Study on meso-damage evolution process of high-energy propellant based on MCT

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Abstract. The complex microstructure of composite solid propellant makes the evolution of meso-damage very complicated during loading. It is always a hot issue to study the damage evolution law of propellant from the microscopic point of view.Based on the established tensile platform of MCT, the tensile test of high energy propellant specimens was carried out. The variation trend of internal porosity with the increase of tensile strain is obtained. It can be seen that during the drawing process, the internal porosity of high-energy propellant increases exponentially with the drawing rate.

Keywords: Meso-damage; Evolution process; High-energy propellant; MCT; Porosity of propellant.

1. Introduction

The complex microstructure of composite solid propellant makes the evolution of meso-damage very complicated during loading. The research on the damage evolution law of propellant from the microscopic point of view has always been a hot issue at home and abroad, which is of great significance to understand the propellant and reveal the failure mechanism of its macro-mechanical properties.[1, 2]

At present, the research on meso-damage of solid propellant is mainly carried out from two angles: numerical simulation and experiment. Due to the influence of external factors, there are many initial defects on the surface of propellant, which affects the observation results. In addition, scanning electron microscope is also slightly insufficient in quantitative analysis, so it is necessary to study the evolution of micro-damage of high-energy propellant during loading. Collins et al. [4] and Lee et al. [5] used MCT to reconstruct the three-dimensional morphology of solid propellant, and obtained the formation and propagation process of microcracks during stretching. Wang Guang et al. [6] analyzed the reconstructed images of solid propellant after CT scanning; Li Shiqi et al. [7] further characterized the microstructure of HTPB propellant by using MCT, and analyzed the micro-defects in the initial state of the propellant, but did not study the damage evolution process of the propellant under load. Liu Xinguo et al. [8] quantitatively analyzed the dewetting damage of HTPB propellant during stretching with the change of gray value and porosity, but did not give the change of microstructure of propellant in the loading direction.

There are two commonly used composite solid propellants: HTPB propellant and high-energy propellant. High-energy propellant has the characteristics of high energy, wide temperature adaptability and good mechanical properties at low temperature because of the use of high-energy explosives. HTPB propellant is widely used because of its early development, and there have been many researches on it, but the research on high-energy propellant is not enough now.[9]

2. Experimental process and data processing method

In order to visually see the influence of tensile load on the microstructure of propellant, the reconstructed image is processed by MCT post-processing software, and the microstructure of propellant in the loading direction is obtained.

The workbench structure of MCT is shown in Fig. 1. The workbench can be divided into upper and lower parts. The upper part is mainly used for loading test pieces, while the control system and transmission system of the mechanical workbench are located in the lower part. The bottom of the mechanical workbench is provided with a sensor interface for data transmission and a power interface for supplying power to the workbench.

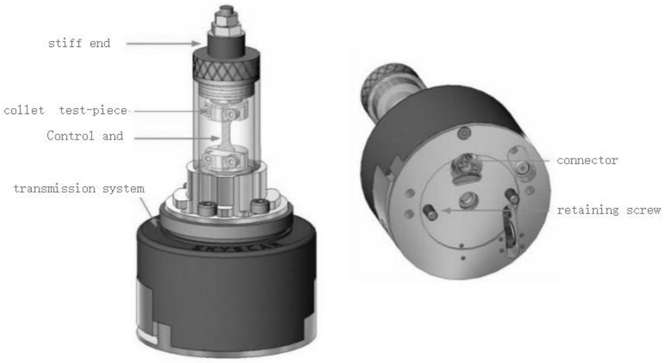


Fig. 1 Schematic diagram of mechanical workbench

The maximum load of the mechanical workbench is 444 N, and the load measurement accuracy is 1%. The maximum stroke is 5.5 mm, and the accuracy of the displacement sensor is 0.01mm；The loading speed is 0.2mm/min.

2.1 Test flow

There is no need to apply load when scanning the microstructure of HTPB propellant in the initial state, so it is only necessary to cut the specimen suitable for micro-CT space size from the standard dumbbell-shaped specimen. The cut test piece is bonded to the special object table for CT scanning by glue stick, and then the experiment can be started by setting the experimental parameters.

The scanning parameters of micro-CT are: working voltage 75KV, current 133 μ A; The resolution is 1 μ m, and the resolution of CCD camera is 4000 × 2672. The rotation angle increment is 0.3, and the scanning angle is 360.

The mechanical loading table holding small specimens was loaded into micro-CT and the experiment began. The uniaxial tension of propellant is controlled by displacement loading. When loading, the upper end of the propellant specimen is fixed, and the lower end is stretched under the action of the internal mechanical structure of the material testing table. Scan after loading to a certain displacement, and continue to load to the next specific displacement for scanning after scanning is completed until the final set displacement is reached. After all the displacements to be loaded are preset in the control software of the mechanical loading table during the experiment, the whole experiment process will be automatically completed. In this study, the damage of propellant under four strains of 0, 10%, 30% and 50% was tested. The scanning parameters of MCT in the experiment are the same as those of CT in the initial microscopic observation. During the experiment, the stretching speed of the loading table is 0.2mm/min.

2.2 Test data processing method

There is often some noise in the reconstructed image of micro-CT. If it is not filtered, it will affect the segmentation, three-dimensional reconstruction and quantitative analysis of the image. Therefore, after obtaining the reconstructed image of two-dimensional slice, the image needs to be filtered first, and the neighborhood average method and median filtering method are commonly used.

Different microstructure and different material properties make the microstructure of propellant very complicated. In order to study a specific microstructure, it is necessary to use image segmentation method to segment the structure of interest. The basic idea of image segmentation is to classify images according to the different characteristics of gray level, color and edge of each region in the image. Gray image segmentation is commonly used in image segmentation, and there are various segmentation methods, such as edge detection-based segmentation, threshold-based segmentation and tracking-based image segmentation methods.

Gray histogram is an important basis of image processing, and each gray image has a specific gray histogram. It is the statistics of gray level distribution in gray image, which can show the size of gray values of all pixels in the image and the frequency/quantity of each gray value. As for the gray-scale image reconstructed by micro-CT scanning, there are obvious differences in the gray-scale values of the meso-structures. Therefore, the threshold segmentation method based on gray-scale histogram is mostly used in the processing of micro-CT reconstructed images, and because of the differences in the gray-scale values of the micro-structures, it is necessary to set multiple thresholds to segment the micro-structures such as AP particles, Al particles, matrix and defects.

In MCT reconstructed images, there is usually uneven distribution of gray values on AP particles and Al particles, which will inevitably make it difficult to completely segment the region or structure of interest in threshold segmentation of reconstructed images, thus affecting the analysis results. Therefore, it is necessary to further process the reconstructed images with the help of related methods in image morphology. Morphological processing of images refers to detecting images with structural elements with certain shapes, and obtaining relevant information about the morphological structure of images by checking the releasability of structural elements in images and the effectiveness of filling methods, so as to achieve the purpose of image analysis and recognition.

3. Test results and analysis

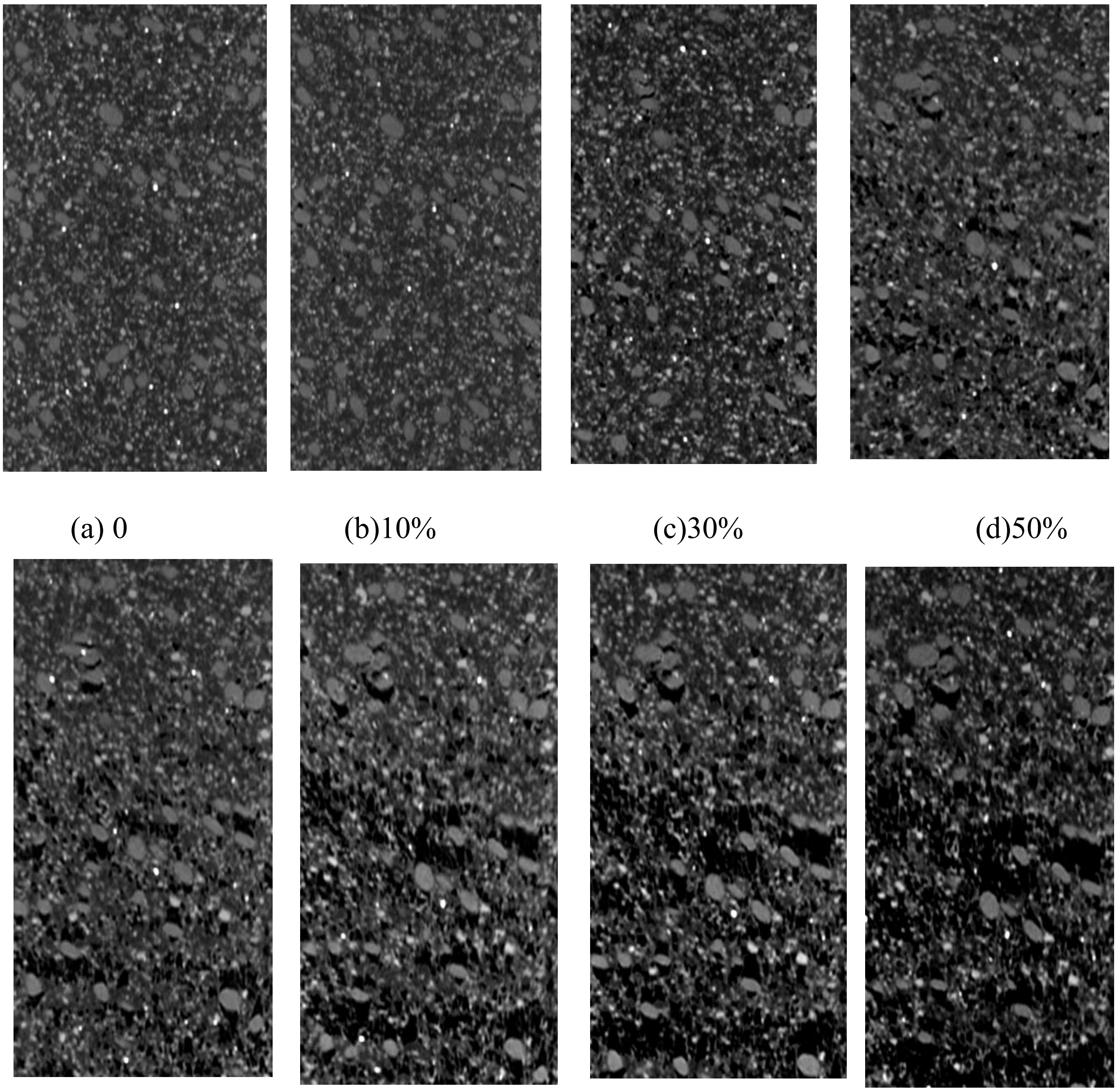
The reconstructed image is processed by MCT post-processing software, and the microstructure of propellant in the loading direction is obtained, as shown in Figure 69. It can be seen from the figure that the microstructure of the propellant maintains good integrity when it is not loaded. When the tensile strain is 10%, no obvious defects are found in the slice image, and the propellant still maintains good integrity.

When the tensile strain reaches 30%, it can be seen that the AP particles have been dehumidified in Fig. 2, and the dehumidification appears on the large-size particles; When the tensile strain reaches 50%, the number of dehumidified AP particles increases, and it can be seen that cracks also appear in some substrates.

Because two-dimensional slice can't reflect all the information of internal defects of propellant, the distribution of internal defects of propellant during loading can be obtained by threshold segmentation of experimental slice images under different tensile strains, and the result is shown in Fig. 3.

As can be seen from Fig. 3, there are some initial defects in the propellant. When the tensile strain reaches 10%, it can be clearly seen that the internal defects of the propellant have increased compared with the initial state, but the size of most defects is still relatively small; A defect with a large size appeared in Fig. 3. When the tensile strain reaches 30%, the number of large-size defects in the propellant also increases, and the size of defects in the previous stage also increases. With the further increase of tensile strain, when the tensile strain reaches 50%, the meso-damage degree of propellant has obviously increased, and a certain amount of defects converge.

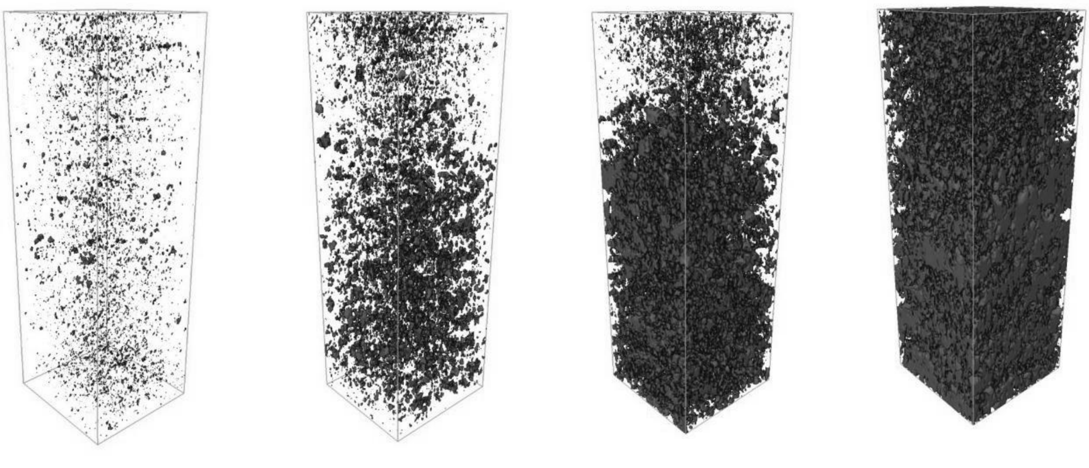
It can be found that the micro-damage of high-energy propellant is different from that of HTPB propellant, but when the tensile strain is small, the damage of propellant is that AP particles dehumidify first, and they are large AP particles; With the further increase of tensile strain, the degree of dehumidification of AP particles further increases, and new AP particles are dehumidified; When the load continues to increase, the defects gradually converge, and finally the propellant breaks.



(a) 0 (b)10% (c)30% (d)50%

(e) 60% (f) 70% (g) 90% (h) 100%

Fig. 2 Microstructure changes of propellant under different tensile strains.



(a) 0 (b) 30% (c) 60% (d) 100%

Fig. 3 Morphology evolution of internal defects in propellant during loading.

In order to quantitatively characterize the damage of propellant during loading, the porosity of propellant is counted, and the porosity change of propellant during loading is shown in Table 1. The fitting curve of porosity versus tensile strain is shown in Fig. 4.

Table 1. Porosity of propellant under different strains

strain/%	0%	10%	30%	50%	60%	70%	90%	100%
Porosity/%	0.04%	0.16%	1.48%	4.09%	7.08%	8.14%	15.38%	25.11%

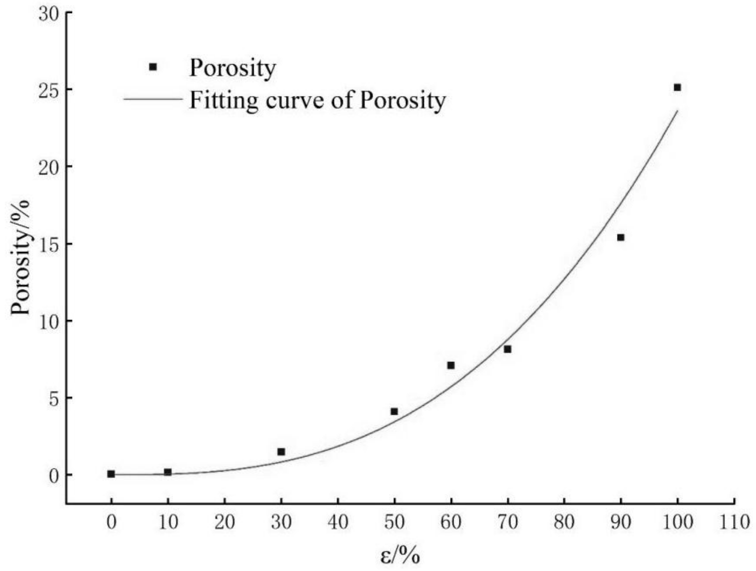


Fig. 4 Pore change curve during stretching process

The size span of AP particles is relatively large, about 170 microns at most; Its shape is mostly ellipsoid.The initial micro-defects in high-energy solid propellant mainly exist at the bonding interface between solid particles and matrix, but there are also a few hole defects in AP particles. The size of initial defects of high-energy propellant is mainly concentrated within 10 microns.

The micro-damage of high-energy solid propellant during uniaxial tension is mainly due to the dehydration of AP particles. With the increase of tensile strain, the dehydration of AP particles will further increase, and other AP particles will also be dehydrated. However, due to the low content of AP particles, the proportion of micro-defects produced by high-energy propellant is relatively low when the tensile strain is small.During the drawing process, the internal porosity of high-energy propellant increases exponentially with the drawing rate.

4. Summary

In order to visually see the influence of tensile load on the microstructure of propellant, the reconstructed image is processed by MCT. Based on the established tensile platform, the tensile test of high energy propellant specimens was carried out. The change trend of internal porosity with the increase of tensile strain is obtained. It is found that the micro-damage of high-energy solid propellant during uniaxial tension is mainly due to the dehydration of AP particles. With the increase of tensile strain, the dehydration of AP particles will further increase, and other AP particles will also be dehydrated. However, due to the low content of AP particles, the proportion of micro-defects produced by high-energy propellant is relatively low when the tensile strain is small.

During the drawing process, the internal porosity of high-energy propellant increases exponentially with the drawing rate.

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