Burst Pressure Prediction On Perforated GFRP Igniter Cases Using Finite Element Method

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Abstract: *The fibre Glass igniter cases of different sizes are used in solid motors of launch vehicles for igniting the propellant. Medium and larger size cases are generally filament wound using glass fibres with wet resin system. On the other hand, smaller size cases are realized through layup of bi-directional Glass fabric because of specific requirement to layer wise disintegration (like petals) after ignition to avoid damage to nozzle. The dome of the case is formed by providing V-cuts (to get petal shape) in the fabric and consolidating with glass fibres. In hydraulic burst tests, failure is seen at the root of the fabric V-cuts at pressures lower than what is capable from glass fabric. This is due to the presence of resin in between the fabric layers and in between individual V cuts of a single layer. In order to predict this behavior, detailed finite element analysis has been carried out. Three dimensional FE model has been developed by modeling each layer in dome separately. Each petal is modeled in unique way with contact established between layers and orthotropic material properties are used in the analysis. The predicted behavior is well correlated with the performance of the case during qualification tests. This paper describes the details of case design, realization, its modeling and validation with test results.*

Keywords: *Perforated, igniter case, GFRP, Burst pressure*

I. INTRODUCTION

The fibre Glass igniter cases are used in solid motors of launch vehicle for ignition of propellant. The igniter cases are realized through wet filament winding technique using Glass fibre with Epoxy resin system. Usually large igniter cases which are known as pyrogen cases are realized using filament winding. The smaller cases which are known as pyrotechnic cases are realized through layup technique with wet Glass fabric. The pyrotechnic cases will have number of holes in the cylindrical region for the flow of hot gases and propellant pellets and hence the name perforated cases. The conventional filament winding approach with unidirectional fibre is not suitable for realization of these perforated cases because of the holes in the cylindrical region. Also after burning, it needs to disintegrate as petals to avoid damage to the nozzle. The expected failure modes of the pyrogen igniter case is shear failure in the threaded region because of lesser inter-laminar shear strength of the composite and dome failure due to stress concentration near the holes. Whereas the failure mode in the perforated case is always on the dome at the root of the 'V' cut provided in the fabric. Though the failure mode is as expected, the burst pressure is having large variation. Hence an attempt is made to understand the behavior and the details are described in this paper.

II. CONFIGURATION OF THE IGNITER CASE

The case is cylindrical in shape with dome on one side and threaded open end on other side. The threaded side is used to mount metallic adapter to interface with the motor. The case configuration is shown in Fig.1.

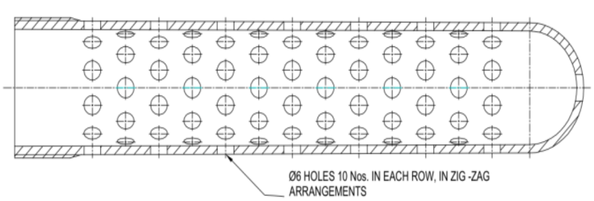

Fig.1. Configuration of the case

In cylindrical region numbers of holes are provided for venting out hot particles/gases at the high rate required. The material of construction is bidirectional Glass fabric with Epoxy resin system and the properties of the same is listed in Table.1

Table.1. Mechanical properties of Glass fabric/Epoxy

Property	Unit	Value
Longitudinal Tensile modulus (warp)	MPa	20000
Transverse tensile modulus (weft)	MPa	17000
Major poisson's ratio	-	0.121
Longitudinal tensile strength (warp)	MPa	300
Transverse tensile strength (weft)	MPa	260

III. DESIGN METHODOLOGY

The case is designed based on netting theory and the cylinder thickness required for minimum burst pressure is estimated considering the stress concentration factor of 4.

The dome is spherical and the stress levels are lower than the cylindrical region. However, due to the presence of resin in between the fabric layers and in between individual V cuts of a single layer. failure/ leakage initiate from dome. Hence stress in the dome region is estimated through finite element analysis.

IV. PROCESSING & TESTING

The case is realized using layup of Glass fabric impregnated with Epoxy resin system. The required size of the fabric is cut such that its length is equal to number of layers times the developed length of the case and the fabric width equals to length of the case. Along one edge of the fabric 'V' cuts are made using template

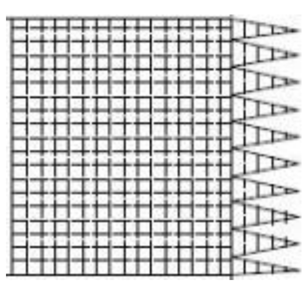

Fig.2. Glass fabric with 'V' cuts

as shown in Fig.2. V cuts are provided to ensure layer wise separation during the firing of motor. The fabric is impregnated with Epoxy resin system The layup of the fabric is done over the mandrel and the dome region is consolidated with hoop layers of Glass fibre. After gelling, case is cured and machining is carried out as per the requirement. Non-destructive testing and dimensional inspection is carried out as part of acceptance. The realized case is shown in Fig.3.

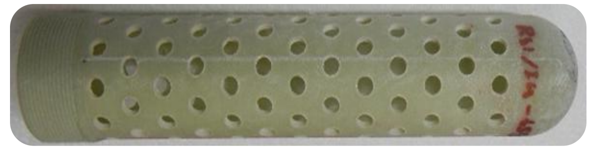

Fig.3. Realized case

The cases are burst tested without hole drilling. The hydro burst tested case is shown in Fig.4 with failure mode initiated at dome region. The achieved burst pressures are varying from 100 bar to 200 bar. The cause of variation is attributed to the higher resin content in the dome region due to petal type layup**.**

Fig.4. Burst tested case

V. FINITE ELEMENT ANALYSIS

The finite analysis is carried with three dimensional finite element model of the case. One representative sixty degree sector of the case is modeled using 3D solid elements as shown in Fig.5. The dome is modeled in unique way to capture the actual deformation behavior. By process, the petals in the dome will have repetitive symmetry for every sixty degree sector. Each layer in the dome is modeled separately including the petals and contact is established between layers (Fig.6). Orthotropic material properties are used for composite and isotropic material property is used for metallic adapter. Symmetry boundary conditions are applied on the faces and the adapter is fixed at the PCD. Pressure is applied on the internal surface of the case. Non-linear analysis has been carried out using commercial FE package ABAQUS. Numbers of iterations are carried with varying frictional coefficient between the layers.

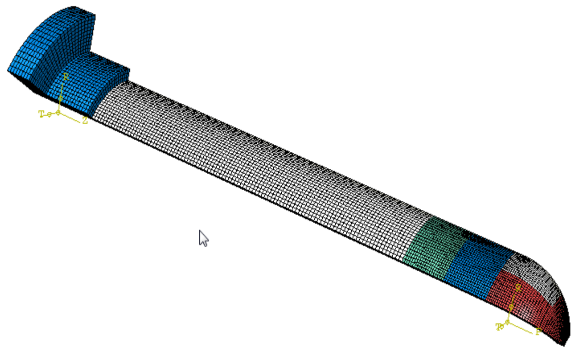

Fig.5 Finite element model of the case

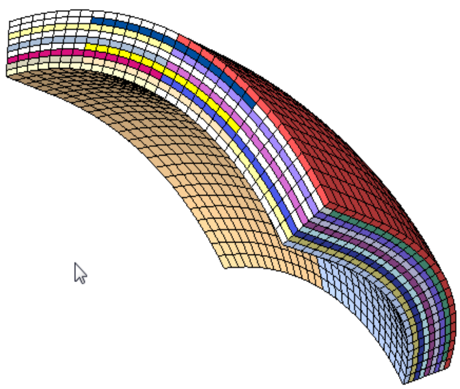

Fig.6 Details of dome model

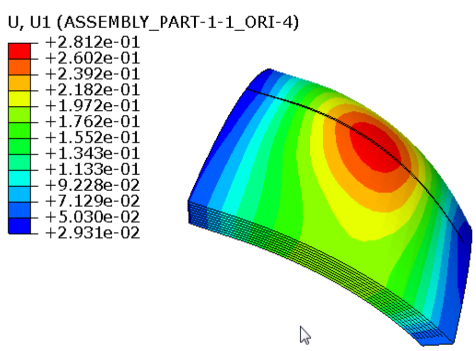

Fig.7. Resultant displacement in the dome

VI. RESULTS AND DISCUSSION

The resultant displacement of the dome region is shown in Fig.7. It is observed that the displacement on the middle of the dome is higher due to opening of adjacent petals. The relative displacement between layers of the dome causes stress increase at the root of the 'V' cuts as shown in Fig.7 & 8. The magnitude of the relative movement of layers is a function of inter-laminar shear capability of the composite. Though the dome is consolidated using hoop layers and cured, the wrinkles formed during consolidation causes resin richness. It affects the inter-laminar shear strength and result in variation in the dome capability. The predicted burst pressure based on the stress at the root of 'V' cut ranges from 80 bar to 150 bar.

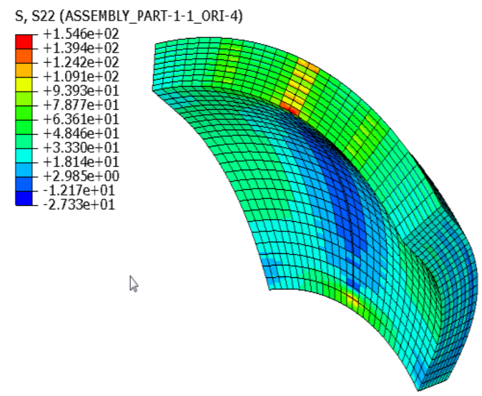

Fig.8. stress in the fabric weft direction

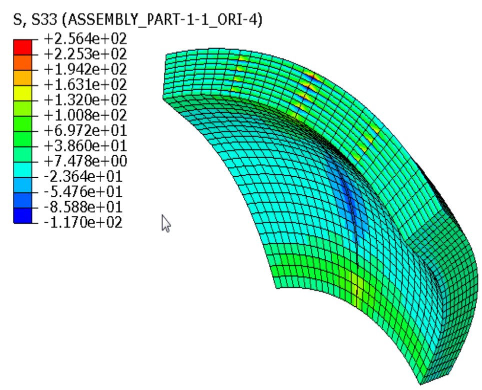

Fig.9. Stress in the fabric warp direction

VII. CONCLUSION

The burst pressure variation of the perforated igniter cases is assessed. It is attributed to the inherent nature of the processing with petal type layup with associated resin richness on the dome. The petal type construction due to 'V' cuts on the fabric has been captured in the analysis and the simulated behavior is well correlated with the actual behavior in the test.

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