

Study on the Mechanical Behavior of New Type Explosion-proof and Impact-resistant Polyurea Elastomers

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Abstract: The new polyurea elastomer material has excellent physical and chemical properties and has a wide range of applications, especially in the field of explosion-proof and impact resistance, which has always been a hot spot in the field of military research. This article obtained the mechanical properties of one kind of military polyurea by Static tension and compression experiment and split Hopkinson bar, and analyzed the mechanical properties of polyurea on different strain rate. The results showed that the mechanical properties of polyurea is highly sensitive to strain rate. For both the tensile and the compression properties of polyurea, the yield strength is greatly increased when the strain rate increase. The above research results provide theoretical basis and technical support for the development of the anti-impact functional structure of the elastomer and the design of the anti-explosive safety device.

1. Introduction

The Spray polyurea (PUA) had been developed firstly by the United States in 1986, and had been popularly used in North America for its' good physical and chemical properties [1]. In 2000, the American Polyurea Development Association made a complete definition of polyurea that polyurea is an isocyanate (referred to as A component) and amino compounds (referred to as R component) reaction of an elastomer material [2]. Compared to the traditional coating, polyurea is widely used in various fields[3,4], such as the field of industrial, construction, water conservancy project, and military defense. In the emerging field [1], polyurea can be used to protect sound, specimen props. polyureas has a lot of advantages, such as friendly to environmental, quickly cured, simply for construction, can be adhesion to metal, excellent mechanical properties, and good resistance to media performance. Many foreign researchers devoted themselves to research the mechanical properties of polyureas. Yi [5] et al. obtained the mechanical properties of polyureas by quasi-static compression test and SHPB test, from which they determined that the stress-strain curves of polyurea showed hysteresis, cyclic softening and highly sensitive to strain rate. And from the DMA analysis, the behavioral properties changes from a rubber state which presented under a low strain loading ($10^{-3}/s \sim 100/s$) to the a leather state or a glassy state which presented under a high strain loading ($10^3/s$). Sarva [6] et al. determined that polyureas is highly sensitive to strain rate, and the transition of polyurea is consistent with the glass transition temperature at different strain rates. The mechanical properties of polyurea under medium strain rate was studied by Shim[7] and Mohr[8] by using the



hydraulically driven Hopkinson bar. As the reflection of multiple waves in the input bar and output bar, the strain rate was not a constant and the strain rate effect is more obvious with the loading pressure increasing. Therefore, it is suggested that a longer bar ($> 20\text{m}$) or a shorter bar ($< 0.5\text{m}$) should be used to obtain a uniform strain rate. By tensile test of polyurea, Pathak[9], Raman[10], Qiao[11,12] found that the strength and rigidity of polyurea increased with the increase of strain rate, and the yield strength of polyurea was also affected. It was found by DSC that the temperature effect of the material was closely related to its micro-phase separation structure. Based on the research results above, this paper researched the mechanical properties of a certain formula of polyurea under different strain rates by experiment.

2 Static Mechanical Properties of Polyureas

The material that used in this paper is SPUA409, and the material parameters are shown in table 1.

Table 1. Parameters of the SPUA409

Tensile strength/MPa	elongation%	shore hardness	rebound rate
20.4	391.7	89.6	17.5

2.1 Static tensile test

2.1.1 Specimen in Static tensile test

As a polymer material, the design of the specimen which made by polyurea and related experimental requirements refer to GB/T528-1998. The specimen surface requires clean and smooth, have no gaps and pores. Figure 1 shows the polyurea specimen.

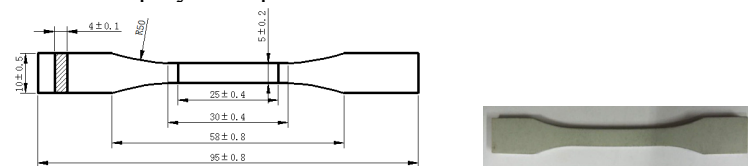


Figure 1. specimen in Static tensile test

2.1.2 Static Tensile Test Process

As a super-elastic material, we used the AGS-X tensile testing machine to conduct related experiment. The middle part of the sample was marked before the experiment. The plate clamps provide sufficient clamping force to hold to guarantee the specimen vertically placed. This paper carried out four group tensile tests of four different strain rates. Each group of one strain rate repeated 3-5 times, and took the average value as the results.

2.1.3 Results of Static Tensile Test

The strain rate was 0.5, 0.05, 0.005, 0.0005 for each experiment, each group of one strain rate repeated for 3-4 times and then take the average value to obtain the true stress strain curve., as shown in figure 2.

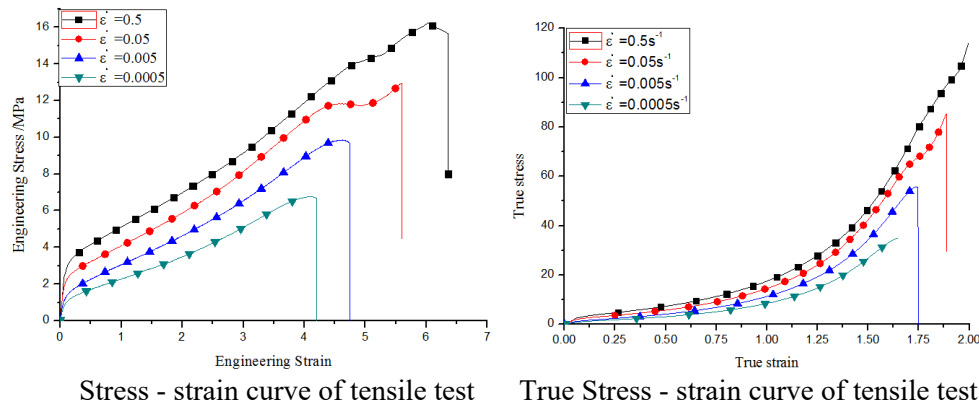


Figure 2. Stress-strain of the results

The results showed that the polyureas have obvious nonlinearity and strain rate correlation, with the increase of the strain rate, the elastic modulus and the yield strength increase. The elongation at break increased from 410% to 635%, and the former elongation at break increased by 54.9%, when the strain rate increased from $5 \times 10^{-4}/s$ to $5 \times 10^{-1}/s$, as shown in Fig2.

2.2 Static compression test

2.2.1 Specimen in Static compression test

The design of the specimen of polyurea which used in the compression tests and related experimental requirements refer to HG/T3843-2008. The surface of a cylindrical sample requires a clean, smooth surface with no gaps and pores. Figure 3 shows the polyurea specimen.

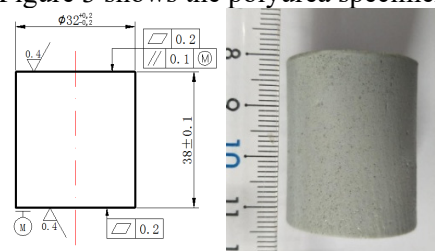


Figure 3. Test specimen in Static compression test

2.2.2 Static compression test process

In compression test, to reduce the friction of the end face, we dabbed moderate petrolatum to the end face. Fig.6 showed the test procedure. This paper carried out four group compression tests of four different strain rates. As is shown in figure 4. After the compression, polyurea can quickly rebound in a short time, it can recover to 90% of the original in about 50h.

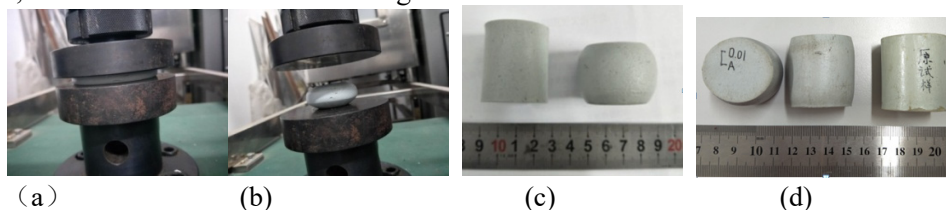


Figure 4. (a),(b),(c),(d) were the states of polyurea Static compression test process before unloading, unloading, unloading 5min, unloading 50h, respectively

2.2.3 Results of Static Tensile Test

It is clear that the polyurea has a strong non-linearity and strain rate correlation, as is shown in figure.5. In the compression process, the polyurea showing linear elasticity to linear strain hardening. At the same strain, the stress increase of the polyurea was more gently with the increase of the strain rate.

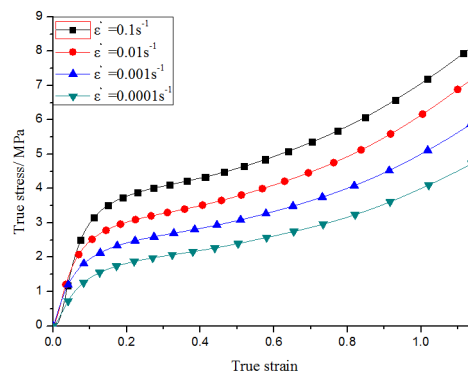


Figure 5. True Stress - strain curve of compression test

3. Mechanical Properties of Polyurea

3.1 Preparation of the specimen

The polyurea specimens that used in SHPB is cylindrical $\Phi 30\text{mm} \times 12\text{mm}$, and it must be processed to ensure that the two loading surface is bright and clean. The tolerance of the parallelism of the polyurea specimens is 0.1mm, as shown in figure 6. The bullet speed in Hopkinson bar test is generally 10-30m/s, to obtain a higher strain rates, the height of the specimens was adjusted from 12mm to 8mm.

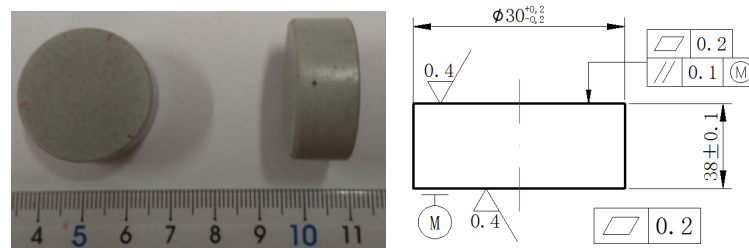


Figure 6. Specimens in Hopkinson bar test

3.2 Hopkinson bar test process

The bar used in the test is $\Phi 37\text{mm}$ aluminum bar, change the speed of the bullet by adjusting the gas pressure in the cavity to obtain different strain rate. In the test, to reduce the friction of the end face, we dabbed moderate petrolatum to the end face. One end surface (the face impacted by the bullet) of the incident bar is affixed with a rubber shaper to reduce the diffuse effect of the incident wave, making the specimen to reach the stress evenly. When the strain rate was 500/s or 800/s, the specimen did not change obviously. When the strain rate was 1500/s, the fatigue wrinkles appeared in the center of the specimen. As the strain rate reached 2000, the center of the specimen was cracked and a lot of heat generated. The specimen after experiment showed in figure 7.



Figure 7. Specimen after experiment

3.3 The Results of SHPB test

This paper carried out four sets of different strain rates, as shown in figure 8. It is clear that the polyurea has nonlinearity and strain rate correlation under dynamic compression, and the linear hardening property of polyureas is obvious.

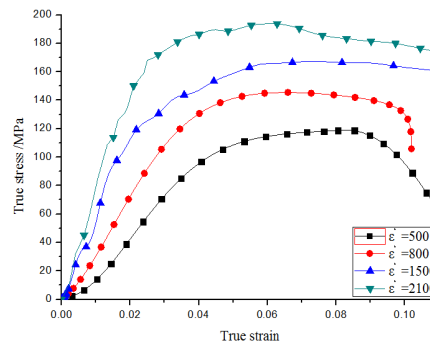


Figure 8. True Stress - strain curve in Hopkinson bar test

4. Conclusions

This paper researched the mechanical properties of polyurea, and obtained the following conclusions.

- 1) Polyurea is a kind of nonlinear and strain rate dependent material. With the increase of strain, the constructive relation has linear hardening.
- 2) During the stretching process, the elongation at break increases from 410% to 635% and the elongation at break increases by 54.9%, as the strain rate increases from $5 \times 10^{-4}/s$ to $5 \times 10^{-1}/s$.
- 3) Polyurea can self-healing, in the static compression process the strain of the specimen reaches to 80%, then it can recover to 70% of the original sample in about 5min, recover to 90% in about 50h.
- 4) In the dynamic compression test, with the increase of strain rate, brittle cracks occur in the center of the specimen and absorb a lot of heat. This indicates that the state of polyurea changed from a rubbery state to a leather state or a glassy state.
- 5) To obtain a higher strain rate, we can reduce the area of end surface of the cylindrical specimen and reduce the specimen thickness.

Acknowledgements

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