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Study on Coupling Effect of Heat Source and Load Holding and Fitting Performance of Rubber Material

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Abstract

As an important part of the isolation bearing, the rubber material is often closely related to the heat source. The study on the whole bearing also shows that the influence of temperature on the performance of the bearing cannot be ignored. In the actual use process, rubber isolation bearing is often subject to the coupling effect of heat source and load holding. At present, there is a lack of research data on rubber mechanical properties under the cross-influence of both, so the degree of mechanical properties degradation of the bearing is unknown. In this chapter, the vulcanized rubber material inside the spacer is taken as the research object, the thermal stability of the material is investigated by thermogravimetric test, and the pyrolysis temperature of the material is determined. Temperature conditions were determined according to the pre-pyrolysis temperature of rubber materials, uniaxial tensile tests were carried out on dumbbell rubber and rubber samples after coupling treatment with high temperature and load, and the changes in tensile properties of rubber materials under the coupling effect of heat source and load holding were investigated, which provided a reference for establishing the constitutive model of rubber materials under relevant influences. In addition, SEM tests were conducted on the tensile section of rubber samples. The degradation mechanism of rubber tensile properties was further analyzed by observing the change of the micromorphology of rubber materials.

Keywords

Heat source; Holding load; Cross action; Fitting performance.

1. THERMOGRAVIMETRIC TEST OF RUBBER MATERIAL

Thermogravimetric test is to measure the change of sample mass by heating the material sample within a certain temperature range, so as to analyze the thermal decomposition process and thermal stability of the sample. The rubber material has poor high temperature resistance and will produce pyrolysis damage under the influence of high temperature, resulting in a decrease in its quality and performance, which will indirectly affect the vibration isolation function of the rubber bearing. Therefore, this paper takes the vulcanized rubber material used in the rubber layer inside the support as the research object, and determines the relationship between the mass percentage of the material and the temperature through thermogravimetric test to study the thermal stability of the material. The sensitivity was 0.01mg. Specific test steps refer to the specification GB/T14837.3-2018 [13] "Rubber and rubber products thermogravimetric determination of vulcanized and unvulcanized rubber composition Part 3: Extracted hydrocarbon rubber, halogenated rubber, polysiloxane rubber", first, the test crucible is weighed and adjusted to zero, the sample material is weighed together with the crucible. The

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sample quality is controlled at about 10mg. Secondly, the sample was put into the thermogravimetric analyzer together with the crucible, and the temperature of the instrument was controlled from room temperature to 800℃ at a rate of 10℃/min. The test environment was nitrogen atmosphere (N) and air atmosphere (N2:02-4:1). Finally, the relationship between mass percentage and temperature is recorded.

2. COUPLING SCHEME OF HEAT SOURCE AND LOAD HOLDING OF RUBBER MATERIAL

2.1. Rubber sample preparation

Tensile property is one of the most basic and important mechanical properties of rubber materials. Since rubber is a kind of superelastic material and almost incompressible, the rubber layer of the support is equivalent to the bidirectional tension state under vertical load during the service period[1], and the rubber layer is equivalent to the plane tension state when the support is shear deformed. Therefore, the tensile properties of the rubber material reflect the mechanical properties of the support to a certain extent.

In order to test the tensile properties of rubber, a standard test sheet should be prepared. According to the requirements of 6.1 in GB/T528 "Determination of tensile stress and strain properties of vulcanized rubber or thermoplastic rubber" 1691, the cutting knife shown in Figure.1 is used, and the punching machine shown in Figure.2 is used[2]. The vulcanized rubber sheet product used in this test is provided by Zhejiang Gutai Testing Company, which is consistent with the equipment.

Figure 1. Dumbbell cutting tool

Figure 2. Film processor

Table 1. Test parameters

Test length(mm)	Stress width(mm)	Thickness (mm)
20.0±0.5	5.0±0.1	3.0±0.2

According to the standard requirements, the length of 20mm is marked on the tensile section (middle section of the sample) of the dumbbell type rubber and rubber sample as the initial marker distance. Within this range, the thickness and width of the middle and both ends are measured with an electronic vernier caliper, and the median of the three measured values is taken as the calculation value to ensure that the dimensional error is within the demonstration range shown in Table.1.

2.2. Test condition

This test mainly investigated the influence of the coupling effect of heat source and load holding on the tensile properties of rubber materials, considering the pre-stress load on the sample, and considering the temperature effect within 100℃ according to the product environment, a total of 8 temperature conditions of 30℃, 40℃, 50℃, 60℃, 70℃, 80℃, 90℃ and

100°C were developed respectively[3~6]. The tensile load holder is used to preload the rubber sample. The tensile load holder is mainly composed of a fixed fixture and a screw. The fixed fixture can grip both ends of the rubber sample, and the rotating screw can slide the fixed fixture. The maximum sliding displacement is 220mm. The rubber sample is fixed after coaxial stretching to 100% elongation. The 100% elongation of rubber means that the tensile length of the rubber standard distance section is 1 times of the initial standard distance (from 20mm to 40mm). The pre-loaded rubber sample is placed in the constant temperature drying oven (up to 200°C) as shown in Figure 3.， See Table 2. for specific working conditions.

In addition, conditions only affected by temperature were set as the comparison group, that is, rubber and rubber samples were placed at 8 temperatures without load for 1.5h. In this paper, T-20 represents rubber and rubber samples under a single condition at 20°C, and LT-20 represents rubber and rubber samples under a condition coupled with load at 20°C, and the meanings of other symbols are similar.

Figure 3. Constant temperature drying oven

Table 2. Details of coupling conditions between heat source and load holding of rubber samples

Temperature condition (°C)	Sample number	Remark
20	LS-20	Elongation 100%; Holding temperature 1.5h; 3 samples
40	LS-40	Elongation 100%; Holding temperature 1.5h; 3 samples
50	LS-50	Elongation 100%; Holding temperature 1.5h; 3 samples
60	LS-60	Elongation 100%; Holding temperature 1.5h; 3 samples
70	LS-70	Elongation 100%; Holding temperature 1.5h; 3 samples
80	LS-80	Elongation 100%; Holding temperature 1.5h; 3 samples
90	LS-90	Elongation 100%; Holding temperature 1.5h; 3 samples
100	LS-100	Elongation 100%; Holding temperature 1.5h; 3 samples

Note: The number of the test piece shall be numbered according to the corresponding temperature condition; L100 represents the load when the rubber specimen is stretched at 100% elongation. After the test temperature was further increased to 110°C, the surface of the rubber sample taken out after 1.5h in the state of no stress was sticky, the overall softening was obvious[7], and the tensile section of the rubber sample was fusing, which was regarded as the rubber failure state, as shown in Figure 4. Due to the failure of the rubber sample, the effect of heat source and load-holding coupling on the rubber material above 110°C was not considered in this test[8].

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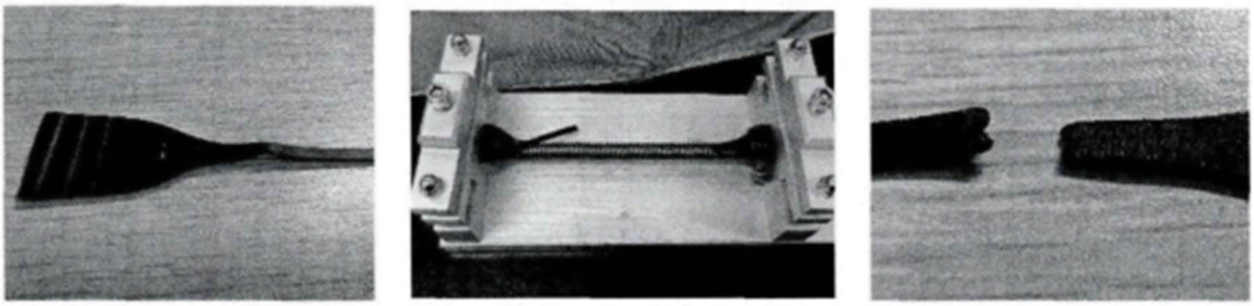

(a) Warping deformation (b) Fusing (c) The fuse fracture

Figure 4 Failure state of rubber samples

3. RUBBER SPECIMEN TENSILE PROPERTY TEST

The tensile property test of rubber materials is to carry out uniaxial tensile to fracture of special dumbbell rubber samples. This test is carried out in the mechanics laboratory of Zhejiang Gutai Engineering Testing Technology Co., LTD. WDW-10 universal testing machine is used to carry out uniaxial tensile test on the above-mentioned rubber and rubber samples. The testing machine can provide a maximum force of 10kN, as shown in Figure 5. The test process was carried out according to the requirements of 13.1 in GB/T528 "Determination of tensile stress-strain Properties of Vulcanized Rubber or thermoplastic rubber" [12]. The rubber sample was uniaxial stretched to fracture at the rate of 500mm/min[9], and the tensile stress-strain curve of the rubber sample during the whole process of tensile fracture was recorded.

Figure 5. Rubber specimen tensile test (universal testing machine)

After observing and comparing the rubber samples, there is no significant difference in the tensile failure state of the rubber samples under different working conditions.

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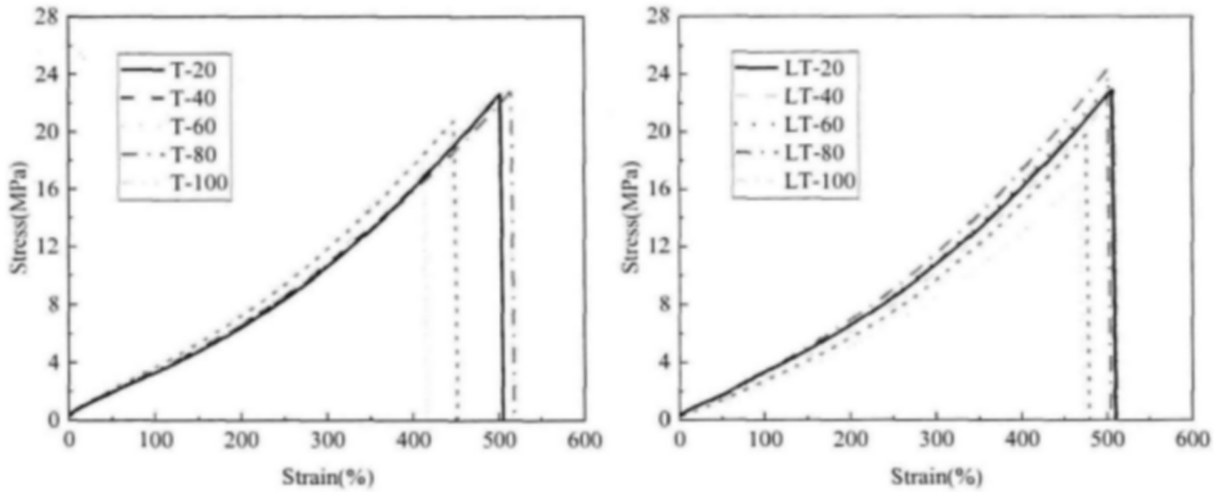

(a) High temperature single condition (b) Coupling condition of heat source and load holding

Figure 6. Tensile σ-ε curve of rubber specimen

FIG. 6 shows the σ-ε stress-strain relationship curve of the specimen during the tensile test, which can reflect the change of the tensile properties of the rubber to a certain extent. By comparing the σ-ε curves under different working conditions[10], it can be seen that the degradation of the tensile properties of rubber materials under different working conditions is different. Under the influence of temperature alone, the tensile strength and elongation at break of rubber materials decrease significantly when the temperature reaches 110°C, while the constant tensile strength increases slightly with the increase of temperature. When the temperature reaches 100°C, the tensile strength, elongation at break and tensile strength of rubber material decrease significantly when the temperature exceeds 110°C. In conclusion, the coupling effect of heat source and load holding has an adverse effect on the tensile properties of rubber materials, which is not completely consistent with the degradation of properties under the influence of temperature alone. 100°C is a temperature turning point for the difference in the change rate of rubber properties.

4. MECHANISM OF MICROCOSMIC INFLUENCE ON TENSILE PROPERTIES OF RUBBER

When observing the microstructure of rubber materials, factors such as porosity, pore size and pore distribution are usually considered, which can reflect the change of mechanical properties of the material. The increase of porosity and pore size will lead to the reduction of elastic modulus and strength of rubber materials, which is because pores will lead to stress concentration and crack growth, and larger pores will lead to more stress concentration and crack growth. In addition, the shape and distribution of pore structure will also affect the mechanical properties of the material, and the uneven distribution of pores or the aggregation distribution will lead to the reduction of the strength and toughness of the material. Table 3. shows the SEM micromorphology of adhesive materials under different working conditions at different magnification.

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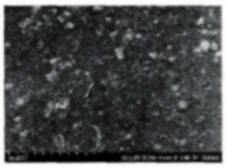
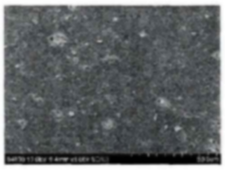
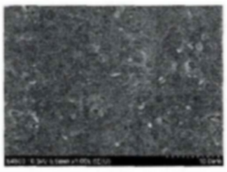
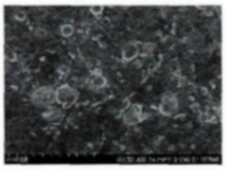
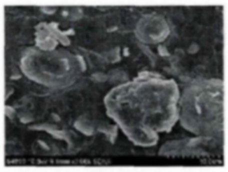
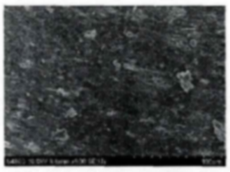
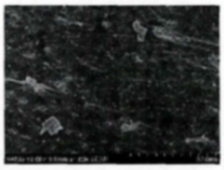
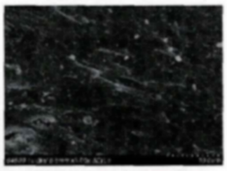
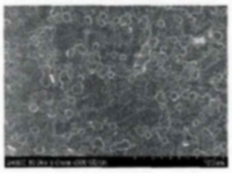
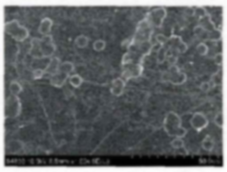
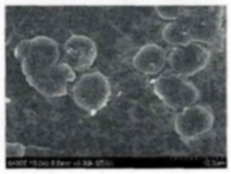
Table 3. Microstructure diagram of rubber material after test

Condition	500times	1000 times	3000 times
LS-30			
LS-100			
LS-30			
LS-100			

By comparing the microscopic maps after various temperature tests in Table 3, it can be seen that the surface of the rubber material is relatively flat at normal temperature, and the tiny pores and cracks on the surface are generated in the manufacturing process, which are common inherent defects. After high temperature action at 100℃, a small number of pores with a diameter of about 40um appeared on the surface of the rubber, and cracks around the pores were found at about 5um, indicating that the rubber had been pyrolyzed at 100℃ with gas emerging, which was consistent with the conclusion obtained by thermogravimetric test that the rubber began to pyrolyze at about 120℃. After tensile stress at room temperature, tear marks appear on the surface of the adhesive material, and the inherent defects show signs of expansion.After the coupling of 100℃ high temperature and tensile stress, a large number of pores with pore size of 40~80um were produced on the rubber surface, and the distribution was relatively dense, indicating that the rubber pyrolysis was intensified under the load coupling action[11], and the mass loss was also greater. Meanwhile, the increase of porosity and pore size reduced the strength of rubber. Therefore, compared with the single effect of high temperature, The coupling effect of heat source and load holding has more obvious effect on the properties of rubber materials.

5. ANALYSIS OF TEST RESULTS OF RUBBER TENSILE PROPERTIES

This test mainly investigated the tensile properties of rubber materials under various working conditions, including tensile strength, elongation at break, constant elongation and constant elongation. The average value of each performance index was taken from 3 pieces. Among them (Table 4), the tensile strength LSS refers to the maximum tensile force of the specimen during the process of stretching to fracture. Elongation at break refers to the percentage elongation of the specimen at tensile break. Constant elongation strength S refers to the stress borne by the rubber sample when the tensile range is stretched to the specified elongation e. Specific values are calculated according to the formula provided in 15.1 of GB/T

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528 "Determination of tensile stress-strain Properties of Vulcanized Rubber or thermoplastic rubber"[12].

Table 4. Detailed test results

Working condition	e: Elongation at break (%)	LS_S: Tensile strength (MPa)	D_S: Constant elongation strength (D-100)	Remark
LS-20	493.28	21.89	2.09	
LS-40	498.39	22.81	2.43	
LS-50	505.99	23.08	2.34	
LS-60	502.34	20.18	2.19	
LS-70	501.92	19.33	2.23	
LS-80	469.49	19.74	2.18	
LS-90	488.90	18.20	2.38	
LS-100	411.09	18.06	2.44	
Working condition	Ge: Elongation at break after treatment (%)	GLS_S: Tensile strength after treatment (MPa)	GD_S: Elongation strength is determined after treatment (D-100)	Remark
GLS-20	480.38	20.86	2.08	
GLS-40	490.16	22.01	2.39	
GLS-50	502.17	22.98	2.29	
GLS-60	500.73	19.28	2.11	
GLS-70	488.39	18.92	2.10	
GLS-80	460.20	19.56	2.14	
GLS-90	480.33	17.29	2.31	
GLS-100	349.23	17.85	2.36	

The data in the table are the average values of the three samples.

5.1. Variation of tensile strength

The tensile strength mainly reflects the ultimate tensile failure performance of rubber material, and the smaller the tensile strength, the more likely it is to cause damage and failure. In this paper, the tensile strength LSS and the initial tensile strength LS(the ratio of DS is defined as the tensile strength ratio) of rubber materials under various working conditions, representing the influence coefficient. The change law of rubber tensile strength can be intuitively expressed by the tensile strength ratio. When the tensile strength ratio is greater than 1, the tensile strength is increased compared with normal temperature; when the tensile strength ratio is less than 1, the tensile strength is decreased compared with normal temperature. FIG. 2.8 shows the variation of tensile strength ratio of rubber material under different working conditions. In the figure, LS(CW) represents the initial tensile strength measured at room temperature (20°C), LS(T) represents the tensile strength under a single condition of temperature T, and LSL(S) represents the tensile strength under the coupling condition of heat source T and load holding.

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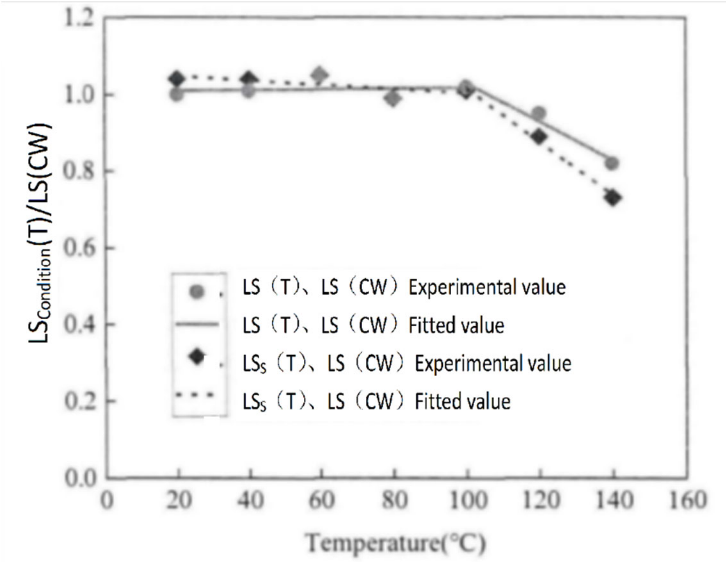

Figure 7. Variation of tensile strength ratio

As can be seen from Figure 7, when the temperature range is 20°C~80°C, the tensile strength of rubber under various working conditions has little change, and the tensile strength ratio fluctuates slightly around 1, while when the temperature range is 80°C~100°C, the rubber tensile strength shows a significant downward trend. The tensile strength of rubber under the coupling effect of heat source and load holding decreased more significantly, and the tensile strength of rubber under the coupling effect of heat source and load holding at 100°C decreased by 15%, compared with the relative decline of 7% under the influence of high temperature alone.

The calculated fitting values were compared with the experimental values. The maximum relative deviation was 3.1% and the average relative deviation was 1.6%. The fitting results are good, so the variation of rubber tensile strength ratio with temperature T can be described under single temperature condition.

In summary, the tensile strength of rubber is less affected when the temperature is between 20°C and 70°C, while the load-holding coupling between 70°C and 100°C will aggravate the deterioration of the tensile strength, especially when the heat source is coupled with the load-holding coupling at 100°C[8], the tensile strength of rubber is significantly reduced. This is consistent with the results of the increase of porosity and pore size in the analysis of the surface microstructure of rubber tensile section under this condition. Therefore, the effect of load-holding coupling on the deterioration of rubber tensile strength should be considered when the temperature exceeds 70°C.

5.2. Change rule of elongation at break

The elongation at break of rubber is related to its tensile strength, and the higher tensile strength can ensure that the rubber has a good elongation, which is not easy to destroy in the deformation process, and the better the resistance to damage deformation. In this paper, the ratio of elongation at break E(T) and elongation at initial break E(CW) of rubber materials under various working conditions is defined as the ratio of elongation at break, representing the influence coefficient. Figure 8 shows the change law of the ratio of elongation at break of rubber materials after various working conditions. In the figure, E(CW) represents the initial elongation at break measured at room temperature (20°C), E(T) represents the elongation at break under a single condition of temperature T, and Ebl(T) represents the elongation at break under the coupling condition of temperature T and load.

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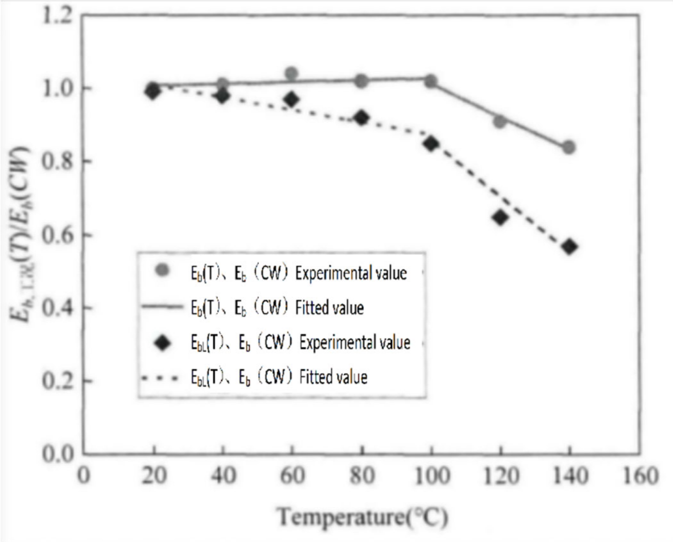

Figure 8. Change law of elongation ratio at break

As can be seen from FIG. 8, when the temperature action range is 20°C~100°C, the elongation at break of rubber under single temperature condition has a small change range, and the ratio of elongation at break fluctuates slightly around 1, while the elongation at break of rubber under the coupling action of heat source and load holding has a slight decrease trend. The main reason is that the coupling effect of heat source and load holding produces residual deformation of rubber. After the coupling effect of heat source and load holding at 100°C, the elongation at break of rubber is reduced by 13% and the reduction is similar to the 15% residual deformation, so it is considered that the 13% reduction is caused by the coupling effect of load. When the temperature range is between 100°C and 140°C, the elongation at break of rubber shows a downward trend, and the reduction rate increases. After high temperature action at 110°C, the elongation at break of rubber decreases by 14%, while for the coupling action of heat source and load holding at 110°C, the elongation at break of rubber decreases by 41%, which is similar to the 45% residual deformation. The relative decline of 26% under the single influence of higher temperature is considered to be caused by the load coupling, indicating that the load coupling is intensified above 100°C.

In summary, for the elongation at break of rubber, the elongation at break of rubber is slightly reduced after the coupling action of load within 20°C~100°C, and after the temperature exceeds 100°C, Coupling under load will aggravate the deterioration of elongation at break, especially when coupled by heat source and load holding at 110°C, the elongation at break of rubber significantly decreases, which is consistent with the result of rubber tensile strength degradation. Meanwhile, the decrease of elongation at break of rubber is related to its residual deformation. Therefore, it is necessary to consider the effect of coupling between heat source and load holding on the elongation at break of rubber, especially when the temperature exceeds 100°C, the elongation at break of rubber deteriorates further. In addition, the fitting formula of the ratio of elongation at break with temperature under two kinds of working conditions can provide a reference for material property testing in engineering.

6. SUM UP

The vulcanized rubber material used for rubber isolation bearing was studied. Firstly, the thermogravimetric test was carried out to analyze the thermal stability of the material and determine the pyrolysis temperature of the rubber. Secondly, the dumbbell rubber sample made of vulcanized rubber material was treated by the coupling of heat source and load holding. The temperature conditions in the range of 20°C~1000°C were considered respectively, and the

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tensile deformation was taken as the load condition to investigate the change of the tensile properties of rubber material after each working condition. Combined with the microscopic scanning electron microscopy detection on the surface of the tensile section of rubber samples, the microscopic damage mechanism of rubber tensile properties under the combined influence of heat source and load holding was analyzed[4]. In summary, the following conclusions were obtained:

(1) Through the thermogravimetric test analysis of the vulcanized rubber material used in the support, the results show that when the temperature reaches about 100°C, although the mass loss of the rubber is small, it has been decomposed; When the temperature exceeds 150°C, the quality of rubber begins to decrease significantly, and the decomposition of rubber is more intense in the aerobic environment, and the residual mass is less, indicating that the thermal action is more unfavorable to the thermal stability of rubber. Due to the existence of protective layer rubber and fireproof structure in the rubber bearing, it is difficult to reach the pyrolysis temperature inside the support, so it is more practical to pay attention to the influence of temperature within 100°C on the mechanical properties of rubber.

(2) When the temperature range is 20°C~80°C, the tensile strength of rubber under various working conditions does not change much, but the rubber elongation at break decreases slightly after the coupling action of heat source and load holding. The rubber elongation at break decreases by 15% after the coupling action of heat source and load holding at 80°C, which is mainly caused by residual deformation. The results show that the coupling effect of load at 20°C~80°C has no obvious effect on the tensile strength and elongation at break of rubber.

(3) When the temperature range is 100°C~150°C, the rubber tensile strength and elongation at break show a significant decrease trend, and the rubber tensile strength and elongation at break decrease by 17% and 13%, respectively, after the high temperature action at 100°C. However, the tensile strength and elongation at break of rubber under the coupling effect of heat source and load holding at 150°C decreased by 27% and 43% respectively, and the relative decreases under the influence of high temperature alone were 7% and 15% respectively, which was consistent with the results of the microstructure analysis of rubber tensile section surface caused by the increase of porosity and pore size under the coupling condition. The results show that the ultimate failure performance of rubber deteriorates and rubber is more likely to be damaged. Therefore, the effect of load coupling on the deterioration of rubber tensile strength and elongation at break should be considered when the temperature exceeds 100°C.

(4) Microscopic scanning electron microscopy showed that a small number of pores and cracks appeared on the surface of the rubber after the action at 100°C, indicating that the rubber was pyrolytic with gas emergence, and the quality of the rubber was lost. After the coupling of heat source and load holding at 100°C, the surface porosity and pore size of rubber increased, and the rubber pyrolysis intensified, indicating that the coupling effect of heat source and load holding will aggravate the degradation of rubber material strength, which is consistent with the degradation of rubber material tensile properties.

(5) The variation rules of tensile strength LS, elongation at break E, constant elongation S100, and ratio of constant elongation So to initial value of rubber materials with temperature T were respectively fitted under the condition of high temperature single factor and the coupling condition of heat source and load holding, and the error analysis was made between the fitting results and the test results. The maximum relative deviation and average relative deviation are less than 10%, indicating that the fitting is reasonable, so the corresponding fitting can be used to describe the variation of tensile properties with temperature.

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