Advances in Engineering Software 41 (2010) 1110–1114

Contents lists available at ScienceDirect

Advances in Engineering Software

journal homepage: www.elsevier.com/locate/advengsoft

An elasto-viscoplastic analysis of direct extrusion of a double base solid propellant

Baris Kalaycioglu *, M. Husnu Dirikolu [1], Veli Çelik [1]

Kırıkkale University, Mechanical Engineering Department, 71451 Kırıkkale, Turkey

ARTICLE INFO

Article history:
Received 6 October 2009
Received in revised form 20 June 2010
Accepted 28 June 2010
Available online 24 July 2010

Keywords:
Solid propellant
Extrusion
Finite element
Elasto-viscoplastic
Simulation
Process optimisation

ABSTRACT

In this study, three-dimensional modelling of extrusion forming of a double base solid rocket propellant is performed on Ansys® finite element analysis program. Considering the contact effects and the time dependent viscous and plastic behaviour, the solid propellant is assumed to obey the large deformation elasto-viscoplastic material response during direct extrusion process. The deformed shape, hydrostatic pressure, contact stress, equivalent stress, total strain values are determined from the simulation in order to get insight into the mechanical extremity that the propellant has undergone during processing. Hydrostatic pressure and contact stress distributions have been found to be important parameters due to safety reasons of the nitro-glycerine content in the bulk of the propellant.

1. Introduction

Complex structural configurations can nowadays be modelled using numerical techniques, and the response of any type and at any desired point of a structure can approximately be determined. Among these techniques, the finite element analysis (FEA) has evolved to be a widely accepted simulation tool for the solution of complex engineering problems. One such problem is the determination of the significance of the value and distribution of stress, strain, strain rate, temperature, and contact and hydrostatic pressures in a solid propellant during production in order to meet the thermal response, integrity, service life, and performance requirements of solid rocket motors. However, it is difficult in terms of experimental setup and specimen preparations as well as lengthy and risky in performing the laborious tests and measurements to predict these physical responses during the design phase. Therefore, the use of computer simulation techniques to analyse the structural behaviour of solid propellants in the preliminary design stage is important and necessary.

Scientists, due to the above mentioned concerns, have carried out analyses regarding the structural behaviour of solid propellants. Jana et al. [1] have studied the effect of the bulk modulus variation of two HTPB-based (hydroxyl-terminated polybutadiene) solid propellants with hydrostatic pressure using both linear and nonlinear elastic FEA, excluding viscous behaviour. They have stressed on the necessity of employing the nonlinear approach for accurate modelling of solid propellants. In a later study, these authors have included the viscous effects in the same analysis. The hoop strain has been obtained as 2.49% after a unit time for the nonlinear viscoelastic FEA solution compared to that of 2.72% calculated after 212 substep-converged nonlinear elastic FEA solution. This represents a 9.2% difference between their elastic and viscoelastic hoop strain estimations [2]. Herder et al. [3] compared the dynamic mechanical properties of an HTPB-based solid propellant with quasi-static test results under tension, compression, and torsion loadings as well as temperatures ranging from −100 °C to 100 °C. Jones and Pierre-Louis [4] analysed the residual stress and strain distributions during cooling while subjected to high hydrostatic pressure of a solid propellant using ADINA® FEA package. Townend and Warren [5] have investigated the effect of nitro-glycerine content on the relaxation behaviour of a double base propellant. Renganathan et al. [6], on the other hand, have obtained the tensile fracture behaviour of an HTPB-based propellant under 15 min^{-1} and 0.015 min^{-1} strain rates using a viscoelastic analysis. In a study by Nerse, the chemical and mechanical characterisation of a double base solid propellant has been carried out [7]. Xu et al. proposed a general 3-D nonlinear macroscopic constitutive law for a high elongation solid propellant that models microstructural damage evolution upon straining through continuous void formation and growth [8]. Lastly, Tussiwand et al. report on a set of fracture tests performed on a composite solid propellant based on ammonium perchlorate hydroxyl-terminated polybutadiene [9]. The last mentioned studies have made contributions to better forming and fracture design of solid propellants.

* Corresponding author. Fax: +90 318 357 2459.
E-mail addresses: kalaycioglu@kku.edu.tr (B. Kalaycioglu), dirikolu@kku.edu.tr (M.H. Dirikolu), celik@kku.edu.tr (V. Çelik).
[1] Fax: +90 318 357 2459.

0965-9978/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.advengsoft.2010.07.001

This study aims at simulating the extrusion stage during processing of a double base solid propellant by using a three-dimensional model on Ansys® finite element package [10]. The modelling details are given in the following section.

2. Modelling procedure

Realistic material and friction models are required for a successful computer simulation. However, there are safety limitations in the case of solid propellants. The actual forming process is carried out with special care at a maximum ram speed of 40 mm/min with successive heating from 40 °C to 75 °C as shown in Fig. 1. Under these forming conditions, the propellant is assumed to obey the elasto-viscoplastic material model which has the capability of accounting for the expected softening behaviour after yielding. The elasto-viscoplastic material model is based upon Perzyna's work [11]. In this model, the material is assumed to have a strain rate dependent isotropic hardening part and a linear elastic behaviour. The isotropic hardening part is considered to be multi-linear. It should be noted that anisotropy arising from the constituents and their nonuniform distribution in a cut section of the propellant are neglected and as a result, macroscopic stress–strain response is assumed. The Perzyna's viscoplastic model has the form:

$$\sigma = \left[1 + \left(\frac{\dot{\varepsilon}^{pl}}{\mu}\right)^{m}\right]\sigma_0 \quad (1)$$

where σ is the current material yield stress, $\dot{\varepsilon}^{pl}$ is the equivalent plastic strain rate, m is the strain rate sensitivity parameter, μ is the material fluidity parameter, and σ_0 is the static yield stress of the material.

The actual forming process has an extrusion ratio of approximately 28.7, a half die angle of around 44°, an exit outside diameter of 70 mm, and a star-shaped minimum inside diameter of 24 mm. Using these measurements and simplifying the container and the spider-type mandrel extrusion die, the approximate representation of the extrusion geometry is drawn and then implemented in the finite element model as shown in Figs. 2a and 2b. As can be seen from Fig. 2b, a quarter of the full model is used for less computational time.

Fig. 1. Extrusion of the propellant (Courtesy of Barutsan A.S. in Turkey).

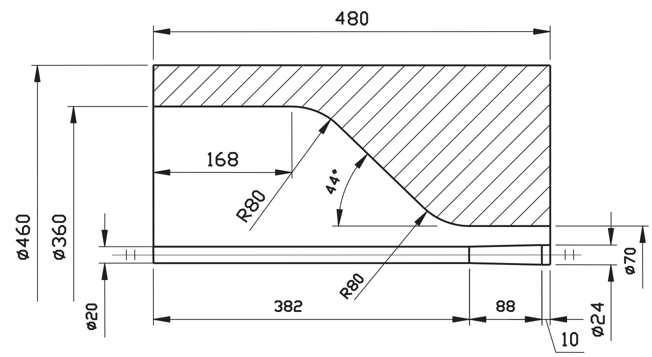

Fig. 2a. The approximate representation of the extrusion geometry.

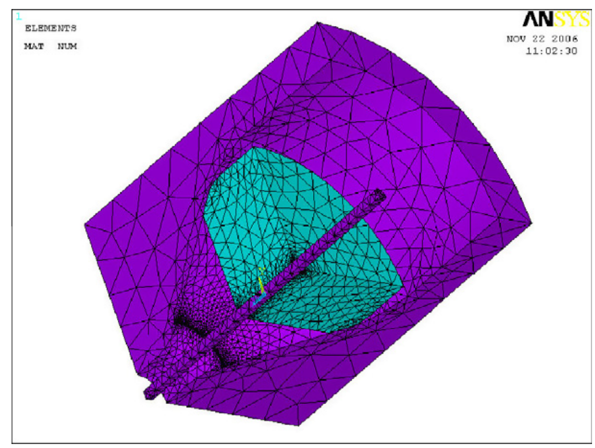

Fig. 2b. A quarter of FEA implementation of the extrusion geometry.

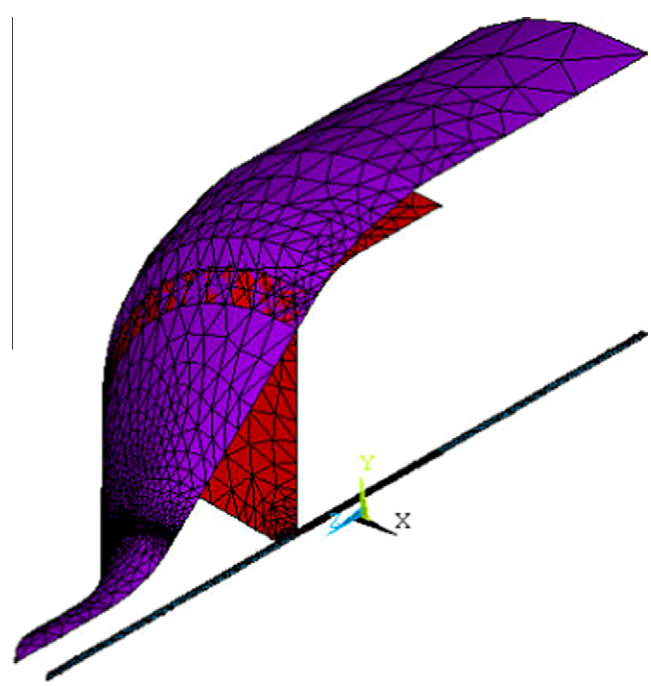

Fig. 3. Contact elements at the container–propellant and propellant mandrel interfaces.

The solid propellant, the mandrel, and the container are all modelled by using a 3-D 10-node tetrahedral structural solid element, named as SOLID92. The numbers of elements, respectively,