Analysis of Sandwich Structures by the FEM

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Abstract The use of sandwich structures is increasing rapidly. This paper is aimed on mechanical properties of sandwich structured composites and their usage in technical practice. The main contribution in paper is realized static analysis of simple sandwiches composed from various materials of core and face sheets. Final results of analysis were fields of data about maximum stresses, displacement fields of structural points of sandwich composite.

Keywords: stress, sandwich structures, face sheet


1. Introduction

The improvement of science and technology gives ability to meet the increasing needs of company. The result of such improvement is high amount of demand of products which have to meet a lot of contradictory conditions. At these days, one of the biggest issue for every constructor is to meet the condition of high strength with the minimum weight of structure. However, there has been elegant solution of sandwich structure offered to use it in this area.

Multilayer structures have been used by industries, mostly in areas where reduction of weight or reinforcement of the structure is required, or in areas where any other needs which are provided by convention materials are needed. Mostly, it is used by the air and space applications, and of course, in the rail and road transport industry. In some specific cases we can use it for the sport sector, like construction of skis and snowboards. For example, the foam materials are required for manufacture of rims for bicycles to reduce a weight and improve of side stiffness of the bicycle. Also the honeycomb core can be used to reduce a vibration of bicycle case [1].

2. Multilayer Structures

Sandwich structures created from the various materials are mutually connected in way of use advantage of individual components. Such type of structure is a special type of multilayer composite structure [2,3].

Sandwich structures are consisted of two thin outer layers (face sheet) which are very solid and stiff and also connected to a light and flexible core. The core has significantly higher height than face sheets. (Find Figure 1)

The adhesive layer which connects bottom plates and its located between the face sheet and the structural core is created from the suitable adhesive material or it is just a part of the face sheet of existing outer layer. Such type of interlayer is very important for the functionality of the whole multilayer structure. The comparison between the multilayer structure and thin-walled structure is the main advantage of sandwich multilayer structure. When it comes about the bending stiffness and weight ratio, sandwich structure is definitely better option. Multilayer of sandwich structures is mostly consisted of one core and two face sheets with the same material, the same thickness and fiber orientation. However, there are some cases when the face sheets are not created from the same material as core and also the fiber orientation or the layers are different. This type of solution can be used when the load only from one side of the structure is required [4,5,6,7].

Figure 1. Basic schematic view of sandwich structure [2]

Figure 2. Similarity of “I” profile and the multilayer sandwich structure [8]
Sandwich multilayer structures are very similar to a beam profile “I” (Figure 2). The bending center is a place where the huge amount of mass material is concentrated and it is located further from the neutral axis. Such type of cross section effectively uses this among of mass material to transfer bending and planar strength in the same way like face sheets. The less amount of mass between the flanges “I” profile creates a connection. This is the way how to spare a weight of components of multilayer sandwich structure [1,3].

The transfer of tensile load and pressure to the face sheet and shear stress which occurs between the face sheets and is transmitted by the core (Figure 3) is the main feature of multilayer structure. From this reason it is necessary to take account the shear strength of the core of multilayer structure [6].

![Figure 3. The characteristic distribution of stress in cross-section during the loading process [8](image)](image)

The core strength of the pressure and the thickness of the face sheet and its stiffness have significant influence on the strength of the pressure in direction of the depth of the structure. The adhesive layer has to transfer the shear stress between the face sheets and the core. According the general rule, that layer has to be able to transfer the shear stress in the same size as the core of the sandwich structure is [6].

There also occurs a damage of multilayer sandwich structures at face sheet or inside the core.

The core of multilayer structure is designed according the specific parameters to gain the weight as low as possible and of course the highest possible stiffness of the structure.

There are several requirements focused on material of the core:

- high shear strength and stiffness
- the good compressive strength
- the low weight (density)
- high temperature resistance
- the water absorption resistance
- the damping capabilities
- the insulating capabilities

The core of the sandwich structures can be made from the foam, honeycomb, etc.

3. FEM Analysis of Designed Model

The FEM model was designed from one honeycomb core and two face sheets (Figure 4).

![Figure 4. FEM model of honeycomb](image)

| Table 1. The properties of used materials (the aluminium alloy and the carbon steel) |
|-----------------|-------------|-------------|----------|-------------|
| Material       | $E$ [MPa]  | $G$ [MPa]  | $\mu$ [-] | $R_e$ [MPa] |
| core            | 2.04·10^5  | 7.9·10^3   | 0.29     | 282,685     |
| outer layers    | 7.4·10^4   | 2.7·10^4   | 0.33     | 317,104     |

There were linear, elastic and also isotropic material used.

The model was fixed from the two sides and was load by the force $F = 15000$ N. The above value was determined as the most suitable value of force according the previous experiments to determine the maximum fatigue and bending (moment) of the material. We selected “a grid” with a size of 5 mm to make sure the sufficient accuracy.

![Figure 5. The cross-linked honeycomb model](image)

The standard characteristics of sandwich structure were determined by analyzes of our results.

There were parameters recorded during the calculation process as we changed the height of the core several times. The example of the static analysis of the selected core thickness $v = 20$ mm can be found at Figure 6, Figure 7.

![Figure 6. Maximal stress of honeycomb with the core height $v = 20$ mm](image)
Figure 7. The fold of the honeycomb with the core height \( v = 20 \text{ mm} \)

Addiction of the maximum stress of the structure to height of core with the constant load of the force \( F = 15000 \text{ N} \), was one of the first investigated characteristics (Figure 8). According the Figure 8, there is not any significant impact on the stress of the honeycomb when it comes about the core height. In case of the core height \( v = 5\text{ mm} \), the value of the maximum stress with the load exceeded the value of the yield stress.

In case of \( v = 10 \text{ mm} \), the value of the maximum stress decreased under the yield stress which means that structure would withstand the stress without any plastic deformation. Of course there is another decreasing of the maximum stress in place if the height of core is increased, but differences between the maximum stresses of the heights are no longer so significant.

Figure 8. Dependence of maximal stress \( \sigma_{\text{max}} \) to the core height (the aluminium alloy and the carbon steel)

Figure 9. Dependence of height of fold to core height (the aluminium alloy and the carbon steel)

A similar situation occurs during the evaluation process of fold from the height of core (Figure 9). According the curve is the most significant difference of resulting folds is between the core height 5 mm and 10 mm. In case of increasing the core height above 10 mm is the fold which is caused by the load decreased, but the tendency of the change is no longer such significant. The main advantage of honeycomb structures is flexibility of wide range materials which can be used for the core and the face sheet production. Thanks to this advantage the properties of the final product are getting close to the ideal state. There were another two examples with the changed material of the core modeled to show the difference between various types of materials. The first example shows the properties of the core created from the copper (Table 2). Figure 10 shows the dependence between the core thickness and the maximum stress.

<table>
<thead>
<tr>
<th>Material</th>
<th>E([\text{MPa}])</th>
<th>G([\text{MPa}])</th>
<th>(\mu) [-]</th>
<th>Re([\text{MPa}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>core Copper</td>
<td>1,1(10^5)</td>
<td>4,10^4</td>
<td>0,37</td>
<td>258,646</td>
</tr>
<tr>
<td>outer layers</td>
<td>1023 Carbon Steel Sheet</td>
<td>7,4(10^4)</td>
<td>2,7(10^4)</td>
<td>0,33</td>
</tr>
</tbody>
</table>

Figure 10. Dependence of maximal stress \( \sigma_{\text{max}} \) to the core height (the copper and the carbon steel)

Figure 11. Dependence of fold to core height (the copper and the carbon steel)

According the Figure 10 it is clear that core height has influence to stress at minimum values only (millimeters). There is not significant influence of the core height to stress such important at values between 10 and 20. Also, the increasing of values above 25mm have no effect at all. The dependence of the fold to core height is shown in...
Figure 11 with a similar pattern. The differences between the values of the fold at the minimum heights of the core are quite distinctly. But there is a significant degradation of core height shown in Figure 11 above the values 15mm.

The core of the third analyzed structure was made of titanium. Table 3 shows the properties of such titanium core and graph 30 shows the dependence of the maximum stress to core height. However, the dependence is very similar to a previous cases.

Table 3. The properties of used materials (the titanium and the carbon steel)

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>core</td>
<td>1.05·10^5</td>
<td>4.4·10^4</td>
<td>0.37</td>
<td>377</td>
</tr>
<tr>
<td>outer layers</td>
<td>1023 Carbon Steel Sheet</td>
<td>7.4·10^3</td>
<td>2.7·10^4</td>
<td>0.33</td>
</tr>
</tbody>
</table>

4. Conclusion

The results which were obtained by simulations give us an idea of the behavior of loaded honeycomb structures. It has been determined the core height has nonlinear impact to distribute of stress fields and shift fields of structure. The most important differences of observed values became with the core height changes below $v = 15$ mm. In case of values above $v = 15$ mm, there wasn’t any significant change of observed parameters. It just created an unwanted increase of the weight of structure.

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References