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Research on Electric Vehicle Battery Box Lightweight Based on Material Replacement

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Abstract: Battery box light weighting and stiffness are two important objectives of battery design and improvement. In order to reduce a battery box's weight without impairment of stiffness, a method of box parts' material replacement from mild steel sheet to Aluminium alloy steel sheet of changed depth is brought forward. The thickness change equation is drawn from structural mechanical analysis and verified by finite element simulation of body parts. After the material replacement, the displacement nephogram and stress nephogram is obtained through the finite element analysis of the battery box and there is no obvious difference between them show that the method presented in this paper is valid.

Keywords: battery box, Aluminium alloy, lightweighting, materialreplacement, stiffness

1. Introduction

With the rapid development of the global economy and society, energy depletion, environmental pollution, the study of new energy vehicles has become the focus of automotive industry[1].It is the international consensus of realizing automobile power electrification and developing electric vehicles. Battery box assembly occupies an important position in the structure of new energy vehicles[2].

At present, the single battery energy density is relatively small, in order to achieve sufficient mileage and power performance, the quantities of battery are large, cause the battery box assembly is overweight, which affects the speed and mileage of the electric vehicle performance. Furthermore, the battery box assembly accounts for 25%-30% of the total weight of the car, consumes a large amount of battery energy, so reducing the weight of the battery box has become the urgent task of the development of new energy vehicles. The battery box structure was optimized , improve and optimize the local structure of the battery box, thus improving the stress concentration on the local structure, the structure strength of the battery box has been improved, it is researched by Dong Xianglong[3].Hartmann[4]use finite element software optimizing the battery box's structure , the natural frequency of the battery box is improved, the battery box wall thickness is reduced, the weight of the battery box is reduced by 20% on the basis of the original structures. Although these scholars optimized the structure of the electric vehicle, and reduced the weight of the metal battery box successfully, but still can not change the fact that the battery box is too heavy.

The battery box lightweighting can be achieved by structure modification or material replacement. The battery box structure modification requires the changes of forming, welding and assembling systems which is costly, while material replacement needs fewer such changes. Furthermore, material replacement is generally more effective in automobile lightweighting than structure modification. Therefore, only the battery box

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lightweighting by material replacement is studied in this paper. In order to reduce the battery box weight, aluminum alloy, high strength steel, composite material, and so on, are widely used as lightweighting materials to replace the traditional material of mild steel, In these materials, aluminum alloy is a very good representative. Only the box lightweight by material replacement is studied in this paper.

This paper will study the aluminum alloy sheet depth determination method with a battery box as an example, displacement nephogram and stress nephogram are obtained through the finite element analysis and comparison.

2. Battery box case thickness analysis

2.1 Thickness selection of the same stiffness

If the elastic modulus of a material is less than that of steel, it is necessary to take into account that the structure of the material will produce greater deformation in the design of the bearing, it is important to pay attention to this point when using aluminum alloy to replace the steel. Battery box is mainly used to withstand the weight of the battery, the bearing structure need to meet the deformation conditions. the elastic modulus of aluminum is only 1/3 of the elastic modulus of steel due to the deformation is 3 times than that of steel. A single load analysis in the center is used to investigate the deflection of a plate [5].

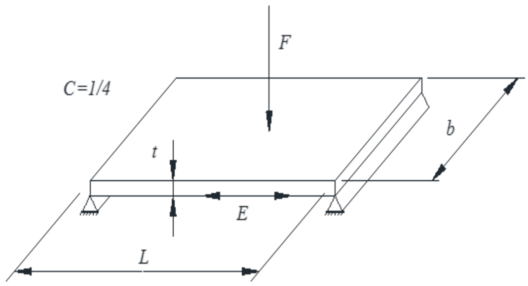


Fig.1. Deflection of a plate

The plate shown in Fig. 1 has a length of L, width of b and depth of t, the original material is mild steel withthe elastic modulus of E, receive load F function on the plate.

As shown in Fig.1, the deflection at the center is

$$w_{\max} = C \bullet \frac{F \bullet L^3}{E \bullet t^3 \bullet b} \quad (1)$$

Among the equation, C is a constant, which takes into account the constraint condition, and F is the load. When the material is replaced, the stiffness should remain the same, so that the deflection should be kept constant.

Before the material is replaced, the bent of the center of the plate is:

$$w_{\max} = C \bullet \frac{F \bullet L^3}{E_{St} \bullet t_{St}{}^3 \bullet b} \quad (2)$$

After the mild steel sheet material is replaced by Aluminium alloy sheet of depth t_{Al} and elastic modulus E_{Al}, with other geometric conditions unchanged, we have:

$$w_{\max} = C \bullet \frac{F \bullet L^3}{E_{Al} \bullet t_{Al}{}^3 \bullet b} \quad (3)$$

In order to maintain the deflection to be the same, we have:

$$E_{Al} \bullet t_{Al}{}^{3} = E_{St} \bullet t_{St}{}^{3} \quad (4)$$

Therefore, the depth of the aluminum plate should be:

$$t_{Al} = \sqrt[3]{\frac{E_{St}}{E_{Al}}} \bullet t_{St} \quad (5)$$

it is often the ideal case in the above material analysis, material may fail under certain strain and most materials have strain rate effect of different magnitude, in order to ensure the validity of Eq.(5), one coefficient α is needed, then we obtain:

$$t_{Al} = \alpha \sqrt[3]{\frac{E_{St}}{E_{Al}}} \bullet t_{St} \quad (6)$$

The coefficient αis equal to approximately 1, itsvalue is correlative with the similarity of strain–stress, relations of mild steel and Aluminum alloy and thereal parts' deformation. Thecoefficient αgoes up withthe increase of materials' failure strain, failure stress andstrain rate sensitivity. The coefficient αmay take thevalue of 1 where no high precision is required.

2.2 Thickness selection of the same stability

For the parameter selection of instability, the stiffness plays a major role in the original design as before.

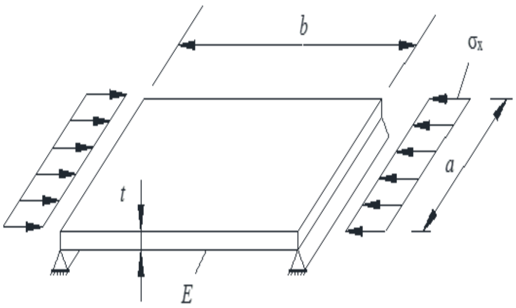


Fig.2 Plate heave

The plate shown in Fig. 2 has a length of b, width of a and depth of t, the original material is mild steel withthe elastic modulus of E, material strength is σ_x。

In the case of a plate subjected to compressive stress, a bulge will occur in the center plane beyond a certain critical stress, which can be calculated as follows:

$$\sigma_x \le \sigma_B = k \bullet \frac{E \bullet t^2}{a^2} \quad (7)$$

Here, K is the bump value associated with the actual situation, the geometric size and stress load is taking into account.

For rectangular fields, the value of the bump value is:

$$k = \left(\frac{1}{\delta} + \delta\right)^2 \quad (8)$$

among the equation, δ=a/b.

before the replacement material, the strength of the steel plate is:

$$\sigma_x \le \sigma_B = k \bullet \frac{E_{St} \bullet t_{St}^{\ 2}}{a^2} \quad (9)$$

After the mild steel sheet material is replaced by Aluminium alloy sheet of depth t_{Al} and elastic modulus E_{Al}, with other geometric conditions unchanged, we have:

$$\sigma_x \le \sigma_B = k \bullet \frac{E_{Al} \bullet t_{Al}^{\ 2}}{a^2} \quad (10)$$

In order to maintain the uplift strength to be the same ,the depth of the aluminum plate should be:

$$t_{Al} = \sqrt{\frac{E_{St}}{E_{Al}}} \bullet t_{St} \quad (11)$$

In a similar way, in view of the inaccuracy of material model ,the above equation maybe revised as:

$$t_{Al} = \beta \sqrt{\frac{E_{St}}{E_{Al}}} \bullet t_{St} \quad (12)$$

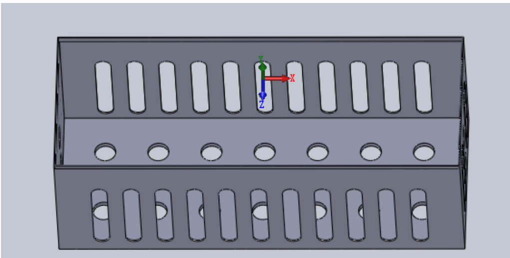
The coefficient β is also equal to approximately 1like the coefficient α in Eq. (6). Thecoefficient βmaytake the value of 1 where no high precision is required.

Box body parts are mostly thin sheet stamping. The above analysis can be used todetermine body partsheet depth after material replacement without a large error.If each part of Aluminum alloy steel has the same strength ofthe part of mild steel sheet, under the restriction ofneighboring parts, the deformation mode and bulge of each part of Aluminum alloysheet is nearly the samewith that of mild steel. Therefore, for body parts whichmay have deformation under bending moment or plasticstretch under tension, the above analysis is applicablefor lightweighting analysis.

Because αand βare close to 1, the estimation of thickness of sheet as in Eq. (6) is less thanthat in Eq. (12). Therefore, the thickness of sheet determined by Eq. (12) could meet the demandof stiffness requirements for both cases.

3. Three dimensional modeling of battery box

According to the lightweight design of the battery box of a pure electric vehicle, this paper designs the inner box and the outer box to make the battery box can be replaced quickly, the design of the battery box is placed in the trunk under the 6-QW-45 containing 6 monomer VARTA battery, the size of battery is 250 * 140 * 250mm, Because the battery box is used to bear the weight of the batteries, so we study the inner box, other parts are similar to the study. As shown in Figure 3 is the innerbox.



Fig,3. Inner box

4. Inner box finite element comparative analysis

Using HyperWorks to do finite element analysis[6], In the case of using the shell element to divide the mesh, the inner shell is divided into two parts: the geometric cleaning, the small size structure, such as the corner and the hole. Ventilation and heat dissipation is in consideration in the initial design, design ventilation holes and the fence are designed, so the lightweight design of battery is the optimization of wall thickness, consistent with the allowable stress range of wall thickness, and the appropriate optimization in box structure, to reduce the concentration of stress.

The distribution of load force imposed on the box bottom and the side wall, four angular contact constraints within the box and the external box. The inner box bears the weight of the battery and the weight of itself. The initial material is ordinary steel plate, the plate thickness is 3mm, the grid size is 2mm, after material replacement, the thickness of the aluminum plate should be:

$$t_{Al} = \beta\sqrt{\frac{E_{St}}{E_{Al}}} \bullet t_{St} = 3.46\text{mm} \quad (13)$$

E_{St}=210000MPa, E_{Al}=70000MPa.

Among the equation,β is defined as 1,.As the aluminum plate is a certain size, so the thickness of the aluminum plate rounded to 3mm.

There are three kinds of special conditions in the battery box:

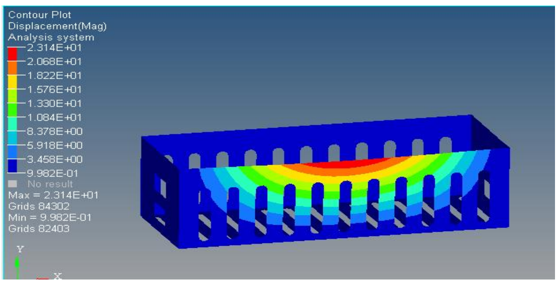
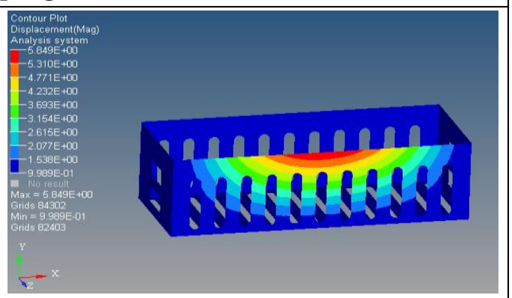
（1）Full load brake, the force is 2408.84N, on the long side plate;

（2）Full turn, under the force of 963.54N, the role of the short side version;

（3）Bump conditions, the force of 4817.68N, the role of the floor.

Build the finite element model andsetup the boundary conditions and initial conditions. Forthe material of mild steel and Aluminum alloy steel, the displacement nephogram and stress nephogram are analyzed..The yield stress of steel is not less than 355MPa and the yield stress of aluminum alloy is 180-250MPa.

1、Full load brake

<table>
<tr><th colspan="2">Displacement nephogram</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">maximum displacement</td></tr>
<tr><td>13.1mm</td><td>9.8mm</td></tr>
<tr><td>a</td><td>b</td></tr>
<tr><th colspan="2">Stress nephogram</th></tr>
</table>

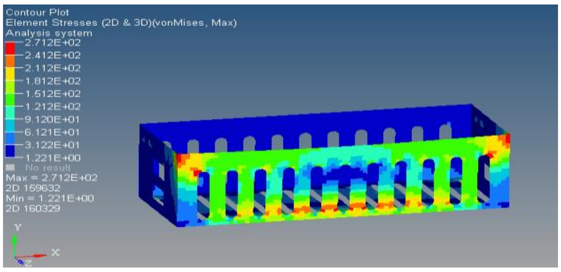
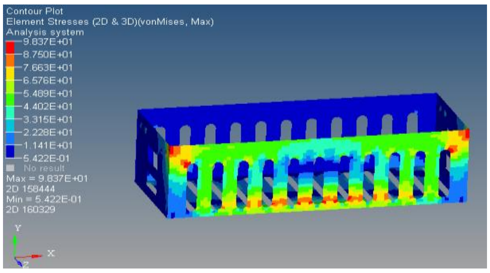
<table>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Maximum stress</td></tr>
<tr><td>171.2mpa</td><td>138.3mpa</td></tr>
<tr><td>a</td><td>b</td></tr>
</table>

Fig.4 Displacement nephogram and Stress nephogram in full load brake condition:(a) mild steel;(b) aluminum alloy

The results show that the maximum displacement and the maximum stress are reduced, and both are within the allowable range.

2、Full turn

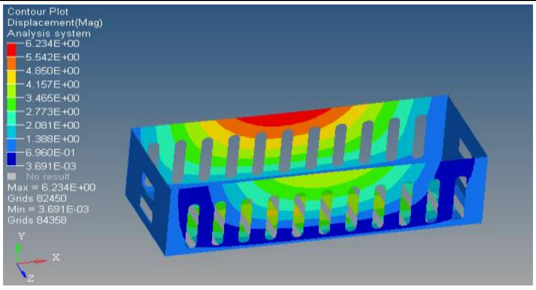
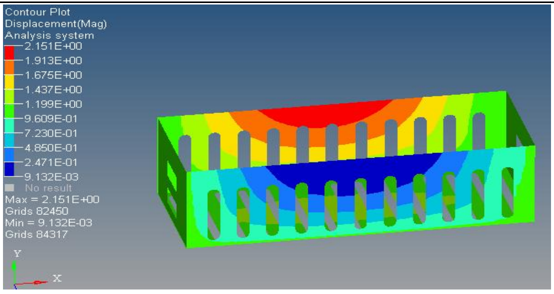
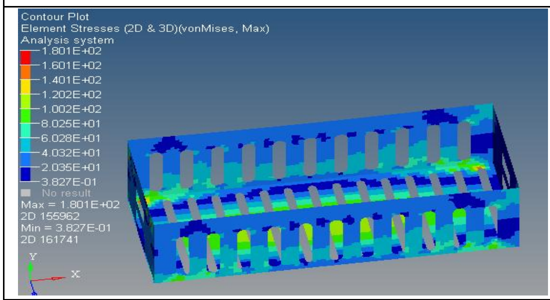
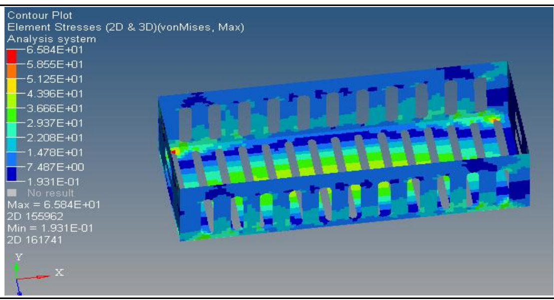
<table>
<tr><td colspan="2">Displacement nephogram</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">maximum displacement</td></tr>
<tr><td>6.23mm,</td><td>2.15mm</td></tr>
<tr><td>a</td><td>b</td></tr>
<tr><td colspan="2">Stress nephogram</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Maximum stress</td></tr>
<tr><td>180.1mpa</td><td>65.8mpa</td></tr>
<tr><td>a</td><td>b</td></tr>
</table>

Fig.5 Displacement nephogram and Stress nephogram in full turn condition :(a) mild steel ;(b) aluminum alloy.

The results show that the maximum displacement and the maximum stress are both decreased in the allowable stress range, and the maximum stress occurs only at a few points, which may be due to improper constraints.

3、Bump condition

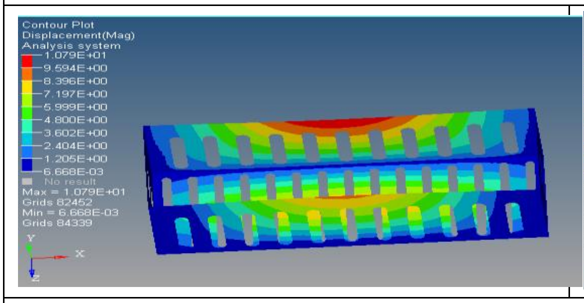
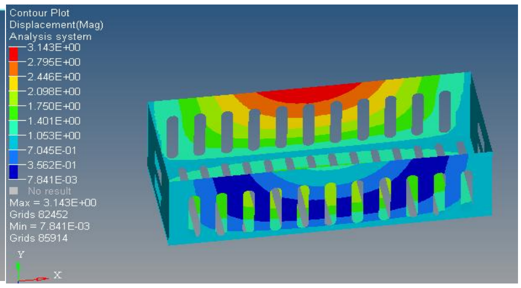
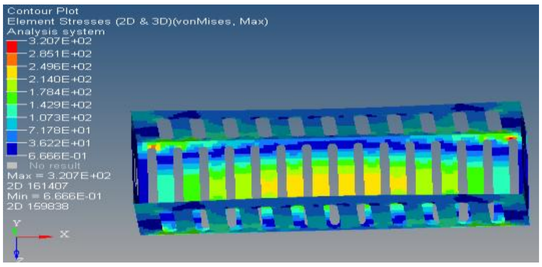
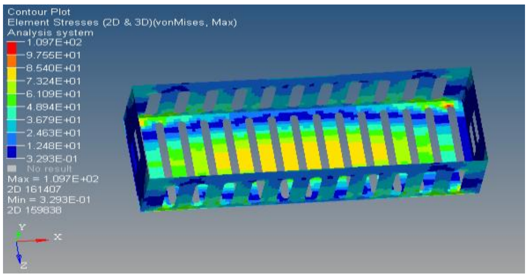
Displacement nephogram	
	
maximum displacement	
10.7mm	3.14mm
a	b
Stress nephogram	
	
Maximum stress	
320.7mpa	109.7mpa
a	b

Fig.6 Displacement nephogram and Stress nephogram in bump condition :(a) mild steel ;(b) aluminum alloy

The results show that the maximum displacement and the maximum stress are decreased, and the maximum stress occurs only at a few points, which may be due to improper constraints.

It can be seen that the difference between the displacement and the stress is relatively small when the material is replaced.

By use of Aluminum alloy sheet, thebody weight is reduced. The weight reduction ratio ofthe parts after material replacement is:

$$\frac{G_{Al}}{G_{St}} \approx \frac{\rho_{Al}}{\rho_{St}} \bullet \frac{t_{Al}}{t_{St}} = 0.5 \quad (14)$$

ρ_{St}=7.85g/cm^3, ρ_{Al}=2.7g/cm^3, t_{Al}=3mm, t_{St}=2mm.

The total weight of the parts for material replacementis 35kg, then the reduced weight is 17.5kg. Through the use of Aluminum alloy sheet, the bodyweight is reduced by 17.5 kg withoutimpairment of the stiffness of the battery inner box. Therefore, the method broughtforward in this paper for determining the depth of Aluminum alloysheet for replacement of the mild steelsheet for automobile body lightweighting is applicable.

5. Conclusions

(1)This paper brings forward the method of box body parts lightweighting using Aluminum alloy steel sheetof different depth to replace the original design of mild steelsheet based on strength analysis. (2)The finite element analysis of the inner and outer box shows the effectiveness of the method. The results show thatthe box body weight is reduced while its stiffness is not reduced, the weight reduction ratio of the part after material replacement is 50%， which means that the methodof box body lightweighting by Aluminum alloy sheet brought forward in this paper is applicable.

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