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A three-dimensional viscoelastic constitutive model of solid propellant considering viscoelastic Poisson's ratio and its implementation

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Abstract: A three-dimensional viscoelastic constitutive model of solid propellant grains incorporating with viscoelastic Poisson's ratio is proposed. To apply the new constitutive equations in the commercial finite element software MSC.Marc, a fully explicit numerical algorithm is developed. Two examples are presented to illustrate the viscoelastic behavior of solid propellant grains under thermal cycling and ignition pressurization loading, respectively. The finite element analysis results show that the Von Mises strain response is safer and more conservative for propellant with viscoelastic Poisson's ratio, while the Von Mises stress response is more dangerous, than those for propellant with elastic Poisson's ratio. In analyzing ignition pressurization, the Von Mises strain and Von Mises stress along the interface of solid rocket motor have a similar distribution law, regardless of viscoelastic and elastic Poisson's ratios. Thus viscoelastic Poisson's ratio of solid propellant should be taken into account for better understanding the viscoelastic behavior of solid propellant grains.

Keywords: solid propellant grains; viscoelastic Poisson's ratio; constitutive model

1. Introduction

Solid propellant is a typical viscoelastic material and its Poisson's ratio plays a dominant role in characterizing material properties. Experimental datum show that Poisson's ratio of viscoelastic materials dependents on time, temperature ,longitudinal strain, preload and storage time[1-10]. Furthermore, the Poisson's ratio master curve has been constructed based on the time-temperature equivalence principle by using Digital Image Correlation Method (DICM)[8]. A minor change of Poisson's ratio strongly affects structural integrity of solid rocket motor (SRM)[11-13]. However, Poisson's ratio is always considered to be a constant and this assumption may not be reasonable according to the above analysis. Thus, it is very essential to use viscoelastic Poisson's ratio rather than a constant to analyze the structural behavior of SRM.

Time-temperature-dependent behavior of solid propellant grains with a range of Poisson's ratio has been simulated by some researchers, and it showed the significant effect of Poisson's ratio on structural integrity of solid propellant grains when it varies from $\nu = 0.5$ (incompressible) to $\nu \neq 0.5$ (compressible)[12, 13]. Poisson's ratios they used are still a constant, therefore, time-temperature-dependent behavior of solid propellant grains with viscoelastic Poisson's ratios is still an unsolved issue. Deng et al. studied a new three-dimensional nonlinear viscoelastic constitutive model with time-dependent Poisson ratio effects by an incremental FEM[14]. Numerical results indicate that the stress and strain for the constant Poisson ratio are relatively smaller than those from the time-dependent Poisson ratio analysis. However, the experimental data of the propellant Poisson's ratio along with time obtained by Pan et al.[9] is too high and converges to a limit of 0.49964 within 200s which can be ignored compared with the long term of 10 years storage. The results may be not accurate in their application examples. Furthermore, the effect of loading temperature on Poisson's ratio was not considered in their study. Therefore, further studies are needed to examine the effects of viscoelastic Poisson's ratio on structure analysis of SRM.

In this paper, a three-dimensional viscoelastic constitutive model of solid propellant considering viscoelastic Poisson's ratio is proposed. A fully explicit numerical algorithm is developed based on the new constitutive equation. Two illustrative examples are presented to show the behavior of solid propellant grains under thermal cycling and ignition pressurization loading. Numerical results are