Honeycomb structures fail

The motivation of this research to find out how different kind of honeycomb structures failed.

Also, it will be interesting to know which is the strongest among the few different types of honeycomb cores that are included in this report which is an elongated hexagonal core, hexagonal core, square core and triangle core. In addition, layers of material with adhesive will also be made to compare the various types of related properties like deflection. However, all problems related are in static. This research does not deal with any dynamic problems.

The research is being done by using vanguard sheet as the testing materials. After which, it is put on a jig to test for the amount the sandwich structure deflected all the way till it failed. Testing result shows that elongated hexagonal cores are the strongest.

This report also discusses about the errors involved in the experiments and how can it prevented or reduced. In addition, suggestion will be given to generate better solution to the problems faced in the course of the research.

The purposes of this report are to research on sandwich structures and determine how different created honeycomb core sandwich structures failed

Sandwich structures gains it popularity after WW2 because of the advantages it brought. Since then, researches have been done to find out more about this particular structures and way to improvise it, lowers it cost and increase it advantages.

The scopes include how are the sandwich structures being constructed, material use and its applications. How the sandwich structures are being created and the type of sandwich structures being created is also part of our scope. In addition, the research only focus on the static problems of the sandwich structures and hence dynamic problems are not included. This report also focuses primarily on the mechanical properties. Furthermore, the result and the procedure for the various experiment done is also indicated in this report

Literature research is to be done with the help of internet resources and various books from the school library. Also, the sandwich structures to be tested is being made with hand and further tested by a jig that is being created.

American Society for Testing and Materials (ASTM) defines, “ A structural sandwich is a special form of a laminated composite comprising of a combination of different materials that are bonded to each other so as to utilize the properties of each separate component to the structural advantage of the whole assembly.”

Sandwich structures usually consist of two faces and one core boned in between the faces with the help of adhesive as shown in Figure 1 above. However, the amount of faces and cores can be varied. In addition, the thickness of the faces used can also be different. Faces provide a counteraction to the bending moment externally by acting with each other to form a stress couple. Core provides for shear resistance

and face stabilization for buckling and wrinkling. Adhesive bond are normally strong enough to provide tensile and shear resistance.

When a sandwich structure is bended, the forces that are acting on the sandwich structure are not only tension and compression but also shearing between the core and face of the sandwich structure

Normally, a sandwich is designed in a way such that the flexural rigidity is being represented by the formula below.

The flexural rigidity of the sandwich structure with a thin face and weak core is represented by.

Generally speaking, the strength of the face material as compared to core materials used in the sandwich structures is normally stronger. Since the materials for face and core are both vanguard sheets, the face and core have the same young modulus

The desired properties that a face material should have are shock resistance, good flexural rigidity and wear resistance

The type of material used for face is normally metallic material like steel, or aluminum alloys. However, it is also possible to use a non-metallic material like cement, fiber composite or reinforced plastic for the face materials.

The requirement for core materials is that they must not add too much to the weight of sandwich structures

Sandwich structures have been widely used in the construction, aerospace, railway and shipbuilding industries. This is due to advantages that a sandwich structure is able to deliver.

The advantages of the sandwich structure is due to the high stiffness, high strength-to-weight ratio, capability of absorbing high energy, increases of flexural rigidity without adding substantial weight and it provides insulation for hear and sound.

For the railway industry, sandwich structures are for the production of trains. For the shipbuilding industry makes use of the ability of sandwich structures to increase the buoyancy to make hulls and bulkheads. For military ship, it is used due to the increased resistance to water explosion.

For the aerospace industry, sandwich structures is used the make wind tunnels, part of wetted surface. Some of the aircraft parts are also made of sandwich structures. Construction industry use sandwich structures to build and reinforce bridges.

For general usage, water sports like kayaks and canoes make use of sandwich structures also. Noise damper due to ability of the sandwich structures to provide resistance to sound.

There are a number of failure modes by the sandwich structure. They are face yield or fracture, core shear, face wrinkling outwards or inwards, shear crimping, face dimpling and local indentation.

These entire failure modes can be designed in a way such that the sandwich structure fails in that particular mode. Hence it can be useful for different kind of applications.

The sandwich structure is designed by:

- Determine the type of core of the sandwich structure
- Determine the shapes of core of the sandwich structure.
- Determine the dimensions of core of the sandwich structure.
- Determine the dimensions of the whole sandwich structure based on the core to attain the best possible conformity for all the various sandwich structure.
- Determination of core height and face height of the sandwich structure.
- Determination of adhesive used.

There are four types of core, honeycomb, foam core, web core, and truss core. Based on the material available, foam core is not being able to be implemented as foam like structure is hard to be achieved. Honeycomb core is being used in favor to web and truss core as manufacturing wise, it is easier. Reason being the core of honeycomb can be constructed without the faces while web and truss core needed the core to construct together with the face.

Honeycomb core comes in a lot of shape. The most common being the hexagonal shape core as it is easy to make. Others that are being taken into consideration are shape like circle, square, triangle etc. The reason that circle is not being used is that it is unable to tessellate nicely like square or triangle with no gaps in between. The finalized four honeycomb core shape is an equilateral triangle, square, hexagonal and an elongated hexagonal shape with twice of the normal hexagonal height.

The core is being manufactured by human hands. Hence, there is a limitation of the core minimum size. On the other hand, the maximum size does not have any limit. However, it is important to notice that as the size of the core increases, the strength of the whole sandwich structure will be weaker in relative to those with a smaller core size. This because with a given dimension, there are more contact with the faces for a smaller core size as the number of core increases. Time is also a factor whereby smaller core will result in more time consumption with more cores to be manufactured.

The hexagonal and elongated hexagonal honeycomb shape is based on a standard hexagonal size of 10mm on each side. However, the square and triangle honeycomb shape is based on a standard size of 20mm on each length. This is because a hexagonal shape has more space in it as compared to square or triangle; hence a 10mm length on each side is still possible for human hand to build. In contrast, the square or triangle has less space in between it. The dimension of the various shape design is shown in Figure 2.

The dimension of the sandwich core is found by making use of autocad to fix pieces of core together to see what type of length and width that can be the same when pieces of core are joined together. Also, the aspect ratio must be approximately 5. Hence, the minimum width we get is approximately 80mm for all cores when pieces of it are joined together will be approximately the same width. For the length, it is 420mm. For the height of the sandwich core, it is a multiple of the height of the vanguard sheet which is 0. 32mm. The end result of the height of the sandwich core is 16mm as Dan (1995) said that core/face thickness ratio is approximately 10 to 50. 16mm is 50 times the height of the vanguard sheet.

The face thickness is determined to be a piece of vanguard which is 0. 32mm as it is the least time consuming to create.

The types of adhesive used are choose between the 3 as shown in figure 3.

From left to right, contact cement (CC), Mapleleaf art glue (ML) and UHU super glue. The selection of glue is based on the following factor relating to the glue instead of mechanical properties:

1. Cost

2. Adhesive Quality (AQ)

3. Easy to use (ETU)

The adhesive is selected based on the ranking table as shown in Table 1.

Hence, from the table UHU scored the lowest. Therefore, UHU is selected. The AQ is determine by apply it on metal and since whether it can let the metal sticks together but ML as failed to do hence the AQ of ML is the lowest.

The motivation behind this experiment is to see what type of microstructures do the vanguard sheets possess.

The equipment used is the image analysis and acquisition sony exwavehad color video camera with the software Image pro plus in it.

Cut a dimension of 6mm x 6mm

2. Put it under the sony exwavehad color video camera in the longitudinal direction

Magnify 10x.

As shown on figure 5 above, the microstructure of the vanguard sheet is randomly distributed. Hence, it can be concluded as a isotropic structures.

The aim of this experiment is to find out in which direction does the paper have the highest Young's Modulus and also to verify experiment 7. 1. Is it the longitudinal or transverse direction?

The equipment that was used for testing is the Hounsfield H5k-W and a hole punch of diameter 8mm is used to make two hole that is required to secure the test specimen on the equipment. The test speed is 1. 5mm/min The equipment is illustrated in figure 6.

The test specimen is being done by tracing over the metal on the right of figure 7 on a vanguard sheet and cut out the size. The photo on the left of figure 7 is the test specimen.

The experiment is being carried out in the following process:

- Cut the vanguard sheet along the longitudinal direction and transverse direction into the tensile test specimen with a gauge length of 65mm.
- Use the hole punch to punch two hole of Æ8mm to allow the test specimen to be mounted on the testing machine.
- Mount the specimen on the Hounsfield tensile testing equipment. Adjust the speed to 1. 5mm/min. If the speed is too fast, the tester is unable to react fast enough to a break in the testing material.

- Determine the E of the vanguard sheet by the method stated in ISO 527-1 or ASTM D638.

The result from the equipment is σ_{max} and ε_{max}. E is being found by finding the gradient of the secant line. Both test specimen break within the gauge line. The method use is taken from ISO 527-1 whereby making use of the formula as shown below.

The reason of us choosing this method is because ASTM D638 which based the line on a point of inflexion which cannot be detected in the result of our experiment. The reason for us modifying the formula is that 0. 25% ε is hard to get from the graph as it is near zero. Instead of 0. 25% ε, 25% ε and 5% ε is being used respectively. The secant line is dry the way show in Figure 8.

The conclusion is that the vanguard sheet has a higher E in its longitudinal direction than its transverse direction. This also implies that this experiment did not support the first experiment 7. 1 as experiment 7. 1 implies a isotropic structure where as a result shown a non-isotropic as E at longitudinal and transverse direction is different.

The young modulus of the vanguard sheet can be seen in table 3.

The aim of this experiment is to find out which adhesive is the strongest.

The equipment that was used for testing is the Hounsfield H5k-W and A hole punch of diameter 8mm is used to make two hole that is required to secure the test specimen on the equipment. The test speed is 1. 5mm/min.

The test specimen is cut into half each and being joined together by adhesive with a contact area of 60 mm. The adhesive we are going to choose from are Mapleleaf glue, UHU superglue and lastly contact cement.

The first few steps of this experiment is the same as step 1 and 2 of experiment 6. 2.

The other steps are as followed:

3. Cut the sample into half and glue a contact area of 60mm.

4. Find E based on result on experiment.

All 3 experiments show the necking of the test specimen beyond the gauge length as shown by figure 6. 4. The method use to calculate E is using the same method as the section 7. 2. 4.

The table 5 shows the young modulus of the vanguard after applying the glue.

The testing is not really accurate as it necks beyond the gauge length. This gives an indication that the glue is stronger than the vanguard sheet. However, it does not lead to a decision to which type of adhesive to be used to bond the sandwich structure together. Despite that, it can be seen that the structure becomes stronger with the adhesive.

The aim of doing this experiment is to determine how the sandwich structure will fail and under what conditions will it fail.

The equipments used are Mitutoyo dial gauge with a magnetic stand, 2 weights and a jig as shown in Figure 9 and Figure 10.

This is how the test specimen looks like on the jig. It is done by failing it by a simply supported 3 point loading. The test specimen includes the sandwich structure with elongated hexagonal core, hexagonal core, triangle core, square core, layers of vanguard bond together.

The layers of vanguard bond together are done by making it as the same length, width and height of the others sandwich structure and also approximate to the average of all the sandwich structures as can be shown in table?. The mass of layers of vanguard with dimensions near to that of the others sandwich structures and the sandwich structures is found by using the electronic balance as shown in figure.

The mass of the layers of vanguard that is near to the size of the others sandwich structures is 494. 5g. The weight of the layers of vanguard that is approximate the average of the sandwich structure is 50. 63g.

The testing will be done under the following procedures with the help of a jig under a simply-supported load after applying a load of 4N. The setup can be shown in the left figure of figure 11.

The steps to carry out the experiment is as followed

- Let the two stand of the jig to be 150mm apart from each other.
- Apply an additional load of 10N and read the deflection of the dial gauge.

- Apply an additional load of 10N and read the deflection of the dial gauge.
- Increase the distance between the two stands to 200mm and repeat step 2 and 3.
- Do the same for length 250mm, 300mm and 400mm respectively.
- If the sandwich structures do not break, increase the load in interval of 5N till failure is being observed in the sandwich structures.

This core failed at 30N with distance 400 mm apart due to wrinkling on the faces as shown in figure 13.

This core failed at 20N with distance 300mm apart due to failure by shear crimping as shown in figure 14.

This core failed at 20N with distance 150mm apart due to wrinkling of faces as shown in figure 15.

This core failed at 10N with distance 200mm apart due to partial delamination as shown in figure 16.

The sandwich structures deflected when put on the jigs with distance 150mm apart. Once a load of 10N is applied, the dial gauge is unable to capture the readings of the deflection.

However, this structure is not tested to its full failure mode.

The experiment shown that the elongated hexagonal is the strongest, followed by the square, triangle and lastly the hexagonal shape. This is being shown by the distance whereby it failed and at the loading at which it failed.

The elongated hexagonal shape displays the highest value of loading and distance when failed. Hence it is the strongest. However, this is only limited to amongst the sandwich structures. The relationships of distance and load to deflections of a simply-supported 3 point load can be shown in formula below.

A jig is needed to allow sandwich structures to be mounted on top for a three point bending test. The final design of the jig is done by using the following equipments shown in figure 17, from left to right and top to bottom which is the hand saw, electrical drill, drill bits and a scissor.

The materials used are wood, string, screw and nuts. This can be shown in figure 18.

The type of loading designed to be able to carry out is simply support and fixed edge. The clamped edge or fixed edge is achieved through the locking of bolts and nuts. The distance in between can also be adjusted.

There is a relationships between experiments 7. 1 and 7. 2 which is the properties must corresponds to the microstructure that the vanguard sheet possess. Experiment 7. 1 tells that the microstructure of the vanguard sheet is rather distributed. Hence this means the vanguard sheet is isotropic. Therefore, the result of 7. 2 which is the find the young modulus of the vanguard in the longitudinal direction and transverse direction should be the same or approximately the same to each other. However, the results prove otherwise. Why is this so?

This might be due to the arrangement of the fibers inside the vanguard sheet. There might be more tends towards the longitudinal directions or is stronger in the longitudinal direction region as compared to that of the transverse direction region when the fibers are at an angle.

Experiment 7. 4 shows that elongated honeycomb structure is the strongest. In addition, it is also strongest than the pile of vanguard similar to the dimensions of the sandwich structures. This indicates the existent of the sandwich effect which improve the flexural rigidity of the structures yet reducing the weight of the structures. This is can be fully shown in experiment 7. 4 with the pile of vanguard sheet being approximately 10 times heavier than the elongated hexagonal core.

Also, the result of square, triangle and hexagonal core might show a relationship of the strength of the sandwich structures and the area of hollowness within each shape. The area of each square, triangle and hexagonal and elongated hexagonal is 400mm ^{2} , 173mm ^{2} , 259mm ^{2} and 520mm ^{2} respectively. This can be shown by the fact that elongated hexagonal shape is the strongest followed by the square shape and they both have the corresponding highest amount of area of space within each core.

However, for the pile of vanguard that is approximately the same weight of the average of the sandwich structures is not strong enough. The deflection is too high. Hence, this further demonstrates the sandwich effect.

Nothing is prefect in this world; hence there is a possibility of the presence of error especially due to the heavy usage of human hands, eyes to carry the manufacturing of sandwich structures and experiments.

The error make in this might be due to the facts that it is hand made. This might be error made when trying to outline the area to cut on the vanguard. For example, if the ruler use is not of substantial length, there is possibility for the ruler to tilt diagonally when drawing the line.

The strip of paper produced might not be even at both sides. In addition, this also imply a possibilities that when the strip of paper are combined together to form a honeycomb structure, the core of each shape might be uneven. Hence, when a face material is applied on it, it might not have contact on all the surface of the core. This might lead to region whereby core and face are not properly joined together by the adhesive which might lead to a weakness in the sandwich structure in that region.

Due to the fact that both core and face material is vanguard sheet. They will be weakening effect in the presence of fluids which is the adhesive that is being applied on it to fuse the face and core materials together. This will occurs if too much adhesive is being used when the operator control of the fluid that is being squeezed out from the tube is not good.

It can be seen that the image of the microstructures of the vanguard sheet is a bit blur. This might be due to fact that the vanguard sheet under the microscope is not of a flat surface.

Since experiment 7. 2 and 7. 3 is both about tensile testing using the same equipment. The errors that arise might be common. One of them is the mounting of the specimen to the equipment. A weakness on the paper may be present if not mounted

properly. However, in both experiment, the operators are careful enough not to be cause a weakness on the paper.

This experiment is the most critical part to the whole research as it helps to determine how strong the sandwich structures are. For this experiment, a number of errors can be committed. One of them might be due to the jig being not rigid enough.

The placement of the dial gauge is also of concern. Due to the mounting of hanger to enable a load to be apply on the sandwich structure. The dial gauge might not be able to measure deflection at the central position of the sandwich structure which deflects the most. Instead, the dial gauge is being placed at a fixed distance near the hanger.

Due to the fact that the hanger is adjustable when placed on the surface of the sandwich structures, error might also arise. One of the possible errors is the sliding of the hanger due to the placement of the load. Also, the point load that is being placed on top might not be in the central position of the sandwich structures. Since the stands are able to adjust the distance in between, there is a possibility that there is error when attempting to adjust the distance.

There is one experiment that is failed as it does not help in the determination of the strength of the adhesive. This experiment was done in the motivation of trying to find out which glue is stronger due to facts that the glue is stronger than the paper. Metals is being used by cutting the test specimen shown in the left figure of figure 19 in to half as shown in of figure 19.

The experiment failed because the glue that is applied on the metal is not strong enough to fuse the metal to breaking. Instead, sliding action of metal occurs and the adhesive is unable keep the metal together. Hence a physical properties approach is done to select the adhesive.

Another failed experiment is something similar to experiment 7. 4. Reason for failure is due to the aspect ratio of the sandwich structures being too small.

In conclusion, it can be seen that the elongated hexagonal honeycomb core is the strongest. The whole report also suggested that the sandwich structure is strong in the sense that it deflected less when compared to a layer of laminates with adhesive. Hence, it has a higher strength-to-weight ratio.

It is suggested that the process in fabricating the sandwich structure to be improved such that paper with straight edges can be cut hence ensuring better contact and fusing with the face materials. Also, it is good to find out way to apply adhesive evenly to provide better adhesion.

For experiment wise, the way load is being applied can be improved by using a stand to put the loading on it such that it will not cause sliding effects.