Research on Buffering Performance of Several Polymer Materials Based on Drop-weight Test

Jingfa Lei [1,2], Zhiqiang Chen [2], Miao Zhang [2,a], Tao Liu [2], Hong Sun [2].

[1] State Key Laboratory of Vehicle NVH and Safety Technology, 401120 Chongqing, China
[2] School of Mechanical and Electrical Engineering, Anhui Jianzhu University, 230601 Hefei, China

Abstract. Polymer materials are widely used in vibration damping and buffering, and different materials and processing techniques would affect their buffering performance. In this study, the buffering performance of four kinds of specimens made of non-foamed polyurethane, foamed polyurethane, silicone rubber and PVC paste resin were examined by drop-weight tests. According to the drop-weight experimental principle and corresponding numerical simulation, the peak acceleration of the falling hammer could be used as the key index of buffering performance. The results show that the buffering performance of the non-foamed polyurethane and silicone rubber samples are relatively worse, while the foaming polyurethane and PVC paste resin samples have similar buffering performance.

1 Introduction

Polymer materials are artificial synthetic polymer materials. Due to its properties of soft and elastic, it has excellent shock absorber performance, and it is strong and durable. Therefore, it is commonly used as buffer or product packaging material [1]. High polymer materials need to be artificially synthesized from a variety of raw materials, the difference of ratio of materials and synthetic technology could affect physical properties of the finished product, such as hardness, elasticity and toughness. In the process of material preparation and process optimization, different samples need to be tested for mechanical properties.

The mechanical properties of specimens are generally tested using impact mechanics test equipment. Drop-weight test device is a common impact pulse input device [2], which is a useful low-speed impact test device because of its compact structure, convenient operation, and can realistically simulate free-fall impact scenes [3]. It is commonly used to study the impact mechanical properties of concrete [4, 5], metal [6, 7], composite materials [8], etc. and their corresponding profiles. And some researchers used finite element simulation methods to simulate drop-weight test [9, 10].

Acceleration sensors are often used during drop-weight tests. The acceleration sensor is an inertial sensor that senses the mechanical motion information of the carrier and converts it into electrical signal [11]. The drop hammer acceleration measured by the acceleration sensor is one of the most important parameters for the numerical analysis of the falling hammer motion. According to related researches, in addition to the drop weight, height, and cushioning properties of the specimen [12], both the drop hammer thickness and the collision surface radius of the falling hammer can impact the acceleration [14].

2 Numerical simulation

The drop-weight release height is set to h_1, and the vertical upward speed is positive. According to Newton's second law, at the moment of the hammer body colliding with the pedestal, the speed of the hammer body is

$$v_1 = -\sqrt{2gh_1} \tag{1}$$

It is assumed that the rebound height of the hammer is h_2. Then the speed of rebound after the collision is:

$$v_2 = \sqrt{2gh_2} \tag{2}$$

The equation (1) and (2) are used as boundary conditions, the speed change of the falling hammer during the process of collision can be described as:

$$V(t) = \cos(\frac{\pi t}{T})(\frac{v_2 - v_1}{2}) + \frac{v_2 + v_1}{2} \tag{3}$$

In equation (3), T is the width of the stress pulse. The drop-weight acceleration during the process of collision is worked out by differentiating equation (3).

$$a(t) = -\frac{\pi}{T}\sin(\frac{\pi t}{T})(\frac{v_2 - v_1}{2}) \tag{4}$$

Thus, the peak acceleration during the process of collision is:

[a] Corresponding author: hfutzm@163.com

$$a_{\text{peak}} = a(\frac{T}{2}) = \frac{\pi}{T}(\frac{v_2 - v_1}{2}) = \frac{\pi}{T}(\frac{\sqrt{2gh_1} + \sqrt{2gh_2}}{2}) \quad (5)$$

The width of the stress pulse T is equal to the time taken by the stress wave to travel forth and back in the hammer body, i.e.

$$T = \frac{2L}{c} \quad (6)$$

In equation (6) , L is the height of hammer body and c is the velocity of stress wave.

The drop-weight release height h_1 and the rebound height of the hammer h_2 reflect the buffering performance of the specimens. According to equation (5), the drop-weight release and rebound height are related to the peak acceleration a_{peak} and pulse width T. According to equation (6), since the size of hammer body and the velocity of stress wave are constant values in the drop-weight test, the pulse width T is a fixed value. Therefore, when the drop-weight release height h_1 is the same, the smaller the peak acceleration a_{peak} is, the smaller the rebound height h_2 is. It is indicated that the buffering performance of the specimen is better.

3 Experiment

3.1. Test specimens

Four kinds of test specimens made of different materials were selected. Sample 1 is non-foamed polyurethane, sample 2 is foamed polyurethane, sample 3 is silicone rubber, and sample 4 is polyvinyl chloride (PVC) paste resin. The samples were uniformly made into circular plates. The diameter is 100mm, and the thickness is 10mm.

3.2. Facilities

The drop-weight test bench used in the experiment is shown in figure 1. The working principle is to install a limiter with a solenoid valve at the upper end of the hammer. The drop hammer only can move up and down along the steel rail because of the limiter. The bottom fixed pedestal is used to place the specimens and withstand the impact of drop hammer. Initially, the solenoid valve is connected and the hammer body is raised to the height required for the test. When the solenoid valve is disconnected, the hammer body falls along the guide rail and finally hits the specimen on the pedestal. In addition, the specimen is surrounded by a protective sleeve. The inner diameter of the sleeve is larger than the diameter of hammer body, so that the hammer body will not be touched during the falling process, but its horizontal movement after it dropped can be limited. Thus, the sleeve plays a role in protecting the guide rail.

The hammer body is made of 40Cr steel, and it is a cylinder with diameter of 95mm and height of 72mm. As shown in figure 2, The upper end surface is a plane with threaded holes for installing the limiter and the acceleration sensor. The bottom surface is spherical with radius of 165mm.

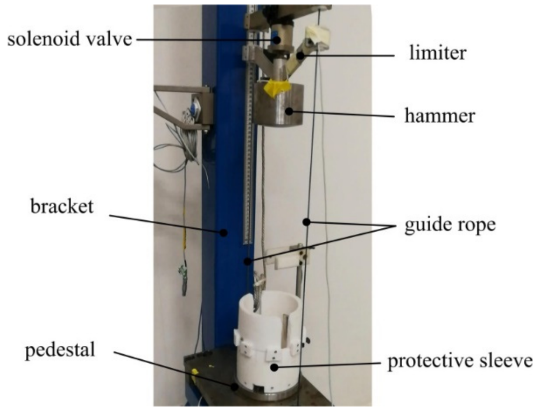

Figure 1. The drop-weight test bench.

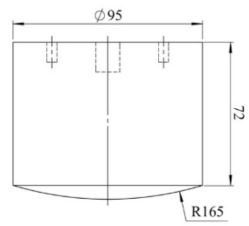

Figure 2. The shape and size of the hammer body (mm).

The acceleration sensor used in this experiment is the 7264C piezoresistive accelerometer producted by ENDEVCO Corporation in USA. The measuring range is ±2000g, and the sampling rate is 20 ks/s, In order to ensure that the center of gravity of the hammer body does not deviate from the center axis, two acceleration sensors are used and symmetrically installed on the upper end of the hammer body with respect to the central axis by bolt. The total weight of the hammer body and its upper fixed limiter and acceleration sensors is 4.5kg.

3.3. Experimental process

After the drop-weight test bench was installed and adjusted, the hammer body was released to four different heights of 400 mm, 600 mm, 800 mm and 1000 mm from the pedestal. The measurement system was set to negative delay trigger mode to record acceleration data of the hammer body. The above four kinds of specimens were tested in sequence after the drop-weight release height was adjusted.

4 Experimental results and discussion

The hammer body is only subjected to vertical downward gravity during the falling process, and when the falling hammer impacts the sample, it is subjected to a vertical upward supporting force, and generates a huge vertical upward acceleration. Only the first wave peak of the acceleration after impacting, which is also the largest peak, need to be focused. And it is called peak acceleration. The follow-up wavelet peaks generated by the oscillation are ignored. For ease of comparison, the time coordinates of the acceleration peak are adjusted to be the same. The drop-weight acceleration curves of the four kinds of samples under different release height conditions are shown in figure 3 - figure 6. It can be seen that, for the same kind of sample, the higher the release height is, the greater the measured peak acceleration is.

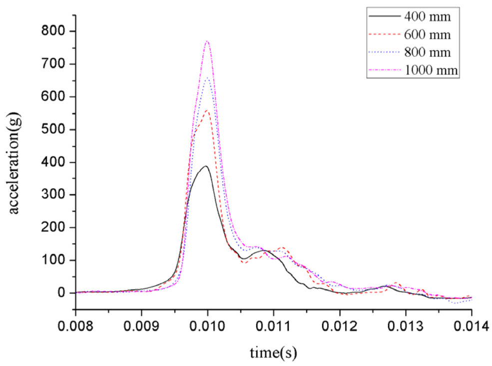

Figure 3. Acceleration response of Sample 1 at different release heights

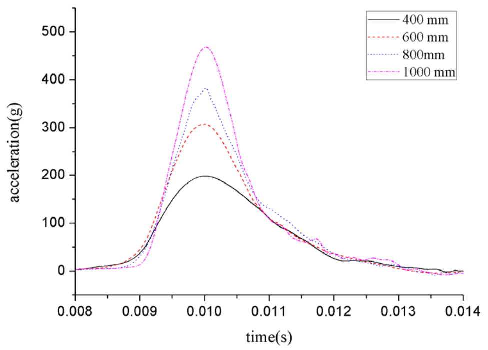

Figure 4. Acceleration response of Sample 2 at different release heights

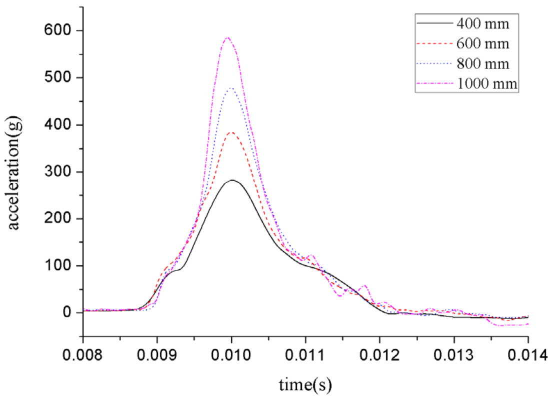

Figure 5. Acceleration response of Sample 3 at different release heights

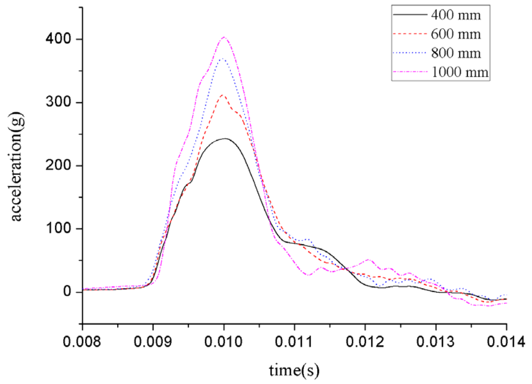

Figure 6. Acceleration response of Sample 4 at different release heights

According to statistics, the peak acceleration measured for the four types of specimens under different release height conditions are shown in Table 1. And the trend of peak acceleration changing with the drop-weight release height is shown in figure7. It can be seen that at the same release height, the peak acceleration measured for the non-foamed polyurethane sample was the largest, followed by the silicone rubber sample. It is indicated that the buffering property of non-foamed polyurethane and silicone rubber samples are weaker than the other two samples. The peak acceleration of the drop hammer for the foamed polyurethane sample and the PVC paste resin sample are approximately equal at 600 mm drop-weight release height; the peak acceleration for the foamed polyurethane sample is smaller when the drop-weight release height is less than 600mm; however, the peak acceleration for the PVC paste resin sample is smaller when the drop-weight release height is greater than 600mm.It shows that the PVC paste resin sample has better buffering effect on larger impact loads.

Table 1. Peak acceleration at different release heights.

drop-weight release height (mm)	Sample number			
	1	2	3	4
400	390.57g	198.23g	283.13g	242.94g
600	567.29g	307.58g	385.84g	312.73g
800	667.25g	383.48g	482.17g	369.75g
1000	781.91g	468.49g	589.23g	404.19g

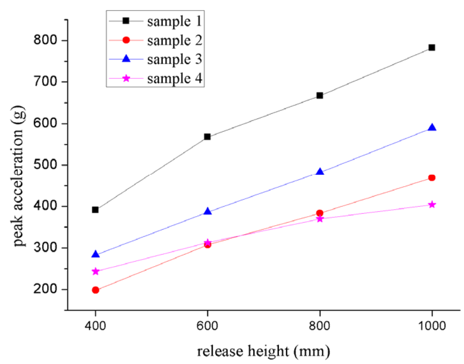

Figure 7. The trend of peak acceleration changing with the drop-weight release height

In addition, comparing the curves of figure 3 to figure 6, it can be seen that the buffering time of the first impact of the foamed polyurethane sample and the PVC paste resin sample is relatively long. And the foamed polyurethane specimens have less fluctuation in subsequent drop-weight acceleration. This is due to the fact that the foamed polyurethane and PVC paste resin specimens are relatively soft. And the foamed polyurethane sample is slightly more vibration-reducing. The non-foamed polyurethane samples have the shortest buffering time for the first impact. Subsequent fluctuations of drop-weight acceleration are also the largest. Because in these four materials, the non-foamed polyurethane sample is the hardest and its vibration damping property is also the worst.

5 Conclusions

According to the principle of drop-weight experiment and its corresponding parameter numerical simulation, the acceleration peak of the drop-weight can be used as the index of sample buffer performance.

According to the test requirements, the hammer body, pedestal and protective sleeve of the drop-weight test bench were designed.

For four samples of un-foamed polyurethane, foamed polyurethane, silicone rubber and PVC paste resin, drop-weight tests of four different release heights were carried out, and the drop-weight acceleration was measured by an acceleration sensor. The results show that the un-foamed polyurethane sample has the worst buffering effect, followed by the silicone rubber sample. The foamed polyurethane and PVC paste resin have similar buffering properties. Besides, the difference in hardness and vibration damping property will also affect the buffering performance of the sample.

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