Analysis on cushioning performance of copper foam-polyurethane structure

Mingsi Qi

School of Mechanical and Power Engineering,
North University of China, Taiyuan 030051, Shanxi, China

Xiaoyang Wang

School of Mechanical and Power Engineering,
Henan Polytechnic University, Jiaozuo 454150, Henan, China

Dong Guo

Handan Polytechnic College,
Handan 056000, Hebei, China

Abstract
Based on the requirements of energy absorption at the situation of high shock and overload, this paper designs a copper foam-polyurethane composite structure, and gets its mechanical model, analyzes the stress, displacement and strain charts of the cushioning structure. Then the paper takes the compression test on the three types of the cushioning structures, and uses the curve fitting function cftool in MATLAB software to fit the maximum pressure which can be borne by the structure under different pitch. At last the following research results are given: under the same compression conditions, the cushioning performance of the copper foam-polyurethane structure is better than the soft pad-polyurethane structure, and the cushioning performance of the soft pad-polyurethane structure is better than the direct pouring polyurethane structure.

Key words: COPPER FOAM-POLYURETHANE, CUSHIONING, COMPRESSION TEST

Introduction

The research and development of metal foams started since the 1940s. The earliest was the patent technology of Sosnick[1] who prepared metal foams through the gasification of low melting point substance in the metal. In 1956, Borksten Research Laboratory Inc. first successfully prepared aluminum foam through molten body direct foaming process[2]. Then Foamalum Corp. and Italy Corp. put this technology into practice[3].

So far people have discussed the influence of cell structure and specimen size on the compressive strength of aluminum foam[4-7] and the performance of copper foam[8,9]. People also have done a lot of researches on the property of polyurethane [10-14], Qi Mingsi etc. have researched the energy-absorption performance of the aluminum foam-polyurethane composite through finite element analysis[15,16], but there are few reports on the cushioning properties of copper foam-polyurethane composite and its structure.

Establishment of the mechanical model

This paper establishes a threaded, cushioning and protective structure of the simple mechanical model, which is shown in Figure 1.

This paper makes the following hypothesis. First, different parts of the polyurethane have the same mechanical characteristics. Secondly, the high-speed movement of the steel shell and the friction between the steel shell and the air results in elevateperature. It doesn’t consider the influence on the properties of the polyurethane. Thirdly, the equilibrium pd temosition is the coordinate origin. The cushioning structure is equivalent to a mechanics model of a damped mass spring system.

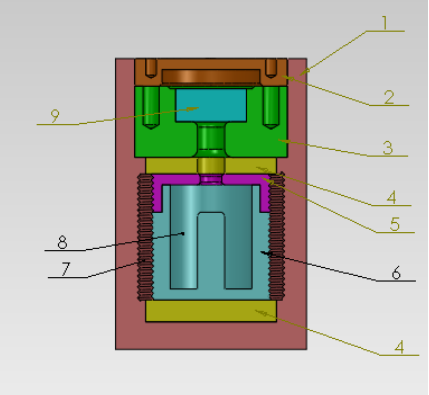

Figure 1. Cushioning structure of the copper foam-polyurethane composite

1-Steel shell, 2-Steel shell cover, , 3-Sensor mounting body, 4- Buffer blankets, 5- Liner cover, 6- liner, 7- Pouring materials, 8- Circuit module, 9- Sensor

Formula 1 is the differential equations of the structure motion.

$$m\ddot{x} = -F + mg - F_\delta = -cx - \mu\dot{x} \qquad (1)$$

It can be rewritten as formula 2.

$$\ddot{x} + 2\delta\dot{x} + \omega_s^2 x = 0 \qquad (2)$$

In formula 2, $\omega_s^2 = c/m$, $\delta = \mu/2m$.

δ is the damping coefficient, and c is the spring stiffness coefficient. Formula 2 is the damped free vibration differential equation in the standard form. It is still a homogeneous differential equation of two order constant coefficient linear. Suppose the general solution of the differential equation is x, and formula 3 is its general solution.

$$x = c_1 e^{\alpha_1 t} + c_2 e^{\alpha_2 t} \qquad (3)$$

When the characteristic root is real or imaginary, the motion rule of formula 3 is very different, and all of these are associated with the value of the damping coefficients δ. It belongs to the category of small damping ($\delta < \omega_s$), and its characteristic roots are a pair of conjugate complex roots, as are shown in formula 4.

$$\alpha_{1,2} = -\delta \pm i\sqrt{\omega_s^2 - \delta^2} \qquad (4)$$

Based on the Euler's formula, the solution of the differential equations can be written as formula 5.

$$x = Ae^{-\delta t}\sin(\sqrt{\omega_s^2 - \delta^2}\,t + \alpha) \qquad (5)$$

In formula 5, A and α are integral constants. Formula 6 can be got by the initial moving conditions.

$$A = \sqrt{x_0^2 + (v_0 + \delta x_0)^2 \big/ (\omega_s^2 - \delta^2)}$$

$$\alpha = \arctan\left[x_0\sqrt{\omega_s^2 - \delta^2} \big/ (v_0 + \delta x_0)\right] \qquad (6)$$

Formula 6 is the motion equations of the system under small damping condition.

Dynamic simulation analysis

Table 1 is the material characteristic parameters.

Table 1. Material characteristic parameters

	Density(g/cm^3)	Modulus of elasticity(GPa)	Poisson's ratio
Steel shell	7.85	210	0.31
Polyurethane ring	1.15	10	0.30
Liner	7.85	210	0.31
Copper foam	0.50	210	0.30

Numerical analysis method is the product of the high development with computer technology and the calculation method; it has been rapidly developed and widely used in the energy absorption area. In order to solve the problem and save cost, this paper first uses finite element method to research the energy absorbing ability of the composite cushioning structure; then adopts compression test method to verify the simulation results. The test pieces are prepared in accordance with GB7314-87 for the compression test method, which uses the technology of data acquisition, data storage and data reading. The compression test is carried by a compressor on the cushioning material structure. Via the compression test results, the paper can research and evaluate the cushioning performance of the copper foam-polyurethane composite structure.

The interface between the polyurethane pouring sealant and the steel shell is the screw type interface, which is one of the innovation points of the paper. In the process of the simulation, this paper uses several different ring clearance and pitch, simulates and analyzes the respective stress nephogram and contacting pressure cloud graphs.

In order to make the simulation easier, the inner contacting surface between the polyurethane and the steel shell is simplified as a plane. When the inner plane subjected to a surface load, the two planes become the contacting surface. The structure of the contacting surface is predigested by the actual thread. There is cohesive force between the polyurethane and the steel structure, so the inner force of the two contacting surface can not be seen as simple friction between two objects. In view of the impacts of various factors, this paper uses the “adding volume” function in the ANSYS software. The polyurethane ring and the steel shell constitute a complete part, which are divided into different materials model by FEM mesh.

During the simulation process, the paper establishes the ring clearance of 2 mm, 3mm, 4mm and 5mm for a group of models. When the same suitable force is applied on the inner plane, the liner moves along the Z axis direction relative to the steel shell. Figure 2(a), (b) and (c) respectively show the stress cloud chart, the displacement in Z direction and the strain nephogram of 2mm clearance after the structure is loaded.

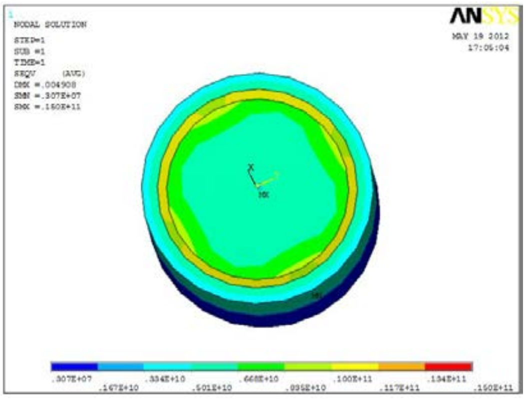

Figure 2(a). Stress cloud chart of 2mm spacing

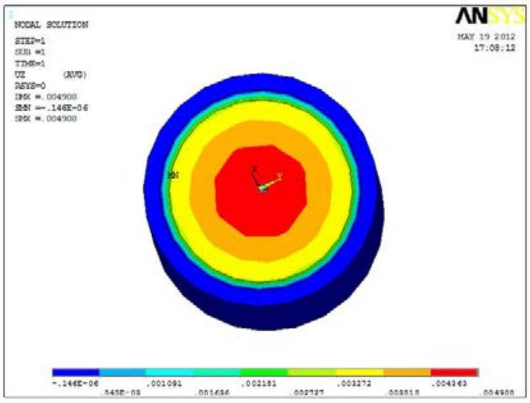

Figure 2(b). Displacement in Z direction of 2mm spacing

Due to the paper space constraint, this paper only lists the stress, the displacement and the strain diagram of the structure with 2mm ring clearance. In order to observe the results better, table 2 lists the maximum stress value, the maximum displacement in Z direction and the maximum value of average strain with 2mm, 3mm, 4mm and 5mm ring clearance.

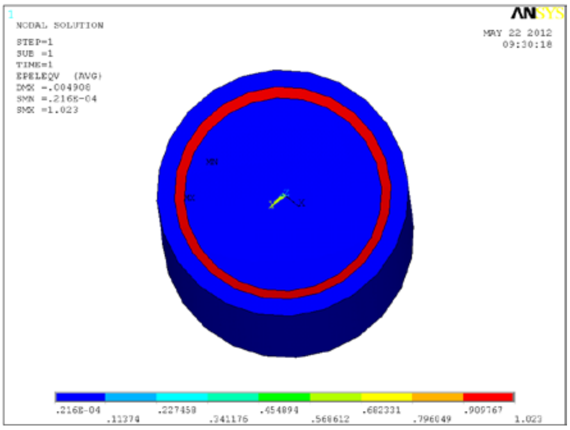

Figure 2(c). Strain nephogram of 2mm spacing

Table 2. Parameters of the structure when the same force is processed on the structure

Ring clearance (mm)	The maximum stress value（Pa）	The maximum displacement in Z direction (m)	The maximum value of average strain
2	0.150×10^{11}	0.004908	1.023
3	0.152×10^{11}	0.005912	0.935734
4	0.155×10^{11}	0.006764	0.890529
5	0.153×10^{11}	0.007459	0.785148

The following results can be derived from figure 2(a) to figure 2(c). First, from the structure stress cloud charts of four different ring clearance, it can be drawn the following points. When the same suitable force is stressed on the inner face, the structure of 2mm ring clearance has the maximum stress. Its value is 0.15×e11Pa. Secondly, from the structure displacement in Z direction of four different ring clearance, it can be drawn the following points. When the same suitable force is stressed on the inner face, the structure of 2mm ring clearance has the minimum displacement value. Its value is 0.004908 mm. Thirdly, from the structure strain nephogram of four different spacing, it can be drawn the following points. When the same suitable force is stressed on the inner face, the structure of 2mm ring clearance has the minimum strain. Its value is 1.023mm.

To sum up, applying the same size of the force on the inner surface to simulate, the structure model of 2mm ring clearance has the best cushioning performance.

Compression test

In order to make the results more accurate, this paper verifies the simulation results by the compression test. This compression test adopts a hydraulic press as the test device. Its working principle is as follows. First, the bottom tape is torn by the manipulator before the compression test, and then the hydraulic press working platform is adapted to a suitable location. A jack is vertically placed on the working platform, and the pressure sensors are horizontally placed on the top column of the jack, and the structure is vertically placed on the sensors. Using the handle to swing the jack up, the jack drives the sensors to tip on the top bar of the hydraulic press structure. The ejector rod restricts the steel shell to move upward, and the protruding column of the sensors tips the liner of the structure to continue moving upward, until the polyurethane failure. At this time, the maximum pressure value can be obtained from the sensors.

Figure 3. The copper foam used in this compression test

Figure 4. Structure after pouring

Diagram of the used copper foam in this experiment is shown in figure 3. Put a certainty circular copper foam into the central location of the steel shell, and make the polyurethane flat to the upper plane of the copper foam. Then vertically place the inner circuit module in the middle of the copper foam, and an annular gap forms between the inner and the inner wall of the steel shell. Pour the liquid polyurethane into the ring clearance until the polyurethane plane is flat to the upper plane of the inner. The copper foam-polyurethane composite structure is shown in Figure 4. The structure diagram of the copper foam after the compression test is shown in figure 5. The data sheet of the compression tests is shown in table 3.

Figure 5. Diagram of the copper foam after the compression test

Table 3. Date sheet of the compression tests

	Pressure (ton)	Ring Clearance (mm)
First group of pitch M1（polyurethane structure）	0.98 0.7 0.9 0.7	2 3 4 5
Second group of pitch M1（soft pad- polyurethane structure）	1.16 1.14 1.10 1.05	2 3 4 5
Third group of pitch M1（copper foam-polyurethane structure）	1.23 1.2 1.18 1.16	2 3 4 5
Fourth group of pitch M2（polyurethane structure）	1.08 0.99 1.07 1.0	2 3 4 5
Fifth group of pitch M2（soft pad- polyurethane structure）	1.15 1.13 1.1 1.05	2 3 4 5
Sixth group of pitch M2（copper foam-polyurethane structure）	1.38 1.35 1.3 1.23	2 3 4 5

Based of the same ring clearance, the paper uses the curve fitting function cftool in MATLAB software to fit the maximum pressure of the structure on different pitch. In figure 6(a) to figure 6 (f) the fitting curves are given. We can draw the following conclusions from table 3, figure 6(a) to figure 6(f).

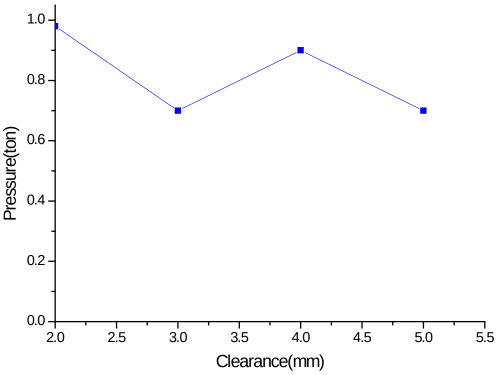

Figure 6(a). Pressure-clearance curve of the polyurethane structure with M1 pitch

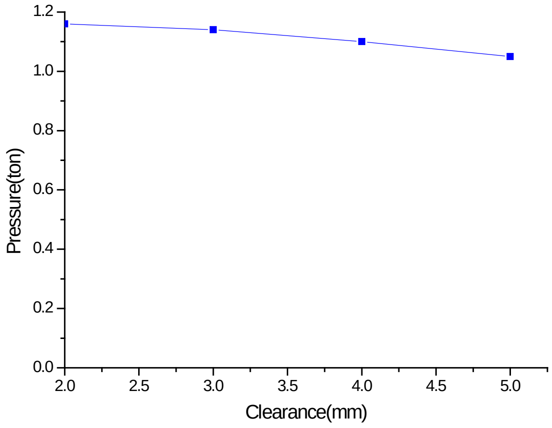

Figure 6(b). Pressure-clearance curve of the soft pad-polyurethane structure with M1 pitch

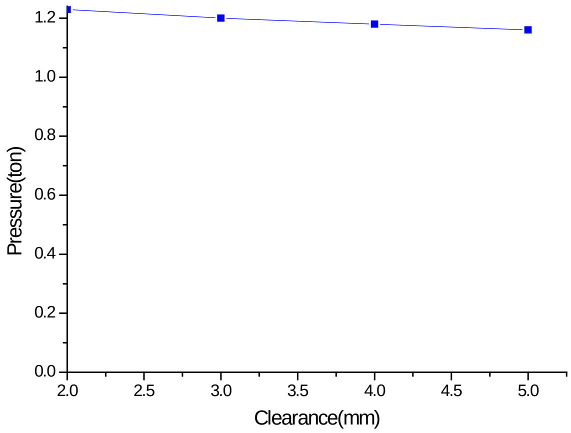

Figure 6(c). Pressure-clearance curve of the copper foam-polyurethane structure with M1 pitch

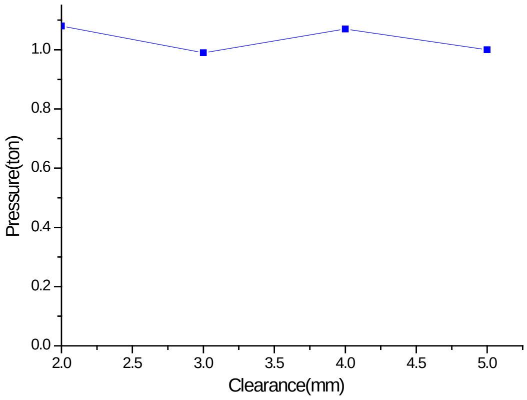

Figure 6(d). Pressure-clearance curve of the polyurethane structure with M2 pitch

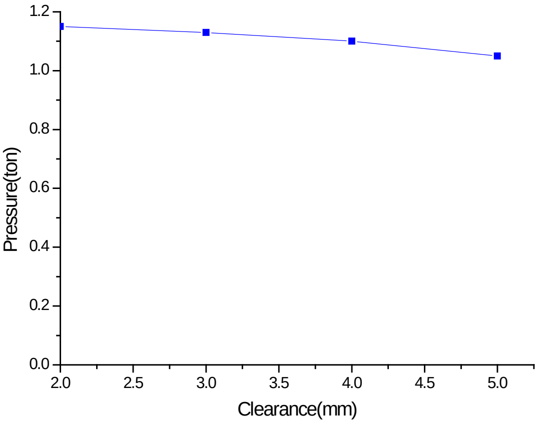

Figure 6(e). Pressure-clearance curve of the soft pad-polyurethane structure with M2 pitch

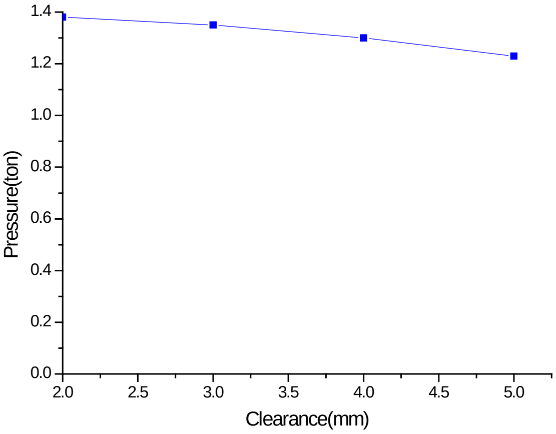

Figure 6(f). Pressure-clearance curve of the copper foam-polyurethane structure with M2 pitch

When the clearance of the screw thread is 1 mm, the maximum pressure borne by the structure with 2mm thread pitch can reach the maximum limit. Therefore the bearable maximum pressure of the polyurethane structure, the soft pad-polyurethane structure and the foam-polyurethane structure are 0.98 tons, 1.16 tons and 1.23 tons, respectively.

When the clearance of the screw thread is 2 mm, the maximum pressure borne by the structure with 2mm thread pitch can reach maximum value. Therefore the bearable maximum pressure of the polyurethane structure, the soft pad-polyurethane structure and the foam-polyurethane structure are 1.08 tons, 1.15 tons and1.38 tons, respectively.

In case the clearance of the screw thread is the same and the thread pitch is from 2 mm to 4 mm, the maximum pressure borne by the polyurethane structure first decreases, and then increases and then decreases again.

In case the clearance of the screw thread is the same and the thread pitch is from 2 mm to 4 mm, the maximum pressure borne by the soft pad-polyurethane structure decreases.

In case the clearance of the screw thread is the same and the thread pitch is from 2 mm to 4 mm, the maximum pressure borne by the copper foam-polyurethane structure decreases.
When the ring clearance is 2 mm, the cushioning structure has the best cushioning performance. Too large or too small pitch is not conducive to improve the cushioning performance of the structural.

The results of compression tests are in accordance with the simulation results. Finally the paper selects 2 mm as the ring clearance of the structure.

Conclusions

This paper sets up a threaded cushioning structure model and mechanical model, analyzes the cushioning structure's stress, displacement and strain state. Then the paper uses the compression test to verify the simulation results, uses the curve fitting function cftool in MATLAB software to get the pressure-clearance curves. The compression test results are in accordance with the simulation results. Finally the paper selects 2 mm as the ring clearance of the structure.

Acknowledgements

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