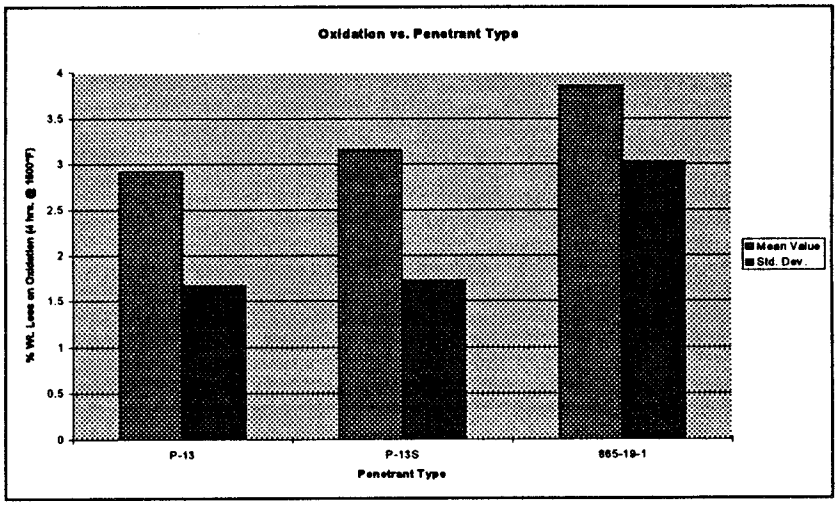

Figure 2

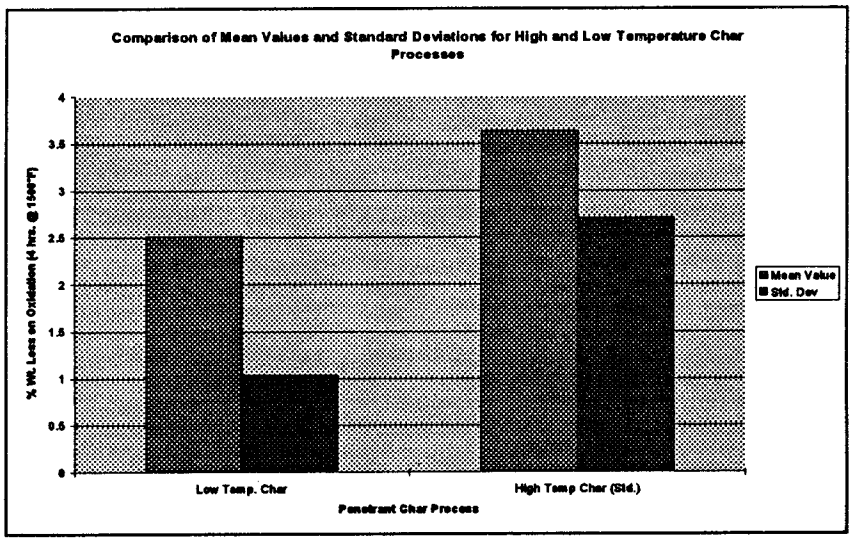

Figure 3