Research on the mechanical character of calceolate LiOH sorbent in space launching condition

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Abstract. This paper researches the mechanical character of calceolate LiOH sorbent used in space station to meet the space launching condition. The performance of calceolate LiOH sorbent in space launching condition is calculated using porous elastic with modified Drucker-Prager model, as there are plenty of micro-voids in the material. And the mechanical experiment is carried out to verify the computed results. Good agreement between the computed results and the experimental observations is obtained, which shows that the mechanical character of calceolate LiOH sorbent can meet the space launching condition.

1. Introduction
The material of LiOH is wildly used in space station to reduce carbon dioxide (CO2), which plays an important role in keep the gas density of CO2. To increase the packing density and reduce the flow resistance, calceolate LiOH sorbent is developed, which is shown in Figure 1.

Compared with LiOH granular materials, the strength limit of calceolate LiOH sorbent is relative low. Once the calceolate LiOH sorbent breaks up into fragments in space launching condition, the flow resistance of the reactor will drastically increase, which will drastically influence the performance of the reactor, so increase the strength limit of calceolate LiOH sorbent is necessary. On the other hand, excessively high strength limit can decrease the CO2 sorbing rate of LiOH. So how to verify the strength limit of calceolate LiOH sorbent with acceptable sorbing rate must be solved. In this paper, the method of numerical simulation and experiment are used.

2. Internal configuration
The manufacturing procedure of calceolate LiOH sorbent is as follows: (1) LiOH powder is extruded by custom-built die to form discal LiOH sorbent; (2) Discal LiOH sorbent is drilled to form plenty of small holes. Inevitably, there are plenty of micro cracks at the edges and micro holes in the internal structure of calceolate LiOH sorbent. Through stereoscan photogragh, the micro cracks and micro holes are shown in Figure 1.
Because of the micro holes, calceolate LiOH sorbent should be treated as quarter-phase structure, including the solid phase of LiOH granule and gas phase of micro holes. With the increase of the amount of micro holes, the contact area between CO2 and LiOH granule increases, and the CO2 sorbing rate of LiOH increases, but the density and strength limit of calceolate LiOH sorbent decrease. So micro holes must be considered for the material model while computing the mechanical property of calceolate LiOH sorbent.

3. Numerical simulation

3.1. Material model

To calculate the mechanical property of calceolate LiOH sorbent full of micro holes, a porous elastic material model is used. It is an isotropic, nonlinear elasticity model, and the pressure stress varies as an exponential function of volumetric strain, which takes void rate into consideration. The material model is as follows:

\[
\frac{k}{(1+e_0)} \ln\left(\frac{P_0 + p_{el}^0}{p + p_{el}^0}\right) = J^{el} - 1
\]

Where \(e\) is void rate, \(P\) is the equivalent pressure stress, \(p_{el}^0\) is the elastic tensile strength, \(J^{el}\) is elastic volume change, \(k\) is the logarithmic bulk modulus. The relation between the deviatoric stress \(s\) and the deviatoric part of the total elastic strain \(e^{el}\) is as follows:

\[
s = 2Ge^{el}
\]

Where \(G\) is shear modulus. To describe the plastic mechanical property of alveolate LiOH sorbent, the modified Drucker-Prager/Cap plasticity/creep model is used.

3.2. Boundary condition

The vibration conditions in space launching are shown in Table 1 and Table 2:

| Table 1. Sine sweep vibration condition |
|----------------------------------------|
| Frequency/Hz | Acceleration/g | Loading scan rate/oct/min |
| 10-90        | 1.5-3.0        | 0.8                       |
| Loading direction | Three axial direction |
Table 2. Random vibration condition

| Frequency /Hz | Power spectral density /g^2/Hz |
|---------------|--------------------------------|
| 10-90         | 0.02                          |
| 90-190        | 0.02-0.05                     |
| 190-490       | 0.05                          |
| 490-1990      | 0.05-0.025                    |

Loading time 90s

Loading direction Three axial direction

Statics loading method is used. For sine sweep vibration, the maximum load 2.5g is used. For random vibration, the total mean square root must be computed because the vibration condition is provided as power spectral density. According to the 3σ law, the peak statics load can overburden with 99.865% load.

The power spectral density curve of random vibration condition is shown in Figure 2, including two plane curves, one upward curve and one descending curve. The total mean square root is calculated as follows:

\[
G_{max} = \sqrt{A1 + A2 + A3 + A4}
\]  

\[
A1 = PSD1 \times (f1 - f0)
\]  

\[
A2 = \frac{PSD2 \times f2}{m2^2} \left[1 - \left(\frac{f1}{f2}\right)^{\frac{m2^2}{3} + 1}\right]
\]

\[
A3 = PSD3 \times (f3 - f2)
\]

\[
A4 = \frac{PSD3 \times f3}{m4^2} \left[1 - \left(\frac{f3}{f4}\right)^{\frac{m4^2}{3} + 1}\right]
\]

With Eq. (3) ~ Eq. (7), the total mean square root is 8.37g.

Figure 2. The power spectral density curve of random vibration condition
3.3. Simulation results

The mechanical property of calceolate LiOH sorbent in space launching condition is calculated using finite element method. The parameters of calceolate LiOH sorbent are shown in Table 3. 3D continuum element with 8 nodes is used, and element number is 34750. A porous elastic material model is used, and the load type is sine sweep vibration and random vibration. 6 blocks of calceolate LiOH sorbent are connected in one chemical reactor. The simulation results are shown in Figure 3.

| Table 3. The parameter of calceolate LiOH sorbent |
|-----------------------------------------------|
| Parameter                   | Value       |
| diameter                    | 110mm       |
| height                      | 30mm        |
| hole number                 | 290         |
| the diameter of hole        | 3.0mm       |
| Density                     | 0.80g/cm3   |

From the simulation results, we can see that the computing maximum stress in axial direction is 0.43MPa, less than the strength limit in axial direction; and the computing maximum stress in radial direction is 0.11MPa, less than the strength limit in radial direction. The simulation results show that: the strength limit of the developed calceolate LiOH sorbent can meet with the vibration in space launching condition.

4. Experiment

To verify the simulation results, a series of mechanical experiment is carried out in a container (containing 6 blocks of calceolate LiOH sorbent) using the vibration condition in Table 3 and Table 4. Before and after the vibration experiments, the flow resistance and outlet purity of the chemical reactor are tested. The experimental results are shown in Figure 4.
Before

After

Figure 4. The image of calceolate LiOH sorbent before and after vibration experiment

From the experimental results, we can see that 6 blocks of calceolate LiOH sorbent keep in good condition after vibration experiments, showing that there is no LiOH fragment. The experimental results show that: (1) the simulation method of calceolate LiOH sorbent in space launching vibration condition is feasible; (2) the strength limit of the developed calceolate LiOH sorbent can meet with the vibration in space launching condition.

5. Conclusion
In this paper, the mechanical property of calceolate LiOH sorbent in vibration spacing launching condition is calculated with finite element method, and a porous elastic material model is used. To verify the simulation result, a series of vibration experiments are carried out. The simulation and experimental results show that: the mechanical property of calceolate LiOH sorbent can meet with the vibration spacing launching condition.

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References
[1] YANG Guowei, BIAN Qiang, YU Qingni, WEI Wei. Influence of Temperature and Humidity on Absorption Efficiency of LiOH in Confined Space. Manned Spaceflight. Vol.18 No.5. 14 - 17. 2012.09.
[2] Zheng Zhiguo, Wang Yufeng. Introduction of Parameters in Random Vibration and their Calculation. Electronic Product Reliability and Environment Testing. Vol.27 No.6 Dec.2009. 45 - 48.
[3] An Changnuan. Parameters Estimation before the Random Vibration Experiment. Electro-Optic Technology Application. Vol.24, No.4. August. 2009. 44 - 46.
[4] Ma Aijun, Liu Hongying, Dong Rui, Feng Xuemei, Zhu Jingtao. Vibration environmental test conditions in fixture dynamic characteristic design. Spacecraft Environment Engineering. Vol.30, No.1. 2013. 2. 78 - 81.
[5] Tian Guangming, Chen Guangju. Time-Frequency Analysis of the Response in A Sine-Sweep Vibration Test. Journal of Vibration and Shock. Vol.24 No.6. 2005. 13 - 17.