Dynamic Impact Mechanical Test of Rubber Based on DIC Method

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Abstract: In order to study the strain field of rubber material in the impact process, the impact test of rubber body was carried out by E-SHPB device. Combined with high-speed photography and DIC technology, the non-contact measurement of rubber materials was carried out, and the obtained data were compared and screened. The impact compression diagram and strain field change cloud diagram of rubber in the impact process were obtained. The test results show that during the dynamic impact process, the strain concentration phenomenon first occurs at the contact area between the rubber body and the incident rod in the early stage of impact. As the stress wave propagates inside the material, the strain concentration phenomenon gradually shifts, and finally tends to the middle area to produce a larger strain concentration. At this time, the rubber body is highly compressed and reaches a critical state of springback.

Keywords: DIC; rubber; strain field; e-SHPB; dynamic impact..

1. Introduction

Rubber materials are widely used in industries including automobile, ship, machinery, construction, and more, which have the capacity of impact resistance, energy absorption and seismic resistance, and have important social and economic benefits, furthermore, rubber materials are widely available for various protective engineering, and their dynamic mechanical properties attract widespread attention from countries around the world. At present, the studies on rubber materials are generally based on quasi-static loading or ultra-high strain rate impact loading. Bingbing Wang [1] et al. performed uniaxial compression tests on semicircular rubber mat under 5 strain rates, and conducted drop hammer impact simulation analysis on the steering column by using quasi-static rubber parameters and considering rubber parameters under different strain rates, respectively.

The study on rubber dynamic properties at different temperatures is also one of the world's research hotspots. Jinping Zhuang[2] et al. proposed the modified formula of the dynamic growth factor of SFRSCC after high temperature, and provided some references for further analysis and discussion of the dynamic properties of self-compacting concrete with steel fiber and rubber after high temperature.

This paper takes the rubber body as the research object, combines the DIC technology, utilizes the strong light source to carry out the non-contact and non-destructive measurement on the rubber body, explores the strain field of the rubber materials under the dynamic load, and studies the whole process of the dynamic impact of the rubber body.

2. Test System

2.1. Introduction to the Test

This test carried out three sets of axial impacts of E-SHPB, DIC software could be used in conjunction with high-speed camera and photoelectric tachometer, and measured various deformations from macroscopic to microscopic. Among them, the experimental technology of electromagnetic drive Hopkinson bar (E-SHPB) is to replace the traditional pressure loading method in Hopkinson bar with electromagnetic drive to drive bullet to impact the incident bar to generate stress wave, and it is a new dynamic loading technology developed by combining electromagnetic drive technology with Hopkinson bar experimental technology.

Ultra-dynamic strain gauge can record the strain history through the strain gauge pasted on the incident bar and transmission bar, it is stored in the form of electrical signals, according to the propagation theory of one-dimensional stress wave, the dynamic stress, strain and strain rate of the specimen can be derived indirectly via the voltage signals collected by the strain gauges, etc. The stress, strain and strain rate of the rubber specimen can be calculated via the experimental stress waveform [3]:

$$\sigma(t)=\frac{AE}{2A_s}[\varepsilon_I(t)+\varepsilon_R(t)+\varepsilon_T(t)] \tag{1}$$

$$\varepsilon(t)=\frac{C}{L_s}\int_0^t[\varepsilon_I(t)-\varepsilon_R(t)-\varepsilon_T(t)]dt \tag{2}$$

$$\dot{\varepsilon}(t)=\frac{C}{L_s}[\varepsilon_I(t)-\varepsilon_R(t)-\varepsilon_T(t)] \tag{3}$$

In the equation: A, E, C are the cross-sectional area, modulus of elasticity and longitudinal wave velocity of the compression bar, respectively; A_S, L_S are the cross-sectional area and thickness of the specimen, respectively; $\varepsilon_I(t)$, $\varepsilon_R(t)$, $\varepsilon_T(t)$ are the incident strain, reflection strain and transmission strain at time t, respectively, and t is the duration of the stress wave.

The studies on mechanical properties of rubber-like deformable materials are different from the studies on metallic materials and rock materials, which measure the deformation of the specimen mainly by means of optical measurement. Optical measurement methods mainly include photoelastic method, moire method, DIC [4] and so on. DIC technology has low requirements for the experimental environment, can measure the strain field of the specimen during the deformation, which has the advantages of non-contact, high precision, full-field measurement, and it is easy to use.

2.2. Test process

This test chooses cylindrical rubber body with a diameter of 50mm and a height of 25mm, as shown in Fig.1. After core-taking, cutting, polishing and smoothing of test block, this test start making speckle, due to operational convenience consideration, the initial production of speckle uses manual paint spraying method, first, the white matte paint is evenly sprayed on the surface of the rubber body, after the white paint dries, a black pen is randomly embellished to the white painting area, so that the dense and randomly distributed black dots appear in the surface of the rubber body sprayed with white paint.

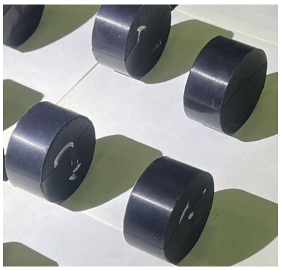


Figure 1. Rubber body

This test adopts the impact bar (bullet) with the length of 400mm, the incident bar with the length of 1600mm, and the transmission bar with the length 800mm. The impact bar is launched by electromagnetic drive, the control voltage is used to change the speed of the impact, and the photoelectric tachometer can record the impact speed of the impact bar. The rubber body and the compression bar are tightly combined during the impact process, and the photoelectric tachometer is put on the parallel position between the impact bar and the incident bar during the test; a strong light source is placed after the high-speed camera to meet the lighting requirements; when the impact begins, it will trigger the high-speed camera to take photos, the camera's position is adjusted based on the lighting conditions at the test site, the impact picture is shot as clearly as possible; after the impact test ends, all speckle photos taken are automatically saved to the computer, and then DIC analysis software is used for subsequent processing to obtain the strain field.

3. Analysis of Test Results

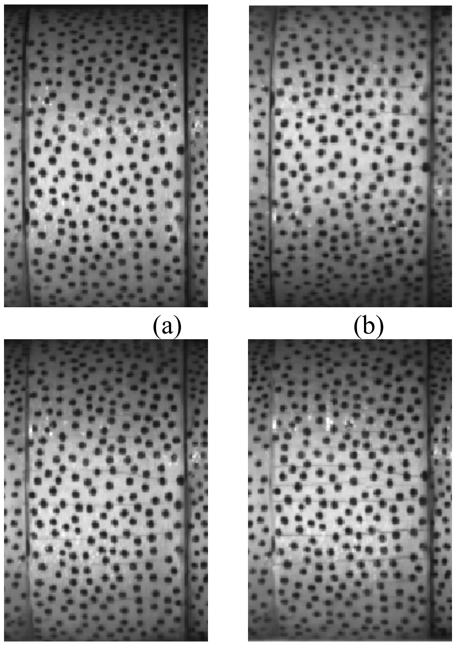
The impact mechanical properties of the rubber body with a on-load voltage of 1600v are tested in this test, and the impact test results are shown in Table.1.

Table 1. Data measured of rubber body in impact test

number	on-load voltage (v)	impact velocity ($m\cdot s^{-1}$)	peak strain ($\mu\varepsilon$)
gx-1	1600	6.431	22900
gx-2	1600	6.430	22889
gx-3	1600	6.433	22921

After the impact test ends, first, the collected speckle photos are screened, the most characteristic images among them are selected, and then the DIC software is applied to process this group of images, after regional division, selection of seed points, analysis, and strain calculation, thus, the strain cloud map of the rubber body can be obtained..

Fig.2 shows the deformation and evolution process of the rubber body under 1600V on-load voltage shock (the rubber surface is coated with white spray paint):



(a) (b) (c) (d)

Figure 2. Shock compression process of rubber body

The following is the variation cloud diagram of strain field of rubber body under the impact of 1600v on-load voltage.

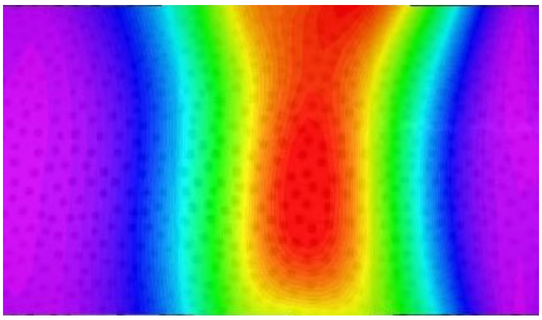


Figure 3. Impact loading step (a)

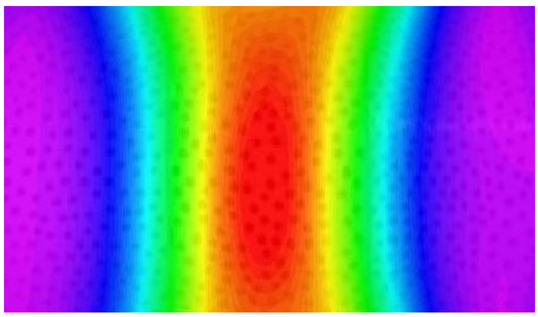


Figure 4. Impact loading step (b)

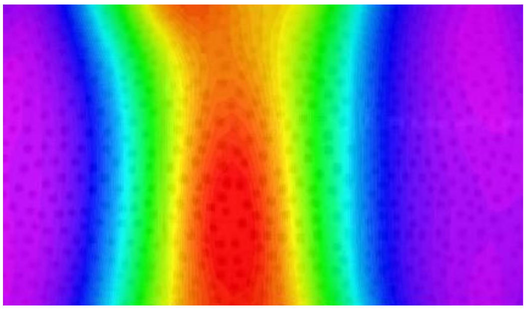


Figure 5. Impact loading step (c)

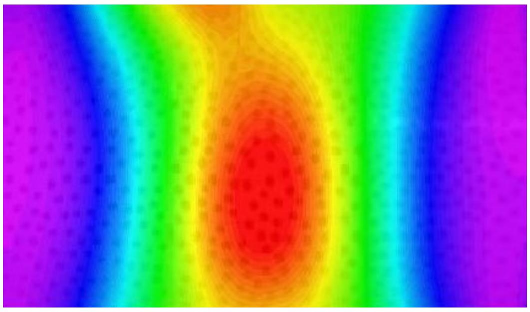


Figure 6. Impact loading step (d)

Fig.3, 4, 5, and 6 show the microstrain of the rubber body during the 1600v on-load voltage impact, respectively. In the early stage of applying impact load, when the stress wave just reaches the front end of the rubber body, large deformation appears in the contact area between the rubber body and the incident bar, with the propagation of the stress wave in the rubber body material, the deformation continuously spreads from front to back, and finally compressed to the extreme, at this time, the compression is no longer increased, and reaches the critical state of springback.

4. Conclusion

This paper is based on the DIC technology and its application methods, and studies the dynamic mechanical properties of rubber materials by using the E-SHPB device to impact the rubber body. The conclusion is drawn as follows:

(1) The test phenomenon suggests that rubber-like easily deformable materials are highly nonlinear, the faster the impact speed (the higher the strain rate), the smaller the rubber compression, and the more obvious the hardening phenomenon of rubber.

(2) In the dynamic impact process, strain concentration phenomenon occurs first at the contact area between the rubber materials and the incident bar in the early stage of impact, with the propagation of the stress wave in the material, the strain concentration phenomenon gradually shifts, finally, a large strain concentration is generated in the middle area, at this time the rubber materials are highly compressed and reaches a critical state that is about to rebound.

(3) DIC technology can better represent the full-field strain of rubber-like deformable materials in the impact process.

References

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