The Influence of Temperature on the Bonding Strength of the Interface

Lei Liu*, Jinfei Li*
Coast Defense College, Aviation University, Yantai, China
*Corresponding author e-mail: lison490@163.com, a490774841@qq.com

Abstract. In order to study the effect of temperature on the bond strength between the propellant and the lining interface, this paper designed a temperature test for the bonded test piece, and conducted a uniaxial tensile test and a stress relaxation test on the test piece. At the same temperature level, the maximum load on the specimen increases with the increase of strain. Under constant strain conditions, the stress on the bonding interface of the test piece gradually decreases with increasing temperature.

1. Introduction
The propellant-liner interface is the bond between the two components of the solid engine. Studies have shown that the number of failed engines caused by this part accounts for nearly one-third of the total number of engine failures [1]. Temperature is a key environmental factor affecting the mechanical properties of the bonding interface and it is worthy of study. In this paper, the mechanical properties of the bonding interface between propellant and lining at different temperatures were studied.

2. Test preparation
2.1. Preparation of test piece
The propellant/liner bonding test piece is designed according to the relevant requirements of the aerospace industry standard QJ2038.2-91 [2]. The dimensions of the test piece are shown in Figure 1. The bonded test piece used in the test consisted of a metal part, a heat insulating layer, a lining layer and a propellant. The propellant for bonding the test piece is selected from the HTPB composite propellant. The composition of the propellant contained 10% by mass of binder, 14% of aluminum powder particles, 69% of AP (ammonium perchlorate) particles, and 7% of additives. The lining material is mainly composed of butyl hydroxy rubber, silica component and the like. The main component of the insulation layer material is nitrile rubber.
2.2. Test equipment
As shown in Figure 2, the test equipment adopts CMT6203 electronic universal testing machine. The testing machine is equipped with high and low temperature test chamber, which can test the mechanical properties of tensile, compression and shearing of materials under different temperature conditions.

![Test equipment](image)

(a) electronic universal testing machine  (b) high/low temperature test chamber

**Figure 2. Test equipment**

3. Test plan
In this test, in order to study the effect of different temperatures on the interfacial bond strength, and taking into account the working conditions of the test equipment, we set up four different temperature test groups. The test temperatures were 20 °C, 40 °C, 60 °C and 80 °C.

Two performance tests were carried out on the test pieces at different test temperatures: one-way tensile test and stress relaxation test. During the test, the test specimens are quickly heated to the test required temperature through the temperature control box, and kept at a constant temperature for 30 min, and the test specimens are subjected to high temperature aging to make the test specimens reach the test conditions. After the test specimen reaches the aging time required by the experiment under the set temperature conditions, a plurality of test specimens in the test group are taken, and a tensile test is performed to measure the maximum tensile strength under the temperature condition. Stretching speed is set to 50mm/min [3]. For the other test pieces in the test group, stress relaxation tests were performed at strains of 0.5%, 0.6%, and 0.7%, respectively.

4. Analysis of test results
4.1. Analysis of results of uniaxial tensile test
In the tensile strength test, the stress calculation formula is:

\[
\sigma = \frac{F}{S} \tag{1}
\]
Where: $\sigma$ is the tensile strength, $F$ is the maximum tensile force at the time of fracture of the test piece, and $S$ is the cross-sectional area of the test piece.

Uniaxial stretching of bonded test pieces at 4 different temperatures. The test results are shown in Table 1.

**Table 1.** Tensile strength of test specimens at different temperatures.

| Temperature (℃) | Tension at break (N) | Cross-sectional area of the test piece (mm$^2$) | Tensile strength (MPa) |
|-----------------|----------------------|-----------------------------------------------|-----------------------|
|                 | 323.7                | 410.9                                         | 0.79                  |
|                 | 271.1                | 400.2                                         | 0.68                  |
|                 | 215.5                | 409.5                                         | 0.53                  |
|                 | 145/7                | 416.4                                         | 0.35                  |

According to the data in Table 1, the equation of variation of tensile strength with temperature can be fitted:

$$\sigma = -7.3 \times 10^{-3} t + 0.936$$

(2)

Where: $t$ is the ambient temperature.

In the tensile test, the mechanical properties of the test piece at each temperature level are shown in Fig. 3. The fracture process and the fracture site of the specimen are shown in Figure 4.

![Figure 3. Force-displacement curve.](image3)

![Figure 4. Fracture process diagram of test specimen.](image4)

It can be seen from the test data that in the tensile test, when the displacement of the test piece is substantially between 1 mm and 1.8 mm, the test piece may be broken. The fractured part is the lining/propellant interface, and the other bonding interfaces are basically unaffected. As the temperature increases, the maximum tensile strength of the test piece gradually decreases, and the rate of decline gradually increases. This is because during the aging process, as the temperature increases,
the damage of the interface between the binder and the solid particles increases, and the enhancement of
the modulus of the solid particles decreases, thereby lowering the tensile strength of the bonded
interface of the test piece. At the same time, as the propellant is subjected to oxidative crosslinking
and degradation and chain scission, the test specimens begin to soften, and this effect becomes more
pronounced with increasing temperature. On the other hand, an increase in temperature accelerates
molecular motion, promotes migration of components at the bonding interface, and increases the
amount of plasticizer entering the liner in the propellant, which also causes a decrease in tensile
strength at the bonding interface.

4.2. Stress relaxation test results
In this test, the test specimens were subjected to strain-strain relaxation tests of 0.5%, 0.6%, and 0.7%
at four temperature conditions of 20 °C, 40 °C, 60 °C, and 80 °C, respectively. By analyzing the test
data, the maximum load corresponding to each strain value at different temperatures was obtained.
The results are shown in Table 2.

| Temperature | Strain | 20°C | 40°C | 60°C | 80°C |
|-------------|--------|------|------|------|------|
| 0.5%        |       | 100.16N | 93.88N | 57.43N | 44.65N |
| 0.6%        |       | 125.76N | 105.57N | 68.57N | 50.81N |
| 0.7%        |       | 150.63N | 117.56N | 84.47N | 64.85N |

From the experimental data in Table 2, the equation of maximum stress versus temperature under
constant strain conditions can be fitted:

\[
F = \begin{cases} 
-0.93t + 118.76 & \varepsilon = 0.5% \\
-1.25t + 150.76 & \varepsilon = 0.6% \\
-1.43t + 179.23 & \varepsilon = 0.7% 
\end{cases}
\]  

The stress relaxation curves of the test specimens with the same strain value and different
temperatures are shown in Fig. 5.

![Stress relaxation curve](image)

**Figure 5.** Stress relaxation curve.

It can be seen from Table 2 that when the test piece is at the same temperature level, as the strain of
the test piece increases, the maximum load that the test piece is subjected to increases. Under the
condition of constant strain, the stress on the bonding interface of the test piece gradually decreases
with the increase of temperature. Since the composition of the propellant, the lining layer and the heat
insulating layer is mostly a high molecular polymer, when the temperature is raised, the elastic modulus thereof gradually decreases, and the elastic state changes to the viscous state. Therefore, when the temperature is increased and the strain is constant during the test, the stress on the test piece is lowered.

It can be seen from the relaxation curve shown in Fig. 5 that under the condition of constant strain, as the temperature rises, the faster the test piece returns to the equilibrium state, basically conforms to the performance change trend under natural storage conditions. However, the stress caused by the strain will not be eliminated for a long time, but will slowly return to the initial state.

5. Conclusion
Through the performance test of the bonded test pieces at different temperatures, the following conclusions were obtained:

1. At different test temperatures, the amount of displacement of the fracture to break is in the range of 1 mm to 1.8 mm. As the temperature increases, the maximum tensile strength of the test piece gradually decreases, and the rate of decline gradually increases.

2. At the same temperature level, as the strain of the test piece increases, the maximum load on the test piece increases. Under the condition of constant strain, the stress on the bonding interface of the test piece gradually decreases with the increase of temperature.

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