Mechanical properties of aramid fiber reinforced rubber sealing gasket at different temperatures

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Abstract. The reliability of sealing connection system mainly depends on the performance of sealing materials. The key to solve the problem of high parameter seal is to develop new sealing composite materials. In view of the seriousness of energy and environmental problems, aramid fiber reinforced composites as an alternative to asbestos composites have received more and more attention. In this paper, the effects of different temperature, tensile rate and sample orientation on mechanical properties of aramid fiber reinforced rubber sealing composites were studied. The results showed that the initial elastic modulus and the tensile strength of the material increase with the increase of tensile rate and decrease with the increase of temperature. The tensile strength of material in longitudinal direction was greater than that in transverse and 45 degree direction. Furthermore, the fracture displacement of material at 20℃ was much larger than that at 100℃.

1. Introduction

Rubber matrix composite material is a new type of composite material after resin, metal and ceramic matrix composites. It has the characteristics of large deformation and high elasticity, etc. It is widely used in aerospace, petrochemical industry, nuclear power and other fields [1-4]. The service temperature of fiber reinforced rubber sealing composites is usually from -50℃ to 250℃. The variation of working conditions will lead to the change of mechanical properties of materials, which will affect the safety of the sealing connection structure.

Kwon et al. [5, 6] carried out the research on rubber sealing gaskets at low temperature environment. Long-period multi-parameter gasket life prediction criterion was proposed. Chen et al. [7] studied the fatigue life of fiber reinforced rubber composites materials. It can be found that the interphase properties had a significant effect on the crack propagation of the composite materials. Li et al. [8] investigated the mechanical properties of carbon nanotube/carbon fiber synergistically reinforced rubber seal composite. It can be seen that the tensile and shear strength of the material were improved by appropriate carbon nanotube content.

This project takes aramid/synthetic mineral hybrid fiber reinforced rubber sealing composite (HFRC) as the object. The effects of different temperatures and tensile rate on the mechanical properties of gaskets are studied in this paper.
2. Experimental investigation

2.1. Specimen
The materials were bought from xinwen sealing gaskets factory in Jiangsu Taizhou. The brand name was GP150. The sheet size was 4600mm×1500mm×3mm. The product was made up of aramid natural fiber, synthetic mineral fiber, nitrile rubber and additives. The material was made by rolling process, and the maximum operating temperature was 200℃.

The material was cut to obtain the test sample. The directions of the samples were transverse direction (x-axis), longitudinal direction (y-axis) and 45° direction, as shown in Fig. 1. The test specimen was standard dumbbell shaped, and the specific size was shown in Fig. 2.

![Figure 1. Cutting Direction of gasket.](image1)
![Figure 2. Specimen shape.](image2)

2.2. Test equipment
The tensile test was carried out on the DDL-100 microcomputer controlled electronic universal testing machine. The force measurement range was 0-2 KN. The measurement accuracy of the testing machine was ±0.5% of the indicated value, the tensile velocity was 0.001mm /min~ 500mm /min, and the displacement velocity accuracy was ±0.5% of the indicated value. The test temperature ranged from -70℃ to 350℃.

2.3. Test scheme
Test in this paper was based on the determination method of tensile stress-strain properties of vulcanized or thermoplastic rubber (GB/T 528-2009). The tensile rates selected in the test were 1mm/min, 10mm/min and 50mm/min, respectively. Considering the different service environment of the gaskets, the test temperatures selected were 20℃ and 100℃, respectively. Three specimens were used in each group of test and then the average value of the test results was taken.

3. Results and discussion

3.1. Mechanical property test at room temperature
The tensile stress(σ) varying with strain(ε) of aramid fiber reinforced rubber gaskets with different tensile rates and sampling directions at 20℃ was shown in Fig. 3. Fig. 3(a), (b) and (c) showed the tensile σ-ε curve of the gaskets in longitudinal, 45° and transverse direction, respectively.

It can be seen from Fig. 3(a) that the σ-ε curve increased rapidly at the initial tensile stage. When ε reached 0.02, the curve rose at a slower rate. The initial elastic modules and the tensile strength of the
materials increased continuously with the increase of tensile rate. When the tensile rate was 1 mm/min, the initial elastic modules, tensile strength and fracture strain were 213 MPa, 17 MPa and 0.08, respectively. When the tensile rate reached 50 mm/min, the initial elastic modules, tensile strength and fracture strain were 240 MPa, 21.6 MPa and 0.09, respectively. As we can see from Fig. 3 (b) and (c), the strength of the materials in the longitudinal direction was greater than that in the transverse direction and 45° direction. Moreover, the fracture strain of the materials in the transverse direction was higher than that in longitudinal direction and 45° direction. Taking 10 mm/min of the tensile rate as an example, the tensile strength and fracture strain of the material in the longitudinal direction were 19.2 MPa and 0.08, respectively. The tensile strength in 45° direction were 7.6 MP and 0.11, respectively. The tensile strength in the transverse direction were 5.6 MPa and 0.12, respectively. The main reason was that the distribution of the aramid fibers in rubber matrix was obviously oriented and most of fibers was distributed along the longitudinal direction. It led to the greatest strength in the longitudinal direction and the highest fracture strain in the transverse direction of the specimen.

![Stress-strain curve at 20°C](image)

**Figure 3.** Stress-strain curve at 20°C. (a) longitudinal direction, (b) 45° direction, (c) transverse direction

### 3.2. Mechanical properties test at high temperature

In this paper, the test was carried out according to the tensile rate at high temperature (100°C) given in the test scheme. The curve of the tension (F) with the elongation (ε) of the materials was obtained, as shown in Fig. 4. The F-ε curves of longitudinal, 45° and transverse tensile direction of the gaskets were presented in Fig. 4 (a), (b) and (c), respectively. The change regulations of the initial modulus, tensile strength and fracture strain of the material at 100°C were basically the same as that at 20°C. However, compared with that at 20°C, the tensile strength
and elongation after fracture of the material were significantly decreased. It can be seen from Fig. 4 (a) that when the tensile rates were 1 mm/min, 10 mm/min and 50 mm/min, the tensile strength at 20 °C was 17 MPa, 19 MPa and 21 MPa correspondingly, and that at 100 °C was 8 MPa, 11 MPa and 12 MPa, respectively. The tensile strength was reduced by 40%. Fig. 4 (c) showed that when the tensile rates were 1 mm/min, 10 mm/min and 50 mm/min, the elongation after fracture at 20 °C was 5.5 mm, 5.7 mm and 6.6 mm correspondingly, and that at 100 °C was 2.6 mm, 3.6 mm and 4 mm, respectively. It can be found that the tensile strength and the elongation after fracture of the material decreased significantly at high temperature.

The fracture strength at different temperatures and rates was shown in Table 1. It can be seen that the maximum tensile strength of the specimen in the longitudinal direction was 22 MPa at 20 °C, while that was 12 MPa at 100 °C. The maximum tensile strength of the transverse specimen was 6.3 MPa. The value was 28.6% of longitudinal strength. It can be found that the aramid fiber reinforced rubber sealing gasket had an obvious orientation effect.

Table 2 showed the fracture displacement of materials at different temperatures and rates. When the temperature was 20 °C, the maximum fracture displacement of the transverse specimen was 6.1 mm, which was 1.2 times the maximum displacement of the longitudinal specimen. The maximum displacement of the longitudinal sample was close to that in the 45° direction. When the temperature increased, the fracture displacement decreased significantly. Taking the specimens in the transverse direction with a tensile rate of 50 mm/min as an example, the fracture displacement decreased by 37.7%, when the temperature increased from 20 °C to 100 °C.

Figure 4. Force-displacement curves at 100 °C. (a) longitudinal direction, (b) 45° direction, (c) transverse direction.


| Tensile rates | Transverse direction /MPa | Transverse direction /MPa | Longitudinal direction /MPa | Longitudinal direction /MPa |
|---------------|---------------------------|---------------------------|-----------------------------|-----------------------------|
| 1 mm/min      | 5.2                       | 6.3                       | 17                          | 4.6                         |
| 10 mm/min     | 5.7                       | 6.9                       | 19                          | 4.8                         |
| 50 mm/min     | 6.3                       | 8.3                       | 22                          | 5                           |

4. SEM analysis

SEM fracture photos of the composite materials was shown in Fig. 5. It can been seen the cross section of the composite materials in the transverse direction. Plenty of aramid fibers and mineral fibers existed in the cross section parallel to the fracture direction. Most of fibers were relatively complete without fracture. The results indicated that the failure form of the specimens in the transverse direction of composite materials was matrix cracking. Fig. 6 showed the cross sections in the longitudinal direction of the composite materials. It can be found that the aramid fibers and mineral fibers were perpendicular to the fracture of the specimen, and most of fibers were fractured. The results indicated that the main failure form of the specimen in the longitudinal direction was fiber fracture.

Figure 5. SEM photographs of transverse sample cross-section
5. Conclusion
The tensile tests of gasket samples at different temperatures and tensile rates were carried out. The effect of tensile rate, temperature and orientation of the specimen on the tensile strength and the fracture displacement were investigated. The results indicated that the initial elastic modulus and tensile strength of the material increased continuously with the increase of tensile rate at 20 °C. The tensile strength in the longitudinal direction were much greater than that in the transverse and 45° direction. The initial elastic modulus, tensile strength and the fracture displacement at 100 °C were basically the same as those at 20 °C. However, the tensile strength and the fracture displacement were significantly decreased at high temperature. SEM analysis was conducted on the fracture surface of gasket. It can be found that the failure form of the specimen in the transverse direction and longitudinal direction of composite materials was matrix cracking and fiber fracture, respectively.

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