Application of Energy Absorption Diagram of Honeycomb Paperboards on Packaging Design[1]

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Abstract: Illustrations are used to describe the application methods of energy absorption diagrams of honeycomb paperboards on the structure optimization and material selection. Energy absorption diagrams are more convenient and universal than traditional stress-strain curves and max acceleration and static-stress curves. The structure optimizing design can be carried out by energy absorption diagrams of honeycomb absorption diagrams with no more experiments.

Keywords: Honeycomb paperboards; Energy absorption diagram; Packaging design

1. Introduction

Honeycomb paperboards are used to make boxes, pallets or cushioning pads for packaging. Due to its different purpose, their optimizing design and selecting materials are different. Honeycomb paperboards used to make box or pallet have not only good resist-bending strength, but also a little resist-compression strength. It optimizing design and selecting material can be referred on document [1]. At present, the design and selecting material mainly depend on the experience of the honeycomb paperboard provider. There is no systemic method of optimizing design and selecting material. The present research is focus on the cushioning properties [2-7]. How to optimize the honeycomb structure, select the honeycomb material and improve the packaging efficiency is the matter of concern between user and maker of honeycomb paperboards.

The design and select of cushioning materials for packaging mainly include two parts. The one is selecting the best materials from the spare materials for the certain application. The other is how to optimize to select the structure, density and thickness of material to realize the max of packaging efficiency. The common method for evaluating cushioning properties such as stress-stain curve, peak acceleration and static compression stress curve can be used to the given material. If optimizing select, it must experiment the cushioning properties of all possible materials and optimize to select from them. In fact, it is impossible to make any possible material and experiment it. It must cost a lot of human resource and material resource. The cushioning properties of honeycomb paperboards are effected by the strain ratio. For anyone material, it wants to experiment its cushioning properties in different strain ratio. It is difficult to optimize design and select material by common stress-strain ratio. Whereas the two type of curves can be referred when optimizing design of honeycomb paperboards. It can not be used to optimize and select the basis paper of honeycomb. The energy absorption figure can be used to resolve the problem [8]. Document [9] researches a new characteristic method, energy absorption figure. It combines static-dynamic compression experiment and physical model and construct energy absorption figure (shown in Fig.1). The aim of this paper is to explore how to use the convenient and universal energy absorption figure into the optimizing design and selecting material of honeycomb paperboards and improve the packaging efficiency.

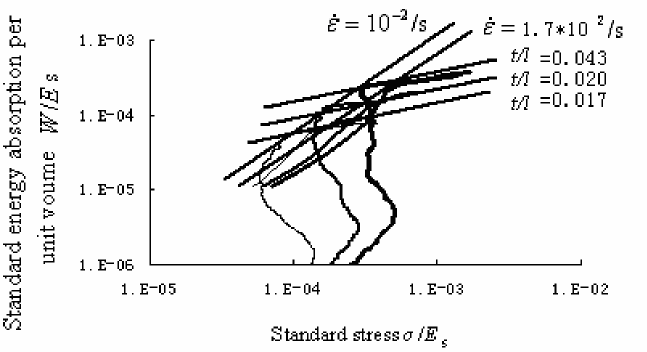

Fig.1 Energy absorption diagrams of honeycomb paperboards

For the honeycomb paperboard given the basis material and thickness-to-length ratio, if known the cushioning strain ratio, the best plateau stress σ_p/E_s and energy absorption per unit volume W/E_s can be sure. According to the contact area A between the honeycomb paperboard and protected product, the peak stress （$F=\sigma_p A$） and honeycomb thickness t can be calculated to absorb the dynamic energy U during logistics process. In fact, the energy absorption figure of Fig.1 have more application, for example, if given cushioning demand and basis paper of honeycomb paperboards, the best

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thickness-to-length ratio and the thickness of honeycomb paperboards can be sure; if given the thickness-to-length ratio, the thickness of honeycomb paperboards and cushioning demand, the elastic modulus of basis paper can be sure.

2. Optimizing structure of honeycomb paperboards for cushioning application

Structure optimizing of honeycomb paperboards mainly design the best thickness of the best thickness-to-length of paper honeycomb core (Due to the face-sheet thickness of honeycomb paperboards commonly far less than the thickness of paper honeycomb core, the thickness of paper honeycomb core can be looked as the thickness of honeycomb paperboards).

Illustration 1: Given the quality m=10kg of packaged product, the contact area A=0.01m^2 between the package material and the packaged product, the drop height of packaged product h=0.5m, the fragility of the packaged product G=30g, the solid modulus of the basis paper E_s=0.87GPa, a new optimizing design method of thickness-to-length of paper honeycomb cell-wall and the thickness of honeycomb paperboard is introduced.

According to the drop height h=0.5m, the max drop speed v = 3.2m/s, the drop energy absorption $U = mv^2/2$ = 51.2J, due to the fragility of packaged product G = 30, the max peak stress $\sigma_p = F/A$ = 300KN/m^2, according to the solid modulus of basis paper Es = 0.87GPa, the max peak stress is calculated σ_p/E_s = 3.4*10^{-4}. Referring to the Fig.1, the structure optimizing design method is shown as follow:

1) A vertical line corresponding the peak stress σ_p/E_s is drawn in Fig.2 energy absorption figure;

2) Given a appropriate thickness t_1 of honeycomb paperboards, the strain ratio $\dot{\varepsilon}_1$ can be calculated

$$\dot{\varepsilon}_1 = \frac{v}{t_1} = \frac{(\frac{2U}{m})^{1/2}}{t_1} \qquad (1)$$

3) The interpolation method is used to find out the strain ratio $\dot{\varepsilon}_1$ line. The line is intersected by the stress line drawn in (1). The log (W/E_s) value can be sure from the intersect point. The energy absorption W per unit volume can be calculated by the solid modulus E_s of basis paper.

4) According to the W value, given energy absorption U and the contact area A between the packaged product and the honeycomb paperboard, the new thickness t_2 of honeycomb paperboard can be calculated.

5) According to the thickness t_2 in (4), the new strain ratio $\dot{\varepsilon}_2$ can be calculated by referring to (2) method. The new coordinate point(log(W/E_s), W) is sure, and then the new thickness t_3 is found by referring to (4) method.

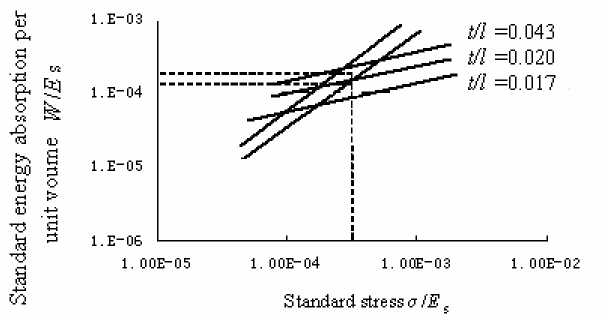

Fig.2 Application of energy absorption diagrams on the optimizing design of honeycomb structures

Repeatedly the above step, until the calculated thickness value converges to the certain one. The value is the best thickness. According to the intersect point between the strain ratio line and stress line and the thickness-to-length families of parallel lines in the figure of energy absorption, the best thickness-to-length of paper honeycomb core can be found. The above detailed iterative process is shown as:

The first iterative process

The first selection of t_1 50mm

The strain ratio $\dot{\varepsilon}_1$ 63.2/s

The corresponding W/E_s to σ_p/E_s=3.4*10^{-4} 7.5*10^{-4}

The energy absorption per unit volume W 6.25*10^{5}J/m^3

The second iterative process

t_2 Calculated by U=WAt 8.24mm

Modified $\dot{\varepsilon}_2$ 383/s

Modified W 5.92*10^{5}J/m^3

The third iterative process

t_3 Calculated by U=WAt 8.65mm

The best thickness-to-length t/l less than 0.020

The thickness of honeycomb paperboards converges to 8.65mm by 3 iterative processes. It can be selected 10mm. The corresponding best thickness-to-length t/l is 0.020.

3. Inclusion

Energy absorption figure is more popular and universal than the traditional stress-strain curve and peak acceleration-stress curve. The optimizing the structure of honeycomb paperboards and selecting the basis paper can be realized by energy absorption figure without much experiment. The optimizing design of the honeycomb paperboard structure can be finished with the iterative process into a final convergence by a little computer program. To be regret, due to the complexity of the effect of temperature and humidity on the paper material, the effect of the temperature and humidity on the paper material is not added into the energy absorption figure, which is the direction to research.

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