COMPONENT PART NOTICE

THIS PAPER IS A COMPONENT PART OF THE FOLLOWING COMPILATION REPORT:

TITLE: JANNAF CMCS/S&MBS Subcommittee Meeting Held at Pasadena,
California on 27-30 November 1984. Volume 1.

TO ORDER THE COMPLETE COMPILATION REPORT, USE AD-B090 908L.

THE COMPONENT PART IS PROVIDED HERE TO ALLOW USERS ACCESS TO INDIVIDUALLY AUTHORED SECTIONS OF PROCEEDING, ANNALS, SYMPOSIA, ETC. HOWEVER, THE COMPONENT SHOULD BE CONSIDERED WITHIN THE CONTEXT OF THE OVERALL COMPILATION REPORT AND NOT AS A STAND-ALONE TECHNICAL REPORT.

THE FOLLOWING COMPONENT PART NUMBERS COMPRISE THE COMPILATION REPORT:

AD#: AD-P004 994 thru AD-P005 008	AD#: AD-P200 326 thru AD-P200 353
AD#:	AD#:
AD#:	AD#:

MEASUREMENTS OF STRAIN-FREE TEMPERATURE AND PARR END CORRECTION FACTOR IN SOLID PROPELLANT GRAINS

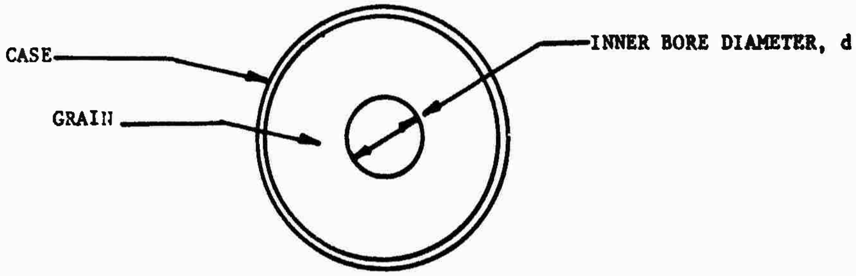
K. W. Bills, Jr. and J. A. Wilkerson
Aerojet Strategic Propulsion Company
Sacramento, California

ABSTRACT

The structural analysis of a rocket motor propellant grain subjected only to thermal loads involves the fundamental assumption that a small thermomechanical reference state exists at which the grain stress and strains disappear. Substantial evidence now exists which shows that the grain stresses and strains do not necessarily vanish at the same reference state, i.e. the stress-free and strain-free temperatures are significantly different. The primary cause of the strain-free temperature shifts was found to be movements of the grain ends, which were experimentally identified through measured changes in the Parr factor.

INTRODUCTION

The strain-free temperature, $T_{\epsilon f}$, of a case-bonded grain is defined as that temperature where thermally induced bore strains disappear. It is standard practice to assume that $T_{\epsilon f}$ and the stress-free temperature, T_{sf}, are equivalent. In fact, they are quite different and the reader is referred to page 17 of Reference (1) where the two reference temperatures are defined and compared. It is believed that strain-free temperature variations are governed primarily by end effects which are unique to finite length grains. They are, therefore, a function of the particular geometry being evaluated. Consider the problem first from the point of view of an infinitely long, case-bonded, right circular cylindrical grain.



The temperature dependence of the inner bore diameter, d, is governed only by thermal expansions of the case and grain. The return of the grain to thermal equilibrium at any temperature will always yield the same bore dimension. Thus, the diameter, d_o, at the strain-free temperature, $T_{\epsilon f}$, will always equal d_o upon subsequent exposures to $T_{\epsilon f}$.

For a cured propellant, subsequent changes in the stress-free temperature do not affect the dimensions of the infinitely long grain. Therefore, there cannot be any effect on the measurements of d or $T_{\epsilon f}$. Thus, for the very long grain, T_{sf} changes may occur, while $T_{\epsilon f}$ must remain constant.

In the case of a finite length grain the ends can rotate (inward or outward, as appropriate) to modify the bore diameter measurements. It is these modified bore measurements which give the apparent changes in $T_{\epsilon f}$. Thus, grain end rotations are the only source of apparent $T_{\epsilon f}$ changes.

In recent studies conducted at Aerojet the strain-free temperature, $T_{\epsilon f}$, was taken to be a derived quantity along with the Parr end correction factor, P_ϵ, for calculation of inner-bore strain, ϵ_θ, in finite length grains. From theory, it is known that

$$\epsilon_\theta = m\bar{P}_\epsilon T_{\epsilon f} - m\bar{P}_\epsilon T \qquad (1)$$

where T is the storage temperature and

$$m = \frac{3}{2}(\alpha_p - \alpha_c)\left(\frac{b^2}{a^2} - \frac{1}{3}\right) \qquad (2)$$

where a and b are the radii of the grain inner-bore and exterior, and α_p and α_c are the thermal coefficients of linear expansion for propellant and case, respectively.

---

* The analysis presented in this paper was prepared in support of work sponsored by the Air Force Rocket Propulsion Laboratory (AFRPL) under Contract F04611-81-C-0038. The AFRPL Project Officer for this effort was Lt. Ira Wade.

In practice, a regression line is projected through the measured bore strain versus temperature data giving the straight line relation

$$\varepsilon_\theta = I - ST \tag{3}$$

where I is the intercept, S is the slope, and T is the temperature.

On comparing equations (1) and (3) it is seen that

$$T_{\varepsilon f} = I/S \tag{4}$$

$$P_\varepsilon = S/m \tag{5}$$

In one study involving an HTPB propellant, ANB-3600, a series of 25 strain evaluation cylinders (SEC's) were prepared and tested. These SEC's involved case-bonded, center-perforated grains of four different ID's with 5 in. ID by 20 in. long steel cases. The testing of each SEC involved an initial stepwise cooling from 120 to 27°F, followed by temperature shock cycling between 120 and 27°F for 20 thermal cycles. Each temperature change required 24 hours to ensure thermal equilibrium.

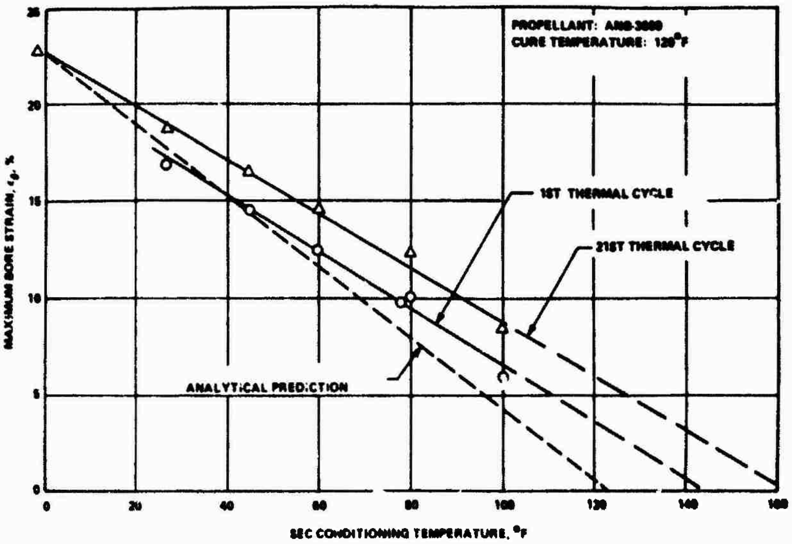


Fig. 1. Deviations of Bore Strain from Analytical Prediction

Typical test results for a given SEC are given in Fig. 1. Here the predicted bore strain curve is seen to differ significantly from the first thermal cycle test data. In fact, both the slope and strain-free temperature intercept differ from the analytically predicted values. For the 25 SEC tests the assumed $T_{\varepsilon f}$ was 123°F (120°F cure temperature plus 3°F estimated cure shrinkage effect) while the observed values ranged from 128 to 148°F. The observed Parr end correction values ranged from 62 to 78% of those given in the Parr nomograph, see Reference (2).

The repeated thermal cycling effect is reflected in the upper curve in Fig. 1. This line falls parallel to the first thermal cycle curve, hence there is no change in the Parr factor. The intercept, however, changes significantly (from 143 to 162°F for the example shown).

The contrasting behavior exhibited in Fig. 1. between the analytical predictions and the first thermal cycle observations is attributed to an interaction between the center (mid-length) of the grain and its ends. The significant reduction of the Parr end correction factor is taken to be a direct measure of this interaction.

In summary, the increase in the apparent strain free temperature is a direct result of the change in the Parr end correction factor. Thus, the strain-free temperature change is configuration dependent and is not a basic material parameter. The progressive increase of this effect during repeated thermal cycling emphasizes the by-product nature of the strain-free reference temperature.

REFERENCES

1. Svob, G. J. and Bills, K. W., Jr., "Stress-Free Temperature Shift," Final Report Contract F04611-81-C-0038, AFRPL-TR-84-043, August 1984.

2. Fitzgerald, J. E. and Hufferd, W. L., Handbook for the Engineering Structural Analysis of Solid Propellants, CPIA Publication 214, p. 3.50 (May 1971)

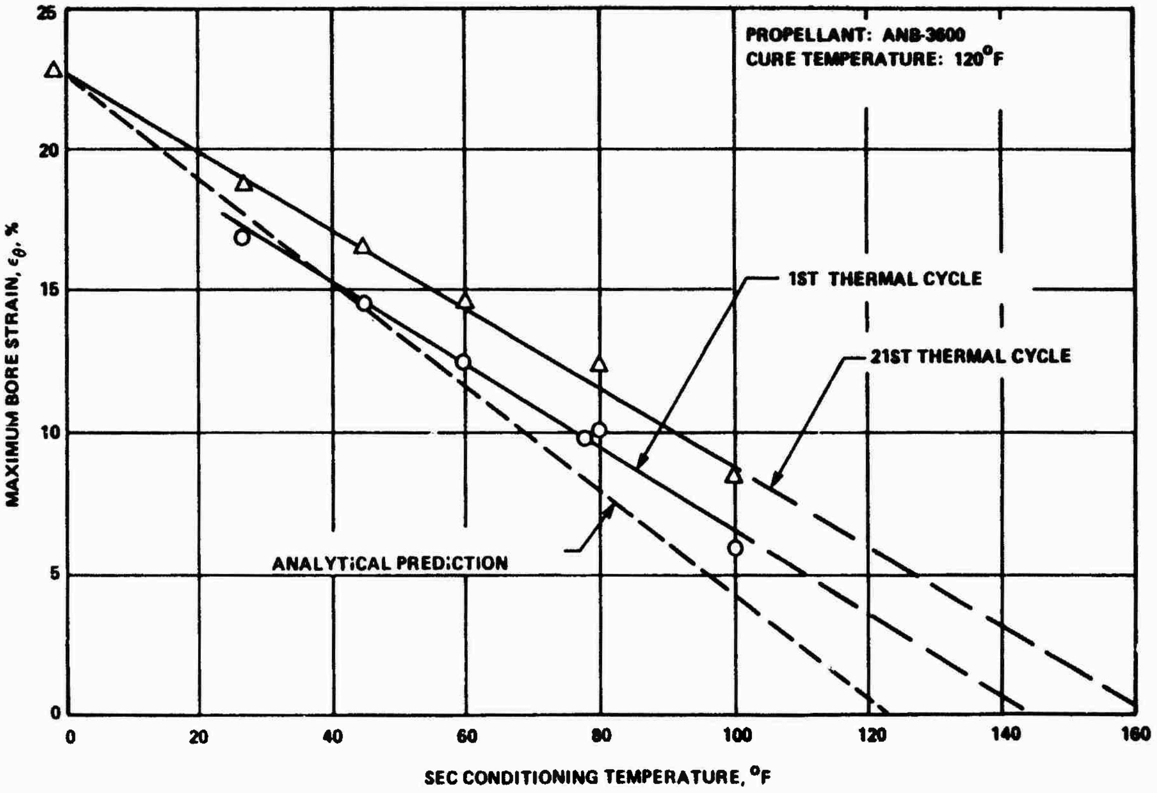


Fig. 1. Deviations of Bore Strain From Analytical Prediction