Study on Crash Characteristics of Uneven Cylindrical Structure by Using Origami Engineering

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Abstract

In this paper, from the prospect of application to origami-engineering, authors tried to develop the crashworthiness maximization of tubular structures by a new proposed uneven cylindrical structure. An optimization system of the uneven cylindrical structure is developed to obtain the objective of absorbing the crash energy as much as possible with four design parameters as the number of divisional sections along axis; the edge number of polygonal cross section; inset concave value and outset convex value. The explicit FEM software LS-DYNA is adopted for simulating complicated crashing behaviour. As the result, the optimal tube with uneven structure is capable of absorbing 2 times more energy than the original square tube structure at the same mass.

Keywords - Optimal Design, Origami Engineering, Crash Characteristics, Uneven Cylindrical Structure, FEM

1 Introduction

During car frontal crash, previous researches have indicated that the front side member plays a major role in the energy absorption. For protecting the passengers, the front side member is expected to absorb crash energy as much as possible.

On the other hand, origami engineering is the scientific study of the techniques of origami, a traditional Japanese craft, and the attempt to apply the craft to engineering problems [1]. From the prospect of application to origami-engineering, we direct our attention to uneven cylindrical structure by using origami engineering as front side member instead of the square tube structure which is generally used [2, 3].

In this paper, we simulate complicated crashing behaviours of uneven cylindrical structure by utilizing multi-purpose dynamic analysis software LS-DYNA. We also optimize design of uneven cylindrical structure to seek the crash energy as much as possible and maintain the structure weight at the same mass with the original square tube structure by using the optimization method of response surface methodology.

2 Uneven cylindrical structure setting and automatically crash analysis system

Fig.1 shows the feature of setting base of uneven cylindrical structure. As shown in Fig.1 (a), two n-regular polygon of different length are arranged in parallel with an interval of h. \( l + \phi \) is the length of up n-regular polygon, \( l - \phi \) is the length of bottom n-regular polygon. The indent and convex \( \eta \) are used into these two n-regular polygon respectively to get 2n-regular polygon (Fig.1 (b)), and then the corresponding nodes are connected to build the basic shape of cylindrical structure (Fig.1(c)). Finally, the base structure of uneven cylindrical structure (Fig.1 (d)) is created by using the bottom n-regular polygon as the mirror surface and copying the basic shape of cylindrical structure along the axis direction.

An automatically crash analysis system is developed to generate analysis mesh data automatically from the parameter \((n, h, \phi, \eta, m)\) of uneven cylindrical structure according to the following procedure as shown in Fig.2. \( n \) is the edge number of polygon cross section; \( h \) is interval between the two regular polygon of basic shape; \( \phi \) is the change value of length of regular polygon; \( \eta \) is the uneven value; \( m \) is the number of divisional sections along axis.

Fig.1 Setting base of uneven cylindrical structure

Fig.2 Process of uneven cylindrical structure
3 Study on structure of maximum crash energy

In order to optimize the front side structure considering the crash energy absorption, it is necessary to calculate the crash energy of crash, and to do optimization analysis of structure based on the crash simulation. We develop an optimization system of the uneven cylindrical structure, in which the objective function is to maximize the energy absorption; the design variables are number of edges of polygonal cross section, number of divisional sections along axis, change value of length of regular polygon and uneven value; mass of optimal structure must be less than the structure with box-shaped cross section.

3.1 Analysis method of crash

We build the crash analysis model as shown in Fig.3, where the model structure impacts the rigid wall with the initial speed of 54km/h and the analysis time is 2.2 msec.

![Image of crash simulation](image)

Here, the material characteristics of model structure is defined by *MAT_PIECEWISE_LINEAR_PLASTICITY command in LS-DYNA. The value of material characteristics is shown as follows:

- Mass density: $7.89 \times 10^{-6} \text{ kg/mm}^3$
- Yield stress: 270 Mpa
- Young’s modulus: 210 Gpa
- Poisson’s ratio: 0.3

3.2 Optimized result

We get the optimized result by using response surface method [4] to analyze the optimization. We build the uneven cylindrical structure with this optimized result, and then do confirmation analysis using LS-DYNA. Table 1 shows the comparison results of square tube structure, optimal RSC structure [5] and optimal uneven cylindrical structure. Fig.4 shows the absorbed energy-displacement curves of threes comparison structure and Fig.5 shows the react force-displacement curves of threes comparison structure.

![Absorbed energy-Displacement curves](image)

![React force-Displacement curves](image)

**Table 1 Comparison results**

<table>
<thead>
<tr>
<th>[n,m, ϑ,η,θ : NS]</th>
<th>Mass [kg]</th>
<th>Absorb Energy [*10^6Nmm]</th>
<th>Ratio by original</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square tube structure</td>
<td>4,0,0,0,0</td>
<td>0.53</td>
<td>6.18</td>
</tr>
<tr>
<td>Optimal RSC structure</td>
<td>5,4,0,0,0,1</td>
<td>0.53</td>
<td>8.47</td>
</tr>
<tr>
<td>Optimal UC structure</td>
<td>8,1,0,8,0,0</td>
<td>0.53</td>
<td>12.39</td>
</tr>
</tbody>
</table>

4 Conclusion

In order to improve the absorb crash energy as much as possible, we designed the uneven cylindrical structure from origami-engineering. The response surface method is used to optimize the uneven cylindrical structure.

(1) According to the optimization result, the optimal tube with uneven structure is capable of absorbing 2 times more energy than the original square tube structure at the same mass.

(2) From the analysis results, it is made clear that, number of divisional sections along axis and uneven value are useful for absorbing crash energy.

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References


