Effect of Temperature on Tensile Fatigue Life of Natural Rubber

J Wu\textsuperscript{1}, L Chen\textsuperscript{1}, H H Li\textsuperscript{1}, B L Su\textsuperscript{1*} and Y S Wang\textsuperscript{1}

\textsuperscript{1}Center for Rubber Composite Materials and Structures, Harbin Institute of Technology, Weihai, China

*Corresponding Author / E-mail: wujian@hitwh.edu.cn, benlongsu@hitwh.edu.cn

Abstract. Research on rubber fatigue properties is of great significance for improving the durability of rubber products. Natural rubber is widely used in rubber products, it is very important to study the effect of temperature on its fatigue properties. Here, tensile fatigue tests of natural rubber have been carried out under different temperatures and strains for studying the influence of temperature and strain on the fatigue life. Results indicate that fatigue life decreases when test temperature increases, and it decreases obviously when temperature is higher than 75°C; with increase of temperature, tensile strength decreases, and the elongation at break increases; the fatigue life decreases with the increase of strain, and the decrease of fatigue life is more remarkable under small strain.

1. Introduction
Due to its elasticity and large deformation capacity, rubber is widely used in automotive, machinery, aerospace and other industries, these applications makes it ideal for vibration isolators, elastic elements, seals of spacecraft and other key structures [1]. Rubber properties have a direct impact on the life of products, especially mechanical properties. Fatigue is the primary failure mode of vibration damping rubber structural parts for aerospace. Fatigue properties of rubber material are affected by many environmental factors, especially the temperature. Due to the effects of ambient temperature and heat in rubber structures, the fatigue life decreases when the temperature of fatigue damage position increases, which has a great impact on the use of rubber structures. It is necessary to study the influence of temperature and strain on fatigue of natural rubber.

Rubber fatigue has been widely studied at home and abroad. When natural rubber material was studied by uniaxial tensile test with positive R, the critical region cracks prone to change into secondary cracks and cracks branching [2]. A uniaxial tensile and compression fatigue tests of carbon black filled natural rubber were carried out by Cam [3, 4], the fatigue crack morphology has been studied. Fatigue test of the natural rubber with different carbon black component was studied by Kim [5], which including N330, N650 and N990. Test results showed that different carbon black materials caused different fatigue life of vulcanized rubber. A uniaxial fatigue test of filled natural vulcanized rubber has been studied by Mars and Fatemi [6, 7]. When the initial load increased, the fatigue life increases. Then, results indicated that the fatigue cracks proned to produce and arise in a special plane whether proportional loading or nonproportional loading under multiaxial loading. The static loading test and the cyclic loading test of natural rubber between air and vacuum have been carried out by Gent and Hind [8]. Results indicated that oxygen promoted the growing of fatigue cracks.
In summary, current researches of rubber fatigue are mainly focused on the influence of material, however, influence of coupling of temperature and strain is also important. For this reason, uniaxial tensile fatigue tests of NR under different temperatures and strains have been carried out for studying the influence of temperature and strain on fatigue life, which provides the theoretical basis for the design of rubber damping products.

2. Experiment set up

2.1. Materials and equipments
A uniaxial tension test at different temperatures is performed by using natural rubber dumbbell specimen with a type 1 shape according to ISO Standard 37:2011, then the stress-strain curves for tension can be obtained. The test is performed by a high-low temperature tension machine. Fig. 1 shows the production process of rubber specimen.

![Figure 1. The production process of specimen.](image1)

The fatigue test at different temperatures has been carried out by using natural rubber dumbbell specimen. Fig. 2 shows the dimensions of dumbbell sample with a thickness of 2 mm. Fig. 3 shows the fatigue machine of integrated MUF-1050.

![Figure 2. Schematic of dumbbell specimen.](image2)

![Figure 3. Fatigue machine.](image3)

2.2. Experiment methods
In this study, the stroke controlled method is used by a sine waveform of 5Hz, which can eliminate the effect of creep. Uniaxial tensile fatigue tests of rubber dumbbell specimen have been carried out under the temperature of 20°C-110°C. Every 15°C for a gradient, each temperature is divided into ten conditions according to strain of 60%-150%. Five tests are carried out under each condition, and the mean of values is calculated as the experimental data. Experimental parameters are shown in table 1.

| Experimental parameters | Values                  |
|-------------------------|-------------------------|
| Temperature (°C)        | 20,35,50,65,80,95,110   |
| Strain                  | 150%,140%,130%,120%,110%,100%,90%,80%,70%,60% |
3. Results and discussion
The definition of fatigue crack nucleation life is the number of cycles when the cracks of a small size appear on the sample. In fatigue test, it can be observed that the cycles of fatigue crack nucleation period is far more than the cycles of crack expansion period. Therefore, the fatigue crack nucleation life can replace the fatigue failure, which is defined as the number of cycles when the maximum load decreases 30%.

3.1. Effect of temperature on Fatigue Performance
The mechanical properties at different temperatures can be obtained by uniaxial test data, tensile strength and elongation at break under different temperatures are shown in Fig. 4. Tensile strength of rubber decreases with increase of temperature, and elongation at break increases. The increase of ambient temperature exacerbates thermal motion, which changes the arrangement of rubber molecular chain. with the effect of external forces, rubber molecular chain is easier to move in the stress direction and harder to rehabilitate.

![Figure 4](image1.png)

**Figure 4.** Tensile strength and elongation at break under different temperatures.

The fatigue life and the tensile strength are shown in Fig. 5. Fatigue life and tensile strength are directly proportional relationship, with the reduction of tensile strength, the fatigue resistance of rubber weakened.

![Figure 5](image2.png)

**Figure 5.** The variation of fatigue life with tensile strength.
3.2. Effect of Strain on Fatigue Life

Fig. 6 shows the maximum load with the fatigue life at 20°C with different strains, the growth of fatigue cracks can be reflected by the variation of the maximum load to a certain degree.

The maximum load decreases according to the decrease in strain, and the cycles require to drop to a critical value with increase in strain. A decrease of the maximum load is observed, which is known as Mullin’s effect. The crack first produces and expands at a faster rate in the rubber specimen with larger strain, the lower cycles required to reach the critical value, results show that the maximum load decreases faster of rubber specimen with a larger strain, fatigue fracture appeared firstly and the corresponding maximum load sharply decreased to 0.

![Figure 6. Cyclic maximum load during fatigue process change diagram.](image)

The fatigue life of rubber specimens under different strains are shown in Fig. 7. Whether low or high temperature, the fatigue life decreases with increase in strain. In the case of strain less than 90%, the fatigue life decreases sharply with increase in strain, and tends to be gentle when the strain reaches 110%.

![Figure 7. Fatigue life of rubber specimen under different strains](image)

3.3. Effect of temperature on Fatigue Life

Fig. 8 shows the fatigue life with the change of temperature.

The fatigue life decreases with increase in temperature under the same strain, which decreases obviously when the temperature is up to 95°C. Fatigue life under small strain conditions is more
significantly affected by temperature, and the fatigue life of 110°C is less than 25% of 20°C under the strain 70%. Due to the increase of temperature, which makes the rubber molecular chain more free and weakens the relationship between molecular, and makes the breakage between the molecular chains easier in the circular movement, the cycles required for fracture failure reduces in the experiment.

![Fatigue Life of Rubber Specimen at Different Temperatures](image)

**Figure 8.** Fatigue life of rubber specimen at different temperatures

4. Conclusions

Natural rubber is widely used, fatigue is one of the main properties of rubber products, which has a significant impact on the life of rubber products, especially the damping rubber products. A uniaxial tension fatigue test under different temperatures and strains have been carried out by natural rubber dumbbell specimen. Then, the influence of temperature and strain on fatigue life of rubber have been studied. According to the analyses above, we have the following points:

1. Fatigue life of rubber specimen decreases with increment of strain. When the strain is less than 90%, the fatigue life decreases sharply with increment of strain.

2. The tensile strength of rubber materials decreases with increment of temperature, and the elongation at break increases.

3. Fatigue life decreases with increment of temperature, which decreases obviously when the temperature is higher than 75°C. Fatigue life under small strain conditions is more significantly affected by temperature, and the fatigue life of 110°C is only about 25% of that of 20°C under the strain 70%.

4. The influence laws of temperature and strain on the fatigue life have been proposed, which provides the theoretical basis for the design of rubber damping products.

Acknowledgments

This work is funded by major special project of Shandong province independent innovation achievements transformation (2014ZZCX03407) and Major Program of National Natural Science Foundation of China (51790502).

References

[1] Mars W V and Fatemi A 2002 A literature survey on fatigue analysis approaches for rubber J. Fatigue 24 pp 949–961

[2] Saintier N, Cailletaud G and Piques R 2011 Cyclic loadings and crystallization of natural rubber: An explanation of fatigue crack propagation reinforcement under a positive loading ratio Mater. Sci. Eng., A 528 pp 078–1086

[3] Cam J B L, Huneau B and Verron E 2008 Description of fatigue damage in carbon black filled
natural rubber *Fatigue Fract. Eng. Mater. Struct* **31** pp 1031–1038

[4] Cam J B L, Huneau B and Verron E 2013 Fatigue damage in carbon black filled natural rubber under uni- and multiaxial loading conditions *J. Fatigue* **52** pp 82–94

[5] Kim J H and Jeong H Y 2005 A study on the material properties and fatigue life of natural rubber with different carbon blacks *J. Fatigue* **27** pp 263–272

[6] Mars W V and Fatemi A 2004 Observations of the constitutive response and characterization of filled natural rubber under monotonic and cyclic multiaxial stress states *ASME J. Eng. Mater. Technol.* **126** pp 19–28

[7] Mars W V and Fatemi A 2005 Multiaxial fatigue of rubberpart II: experimental observations and life predictions *Fatigue Fract. Eng. Mater. Struct* **28** pp 523–538

[8] Gent A N and Hindi M 1989 Effect of oxygen on the tear strength of elastomers *Rubber Chemistry and Technology* **63** p 40