Mechanical Properties and Damage Analysis of Bonding Interface of Solid Rocket Motor

Lei Liu

School of Aerospace, Aviation University, Yantai 264001, China

lison490@163.com

Abstract

In this paper, the propellant/liner which is easily damaged in the solid rocket motor is taken as the research object. The composition of the bonding interface is introduced. The mechanical properties of the bonding interface are described. The various factors causing the bonding interface damage are analyzed. At the same time, the development process of the bonding interface crack caused by different loads is described.

Keywords

SHM, Bonding interface, damage.

1. Introduction

There are three main bonding interfaces in solid rocket motor(SHM): propellant/liner interface, lining/insulation interface and insulation/shell interface[1]. Among them, the interface with the weakest mechanical properties is the propellant/liner interface. Figure 1 shows the distribution of the interface material of the SHM. The lining layer, also known as the cladding layer, is a composite material bonded to the surface of the solid propellant, which affects and controls the combustion during the service of the SHM. Most of the lining layer is composed of SiC, TiO2, Al(OH)3 and other heat-resistant fillers and functional auxiliaries. The specific type of selection is related to the insulation and the propellant composition. Solid propellant is the core of a SHM. It is a solid mixture of specific properties consisting of binders, oxidants, fuels, and some additive components[2]. The mechanical properties of a series of propellants show that the composition has a large or small effect on the mechanical properties of the propellant.

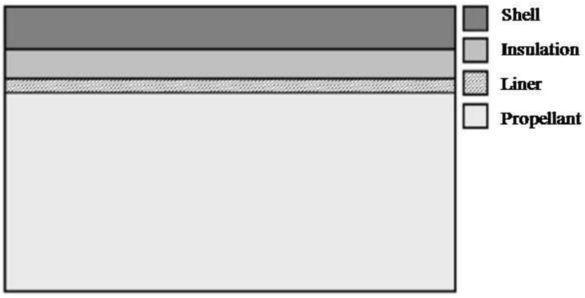

Figure 1 Distribution of interface materials for SHM

2. Mechanical properties of the bonding interface

The performance of the propellant/liner interface in a SHM has an important impact on the overall structure and service life of the motor. Interface debonding is the most prone problem for SHMs. Debonding is fatal to SHMs because debonding destroys the structural integrity of the SHMs and deviates ballistic performance within the motor, causing serious consequences and even explosions. The mechanical properties of the propellant/liner interface are generally characterized as follows:

1) Characterizing physical quantities

The propellant and the liner of the materials on both sides of the bonding interface are all composite polymer materials, so the bonding system has the mechanical properties of the polymer material. The mechanical properties of polymer materials refer to the properties of materials that undergo deformation and damage when subjected to various loads. The parameters that can reflect the deformation process include modulus and Poisson's ratio, etc. The parameters reflecting the failure characteristics are tensile stress, elongation and fracture strength.

2) Viscoelastic properties

Related experiments have shown that the propellant and the liner have both partial properties of the elastic material and the viscous material under external load. The response of the two materials to external loads is a function of loading history, loading rate and temperature, which are typical viscoelastic materials[3].

3) Cumulative damage characteristics

In the SHM manufacturing process, when the propellant is poured into the motor casing, it is subjected to a variety of loads such as alternating load, vibration load, and impact load. Each load will cause some damage to the propellant, and the damage caused by these loads is called cumulative damage.

3. Analysis of damage factors in bonding interface

Due to the influence of self-gravity, transportation vibration and storage cycle temperature, the propellant column is subjected to continuous stress, which tests the interfacial bonding strength between the solid particles such as the oxidant inside the propellant and the binder matrix.

1) Effect of temperature load

The solid propellant is heat-cured after casting and bonded to the inner wall of the motor casing. Since the coefficient of thermal expansion of the column is an order of magnitude higher than the material of the motor casing, thermal stress and thermal strain will develop inside the column as the propellant column drops from a higher temperature to a lower storage temperature. At this time, some weak parts of the column will generate large shear stress, which will easily cause debonding of the propellant/liner interface.

2) Effect of acceleration load

The SHM is overloaded by axial or lateral acceleration caused by vibration loads and impact loads during transportation, loading and unloading. This type of load has a short acting time and the propellant is not substantially destroyed. The SHM is subjected to continuous low-frequency vibration when it is on duty at sea, with the coupling of gravity, the load on the head and the tail of the bonding interface is severe, and the debonding may occur with the increase of time.

3) Effect of gas pressure

When the SHM is ignited, the pressure in the combustion chamber rises in a very short time to reach the maximum working pressure. Under the action of pressure, the shell and the column are deformed, and the interface strength is reduced, which may cause cracks on the surface of the propellant.

4) Effect of changes in chemical properties of propellants

During the storage of the SHM, the curing reaction continues and the crosslinking density increases. This causes the propellant elongation to drop. Under the influence of environmental factors such as temperature and humidity, the molecular chain breaks inside the polymer, the propellant becomes soft, and the tensile strength decreases remarkably.

4. Damage Characterization of Solid Rocket Motor Bonding Interface

As a composite material, when a load of a certain strength acts on the propellant/liner interface, it will cause damage to the internal physical and chemical structure of the material. The interaction between the solid particles and the interface in the material changes, causing local cracks at the bonding interface.

1) Local crack at the bonding interface

When the propellant/liner interface is subjected to continuous external loads such as vibration, impact, and stretching to achieve maximum endurance, the interaction between the material matrix and other components on both sides of the interface is weakened or disappeared. A side of the bonding interface near the propellant produces microcracks that destroy structural integrity.

2) Crack propagation at the bonding interface

The crack at the bonding interface mainly occurs on one side of the propellant. When the propellant is continuously subjected to external loads, local cracks will continue to expand due to the load. When local cracks occur at the bonding interface, many external environmental factors also become factors that cause cracks to expand.

3) Debonding of the bonding interface

After the local crack is generated, the crack propagates due to the continuous action of the external load. If the duration of the force is long enough and large enough, it can even lead to breakage of the composite solid propellant, eventually resulting in debonding of the propellant interface.

Under the action of external load, the damage of the bonding interface may be a single factor or may contain multiple factors. The proportion of these damages depends not only on the mechanical properties of materials such as binders, metal fuels and solid oxidizer particles, but also on external environmental factors. The reason for the crack propagation is that the absorption of external energy by the propellant near the crack destroys the internal chemical bond of the propellant. Regarding the material damage problem, Prof. Reifsnider proposed the concept of "composite damage" when the composite material was damaged by fatigue in 1977. And the process of composite failure is described[4].

5. Conclusion

Through analysis, the following conclusions are drawn:

1) The propellant/liner bonding interface serves as the interface between the two composite materials, and its mechanical properties are closely related to the properties of the composite.

2) Different external environmental factors have different forms of damage to the bonding interface. During the use of the SHM, it is important to pay attention to the influence of temperature, humidity and vibration factors.

References

[1] X. Guo: Investigation on bonding, failure mechanism and mechanical performacnce tuning of interfaces between NEPE solid propellant and liner (Wuhan University of Technology,China 2017), p. 1-2.

[2] L.F. Hou, Z.X. Yang, K.Y. Wang, etc: Composite solid propellant (Solid propulsion technology monograph,China 1994), p. 1-13, 6-76, 218-284.

[3] A.M. Pang: Solid rocket propellant theory and engineering (China Aerospace Publishing House,China 2014), p. 58-60.

[4] K.L. Reifsnider, A. Talug: Analysis of fatigue damage in composite laminates. (International Journal of Fatigue), Vol. 2(1980) No. 1, p. 3-11.