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PERFORMANCE EVALUATION OF FLEX NOZZLE ABLATIVE LINERS BY CONDUCTING SOLID ROCKET MOTOR GROUND FIRING TEST

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ABSTRACT

The Rocket motor assembly with their different sub systems should be done with utmost care because these have to withstand very high operating pressures upto 80 bar, high temperatures of 3200K and velocity of gases. The erosion resistance is one of the key attributes of Composite ablative liners. The reasons for minimizing erosion rate of ablative liner will enhance the performance of the liner. The Flex Nozzle ablative liners are used to protect the nozzle structural members from the severe thermal environment in solid rocket nozzles. For this purpose, ablative composite liners made up of Phenolic resin matrix combined with reinforcement material like Rayon Carbon fabric, E-glass and silica fabric are extensively used.The nozzle ablative liners are made with carbon phenolic prepregs by tape winding process.Nozzle ablative liners are manufactured by using the optimized process parameters and these liners are assembled to the structural members of the flex nozzle assembly. The char, erosion, virgin thickness are measured and checked against the predictions.

Keywords: *Solid rocket motor, Ablative liners, Firing test and Structural members.*

1. Introduction

Solid Rocket Motor generates high thrust by accelerating high pressure gases to supersonic velocities in convergent divergent nozzle, thus converting pressure energy to kinetic energy of propulsion [1].Near the throat, the radius of curvature of profile must be sufficient to ensure a progressive velocity increase. The convergent divergent sections are joined by two to three throat radii, connected by a small cylinder section and the area increases along the divergent section. Fulfilling mission requirements may require a simple fixed nozzle configuration or movable nozzles with thrust vector control concepts. In the nozzle system divergent portion plays major role in expanding the gases resulting thrust to the vehicle [2]. Depending upon the operating conditions of nozzle and exhaust requirements, divergent is designed and tested.

As exhaust gas from chamber is of high temperature, the members of nozzle should be protected from hot gases by highly erosion resistant thermal liners. For this purpose, ablative composite liners made up of Phenolic resin matrix combined with reinforcement material like Rayon Carbon fabric, E-glass and silica fabric are extensively used [3].

The combustion gas flow conditions are more severe near the convergent portion of the nozzle. The factor of safety in the entry section of the nozzle is higher than in the exit section [4].Divergent being largest component and contributes more to nozzle weight, the thickness of liner should be as minimum as possible, at the same time it should be more erosion resistant [5]. The erosion resistance due to hot gases can be increased by fabricating the liner in such a way that the flame only touches the edge of the composite ply of the liner. The 2D View of Solid Rocket motor casing, Igniter with Flex Nozzle System is shown in Fig. 1.

1.1 Solid Rocket Motor Casing Parts

1.1.1 Motor case

Motor case is usually made either from metal (high-resistance steels or high strength aluminum alloys) or from composite materials (Glass, Kevlar and Carbon).The case must be capable of withstanding the internal pressure resulting from the motor operation, approximately 3-30 MPa, with a sufficient safety factor.

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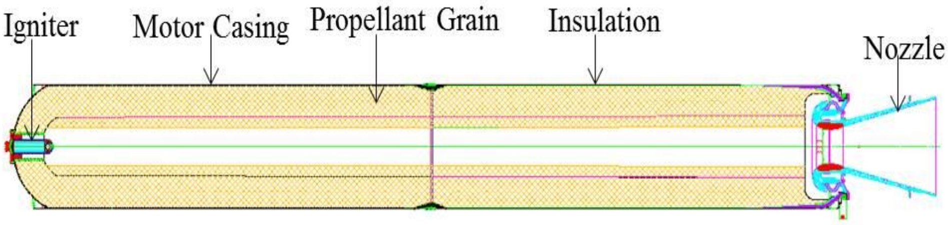


Fig. 1 2D View of the Solid Rocket Motor Casing

1.1.2 Insulation

High temperature of the combustion gases, ranging from approximately 2000 to3500 K, requires the protection of the motor case or other structural subcomponents of the rocket motor.Most commonly used insulation materials are EPDM (Ethylene Propylene Diene Monomer) with addition of reinforcing materials.

1.1.3 Igniter

The ignition system gives the energy to the propellant surface necessary to initiate combustion. Ignition usually starts with an electrical signal. Conventional heat releasing compounds are usually pyrotechnic materials, black powder, metal-oxidant formulations and conventional solid rocket propellant.

1.1.4 Nozzle

High temperature, high pressure combustion gases are discharged through the converging-diverging nozzle. By this way, chemical energy of the propellant is converted to kinetic energy and thrust is obtained. Once ignited, a simple solid rocket motor cannot be shut off, because it contains all the ingredients necessary for combustion within the chamber in which they are burned.

Fig. 2 Ground firing test of rocket motor with flex nozzle system

2. Ground Firing Test Set Up

The Ground Firing test is carried out to ascertain design margins of nozzle hardware and ablative liners. Demonstration of adequacy of motor, igniter and nozzle interfaces, during static test the temperatures, strains, vibrations at various locations on motor and nozzle are measured by using suitable instrumentation.

The motor is ignited by pyrogenigniter, the propellant burns and gives high pressure exhaust gases resulting in forward thrust [6].The exhaust gases expand in nozzle from high pressure to ambient pressure. The Ground firing test of Rocket motor along with flex nozzle system is shown in Fig. 2. The pressure time curve measured during static test is shown in Fig. 3.The flex nozzle system used for ground firing test is shown in Fig. 4.

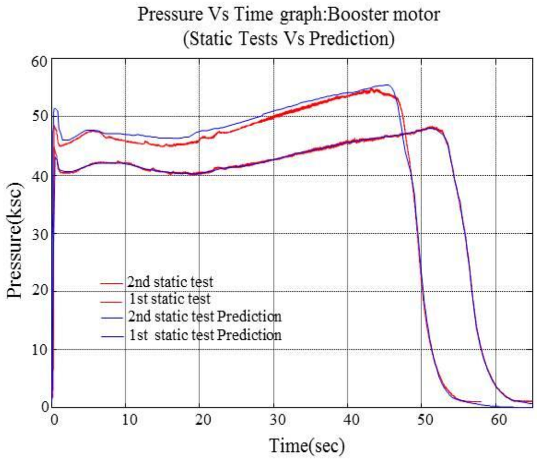


Fig. 3 Pressure–time graph of rocket motor ground firing test

Fig. 4: Flex nozzle system for ground firing test

2.1 Results and Discussion on Ground Firing Test of Flex Nozzle System

After the static test nozzle liner weights are measured and the mechanical erosion is calculated. After dismantling the nozzle components the charred material is removed and the mechanical erosion, char and the virgin materials thicknesses are measured and given in Table 1 and shown in Fig. 5.These results are compared with the design estimations and the margins are verified. The contribution of erosion, char and virgin for each liner is shown in Fig.6.The erosion rates measured in ground firing test are given in Table 2 and comparison of two static tests is shown in Fig. 7.

Table 1 Erosion, char, virgin thickness of liners measured after ground firing test

Sl. No.	All values in mm Component name	Design thickness	Virgin thickness	Erosion thickness	Char thickness
1	Nose Insert	53.30	34.40	10.10	08.80
2	Radiation shield	63.00	44.60	07.40	11.00
3	Throat Graphite	57.00	52.80	04.20	---
4	Thermal Boot	25.00	17.00	08.00	---
5	I/D rubber lining	20.00	13.50	06.50	---
6	Divergent entry	46.70	37.30	6.20	3.20
7	Divergent middle	27.90	16.20	1.70	10.00
8	Divergent exit	15.10	5.00	0.30	9.80

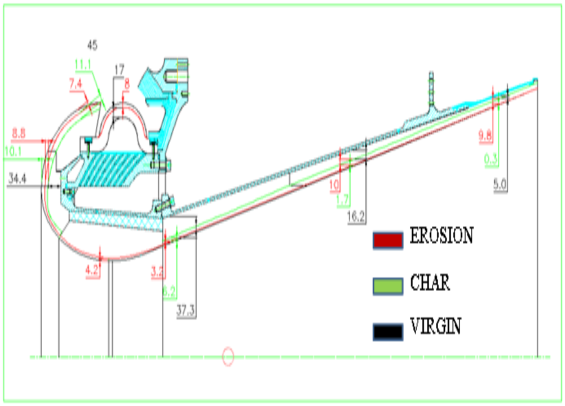
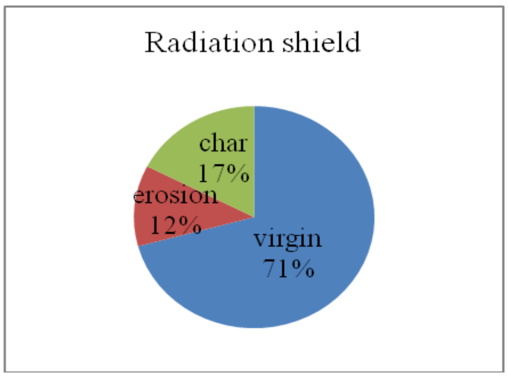


Fig. 5 Erosion, char & virgin profile of flex nozzle



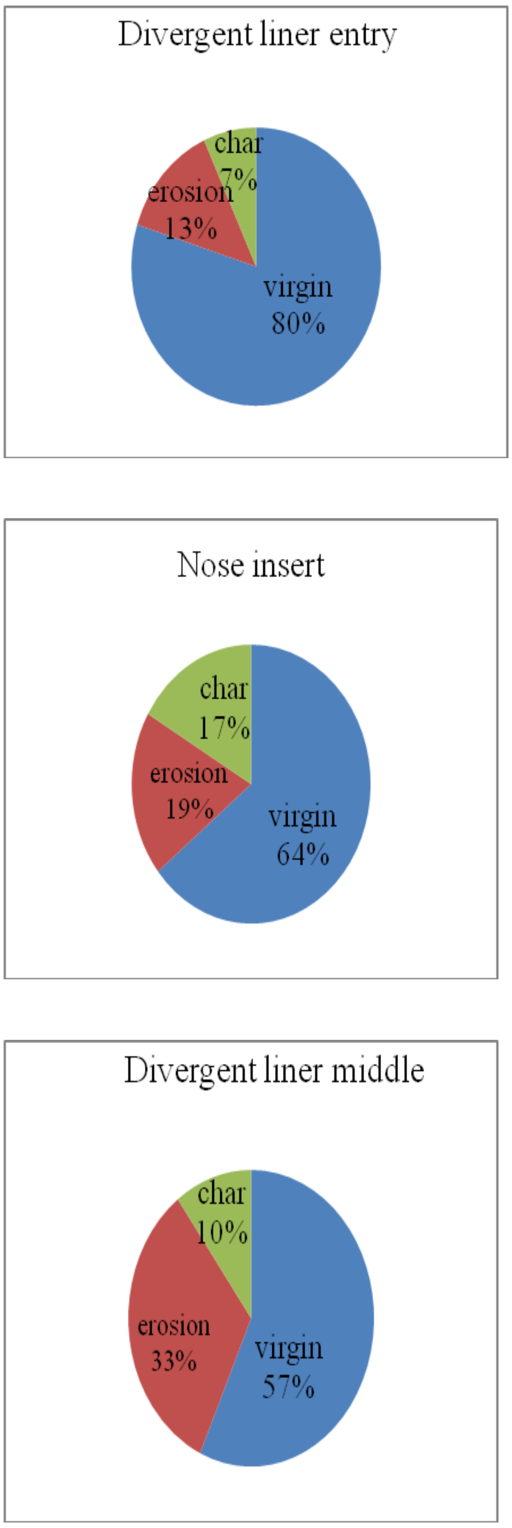


Fig. 6 Contribution of erosion, char & virgin profile of nozzle liners

Table 2 Erosion rate measured after ground firing test

Sl. No.	Erosion rates measured (max.) mm/sec			
	Material	Predicted values	Static test 1	Static test 2
1	Graphite	0.12-0.15	0.12	0.14
2	Convergent liner	0.32-0.35	0.33	0.34
3	Divergent Liner	0.28-0.32	0.30	0.31
4	Rubber (Thermal Boot)	0.12-0.15	0.13	0.14

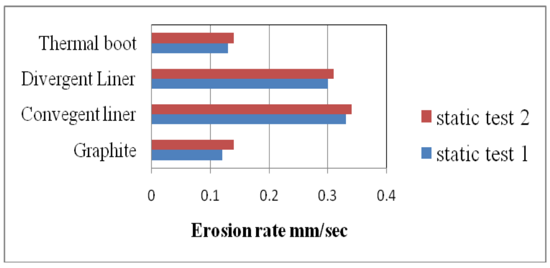


Fig. 7 Erosion rates measured after ground firing test of nozzle

3. Conclusions

A solid rocket motor with Hydroxyl Terminated Poly Butadine (HTPB) as propellant is designed developed and ground tested before using in Flight test to know the performance of the Flex Nozzle ablative liners. The posttest analysis is done after ground firing test. Two ground firing tests have been conducted and the erosion rates measured after the test have been shown in Table-2 and the erosion rates are almost matching with the predicted values. Divergent being largest component and contributes more to nozzle weight the thickness of liner should be as minimum as possible, at the same time it should be more erosion resistant. The erosion resistance due to hot gases can be increased by fabricating the liner in such a way that the flame only touches the edge of the composite ply of the liner. The char, erosion, virgin thickness are measured and checked. The ground firing test results proved that improved erosion resistant liners obtained has enhanced the performance of the flex nozzle system.

The nozzle ablative liners developed by adopting optimum process parameters showed remarkable enhancements in performance of flex nozzle system by carrying out ground firing tests. It is concluded that the influence of erosion resistance, manufacturing methods, mechanical tolerances and accuracies on the performance of nozzle ablative liners is admirable.

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