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Stress Strain Analysis of Rocket Engine Thrust Chamber

KEYWORDS

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ABSTRACT *High performance rockets are developed using cryogenic technology. High thrust cryogenic rocket engines operating at elevated temperatures and pressures are the backbone of such rockets. The thrust chambers of such engines which produce the thrust for the propulsion of the rocket can be considered as structural elements. Often double walled construction is employed for these chambers for better cooling and enhanced performance. The double walled rocket engine thrust chamber investigated here has its hot inner wall fabricated out of a high thermal conductive material like copper alloy and outer wall made of stainless steel. Inner wall is subjected to high thermal and pressure loads during operation of engine due to which it will be in the plastic regime. Major reasons for the failure of such thrust chambers are low cycle fatigue, creep and thermal ratcheting. Elasto plastic material models are required to simulate the above effects through a cyclic stress analysis. This paper gives the details of cyclic stress analysis carried out for a thrust chamber using the Chaboche nonlinear kinematic hardening plasticity model.*

INTRODUCTION

Thrust chamber is one of the main components of a cryogenic rocket engine. It is the subassembly of rocket engine in which propellants are injected, mixed and burned to form hot gas products which are accelerated and ejected at high velocity. The thrust chamber investigated in this work is double walled and regeneratively cooled using Liquid Hydrogen. The inner wall of the thrust chamber is made up with a special copper alloy whereas the outer wall is fabricated from stainless steel.During operation, both the walls experience severe thermal and pressure loads. The inner copper wall has to take care of two contradictory functional requirements. The wall thickness has to be optimised to offer least resistance for heat transfer rate and thereby limit thermal gradients. The inner wall also should have sufficient thickness to withstand the pressure and mechanical loads exerted by coolant pressures and combustion gas pressures. Normally an engine has to undergo repeated cycles of operation before putting to actual use in the flight. Hence cyclic stress analysis of the thrust chamber is of paramount importance so that its structural integrity during flight is ensured. Stress analysis predicts the manner in which a mechanical component will perform structurally under anticipated working conditions. The goal is to design an element with sufficient, but not excessive, strength in every detail. Cyclic stress analysis of a rocket engine thrust chamber using Chaboche model is reported in this work.

PLASTICITY MODELS

Development of models for in-elastic behavior of materials has been an area of substantial development over the past 20-30 years and is still a very active research area. New models are developed even recently. Today's FE codes provide models for the analysis of plastic deformation of metallic materials, even though the most recent models are yet to be implemented. Plasticity models provide a mathematical relationship that characterizes the elasto-plastic response of materials. Choice of plasticity model depends on thexperimental data available to fit the material constants

The basic requirements of a plasticity model are

- Yield criterion
- Flow rule
- Hardening rule

Conventional plasticity models are

- Linear isotropic hardening models
- Linear kinematic hardening models
- Linear isotropic hardening models

These models are appropriate for large strain, proportional loading situations. They are less preferred for cyclic loading. Isotropic hardening model alone is incapable of describing a cyclic behaviour that includes repeated cyclic deformation, however these models are capable of simulating complex cyclic behaviours when combined with kinematic hardening models.

Linear kinematic hardening models

They follow a linear hardening curve in cyclic loading situations. The hardening rule is given by

$$d\alpha_{ij} = c\, d\varepsilon^{p}_{ij}$$

$\mathbf{d\alpha_{ij}}$ = incremental back stress

$\mathbf{d\varepsilon^{p}_{ij}}$ = incremental plastic strain

They can describe stable loops in cyclic loading, including the Bauschinger effect. For a prescribed uniaxial stress cycle with a mean stress, they fail to distinguish between shapes of the loading and reverse loading hysterisis curves and consequently produces a closed loop with no ratchetting.

Non linear kinematic hardening models

They follow follow a smooth non linear hardening curve in cyclic loading situations. The hardening rule is given b

$$d\alpha_{ij} = \frac{2}{3} c\, d\varepsilon^{p}_{ij} - \gamma \alpha dp$$

α = back stress

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They siimulate ratchetting and shakedown in a FEA simulation. Nonlinear kinematic hardening implies a shift (or movement) of the yield surface along a nonlinear path. It is similar to linear kinematic hardening except for the fact that the evolution law has a non linear term called recall term. Non linear kinematic hardening does not have a linear relationship between hardening and plastic strain. The non linear term is associated with the translation of the yield surface.

CHABOCHE MODEL

The Chaboche model is a type of non linear kinematic hardening model commonly used to simulate the plastic deformation of metals. It was added in ANSYS 15 to complement the existing isotropic and kinematic hardening rules. Chaboche model is based on von Mises yield criterion. The yield function for the non linear kinematic hardening model is

$$F = [\tfrac{3}{2}(\{S\} - \{\alpha\})^T [M] (\{S\} - \{\alpha\})]^{1/2} - R = 0$$

F = - = 0
{S} = deviatoric stress tensor
{α} = back stress tensor
[M] = matrix containing information on different yield strengths in different directions
R = yield stress

CYCLIC STRESS ANALYSIS OF THRUST CHAMBER

Analysis of 2D Finite element model of a cross section of thrust chamber is carried out using

- KINH model
- MISO model
- CHAB+MISO model

Plane strain FE models are chosen at different locations. Sections considered for analysis are

- at a distance of 350 mm (near throat)
- at a distance of 90 mm (near convergent section)

Figures show the details of cross section chosen and meshed section plot.

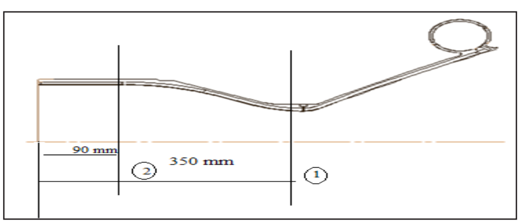

Fig 1: Details of cross section chosen

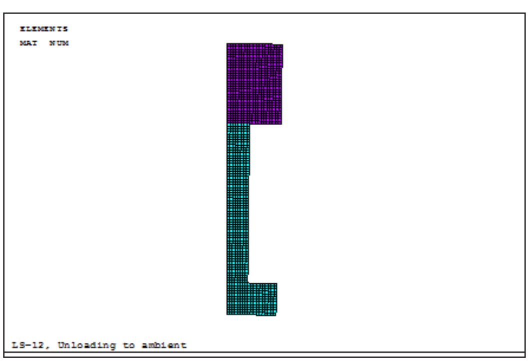

Fig 2: Meshed section (near throat)

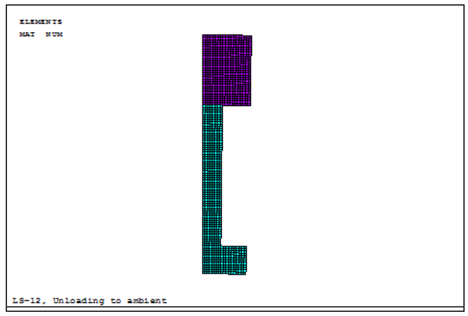

Fig3: Meshed section (near convergent section)

- CYCLIC STRESS ANALYSIS RESULTS
- Thermal Loads Alone For Section Near Throat
- MKIN Model

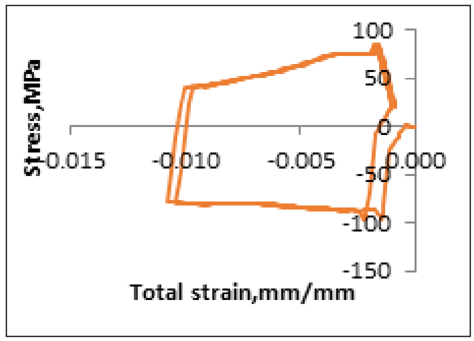

Fig4:Variation of stress with total strain MISO Model

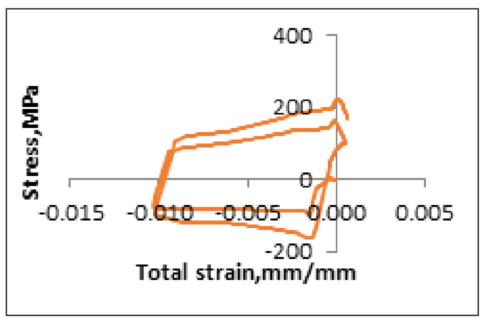

Fig 5 Variation of stress with total strain MISO+CHAB Model

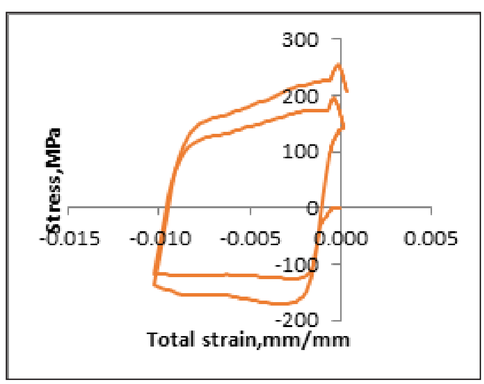

Fig6 Variation of stress with total strain Thermal Loads and Pressure Loads For Section Near Throat MKIN Model

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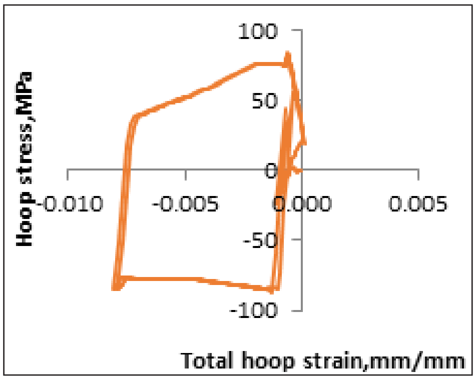

Fig7 variation of stress with total strain
MISO Model

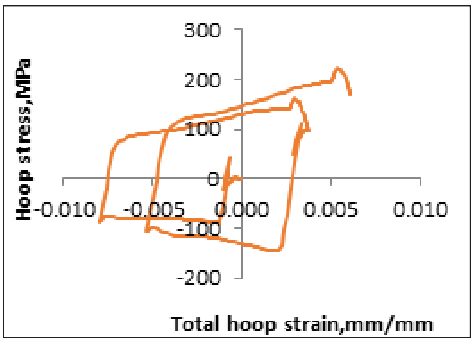

Fig8 variation of stress with total strain
MISO+CHAB Model

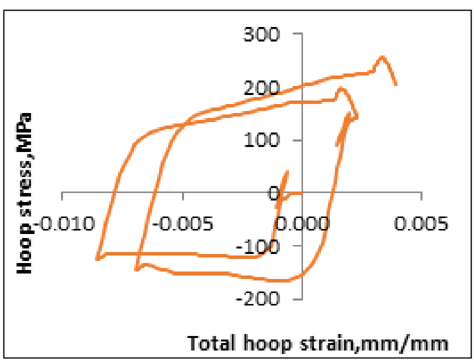

Fig9 Variation of stress with total strain
MKIN model

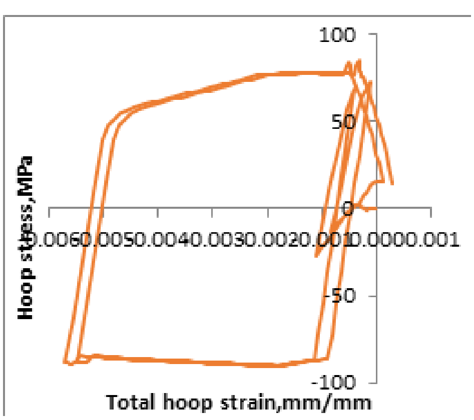

Fig10 Variation of stress with total strain
Thermal Loads And Pressure Loads For Section Near
Convergent Section
MISO Model

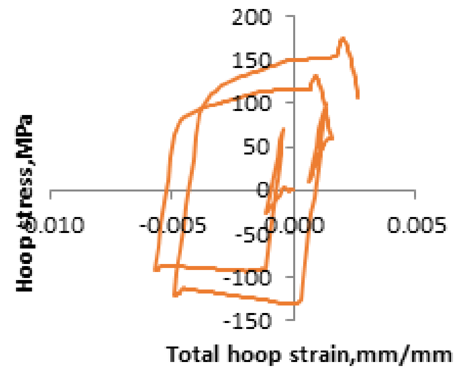

Fig11: variation of stress with total strain
MISO+CHAB Model

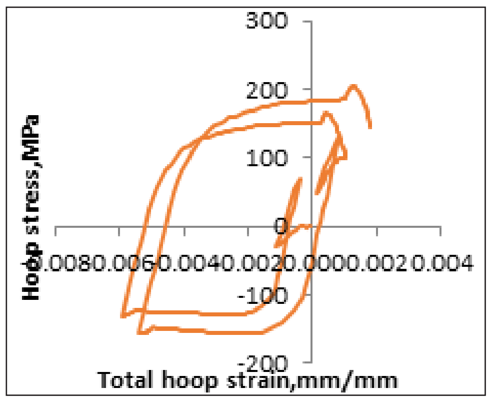

Fig 12 : variation of stress with total strain

CONCLUSIONS

Thrust chamber analysis using thermal loading alone indicated similarity in behaviour compared to displacement loading and the behavior is best simulated by CHAB+MISO model.

Thrust chamber is subjected to pressure and thermal loads during its operation and as expected analysis using CHAB+MISO model shows better stress strain behaviour compared to other models.

Results indicated CHAB+MISO model as the best model available

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