Design and Analysis of Shipping Container made of Honeycomb Sandwich Panels

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Abstract:
This paper applies to the design and simulation of a shipping container made of sandwich panels. The amount of stresses acting on the body of the container is calculated and is optimized to reduce stresses for the better design output of the structure. The design aims to produce an application to reduce the tare weight of the container in order to increase the payload. Finite Element Analysis (FEA) is performed to evaluate the strength of structures of both old and new models helps us to compare which model is better and more efficient. Complete design and analysis is performed using Autodesk Inventor.

Keywords:
Finite Element Analysis, Autodesk Inventor, Honeycomb structures, Design and Simulation.
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Notation

$A$ Area

$b$ breadth

$d$ diameter

$ft$ feet

$GPa$ giga pascal

$h$ height

$Kg$ kilogram

$kN$ Kilo newton

$KPa$ kilo pascal

$l$ length

$m$ meter

$mm$ millimetre

$MPa$ Mega pascal

$N$ newton

$Pa$ pascal

$t$ thickness
Abbreviations

CAD  Computer Aided Design
CFRP  Carbon fibre reinforced plastic
EPS  Expanded Polystyrene
FE  Finite Element
FEA  Finite Element Analysis
FEM  Finite Element Method
ISO  International Standards Organization
XPS  Extruded Polystyrene
1 Background
Honey comb structures are natural and man-made structures employed to allow the minimization of the amount of material to be used in order to decrease the weight and material cost to some extent. Its geometry vary widely but common feature of these structures is an array of hollow cells formed in between the thin walls. Cells can be columnar or hexagonal in shape but only the structure made of hexagonal sandwich panels has been employed and studied in this paper. The honeycomb shaped structure provides a material with minimal density and relatively high out of plane compression and shear properties.

2 Introduction
Application of honeycomb structures helps in avoiding the wastage of the material which leads to the reduction in weight of the component. It also helps to attain greater specific strength with minimum use of material. It helps to increase the capacity of the structure. Because of its valuable properties most of the Automobile industries are trying to develop and apply this technology. Already these structures are being used in the Aerospace industry, boats, trains etc. for the maximum strength.

![Figure 2](image.png)
Figure 2 1 CAD model of the sandwich panel
Sandwich panels are the combination of stiff plates and a low density core. Hexagonal honeycomb structure has been considered. The core material can
also be different shapes but the hexagonal shape has been employed because of its performance.

Figure 2.2 CAD model of the honeycomb core

Figure 2.2 denotes the shape of a honeycomb core. It is just designed for the explanation purpose and has not been used in any following design or analysis part.

In this work only a 20 feet dry container is considered of all the existing designs because these parameters are standard in almost all the countries. There are different types of containers with different design parameters but the containers with honeycomb structures are never designed.

In this paper, design and analysis been performed on a sandwich panel in comparison with the existing designs to clarify that the application is valid before continuing to the full structure. The maximum stresses acting on the sandwich panel helps in depicting how stresses acting on the complete model.
2.1 Problem Description

Most of the containers in the present day are made of a single material like Mild steel, Aluminium, Weathering steel, wood etc. but the honeycomb structure is a combination of two structures with two different materials helps in strengthening the structure. Anytime in the present or in the future saving or reducing the material wastage is very important. The main challenge of this paper is to present a standard structure with the application of sandwich panels to the container to minimize the wastage of material with better strength. Therefore the structural analysis is in need to perform on the structure to prove the structure is better than the previous designs.

In the Figure 2.3 the CAD model of the container designed with sandwich panels is shown. Actually each and every part in the CAD model shown above is assembled by designing each and every part individually for the better output. The outer cover of the model looks like same as the previously existing models because the inner parts of the model cannot be seen. But the complete model design and its description will be provided in the next steps.
2.2 Aim and Objectives

The aim of this work is to build a container employed with sandwich panels applied in the place of side and roof panels and to present an advanced structure with all necessary data for the future use. The structure is compared with already existing container to prove the design is better and efficient. This aim can be achieved by designing a finite element model in the software and perform the structural analysis on the component and to determine the application helps in reducing the stresses acting on the structure.

The objectives include the following steps:

- Literature study to be performed on the containers, materials, honeycomb structures and its application
- Design a Finite element model of a honeycomb panel and compare with pre-existing panels to verify the honeycomb panels are strength enough.
- Selection of standard container existing and used in the market globally and the materials need to be applied for better performance of the structure.
- Use FEA tool to design a standard container and a honeycomb panelled container and perform structural analysis.

Compare the results

2.3 Research Question

1. How the application of hexagonal honeycomb structures to a shipping container effects its strength and performance?
2. What are the advantages of replacing shipping container panels with honeycomb sandwich panels?
3 Related Work

Information gathered about sandwich panels is being explained in here. In a book written by T.N Bitzer [2], the concept for the construction of sandwich panels is presented. In a book written by R.K Rajput [1], the techniques used in production and fabrication of sandwich panels is explained. In a book written by Sascha Peters [3], different materials used for different designs is explained clearly. The core of the sandwich panels are of different kinds. The design and analysis of different kinds of sandwich panels is performed and explained in a book written by Howard G. Allen [4].

Application of Carbon Fibre Reinforced Plastic (CFRP) to the honeycomb structures helps in increasing the strength of the structure even more because of its low density which has been glued by metal plated on the both sides helps in adding strength. The outer layers may be coated with aluminium, stainless steel, polypropylene etc. The effect of CFRP when the honeycomb is filled with circular CFRP tubes has been explained in a journal by Wang and Liu [5]. R. Wang and J. Wang explained the modelling behaviour of honeycomb structures made of laminated cell walls helps in understanding the behaviour of the honeycomb structures to some extent [6].

Modelling and analysis of the shipping containers has been performed by the Kevin, Sezen and Rebecca and explained the behaviour of shipping container when a load has been applied. This helps us to understand the existing model behaviour. As the dimensions are considered based on the ISO standard, the journal gives the real time behaviour of the container [7].

The experimental and numerical analysis performed in a journal written by Vinicius [8], explains the multiple stack dynamics used to study the structural response of container when the container stacks are excited. The model considered is a 20 feet container to study the losses and structural response in a container has been explained clearly.
4 Studied Model

A 20 feet dry container is studied for the application. There are 14 different most common types of containers they are

- Dry containers
- Flat Rack containers
- Open top containers
- Tunnel containers
- Side open storage containers
- Refrigerated ISO containers
- Insulated or thermal containers
- Tanks
- Cargo storage roll containers
- Half height containers
- Car carriers
- Drums
- Special purpose containers
- Swap bodies

Based on the application and usage, containers are divided in to 13 types and the names listed above the types of containers used for specific purpose. Of all these, dry containers are the most considerable and acceptable throughout the globe. Swap bodies are the container sheets which are used only in Europe. These are also providing very good service but they are not strong on the sides. These dry 40 feet and 20 feet containers are constructed to handle cargo and there are some types which are constructed for the different purposes like to handle garments on hangers. These dry containers available in different sizes (10, 20 and 40 feet). 20ft containers are again divided in to two types based on their size.

They are:
Standard container
High cube container
<table>
<thead>
<tr>
<th>Size (containers)</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 feet standard</td>
<td>6060</td>
<td>2440</td>
<td>2590</td>
</tr>
<tr>
<td>20 feet High cube</td>
<td>6060</td>
<td>2440</td>
<td>2900</td>
</tr>
</tbody>
</table>

**Table 4.1 External dimensions (mm)**

In the table 4.1, the dimensions of a high cube dry container have been tabulated.

<table>
<thead>
<tr>
<th>Size (containers)</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 feet standard</td>
<td>5891</td>
<td>2440</td>
<td>2390</td>
</tr>
<tr>
<td>20 feet High cube</td>
<td>5891</td>
<td>2440</td>
<td>2690</td>
</tr>
</tbody>
</table>

**Table 4.2 Internal dimensions (mm)**

Table 4.2 denotes the dimensions of a 20 feet standard dry container. The main difference in between stand and high cube containers is the variation in height. High cube container will be 100 mm higher compared to standard container. The figure shown below can clearly show the difference between standard and high cube containers.
In this paper only a standard 20 feet standard container is considered. The paper only explains the effect of the application of honeycomb structures to the container. Based on this, the stresses and strength can be determined for other types of containers. Therefore, it is not so important to consider any other type of container.

4.1 Material Data and Material Model

The containers which are available in the present day are mostly made of Aluminium and steel. Aluminium dry containers have a slightly larger payload compared to steel dry containers. Steel dry containers have a slightly larger internal cube therefore the volume of the container is more in steel dry containers. Steel shipping containers are the most commonly used type of containers. Older dry containers were built by using Aluminium and the present day containers are built using steel and these are much apt and useful for heavy cargo because of its properties.

On the surface of steel containers heavy duty coating is applied for the optimal strength and corrosion resistance. These containers are used for different purposes and they are available as storage containers, portable storage units, office containers and semi-trailers.
Aluminium containers are mostly used in refrigerated shipments as they need to be much lighter in load capacity. These are developed normally using Aluminium and stainless steel. The overall weight of Aluminium is much less compared to steel and in the refrigerated container a thick insulated layer has to be placed for the maintenance of temperature inside the container. Aluminium container also has an advantage of thermal efficiency and has the ability to maintain minimum air leakage.

Steel and aluminium containers are used for the same function. Therefore based on the needs these containers are used. Steel containers are used as it is king with dry goods and aluminium containers are the best choice for the frozen goods. All these containers are manufactured based on the ISO standard.

In this paper the structure is designed and analysed in two combinations they are

- Mild steel and Aluminium 6061
- Aluminium 6061 with mild steel

The combinations mentioned above are applied for the product and simulated as we expect the model could be more strength enough compared to the single alloyed structure.

Material properties of steel and aluminium 6061 are tabulated below for comparison.
<table>
<thead>
<tr>
<th>Property</th>
<th>Steel</th>
<th>Aluminium 6061</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (Kg/mm^3)</td>
<td>7.9e-6</td>
<td>2.70e-6</td>
</tr>
<tr>
<td>Elasticity Modulus (GPa)</td>
<td>200</td>
<td>68.9</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.25</td>
<td>0.33</td>
</tr>
<tr>
<td>Yield strength (MPa)</td>
<td>250</td>
<td>276</td>
</tr>
<tr>
<td>Shear strength (MPa)</td>
<td>375</td>
<td>207</td>
</tr>
<tr>
<td>Shear modulus (GPa)</td>
<td>80</td>
<td>26</td>
</tr>
<tr>
<td>Ultimate tensile strength (MPa)</td>
<td>420</td>
<td>310</td>
</tr>
</tbody>
</table>

Table 4.3 Material properties

These are some of the properties of the materials employed in the container made of honeycomb sandwich panels. These sandwich panels consisting of a core honeycomb structure and is being glued with two outer surfaces on either sides. Honeycomb sandwich Panels made of steel core with aluminium outer layers, aluminium core with steel outer layers have been analysed. These combinations are analysed for the better performance.
4.2 Stacking

Stacking of container is the process of arranging the shipping containers one on the other. They are stacked one on top of the other by using a lifting machine like crane. The height of stacking is limited to which the lifting machine can stack. The present stacking height is 6-7 container tier high.

During the stacking test, a weight of 3392 kN will be applied on the corner or end fittings. According to ISO, every container can safely withstand a vertical load of 192 tonnes with a factor of safety of 1.8.

There are many methods and types are involved in container stacking. It is being explained by Rommert Dekker in his book titled “Advanced methods for container stacking”.

4.2.1 Advantages of container stacking

International shipments normally need greater protection when compared to domestic shipments. Other issues such a handling of products, climate. Potential for pilferage, communication & language difference, freight costs etc. also influence the decision of containerization. Also, the bottom, line in all international package decisions is that the consignment must arrive at its destination undamaged. To facilitate product handling and protect the product during the movement and storage, many companies use containers, especially when these moves by sea.

Advantage of containerization:

1) Cost due to loss or damage are reduced

2) Labour costs in freight handling due to the use automated materials handling equipment.

3) Lower warehousing & transportation costs since containers are more easily stored and transported.

4) Containers can also be used for temporary storage at ports with limited warehousing facilities.
4.2.2 Disadvantages of container stacking:
1) Ports or terminals with container facility may not be available in certain parts of the world.
2) Even where such facilities are available, delays may occur due to overburden of loads.
3) Large capital expenditure may be essential to handle ‘container based’ networks.

4.3 Manufacturing methods of sandwich panels
Sandwich panels are normally manufactured or produced by two techniques. They are
- Continuous process
- Discontinuous process

4.3.1 Continuous panel production
- All the used materials are processed together and cut into the desired or required shape and length without stopping the line.
- A continuous line has an average speed of about 14 meters per minute in production of medium panel of thickness 40-50mm with metal facings.
- A typical continuous panel production has three sections
  - External layers processing section
  - Insulating material processing section
  - Panels handling section
- In a typical case of a sandwich panel with both exterior surfaces in sheet metal and an insulating core in polyurethane rigid foam, the first section starts with the sheet de coilers and continues with all the equipment for forming the two sheets into the desired shape.
- The panel could be a panel for walls or for roofs. Sandwich panels with flexible layers (aluminium, glass fibre sheets, and asphalt paper) are not roll formed. Both surfaces of the final panels are entirely flat. The surfaces are pre-heated to the temperature required by the process (usually between 40 and 65°C) and then the insulating material is prepared.
4.3.2 Discontinuous panel production

- Materials are processed separately. This means facings are formed and cut to the desired length and then assembled together in a press where the foam is injected.
- The discontinuous process has a lower level of productivity that cannot be compared with that of the continuous one.
- It is used today for products with shapes that do not allow the continuous process, or when the production rate required does not justify investment in a continuous line.
5 Method Overview

Figure 5.1 Flow chart of the method followed
The method followed in carrying out the project is shown in a flow chart above in the Figure 5.1.

The method chart start with the pre-processing. This is nothing but the selection of the thesis. The most advanced technologies and the subjects developing in the present day are considered for the selection of thesis. The thought of application of most advanced honeycomb structures is the main motive behind the selection of this topic.

It is followed by the literature review in which the complete background and the developments took place till now are studied and analysed. Material selection is one of the important step for this paper. These materials are taken in to account after several deep studies.

The complete project is about the FEA analysis of the container with the application of honeycomb structure. To perform analysis of the structure Autodesk Inventor is chosen. The results from the two different structures are compared and is verified for the best results.

The report completely describes and explains the steps followed in carrying out the project. By following this method for the present work, the results or the knowledge obtained can be used for the future use.
6. Autodesk Inventor

Autodesk Inventor is a 3D CAD modelling software used to design, visualize and test products. It allows to create product prototypes that accurately simulate the weight, stress, friction, driving loads, and much more of products and their components in a simulated 3D environment. Everything from basic mould designs to detailed mechanical engineering models can be created and tested using Inventor's integrated motion simulation and assembly stress analysis tools. Inventor is well known for its accurate 3D modelling features that help you create and visualize your products. Inventor also includes integrated CAD simulation and design communication tools that not only enhances CAD productivity and help to reduce errors but also can be integral in cutting development timelines in half.

It is normally used by the professionals to minimize the gap between design, engineering and manufacturing. For example, mountain bike manufactures may use Inventor to create digital prototypes of end products to virtually optimize suspension component interactions and ensure that clearances and tolerances are correct. In the case of yacht manufacturers, Inventor may be used to accurately model and prototype ground-breaking flagships and run stress tests to identify where to trim weight and improve boat performance.

Another example of how Inventor may be used is in the case of a mining machinery manufacturer. In this case, Inventor could be used to conduct stress analysis and simulate a machine's motion to identify unexpected collisions and other errors that might not otherwise manifest until physical production. Ultimately, Autodesk Inventor is used to cut production costs drastically via digital prototyping and virtual testing. This, in turn, helps to reduce errors and labour-intensive manual reworking, which ultimately speeds up production cycles and helps to get finished products to the market faster.

Inventor offers a familiar design environment and many AutoCAD-compatible shortcuts; and with true DWG (drawing) file support, Inventor allows AutoCAD users to leverage their existing 2D drawings to build accurate 3D models. These are some of the factors made us to choose the software to design and simulate the structure.
7 FE Analysis for integral parts (Panels)

There is no pre designed model. Therefore the models existing and the model proposed are designed and the results are presented from the both simulations for the comparison. The complete design of both models is being done in Autodesk Inventor and the FEA is also performed in the Autodesk inventor itself. Each and every part of the container is designed separately and is assembled to encounter the precision. Two CAD models are designed and four simulations are performed. Two simulations on the existing design and two simulations on the developed design are performed and being compared.

7.1 Design

Before designing the complete model sandwich panel and the previously existing panel of the container are designed and simulated for the verification. A load of 5000 N is applied on both the models for the verification.

Figure 7 1 Integral part of the container panel
7.2 Materials

Aluminium 6061 is applied to the outer part of the sandwich panel and Mild steel is applied to the core honeycomb structure. These honeycomb core and the outer plates are joined by using adhesives like EPS foam, XPS foam, Polyurethane, rock wool, mineral wool etc.

In this paper we are using extruded polystyrene (XPS) foam as an adhesive to join the face sheets with honeycomb core. XPS or extruded blowing agents stay embedded in the material for years whereas EPS or expanded foam blowing agents will leave the bead very soon and are not strong enough compared to extruded (XPS) sheets. These both closed cell insulation is made from the same base polystyrene resins and are manufactured in different ways.

EPS or expanded foam sheets are made by moulding or cutting the foam sheet in to different shapes and sizes whereas XPS are the extruded sheets. If we take a 1 inch thick sheet of same material, XPS has a lower moisture absorption rate than EPS due to the differences mentioned above.

Using the materials mentioned above, sandwich panels are designed and are being analysed.

7.2.1 Benefits of using XPS and EPS foam sheets

- Light weight
- Tough
- Insulating
- Versatile and easily branded
- Hygienic safe
- Water proof
- Low carbon impacts and
- Economic
After simulating the integral part of the container panel using steel, Aluminium and different alloys, Aluminium 6061 has better strength compared to all other materials. Therefore Aluminium 6061 is applied to the complete portion of the integral part and being simulated in the following steps.

7.3 Meshing

Honeycomb sandwich panels looks like
Meshing is done carefully to reach the most accurate point. Meshed part of both the structures with loads can be seen in the below figures 6.5 and 6.6.

Figure 7.2 Meshed model of the integral sandwich panel
Figure 7.2 denotes the meshed part of the honeycomb sandwich panel.

The figure shown above denotes the layers of honeycomb sandwich panel. The outer most face sheets and the core honeycomb structure are being joined using adhesives which is XPS foam sheet considered in this paper.

7.4 Results
Simulated parts are shown below, describes the von-misses stresses on these parts, and helps to verify which combination of materials is more efficient and strength worthy. As the maximum von-misses stress value acting on the existing model is more than the stress value on the sandwich panel used for the construction of the container.
Figure 7.3 Stress distribution on the integral part of the container.
Figure 7.4 Displacement of the integral part
Figure 7.5 Stress distribution on the sandwich panel
Figure 7.6 Displacement of the sandwich panel
7.5 Comparison

Von misses stresses acting on the sandwich panel and the integral part are compared to verify whether the design is worthy or to terminate itself.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sandwich panel</th>
<th>Integral part</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Von misses stress (MPa)</td>
<td>6.7</td>
<td>7.135</td>
<td>6.096%</td>
</tr>
<tr>
<td>Displacement (mm)</td>
<td>1.307</td>
<td>1.325</td>
<td>1.35%</td>
</tr>
</tbody>
</table>

Table 7.1 Comparison of integral and honeycomb panels

The model can be termed as more strength enough compared to the panels already existing can be said based on the difference in von-misses stress. Therefore the difference in maximum stresses and the maximum displacement value clearly defines the sandwich panel has the better outcome with 6.096% minimum stresses acting on its body compared to the existing model. The model proposed is acceptable. Therefore, the complete model can be designed and simulated to know the maximum stresses acting on the container.

The deviation in the value of displacement is just 1.35% for the same volume of the material but when we consider for the whole part of the model, we will get to understand the reduction in stresses and the amount of difference in deviation involved.
8 Finite Element Analysis of the Complete Model

In this part of the work after verifying that the application of honeycomb structure has better use compared to the existing model, the CAD models of the containers are designed and simulated. Only the side panels, floor and the roof panels of the container are replaced with the sandwich panels or the hexagonal honeycomb structured panels. Remaining design is not changed as it becomes more complicated for the assembly. Each and every part of the container was assembled by using joint condition. This helps in binding the object with other parts. Therefore helps in performing static analysis on the complete structure.

As it is said before, a 20 feet standard dry container is designed and being simulated for the comparison with the existing model. The models are designed on the basis of the ISO standard.

8.1 Design Description

All the parts like frame, door, side panels, roof panels and the layers involved in the panels are all designed separately and being attached. But the analysis is done only on the assemble part of frame and the floor. It is because in the static analysis only the floor panel will be deflected as all other panels are being kept constant or fixed.

Already existing dimensions are being considered for the project. These are standard dimensions given by the ISO.

The difference in dimensions helps to find the thickness of the structure in each direction. The design has been performed in Autodesk inventor.
Figure 8.1 Corner casting
Figure shown above is the corner casting, is a part used in the connection of bottom and upper side rails of the container.

Figure 8.2 Lock rod
The lock rod shown above is attached to the door as a locking system to open and close the door.
The panel shown above is used as a outer cover for the container is assembled by welding it to the bottom and upper side rails.

Plate shown above is used as floor for the container. There are still many parts which are designed and are being assembled to form the container. The remaining parts will be attached in the appendix.
8.2 Assembly

The honeycomb design shown above in the figure 7.1.3 is being extruded to form the plate. In the figure 7.1.4 the three layers are being joined in the assembly section. The complete three layered plate is being attached or assembled to the frame shown in the figure 7.1.2. The complete model is being created but the stresses in the container acts only on the floor and almost remaining part is assumed to be stationary as the analysis performed is only static structural analysis.

The complete project has been carried out using the software available at the University. The software has limitations as we cannot perform very large simulations. Therefore, in place of 40ft container, we have designed 20ft container and being simulated in the software.

![Figure 8.5 Assembled model](image)
The analysis performed in the paper is static analysis. For this, the bottom rails of the structure are being fixed. A load 300kN is being applied on the floor panel. It gives us the maximum stresses acting on the body along with the positions of stress. The stress obtained is helpful to study the behaviour of the container. The bottom side of the container has been fixed as it will be installed or attached to the chassis of the truck body or even during shipping of the container it will be places on the floor. So, in most of the cases the container will be fixed to the floor. Therefore only static analysis with bottom face fixed has been simulated.
8.4 Meshed model

Figure 8.7 Meshed Model

Figure 8.8 Mesh Settings
From the sources, it has been observed that the maximum payload is around 30000 kg which is equal to 294kN (for the full model). Therefore to analyse the stresses acting on the body at the maximum load are being considered for the comparison. This helps in depicting how much the newly proposed model is strength enough compared to the available models.

Automatic meshing is applied as if the mesh goes on complicating, the model could not get simulated in the available software. The load is applied uniformly on the floor panel. This doesn’t happen in the real life but can be depicted by considering the load based on the type of the cargo used to be transported,

From the mesh settings figure we can observe the average element size is given as 0.1 with grading factor equal to 0.5 and turn angle equal to 60 degrees. These parameter settings makes the mesh more biased and will give more precise results.
8.5 Material Usage

The material wastage and the stress distribution are the main goals of this project. Therefore the stress distribution can be explained in the following section. The reduction in material wastage is explained in this section.

![Honeycomb core](image-url)

*Figure 8.9 Honeycomb core*
The figure shown above is the sketch of the honeycomb structure. The volume of the material considered for the existing model and the proposed model are calculated and the reduction being explained with mathematical formulae.

The volume of material used in construction of container can be calculated based on its internal and external dimensions.

<table>
<thead>
<tr>
<th>Dimensions (mm)</th>
<th>Length</th>
<th>Breadth</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>External dimensions</td>
<td>6006</td>
<td>2440</td>
<td>2591</td>
</tr>
<tr>
<td>Internal dimensions</td>
<td>5891</td>
<td>2340</td>
<td>2390</td>
</tr>
</tbody>
</table>

Table 8.1 External and Internal dimensions of the standard container

Usage of sandwich panels have become more prominent in the construction due to its wide range of advantages. The panels will be in 5 layers with two outer layers and inner honeycomb structured core glued by an adhesive of two layers. The complete model becomes very stiff enough. These advantages made these structures to become prominent in Aerospace and automobile industry.

8.5.1 Replacement for the panels

The shipping container have four walls of which one roof panel, one floor panel and two side panels. The two side panels are of the same dimensions whereas the roof panel and the floor panel will have slight thickness change. It is because, normally most of the weight will be acting on the floor of the container. Therefore the roof panel will be made bit thin compared to the floor panel helps in increasing the volume of the body.

Now, In this paper these panels are being replaced by honeycomb structures with similar dimensions helps in reducing the volume of the material used with same inner volume of the container with reduced stress.

This helps in increasing the maximum payload and decreases the tare weight of the container. In this way, by decreasing the tare weight of the container and increasing the pay load will bring the gross weight of the container to the similar stage as before.
Replacement of these panels will save an amount of 7.7 cubic meters of material of 29 cubic meters. Therefore it can save up to 27% of the material and helps to carry the same weights without any problem.
8.6 Parts for assembly

Number of parts used in structuring the model is shown below. Only names of the parts are being attached here. The designs or models will be attached in the appendix. Each and every part are designed using Inventor and is being assembled and simulated. There are several parts and some of the parts are similar in shape but with different sizes. Therefore, only the parts with different shapes are being attached in the appendix.

The parts of the model are being shown below and the list is attached with name and number of that component.
There are many parts as shown in the above figure. All the parts have been designed and for the design of parts which are needed to be assembled have been mentioned in the appendix.

The final assembled full model is shown below

Figure 8.11 Full model after assembly
8.7 Results

8.7.1 Stress analysis on the Existing model

Figure 8.12 Stress distribution on the existing model (Aluminium)

In this the stress analysis is performed on the structure with a load of 294 kN (which is the maximum load can be carried by a pre-existing container). The maximum von misses stress value is 0.1416MPa. This is really small. This is the stress analysis performed on the existing design model. The stresses acting in this is being compared with the stress outcomes from the model made from high strength low alloy steel. These two are the materials normally considered for the construction of a shipping container.
The maximum displacement is obtained as 0.6645 mm. It is very small but the stresses can be even reduced. This helps in increasing the capacity of the container.
8.7.2 Stacking model

Figure 8.15 Stress distribution on the stacked container

Figure 8.16 Displacement on the stacked container
The stress distribution and the displacement figure is shown above.

Figure 8 17 Safety factor of stacked container
8.7.3 Honeycomb structured model

The stress distribution is shown in the above figure. The maximum von misses stress is observed as 61.29 MPa. It is very low compared to the existing model.
Displacement or the deviation value obtained as 0.2378 mm. It is also very small compared to the observation model. These values makes the structure more efficient. The model is light in weight and possess high strength. If some failure occurs the deviation mainly occurs on the honeycomb structures. It can be observed only at very heavy loads but the simulations before helps in avoiding such heavy loads.

The model is highly safe compared to the aluminium or steel made existing models. Complete weight of the body acts on the stripes shown on the surface of the panel. This helps in reducing the loading effect on the body of the panel. The resultant stresses shows the effect of uniform distribution of load on the container.
Figure 8 20 Safety factor
9 Comparison of results

The stress distribution, displacement and safety factor figures are shown and discussed above. In this section the results obtained are compared for the better understanding of the effective model which has to be considered finally. The von misses stress values and displacement values of two simulations are being tabulated below.

<table>
<thead>
<tr>
<th>Type of the model/parameters</th>
<th>Max. Von misses stress (MPa)</th>
<th>Displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing model made of Aluminium 6061</td>
<td>287.6</td>
<td>0.6645</td>
</tr>
<tr>
<td>Honeycomb model made of Aluminium 6061</td>
<td>61.29</td>
<td>0.2378</td>
</tr>
</tbody>
</table>

Table 9.1 Comparison of final results

- The deviation of maximum stress compared in between Aluminium made existing model and the honeycomb model is 70.52% and the deviation in maximum displacement is 65.19%.

- The stress analysis is also performed by stacking the containers. The analysis is performed on the model not with the empty containers. It is analysed when the containers are with maximum payload.

- The maximum von misses stress value is 482.3 MPa and the maximum displacement is 6,083 mm.

- 5 cubic meters of material has been reduced which can cut the material cost to a great extent.
10 Summary and Conclusions

10.1 Discussion

The results obtained are compared to the previously existing models are being acceptable. The very low stress values indicates that the model previously accepted is being optimized to a large extent. The project performed here is somewhat related to the optimization of the structure when we consider the structure and the material change. But the results presented in this paper describes the stress and the deviation results and are helpful in the future for better understanding of application of structures and materials.

These honeycomb structures are of different shapes like rectangular, triangular, hexagonal etc. but only hexagonal honeycomb structures are considered because these structures are the standard structures already been proved based on many calculations. Therefore only hexagonal structures are taken in to account.

The stress values obtained when the materials like aluminium, steel and CFRP are mixed together and are being applied to the existing structure helps to know the strength factor of the combination of the materials and different structures. The deviation in the result is very high when it is compared to the existing model.

The complete project has been performed in Autodesk Inventor. We tried the simulation using Solid works and CATIA v5 but then we tried with Inventor and we felt it is easy and compatible for the structure we are analysing.

The materials selected are Aluminium 6061, high strength and low alloy steel and Mild steel. Before considering these materials many trials have been performed using stainless steel, iron, CFRP and other combinations to find the best possible outcome. Aluminium and steel are the most commonly used materials in construction of shipping containers. Therefore many alloys of steel and Aluminium are also tested with the verification model. Of all these, the combinations of aluminium 6061 and mild steel core combination has given the best results.
Our research question describes just to showcase the effect of application of honeycomb structures to the existing container models. The report clearly explains the steps and method followed during the project. The verification model or just the simulation of the integral parts of both existing and proposed models are done to get clear understanding of which materials are need to be used and how the load and constrains have to be defined on the complete model. This made us to understand the effect to some extent. When the simulation of honeycomb sandwich panels is performed, the deviation results are just around 6 percent but when the simulation performed on the complete model the deviation has been increased to around 60 percent when is very huge. But this cannot be applied directly in the industry. This is because the validation is not performed on the structure. Before that it need to be simulated or should have been tested with a verification model and should be analysed. This helps in a perfect success of the structural application and helps the industry to increase the capacity of the container.

The dimensions considered in the paper are the standard dimensions. Therefore there is no need of changing the length of the truck or the rail used to stick the container.

10.2 Conclusion

The main motive of the project is to show the alloying of materials can differ the strength and will be helpful in increasing the strength. With almost 5 cubic meters of less material, 60% less von misses stress is achieved compared to the existing model. The load carrying capacity will be increased to a greater level. The values may differ when the model being analysed but the structure proposed is having phenomenal strength. The aim of reduction of material wastage and the maximization of strength has been successfully achieved.
10.3 Future works

- Optimization of the structure can be performed considering different optimization techniques.

- Dynamic simulation of the complete model constrained to truck helps in better analyzation of the stresses and effects at different conditions.

- Different load cases can be considered during the dynamic simulation helps in finding the maximum load capacity the structure can bare and the optimization of the structures helps in reducing the stresses.

- There are many different materials are still discovering and there are still many types of materials and material combinations can be applied and to be tested for the best outcome.
References:


APPENDIX

There are many parts designed and assemble to form the final component. Some of the parts are attached above in the document and the remaining are being attached here.

Parts shown in the above figure are designed and are shown below. These are used in assembling of parts to form the complete model.
Figure Ap 1 floor joist over floor pocket

Figure Ap 2 floor joist
Figure Ap 7 Corner post

Figure Ap 8 Base rail 20 feet
Figure Ap 11 Fork pocket

Figure Ap 12 Door post end

Figure Ap 13 Door pocket
Figure Ap 14 Door plate

Figure Ap 15 Side panel rib

Figure Ap 16 Roof panel
Figure Ap 17 Roof joist

Figure Ap 18 M12*80

Figure Ap 19 M12*40
Figure Ap 20 M12 spring washer

Figure Ap 21 M12 nut

Figure Ap 22 M12 washer
Figure Ap 23 Lock rod lever

Figure Ap 24 Lock rod keep
Figure Ap 30 Hinge plate

Figure Ap 31 Hinge bracket
Figure Ap 34 Door rail trim