Quantitative Assessment of Thermal Liner Delaminations in Large Size Composite Rocket Boosters for its Repair using X-Ray Radiography

S K Sahoo, M K Bhatt, K K Rai, Abhay Sori, S K Singh, M VL Ramesh and J Ram Mohan

SF Complex, DRDO, Jagdalpur - 494 001, INDIA

E-mail: sonysanjaya77@gmail.com, mahbhatt@gmail.com

Abstract

Advent of long range rocket motor has inevitably forced the designers to accord prime importance to the low weight and high strength materials and thus composites are preferred. Technological challenges in manufacturing a composite material large size rocket booster are enormous and therefore production of a defect free motor is a formidable challenge. The metal shell and composite shell both of them have thermal liner, but unlike metal shell, composite shell does not support Ultrasonic Echo Technique for bond evaluation prior to propellant filling. Ultrasonic Transmission Technique has its own limitation for the quantitative assessment of gaps. With the current processing methods, unlike metal shells, delamination occurrence between composite shell and thermal liner are more frequent and critical in nature. Tap Test give quick view of the bond integrity of thermal liner, but in few cases, delaminations are evident by naked eyes and it looks like a hump. Here lies a scope for the rectification of hump.

This paper presents the adopted technique for providing insight into hump and quantitative assessment of the de-lamination by evaluating angular & radial extension, gap, surface area and volume using RT (Radiographic Testing). Apart from tap test, RT revealed additional delamination areas. The mapped details helped the engineers in visualizing the internals of hump and designing a suitable repair scheme. Then after, the soundness of repair process was confirmed by RT and cleared for further processing. The entire exercise was validated by a successful static test. The post test evaluation of the repaired zone was performed using RT. Here, RT played a vital role and the efforts put from investigation to rectification of the problem generated good data & gives enough confidence to tackle problems of similar nature in future.

Keywords: Radiographic Testing, Composite Rocket Shell, Thermal Liner, Delamination, Hump

Introduction

Solid rocket motor is the main work horse for present generation long range missiles or space vehicles. Their inherent simplicity and minimum preparation time for launch are some of the advantages. In the fast developing technological society, there is always cut throat competition to demonstrate their capability in developing reliable, efficient and cost effective solid rocket motors. In the present era of rocketry, composites are playing vital role mainly in making rocket shells, Nozzles and other hardware components. Composite Rocket Shell (CRS) with high strength to weight ratio compared to metal shell has made it possible for the designer to think it as the future generation rocket shell. Producing solid rocket motor using CRS is challenging and state of art in itself. Thermal liner lining is carried out on inner surface of the rocket shell to protect the rocket shell till completion of the burning of the solid propellant. To achieve the required thermal liner thickness at a particular area, thermal liner buildup is done by laying subsequent layers, hence thermal liner lining is also a state of art technology, which involves laying thermal liner by layers and vulcanization finally at elevated temperature and pressure. As the thermal liner is bonded to rocket shell, due to non homogeneity there are possibilities of development of delaminations during subsequent processing. Now, delaminations
can occur between rocket shell to base layer or may occur within thermal liner layers. They cannot be left as it is which may form humps when subjected to high temperature.

Delaminations between shell to base layer can be primarily inspected through Ultrasonic Testing either by Ultrasonic Echo Technique or Ultrasonic Transmission Technique. But volumetric assessment of big delaminations / humps is not that easy. Tap test is a quick NDT method for revealing big delaminations / humps, but requires inspector experience. X-Ray radiography here can be used to get insight of such big delaminations.

This paper presents the adopted technique for providing insight into hump and quantitative assessment of the delamination by evaluating angular and radial extension, gap, surface area and volume using RT (Radiographic Testing). Apart from tap test, RT revealed additional delamination areas. The mapped details helped the engineers in visualizing the internals of hump and designing a suitable repair scheme. Then after, the soundness of repair process was confirmed by RT and cleared for further processing.

**Probable Causes of Delamination**

After thermal liner lining, the insulation surface is coated with liner material which helps in better bonding to the propellant. For this, the motor needs to be heated to 105°C to drive out the moisture or any solvent traces present on the insulation surface. During this, there are chances that the entrapped moisture or solvent traces if any underneath the thermal liner surface can vaporize and form humps. In case any moisture enters into the composite fibers and stored inside, they can also cause similar defects. This entrapment of vapors is not recommended as they can further expand and grow the delaminations due to high temperature generated during burning of solid propellant. In one such situation, in one of the CRS booster, in the nozzle end side where composite layers of thermal liner are laid, thermal liner found bulged and entrapped vapors are found inside the composite thermal liner layers. These humps in thermal liner can cause further de-bonding of the thermal liner layers due to increase in temperature caused by burning of the solid propellant during testing of rocket motor. Apart from this, due to vacuum application during propellant casting, delamination can further grow and complete collapsing of thermal liner from rocket shell can happen. Due to these reasons, it is essential to carry out repair on these humps.

**Hump Diagnosis and Assessment**

In one of the CRS booster, delaminations were reported after tap test. Careful visual inspection of the same was carried out and the delamination regions were having hump like appearance. It was decided to examine hump using RT. The suspected locations were marked as shown in Fig. 1 and confirmatory exposures were planned first. Following inferences were drawn:

a) Hump like appearance at certain locations were because of the waviness of the shell (refer Fig. 3).

b) At most of the locations, big delaminations between shell and thermal liner were confirmed.
At delamination confirmed locations, thorough exposure plan was prepared so as to know the angular and radial extension, gap, surface area and volume. Exposure plan also included random shots at various locations to hunt for delaminations missed by tap test. The observations were mapped as shown in Fig. 5 and Table 1 gives the dimensional details of delaminations. The RT observations including the dimensional details were forwarded to the designer for calculation of surface area and volume for rectification of the humps.

**Glimpses of Repair Scheme**

To repair the hump, a suitable repair scheme was framed, which includes the following operations:

a) Runner and riser design  
b) Puncturing  
c) Filling with resin  
d) Curing  
e) Sealing of holes  
f) Finishing

The repair scheme was first validated on a similar hump sample before implementing in the actual motor. Then after, it was recommended for re-radiography.
Evaluation of Hump Repair

To evaluate the repaired zone, an optimized exposure plan was generated. Following considerations were taken into account for generating the exposure plan:

a) As the angular extension and maximum gap of the hump were known, exposure plan was focused on those locations.

b) In case of any unfilled patches / gaps are noticed, then earlier hump diagnosis and assessment exposure plan is to be adopted.

c) To check propagation of existing repaired delamination area because of shrinkage / expansion during curing of resin.

d) To ensure proper sealing of runner and riser

e) To ensure no harm to the shell during puncturing operation

The findings of RT are shown in Fig 6. Based on the above checks and test data, the rocket motor has been cleared for further processing.
Post Static Test Radiographic Evaluation for Validation of Repair

After casting and further processing of the rocket motor, it has been static tested. The motor performed well without any flaw in the static testing. Apart from standard post static test evaluation of rocket motor, RT was performed to know the condition of the repaired zone. Following considerations were taken into account for generating the exposure plan:

a) To check for propagation of existing repaired delamination area because of excessive thermal exposure during static test
b) Crumbling of the repaired hump due to combustion chamber pressure.

The findings of RT are shown in Fig. 7.

Conclusion

After repair, RT inference gave confidence to take up jobs for further processing. The static test not only validated the repair procedure, but also validated the RT inferences. In the overall process of processing this defective article, RT played a vital role and the efforts put from investigation to rectification of the problem generated good data and gives enough confidence to tackle problems of similar nature in future. RT provided valuable inputs to the designer to convert / utilize a likely to be rejected article and has saved huge resources and efforts. However, further studies are required to assess the performance during flight conditions of the rocket motor.

References