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Experimental Investigation on Dynamic Compressive Behavior of Polyurea over a Range of Temperatures

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ABSTRACT

Polyurea elastomer is finding new applications in increasing the resistance of the structures to blast effects and minimizing the fragmentation and collapse potential of the wall structure. The study on the dynamic mechanical behavior of polyurea is essential for its application as an effective protective material. In this paper, the mechanical properties of polyurea materials under different temperatures are studied. The rate-dependent stress–strain behavior of the materials under uniaxial loading and confined pressure are obtained by split Hopkinson pressure bar (SHPB) testing. The experimental results show that the finite deformation stress-strain behavior of polyurea under uniaxial compression is temperature-dependent and highly non-linear. However, the axial stress-strain relationship for polyurea under confined pressure is weaker on temperature-dependent and approximately linear. The dynamic softening behavior of polyurea becomes more remarkable along with the temperature increasing. Based on the findings of the experiments, the deformation mechanism and mechanical characteristics of the materials are analyzed and discussed.

Key words：*Polyurea; Dynamic Behavior; Uniaxial Compression; Confined Pressure; Temperature Effect*

1. INTRODUCTION

With the development of science and technology, the power of weapons is greatly improved, which can easily cause a great loss of lives and properties. Therefore, the performance of protective structures is required higher and higher. The study on improving the performance of protective structure has become focus of many scholars to study. The researchers hope to find out a kind of new defense method which can enhance the resistance of the structures to blast effects and minimize the fragmentation and collapse potential of the wall structure. Recent studies show that applying a layer of polyurea backing to hard materials significantly enhances the resistance of the materials to the impulsive loading [1-3].

As a kind of new polymer material, polyurea has the advantages of low cost, light weight, wear resistance, impact resistance, corrosion resistance and waterproof. In addition, polyurea has characteristics of convenient spraying and fast curing, and has a strong adhesion with the matrix material including concrete and metal. Accordingly, polyurea elastomer can change the dynamic response characteristics of the structure under shock loading, and enhance its protective performance. A systematic study on the mechanical properties of polyurea is the premise to deeply understand and optimize the impact resistance of polyurea coating. Therefore, with the increasing application of polyurea in enhancing the impact resistance of the material or structure, more and more scholars begin to study its mechanical properties. Up to now, to the best knowledge of the authors, the research on the mechanical properties of polyurea is mainly concentrated in three areas, i.e., compressive properties, tensile properties and constitutive modeling. Yi et al. [4] studied the dynamic compressive mechanical behavior of polyurea material using the split Hopkinson pressure bar system, and the results showed that its compression behavior demonstrated highly non-linear stress-strain relationships, indicating strong hysteresis and rate dependency. Guo et al. [5] conducted a systematic theoretical and experimental study of the dynamic compressive mechanical properties of polyurea samples over the strain rates range from 10^{-3}/s to 10^{4}/s, and found that the significant sensitivity of compressive stress-strain behavior of polyurea to strain rate within and beyond linear viscoelastic region. Raman et al. [6] carried out the stress-strain measurements of polyurea in uniaxial tension over the strain rate region from 0.006/s to 388/s, and concluded that the modulus of elasticity of polyurea was observed to be enhanced with the strain rate increasing. Rinaldi et al. [7] conducted the measurement of the macroscopic mechanical behavior of polyurea at different tensile loading histories, and provided insights into the strain and time dependence of the structural evolution. Mohotti et al. [8] analyzed the Young's modulus; yield stress and failure strain of polyurea under the high strain rate, and developed a rate-dependent viscoelastic constitutive model based on the original Mooney–Rivlin model. Li et al. [9] also proposed a nonlinear viscoelastic model describing the finite deformation behavior of polyurea, and proved the validity and correctness of the model based on the test data of shear relaxation modulus. However, it is still necessary to study systematically the failure mechanism of polyurea, such as multiaxial loading, coupling effect of strain rate and temperature.

In this paper, the dynamic compressive mechanical properties of polyurea samples under uniaxial loading and confined pressure were examined. For this purpose, the systematic experiment research on the dynamic stress-strain curves of polyurea at the temperature range of -40°C- +20°C are carried out based on the split-Hopkinson pressure bar (SHPB). The dynamic stress–strain characteristics of two kinds of polyurea at different temperatures are analyzed in this paper. The results of this study can enhance the present limited knowledge on the dynamic compression characteristics of polyurea under different temperatures.

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2. EXPERIMENTAL DETAILS

2.1. Materials

The polyurea samples utilized in this study are provided by the Center of Excellence for Advanced Materials. The polyurea elastomer is synthesized by a rapid copolymerization reaction between an isocyanate component (Isonate 143L from Dow Chemical; 144.5g/eq) and an amine-terminated resin blend component (Versalink P-650 or Versalink P-1000; Air Products). Theoretically, the isocyanate-to-amine ratio should be mixed in a stoichiometric ratio of 1:1. However, in most polyurea formulations, a slight excess of the isocyanate component is used beyond the stoichiometric ratio so as to ensure that the reaction went to completion. The two component molar ratio of polyurea elastomer is selected as 1.05 in the present study. As shown in Fig.1, the sizes of the samples of this study are designed as Φ6mm×2mm and Φ12.7mm×5mm. The dynamic compression experiments are conducted at the temperatures range from -40°C to +20°C.

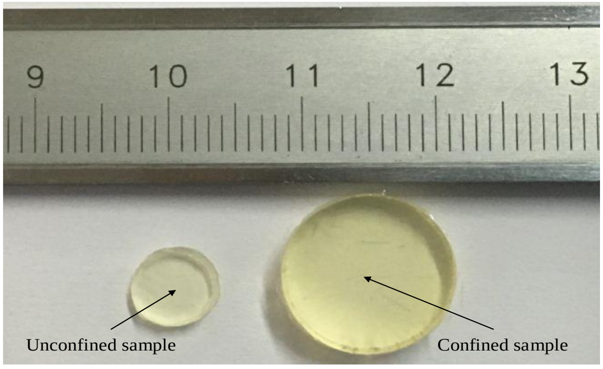

Fig.1. Schematic view of the polyurea samples.

2.2. Testing equipment

The high strain-rate compressive properties of polyurea samples at different temperatures are tested using a split-Hopkinson pressure bar apparatus (SHPB), as schematically illustrated in Fig.2. This apparatus employs chromium-nickel steel pressure incident and transmission bars, both with a length of about 2.3 m and a diameter of 12.7 mm. The strain gages for measuring waveform signal are positioned near the center of the input bar and near the output bar/specimen interface. The two end-faces of the specimen which contact the incident bar and the transmission bar are lubricated with thin petroleum jelly to minimize end frictional effect, so that a homogeneous deformation state is achieved. Annealed copper discs are used as pulse shapers to reduce the strain level at which dynamic equilibrium is achieved [10, 11]. Based on the one-dimensional stress wave and the stress uniformity assumptions, the time histories of strain, strain rate, and stress in the specimen can be obtained from the following equations.

$$\varepsilon_s(t) = \frac{2C}{l_s}\int_0^t \varepsilon_r(\tau)d\tau \tag{1}$$

$$\dot{\varepsilon}_s(t) = \frac{2C}{l_s}\varepsilon_r(t) \tag{2}$$

$$\sigma_s(t) = \frac{EA}{A_s}\varepsilon_t(t) \tag{3}$$

where A_s and l_s are the initial cross-sectional area and length of the samples, respectively; A, E and C are the cross-sectional area, Young's modulus and elastic wave velocity of the bar; ε_r and ε_t are the reflected pulse and transmitted pulse, respectively.

The dynamic compressive stress–strain behavior of polyurea at different temperatures is evaluated by unconfined pressure test and confined pressure test. The length-diameter ratio of unconfined sample is 1/3 (Φ6mm×2mm), and that of confined sample is about 1/2.5 (Φ12.7mm×5mm). This is because the polymer sample aspect ratios range (l/d) of 0.25 to 0.5 can be effective in minimizing wave attenuation while also keeping frictional effects under control [12, 13]. A 60Si2Mn spring steel tube with an internal diameter close to the test samples' external diameter plus a very small tolerance is used to restrict the lateral movement of the samples in the confined pressure test (confining steel tube, outer diameter 25.4mm, inner diameter 12.7mm, length 50.8mm). The assembly diagram of confining pressure device is shown in Fig.3. The post-experiment visual inspection of the confining tube shows no plastic deformation of the confining steel. All curves under confined pressure have contained a small lead region until the specimen makes full radial contact with the confinement chamber; this region isn't accurate, and should be removed from the data shown.

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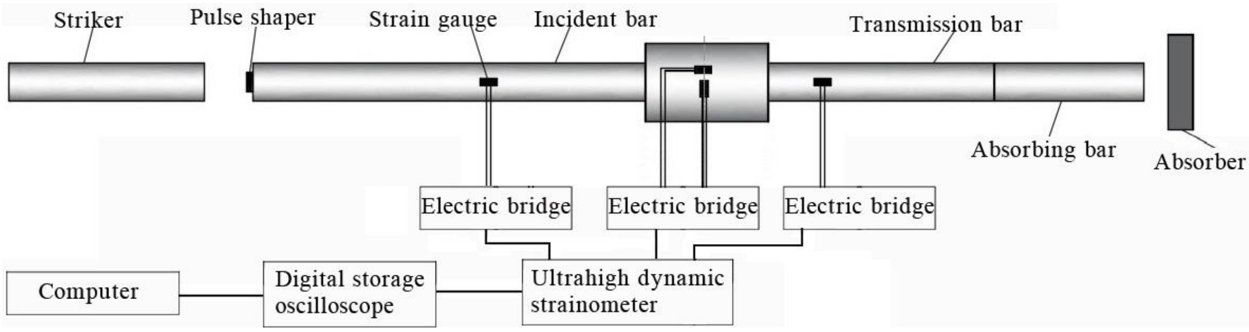

Fig.2. Schematic diagram of the split-Hopkinson pressure bar system

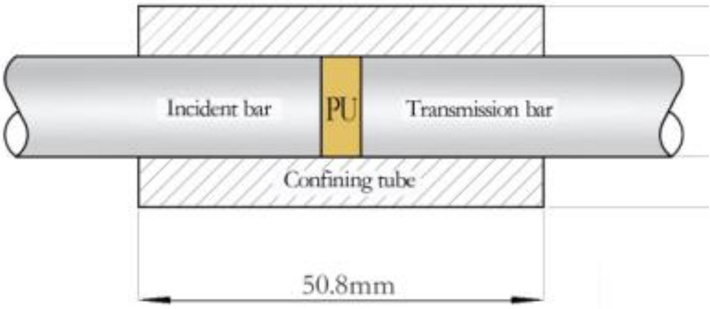

Fig.3. Assembly diagram of the confining pressure device

3. RESULTS AND DISCUSSION

The large deformation compression mechanical behavior of polyurea elastomer at high strain rates and different temperatures was examined using the techniques described in above section. Some key mechanical properties of the materials were determined under unconfined pressure and confined pressure. For nominal strain rate of 12000/s, the uniaxial compressive stress-strain curves of polyurea at four different temperatures were shown in Fig.4. The stress-strain curves of polyurea with the strain rate of 4000/s under different temperatures in the confined configuration were shown in Fig.5. The micro-damage morphology of polyurea was scrutinized using field emission scanning microscopy, and the scanning microscopic photos are shown in Fig.6.

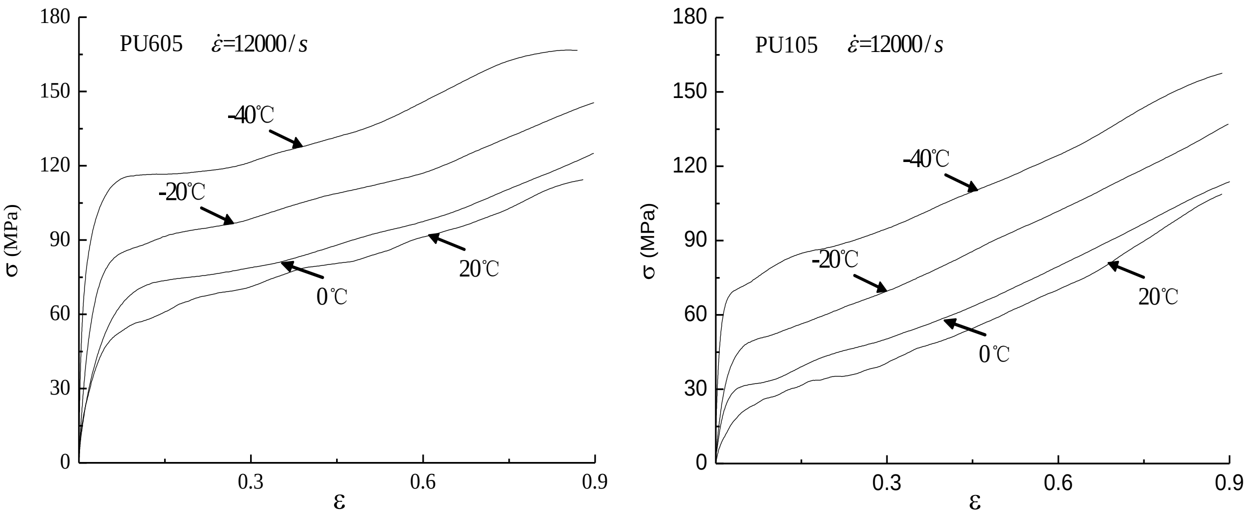

Fig.4. Dynamic uniaxial compressive stress-strain behavior of polyurea at different temperatures

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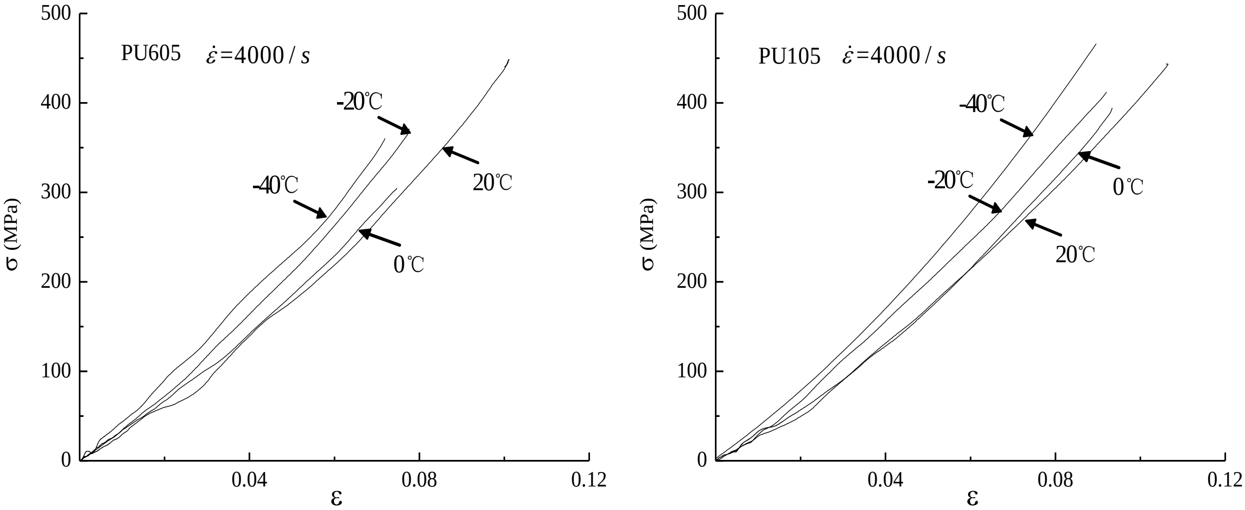
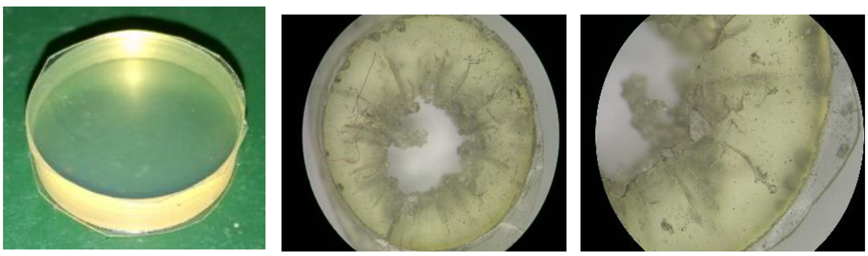
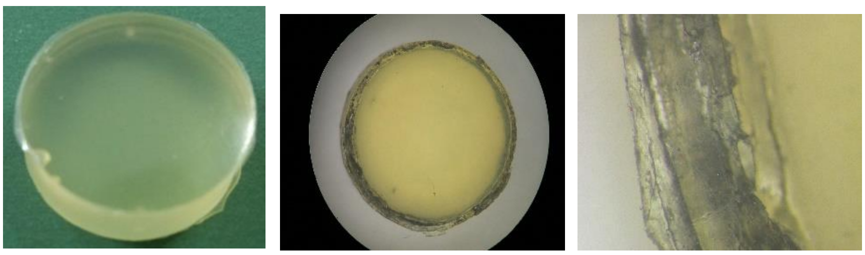


Fig.5. Dynamic stress-strain behavior of polyurea under different temperatures in the confined configuration

The experimental results indicated that the finite deformation stress-strain behavior of polyurea under uniaxial compression was temperature dependent and non-linear. However, the axial stress-strain curves for polyurea under confined pressure was weaker on temperature dependence and approximately linear. The stress-strain relationship of polyurea exhibited significant temperature sensitivity. The experimental data depicted in Figs.4 and 5 showed that for a certain high strain rate, the flow stress value corresponding to the same deformation amount decreased along with the rise of temperature, and the dynamic softening behavior became more remarkable. In addition, it can be concluded from Figs.4 and 5 that the temperature-dependent effect of polyurea at confined pressure was decreased compared with that of the samples at unconfined pressure, and the flow stress of polyurea at confined pressure was significantly increased. It can be observed from Fig.6 that the micro-damage morphology of unconfined and confined samples had great difference. Thus it showed that the deformation mechanism of polyurea in three-dimensional pressure state (confined pressure state) was greatly changed compared with that of the materials in uniaxial stress state (unconfined pressure state).



Unconfined sample before the test **Damage morphology of unconfined sample after the test**



Confined sample before the test **Damage morphology of confined sample after the test**

Fig.6. Micro-damage morphology of polyurea samples

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6. CONCLUSIONS

The dynamic compressive properties of polyurea elastomer were investigated in this study and the stress–strain characteristics of the materials at various temperatures were presented. It was observed that the dynamic stress–strain behavior of polyurea exhibited significant temperature dependency. The flow stress of polyurea under confined pressure was significantly increased compared with that of the samples under unconfined pressure. The deformation mechanism of polyurea in three-dimensional pressure state (confined pressure state) was different from that of the materials in uniaxial stress state (unconfined pressure state).

Acknowledgements

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