CORRELATION OF A PHYSICALLY BASED STATISTICAL THEORY OF FRACTURE WITH FULL SCALE GROUND TESTS OF REENTRY NOSETIPS

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Introduction

Ballistic reentry environments impose a severe thermostructural requirement on graphite nosetips. Analytical methods are needed to define the material property-reentry performance relationships through a failure criterion. Deliberate conservatism in the definition of allowable strains is not an acceptable approach because of the resulting artificial limitations on reentry capabilities. Consequently, the need exists for an accurate representation of graphite behavior in thermostructural analytical techniques.

Background

Molded graphite is a transversely isotropic material with highly variable fracture stresses and strains. The statistics themselves exhibit anisotropy with lesser fracture variability in across grain than in the with grain direction. The deformation is nonlinear, temperature dependent, different in tension and compression and anisotropic. The nonlinearity cannot be described by plastic slip concepts as evidenced by its unique measured biaxial response (Ref. 1). The accurate representation of graphite response therefore requires appropriate fracture and deformation theories.

A physically based, anisotropic, statistical and polyaxial failure strength theory was previously described and correlated with all reported ATJS laboratory failure data (Ref. 2). The physical basis for this model is the preferred orientation and strength distributions for flaws which persist through molding and graphitization. A nonlinear multiaxial stress-strain behavior model of graphite which reflects the above unique behavior has been developed by Jones and Nelson (Ref. 3) and reduced to practice for ATJS graphite (Ref. 4). These procedures constitute the basis for an accurate description of graphite thermostructural failure response.

Thermostructural problems are driven by thermal expansion strain compatability and consequently the thermally induced mechanical strains are relatively insensitive to the nonlinear mechanical behavior as shown in Reference 5. The predicted stresses, however, will be considerably in error if nonlinearity is incorrectly taken into account. A post processor (Ref. 4) was established to transform predicted thermomechanical strains into representative stresses, via the Jones and Nelson stress-strain model (Ref. 3). Then, the failure probabilities are found by the anisotropic statistical failure theory (Ref. 2). The material constants and their temperature dependence were obtained from the extensive experimental programs conducted by Southern Research Institute. The remainder of this paper describes the application of this methodology to full scale ground tests of ATJS nosetips.

Ground Test Experiments

The hyperthermal environments of rocket nozzle exhausts (Ref. 6) and arc plasma jets (Ref. 7) have been used to provide controlled studies on fracture of full scale ATJS nosetips. The "plug" and "shell" configurations studied are indicated in Figure 1, as well as the locations and states of stress which promote fracture.

In the 21 rocket nozzle tests (Ref. 6), the transition from nosetip survival to failure for plug nosetips was experimentally determined by selecting varying levels of severity of thermal exposure and subjecting several nosetips to each level of severity. Post test observation and sectioning established the pass/fail ranking.

For a given test condition, the failure probability was defined by the ratio of failures to total number of tips tested in that condition (N_f/N). Error bounds were estimated by assuming that the outcome of a hypothetical additional test would be completely random.

State-of-the-art nosetip heating codes were used to define the time dependent temperature distributions. These were input to the thermostructural analysis code to define the strain distributions which were subsequently post processed to determine failure probability.

The predictions and experimental data are shown in Figure 2. The correlation is good with a slight trend to conservatism (5 to 7 percent). Statistical analysis indicates that the confidence in meeting or exceeding the predictions is approximately 90 percent. Adjustment of material parameters to eliminate the apparent conservatism and "improve the fit" could be performed, but would reduce the confidence in meeting or exceeding predictions. The ground tests therefore indicate that high reliability without excess conservatism is a characteristic of the methodology.

Similar agreement with the arc heated shell tip experiments was obtained (Fig. 3). However, because only one tip per test condition was studied, statistical confidence cannot be specified.

Attempts to correlate these ground tests with stresses predicted by elastic-plastic modeling resulted in large conservatism and poor correlation with data. In effect, predicted stresses are too large as they do not account for the increased compliance (biaxial softening) directly observed in laboratory studies (Ref. 1). The correct nonlinear multiaxial response must be taken into account to predict accurate stress distributions.

Conclusions

Careful attention to accurate representation of the unique deformation and failure characteristics of graphite has resulted in a proven analytical methodology for reliable thermostructural predictions with minimal conservatism. The methodology constructed is consistent with all known laboratory observations on deformation and fracture and with full scale nosetip studies. The approach to thermostructural response developed herein has application to other graphites as well.

References

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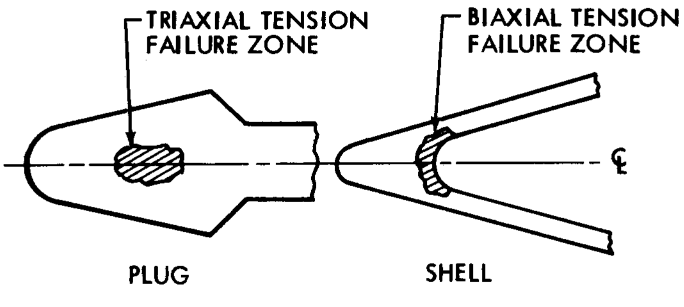

Figure 1. Typical Nosetip Geometries and Potential Fracture Sites

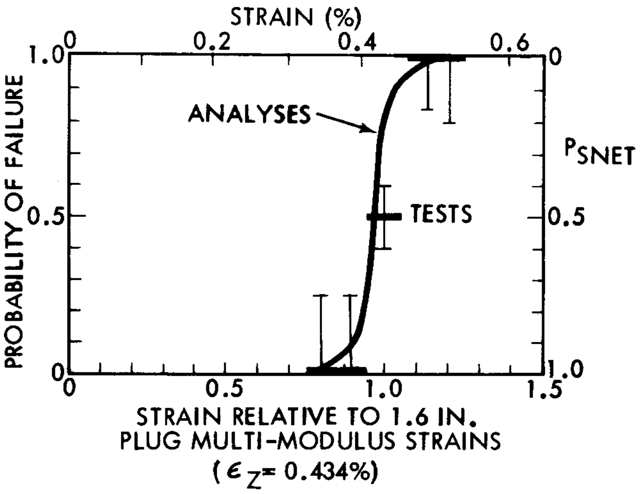

Figure 2. Failure Probability Vs. Peak Axial Strain for LORN ATJS Plug Nosetips (Ref. 6)

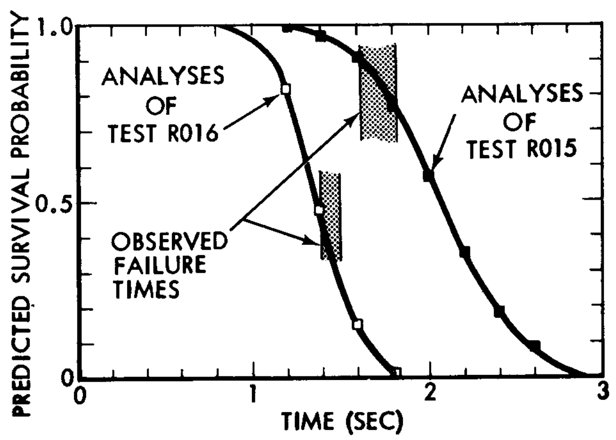

Figure 3. Survival Probability Vs. Time for 50 MW ATJS(WS) Graphite Shell Nosetips (Ref. 7)