Numerical Analysis of Impact Behavior of Rotary Centrifuge Guarded Body

Weizhou Zhong, Xicheng Huang, Chengang Luo, Gang Chen and Zhifang Deng

Abstract Numerical simulation of dynamic mechanical responses of a rotary centrifuge at different impact velocities and angles is performed. The impact velocities are 25 m/s, 50 m/s and 270 m/s and the impact attitudes are 0° and 45° respectively. Stress fields and failure modes of the guarded body, cavity wall, cover and rotary components are obtained. It indicates that the cavity wall can withstand impact action. The deformation of the cavity wall and cover is elastic when the turntable velocity is lower than 25 m/s. Centrifuge guarded body will be broken when turntable velocity is over 50 m/s. This analysis can guide design and safety assessments of rotary centrifuge.

Keywords Centrifuge · Impact resistance · Numerical simulation · Safety assessment

1 Introduction

The energy absorption of a cushion material is an important property for the impact safety of a product. Wide range plateau stress is necessary for an ideal cushion material. According to the actual usage of cushion materials, they can be classified

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A. Öchsner and H. Altenbach (eds.), *Mechanical and Materials Engineering of Modern Structure and Component Design*, Advanced Structured Materials 70,
DOI 10.1007/978-3-319-19443-1_13

into energy dissipation and energy storage. Energy dissipation materials such as foam metals are widely used. For the energy storage material, kinetic energy converts into elastic potential energy under impact conditions, such as rubber materials and springs. So cushion material and their structure mechanics behavior are important for impact safe protection. High strength steels and porous materials have recently been found to be effective for resisting and reducing the force of impact. Examples of recent uses of cushion materials and structures can be found in product packaging buffers and highway guardrails. Many researchers have performed studies in field of structure impact resistance. For instance, Guillow [1] experimentally investigated the axial compression of thin-walled circular tubes, a classical problem studied for several decades. Experimental results show both axisymmetric and non-symmetric modes lie on a single curve. Li [2] established a close-celled aluminum foam model under low velocity impact condition, and validated with drop hammer test and systematically explored the influence of impact mass ratio, porosity and geometrical dimensions of foam protection on the critical velocity and acceleration. Jeenager [3] produced metal foams and thermally treated them to enhance their properties and examined the changes in the microstructure and thermal treatment. Fracture test affirms the role of the microstructure for property enhancement. Alavi [4] analyzed the energy absorption capacity of simple and multi-cell thin-walled tubes with triangular, square, hexagonal and octagonal sections. The results showed that the energy absorption capacity of multi-cell sections is greater than that of simple sections. Further more, hexagonal and octagonal sections in a multi-cell configuration absorbed the greatest amounts of energy per unit of mass. Ajdari [5] investigated in-plane dynamic crushing of two dimensional honeycombs with both regular hexagonal and irregular arrangements by using detailed finite element models. Numerical simulations showed three distinct crushing modes for honeycombs with a constant relative density: quasi-static, transitional and dynamic. Kumar [6] experimentally investigated the effect of stiffening the syntactic foam core with a resin impregnated paper honeycomb structure on compression behavior and energy absorption capacity of sandwich composites under flatwise and edgewise loading configurations. Lee [7] reported on the mechanical behavior of an interpenetrating carbon/epoxy periodic submicrometer-scale bicontinuous composite material fabricated following the design principles deduced from biological composites. Using microscopic uniaxial compressive tests, the specific energy absorption is quantitatively evaluated and compared with the epoxy/air and carbon/air precursors. Karasek [8] applied dropped weight impact testing to evaluate the influence of temperature and moisture on the impact resistance of unmodified and modified epoxy/graphite fiber composites. The results indicated moisture was found to have little effect on the damage initiation energy or subsequent energy absorption at ambient and low temperatures. Much study on the energy absorption of materials and structures has been and is being investigated by researchers [9–12].

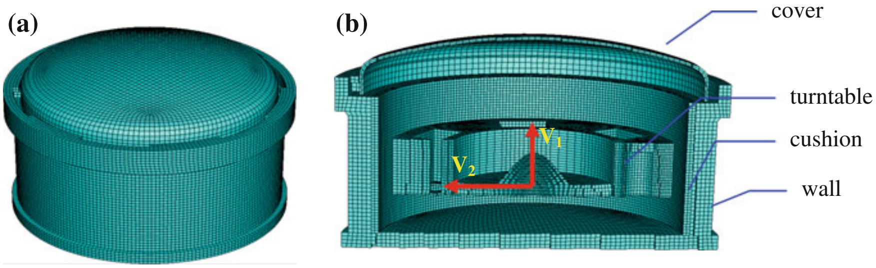

Fig. 1 Finite element structure

The rotary centrifuge is made up of cavity wall, cover, safety gate and steel box. Maximum rotating speed is about 220 rad/s. In order to ensure a safe operation of the centrifuge at high rotating speeds, the impact response of a centrifuge guarded body should be studied. In the present work, numerical analysis on the impact behavior of the rotary centrifuge guarded body is carried out to investigate the centrifuge's protective capacity in an accident environment.

2 Rotary Centrifuge Structure Model

A rotary centrifuge is high speed rotation equipment. The system is made up of spindle bearing, driver motor and centrifuge body. The impact resistance of centrifuge body should be taken into account in the rotary centrifuge safe design stage. Numerical simulation is a feasible way to predict the structure impact response. The finite element model of the centrifuge body is created by the commercial ABAQUS software, as shown in Fig. 1. There are 158,277 hexahedral elements in the numerical model. The junction between the cover and the centrifuge is structural constraint, being similar to a pressure cooker. The bottom of the centrifuge body is fixed in the numerical analysis.

3 Material Properties

In the rotary centrifuge structure, the centrifuge wall and cover are made of Q235 steel. The turntable is made of LD12 alloy metal. The elastic-plastic constitutive model is adopted describe mechanical properties of Q235 and LD12, as shown in Table 1. Rubber is taken as the cushion material on the centrifuge cavity wall. The stress versus strain relation of rubber is described as the potential energy of strain.

Table 1 Material mechanical properties

Material	ρ/kg/m^3	E/GPa	v	σ_s/MPa	σ_b/MPa	Failure strain
Q235	7820	201	0.33	235	635	0.4
LD2	2700	71	0.32	294	436	0.4

The polynomial model expresses the rubber potential energy in simulation. The mathematical relation is shown in expression (1).

$$U = \sum_{i+j=1}^{N} C_{ij}(i_1 - 3)^i (i_2 - 3)^j + \sum_{i=1}^{N} \frac{1}{D_j} (j_{el} - 1)^{2i} \tag{1}$$

U is the potential energy of strain. Symbol j_{el} is the elastic volume ratio. D_i and C_{ij} designate the material compression and Rinvlin coefficient. As rubber is an incompressible medium, C_{01}, C_{10} and D are equal to 0.36, 0.09 and 0 respectively in this work.

4 Simulation Results

The dynamical response of the rotary centrifuge subjected to four impact cases is simulated with the commercial ABAQUS/Explicit software. The impact cases are: velocities of 25 m/s and 50 m/s normal to the impact cover, 270 m/s normal to the impact cover wall and 270 m/s inclined to the impact cavity wall, respectively. Stress and strain distributions of the cover, centrifuge wall and turntable are recommended in the following.

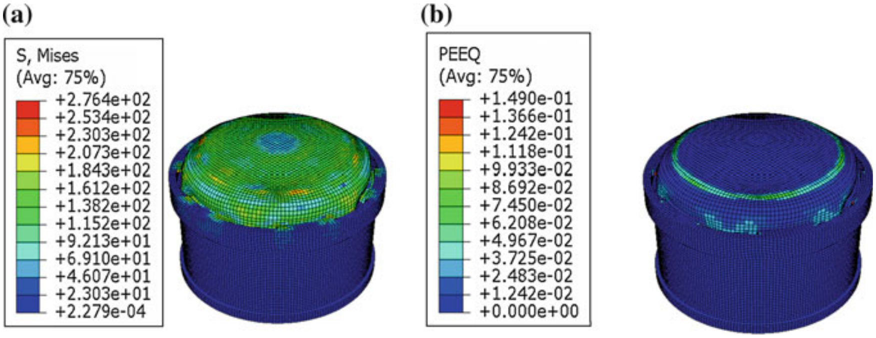

Fig. 2 Stress field and deformation of centrifuge

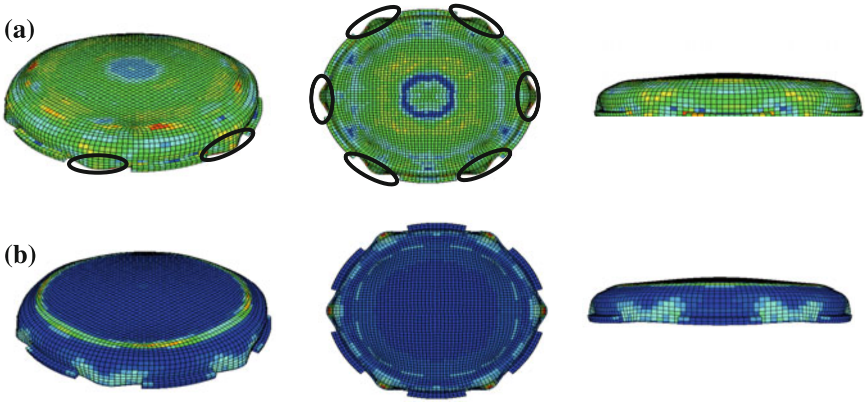

Fig. 3 Stress field and deformation of cover

4.1 Velocity of 25 m/s Normal to the Impact Cover

The dynamic response of the turntable impact normal to the cover is simulated. The turntable impact velocity is 25 m/s. The cover does not separate from the centrifuge body during impact process. The von Mises stress distribution is shown in Fig. 2a. It indicates that the cover brim is under high stress. The equivalent plastic strain of the centrifuge is shown in Fig. 2b. Plastic deformation occurs in the brim of cover's ears. Detailed stress and plastic deformation distribution of the cover is shown in Fig. 3. The elliptical outline means large plastic deformation area in the figure. Therefore we can conclude that the rotary centrifuge can endure turntable impact of 25 m/s. There is no potential safety hazard under this impact condition.

4.2 Velocity of 50 m/s Normal to the Impact Cover

At a normal impact speed of 25 m/s the cover of the rotary centrifuge is safe, therefore the turntable velocity is increased to 50 m/s. The dynamic behavior of the centrifuge under an impact of 50 m/s is simulated. The cover separates from the centrifuge body during the impact process. The von Mises stress distribution is shown in Fig. 4a. It indicates that the cover brim is under high stress. The equivalent plastic strain of the centrifuge is shown in Fig. 4b. Large plastic deformation occurs in the brim of the cover's ears.

Detailed stress and plastic deformation distribution of the cover is shown in Fig. 5. The cover's ears distort to the center during the impact process. The junction between cover and centrifuge is broken. It shows that the rotary centrifuge can not endure a 50 m/s turntable impact. It will bring potential safety hazards under the impact condition.

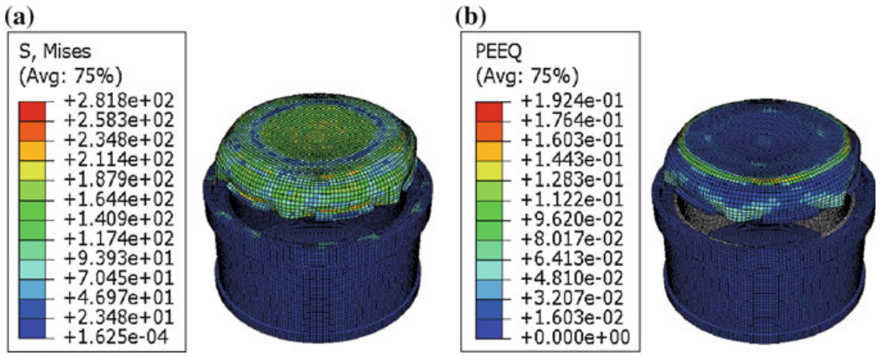

Fig. 4 Stress field and deformation of centrifuge

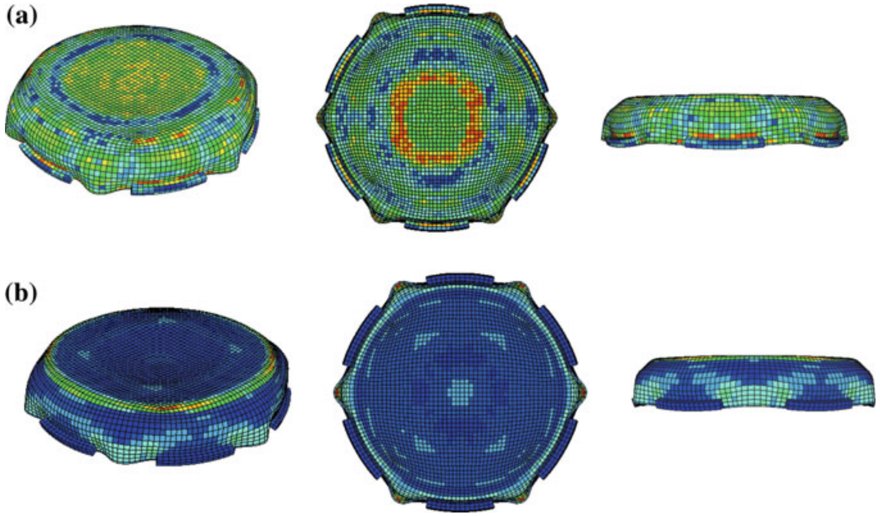

Fig. 5 Plastic deformation of cover

4.3 Velocity of 270 m/s on the Normal Impact Cavity Wall

In order to obtain the centrifuge wall impact resistance, the dynamical behavior of the turntable impacting cavity wall is analyzed. The speed of the turntable is 270 m/s. Stress and equivalent plastic strain distribution of the centrifuge wall is shown in Fig. 6. It becomes drum shape during the impact process. The wall undergoes large plastic strain, but without breaking.

The cover is well connected with the centrifuge body. The deformation of the cover and turntable is shown in Fig. 7. The cover almost undergoes elastic deformation in the impact process, as shown in Fig. 7a. The turntable breaks into pieces,

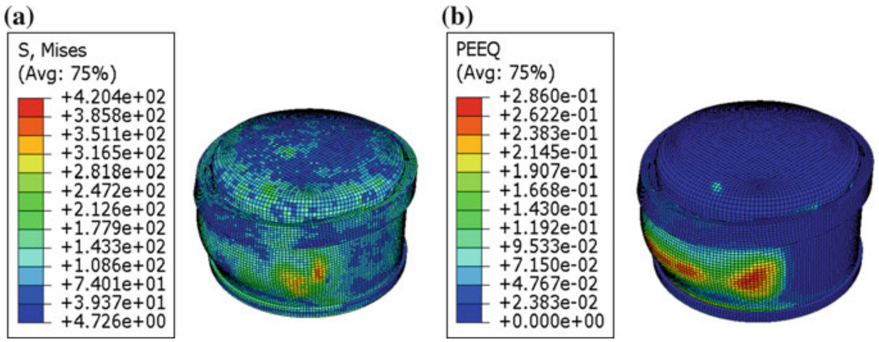

Fig. 6 Stress field and deformation of centrifuge

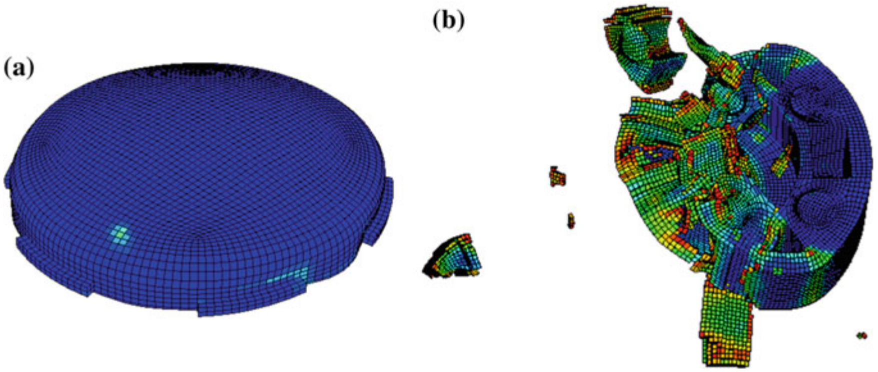

Fig. 7 Deformation of cover and turntable

as shown in Fig. 7b. It indicated that the centrifuge wall is strong enough to resist a turntable impact of 270 m/s.

4.4 Velocity of 270 m/s Impact Slanted to the Cavity Wall

The slanted impact should be considered in the centrifuge safety evaluation. The dynamic behavior of the slanted turntable impacting cavity wall is analyzed. The speed of the turntable is 270 m/s. The stress and equivalent plastic strain distribution of the model is shown in Fig. 8. The centrifuge wall becomes drum shape, without breaking, while the Cover breaks and separates from the centrifuge body.

The deformation of cover and turntable is shown in Fig. 9. The cover suffers large plastic deformation, as shown in Fig. 9a. The turntable is compressed up to

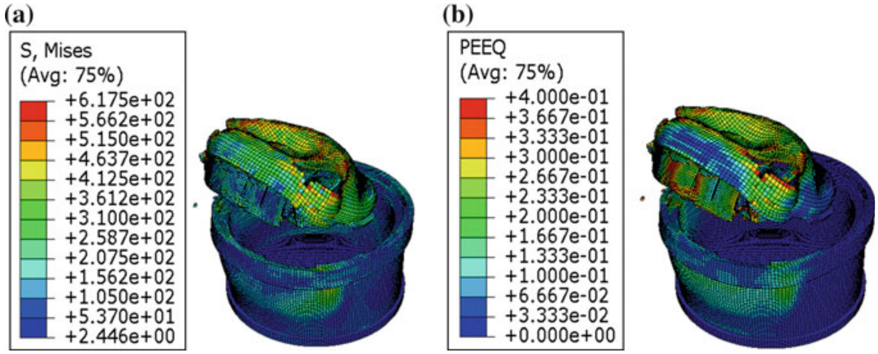

Fig. 8 Stress field and deformation of centrifuge

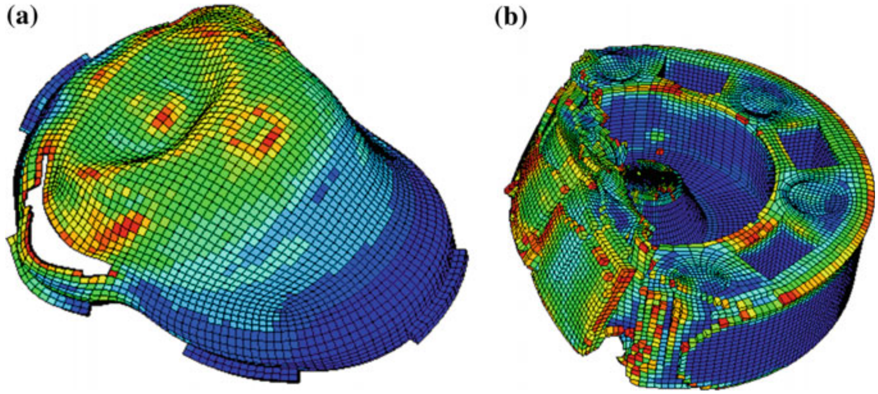

Fig. 9 Deformation of cover and turntable

two-thirds, as shown in Fig. 9b. It can be concluded that it is dangerous in the high speed oblique impact condition.

5 Discussion

For a conventional impact cushion structure, the stress versus strain curve of an ideal cushion material is with wide range plastic plateau phase. The stress value is almost a constant in the compression process. Cushion materials are usually classified into energy dissipation and energy storage. The rotary centrifuge guarded body is taken as energy dissipation type in this work. It shows that the cover separates from the centrifuge body under normal impact cavity wall conditions, as

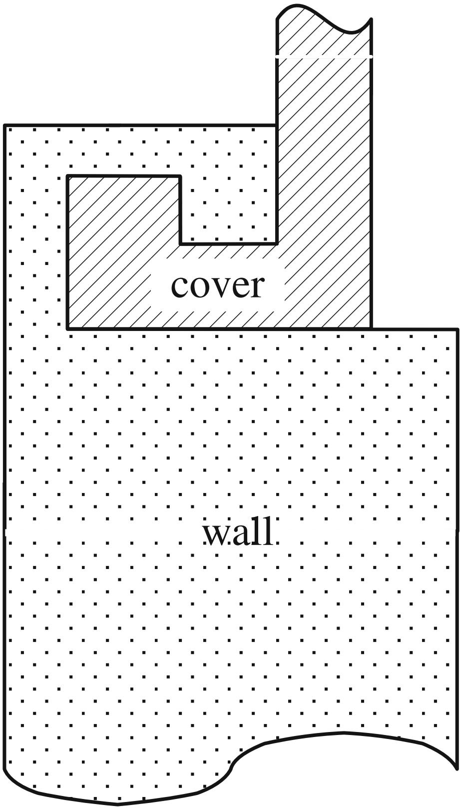

Fig. 10 Schematic illustration of cover and cavity wall

shown in Figs. 4 and 8. The cover is with large plastic deformation, but without breaking. An optimization constraint design between the cover and the cavity wall is provided to enhance the rotary centrifuge structure safety, as shown in Fig. 10. The improved constraint structure is like a high pressure pot, which can restrict axial and radial displacements of the cover. It will induce deformation mode of cavity wall and cover under high speed impact condition. Much more energy dissipation is realized for the improved structure. It is benefit to enhance rotary centrifuge impact guarded properties.

6 Conclusions

According to the simulation results of the rotary centrifuge under different impact conditions, a number of conclusions are obtained. The rotary centrifuge wall is strong enough to endure a 270 m/s impact in a 45° angle. The rotary centrifuge cover can endure 25 m/s impact at normal conditions. The cover suffers from large deformation and separates from the centrifuge body when the impact speed is over 50 m/s. Improving the connecting between the centrifuge cover and body is a feasible way to enhance the mechanical shock resistance of the rotary centrifuge.

Acknowledgments The authors gratefully acknowledge the funding by the National Natural Science Foundation of China under the contract No. 11302211, 51174173, 11390361 and National Basic Research Program of China (973 program) under the contract No. 2010CB832700.

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