DEVELOPMENT OF HONEYCOMB CORE FROM WASTE A4 PAPER AND INVESTIGATION ON ITS COMPRESSIVE PROPERTIES.

by

Fauzan Azmi b. Mohd Sabri

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Muhamad Ridzuan B Abdul Latif)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(FAUZAN AZMI B MOHD SABRI)

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ABSTRACT

This report discusses on the progress research and work done of basic understanding on the **Development of hexagonal Honeycomb core from waste a4 paper.** The objective of this project is to develop a production route in order to create the hexagonal honeycomb using waste paper. Abundance of waste paper in the engineering department can be added value to create this product which in the future can be used in engineering application. The development starts by using the raw material which is the waste paper (A4 paper 70 gsm -80gsm) to create a bare core. The development mainly focuses on the expansion process which is the most feasible way to produce the core in the absence of specific machinery. The core will then be strengthened by applying resin as a coating to improve the core properties. Resin curing temperature will be set into three different temperatures. The project also aims to test the properties of the developed honeycomb core. The testing will be done accordingly to the ASTM standards

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 Background of Studies

1.1.1 About honeycomb

- Paper honeycomb was introduced for the airplane industry as a cost and material saving product in Europe due to shortage of building material (wood, bricks, etc.) after the Second World War. Paper honeycomb was an excellent alternative for solid materials like wood. In the sixties paper honeycomb was mainly used in inner doors, separation walls and furniture (kitchen cabinets). Until today, paper honeycomb is being used widely. Due to its lightweight, high strength and favourable cushioning properties, paper honeycomb sandwich panel has been widely used in packaging industry and others such as aviation, furniture and building industry **[1].**

1.2 Problem Statement.

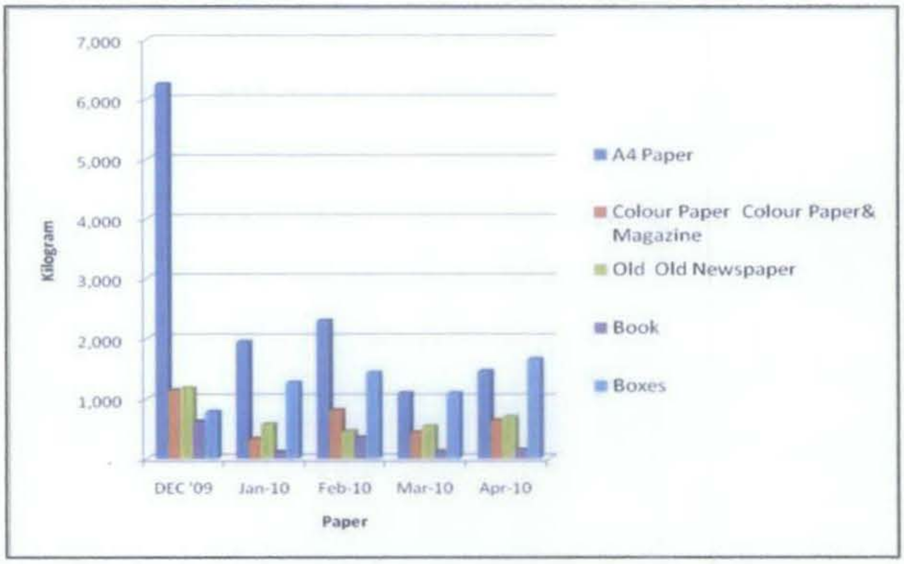


Figure 1: Waste paper collected in UTP**[2]**

- According to HSE UTP department, From November 2009 until 30 April 2010, more than 6 metric tons of **plastic bottles** and more than 13 metric tons (13,034kg) **A4 paper** (this is equivalent to the weight of 13 nos. of small pick-up lorry) were collected by the recycle vendor from our campus.

- Do you also know that the amount of money spent to purchase **A4 paper** last year can be used to build a single storey bungalow house at Batu Gajah or Bandar University?

- It is reported that in the month of April the amount of A4 paper usage has increased again. Therefore, the UTP HSE department are expecting a reduction in A4 usage.

- Paper is a necessity nowadays. Most paper went through the recycling process to reduce the iMPact of the environment as papers are made from tree. Recycling the paper requires additional energy. However, it can be minimize by using them as a raw material for an engineering application. Due to its lightweight and sturdy features, paper can be used as the basis of the honeycomb core structure. As honeycomb core structure can be made out of any thin and flat sheet of material, the abundance of waste paper in mechanical engineering department can be put into use.

1.3 Objectives and Scope of Studies

1.3.1 Objectives.

- This projects main objectives are:
    - To develop a honeycomb core using waste A4 _paper
    - To investigate the effect of different curing temperature and time on the compressive properties of the core.

1.3.2 Scope of studies:

- This project focuses in developing a hexagonal honeycomb core from the waste A4 paper.
- Once it is produced, the properties of the product compressive properties will be further investigate trough ASTM testing in laboratory by using several equipments available in UTP.

CHAPTER 2:

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1 Honeycomb Core

- Honeycomb core consists of multiple hexagonal or columnar cells stacked together in arrays and separated by thin wall. It was inspired by the beehive shape. The shape provide high stiffness ratio to its weight. It can be made out from any thin and flat material.

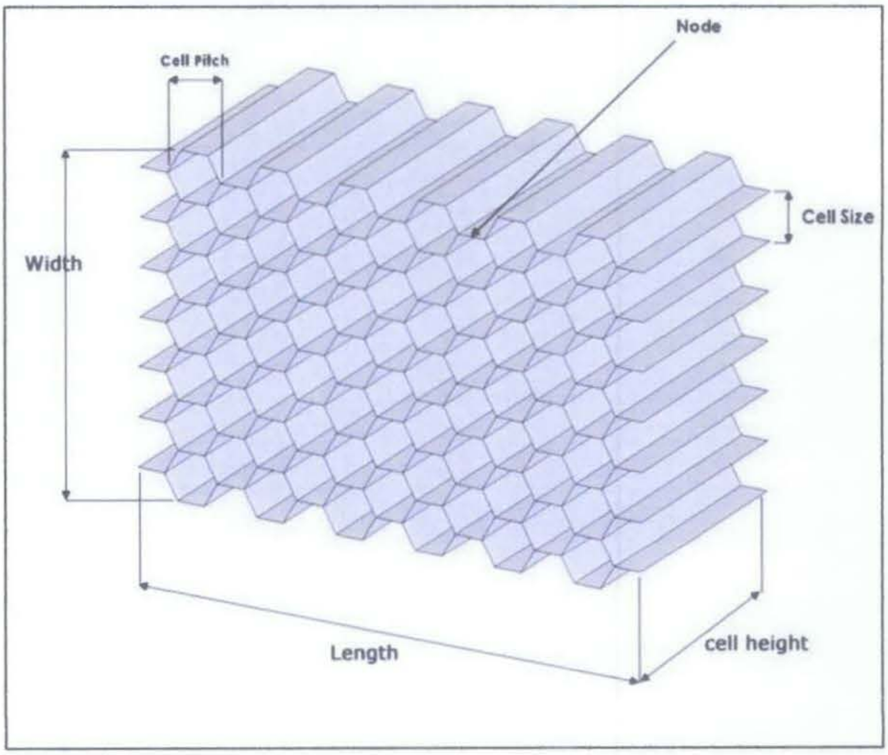


Figure 2: Honeycomb Core **[3]**

2.2 Sandwich panel

- Structural sandwich panels are widely used in lightweight construction especially in aerospace industries because of their high specific strengths and stiffnesses. The typical sandwich panel consists of a lightweight core covered by two thin face sheets. Each face sheet may be an isotropic material or a fibre-reinforced composite laminate while the core material may either be of metallic/aramid honeycomb or metallic/polymeric foam. **[4]**

- Low-density, hexagonal honeycombs are preferred as the core material on performance basis. The Sandwich Panel" which is composition of a "weak" core material with "strong and stiff" faces bonded on the upper and lower side. The facings provide practically all of the over-all bending and in plane extensional rigidity to the sandwich. In principle, the basic concept of a sandwich panel is that the faceplates carry the bending stresses whereas the core carries the shear stresses. The core plays a role which is similar to the I beam web while the sandwich facings perform a function very much like that of the I beam flanges.

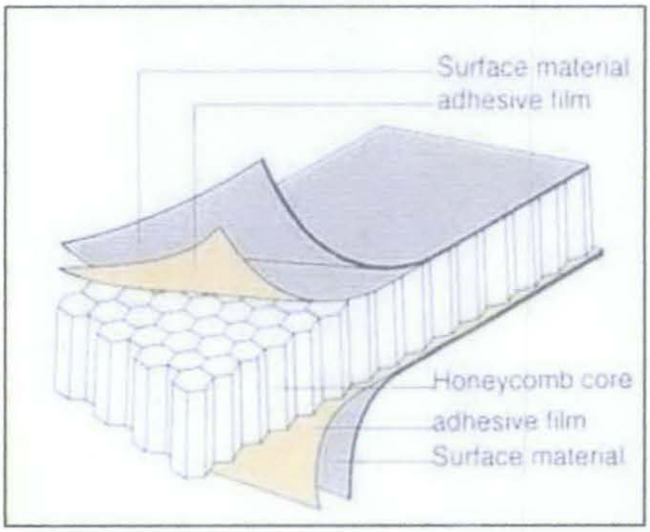


Figure 3: Sandwich panel **[5]**

2.3 Shellac

- Shellac is a very widely used single component resin varnish that is alcohol soluble. This resin makes excellent wood adhesives for wood and other materials. Particle board because they form chemical bonds with the lignin component of wood. They are especially desirable for exterior plywood, owing to their good moisture resistance, non-toxic and easy to apply.

2.4 Glue

- Glue is a mixture of a liquid or semi-liquid that adheres surface together. The source of glue can either be natural or synthetics. The glue bond by evaporating a solvent or by chemical reaction that occurs between two or more surfaces.

2.5 Manufacturing process

2.5.1 Expansion process.

- Low cost paper honeycombs are produced with the same process, shown in figure 1. First, glue lines are printed on flat sheets. Second, a stack of many sheets is made and the glue is cured. In the third phase, slices are cut from these blocks. Finally, the sheets are pulled apart, thus expanding into a hexagonal honeycomb core. The residual stresses in paper honeycombs have to be relaxed after expansion by heat **[6]**.

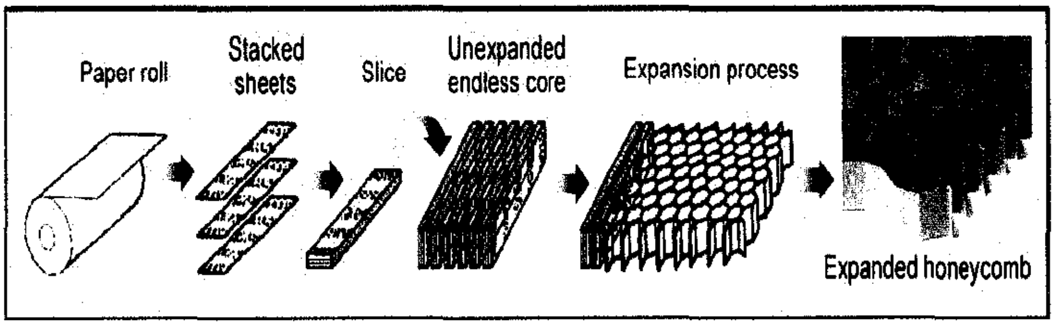


Figure 4: Expansion process [7]

2.5.2 Corrugation process.

- The corrugation process is the original used to fabricate honeycomb core. Although this method is labour extensive, this method is still used to create a high density metallic cores and some non-metallic cores.

- In the corrugation, the sheets are first corrugated, then adhesive is applied to the nodes and the sheets are stacked and cured in an oven. Since only light pressure can be applied to the stacked block the node adhesive is much thicker than the expanded core [7].

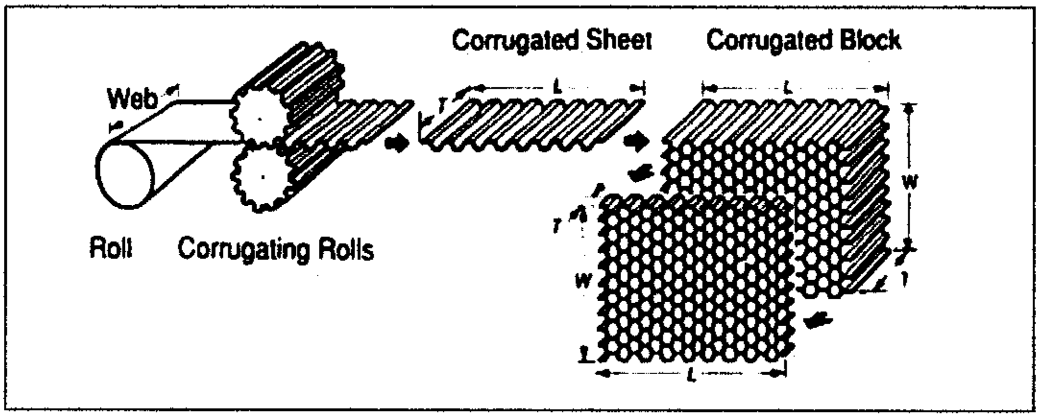


Figure 5: Corrugation process [7]

2.5.3 Folding methods.

- The folded honeycomb material and its production concept has been developed and patented by the K.U.Leuven. In Fig. 1 the folded honeycomb concept is presented as the synthesis of the honeycomb structure and the corrugated cardboard production principle. The inner structure of folded honeycombs is similar to conventional expanded honeycombs thus yielding excellent shear and flat-wise compression properties. Nevertheless, their production concept and their core-skin bonding concept are derived from the very efficient mass sandwich production technology of corrugated cardboard.[8]

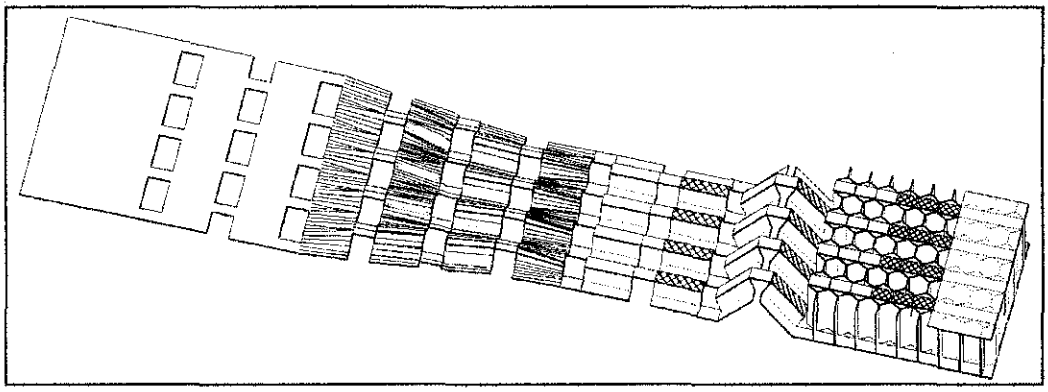


Figure 6: Folding process **[8]**

2.6 Cell Configurations

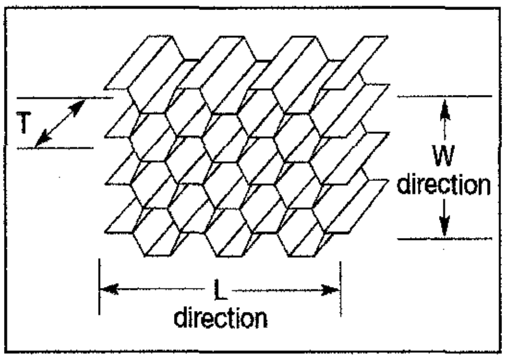


Figure 7: hexagonal core**[9]**

The standard hexagonal honeycomb is the basic and most common cellular honeycomb configuration and is currently available in all metallic and non-metallic materials.

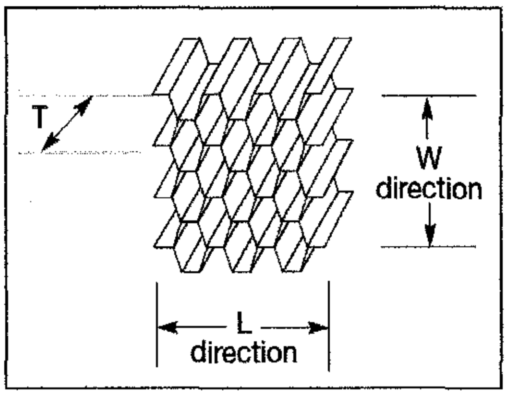


Figure 8: OX™ core**[9]**

The OX™ configuration is a hexagonal honeycomb that has been over expanded in the W direction, providing rectangular cell configurations that facilitate curving or forming in the L direction. The OX process increases W shear properties and decrease shear when compared to hexagonal honeycomb.

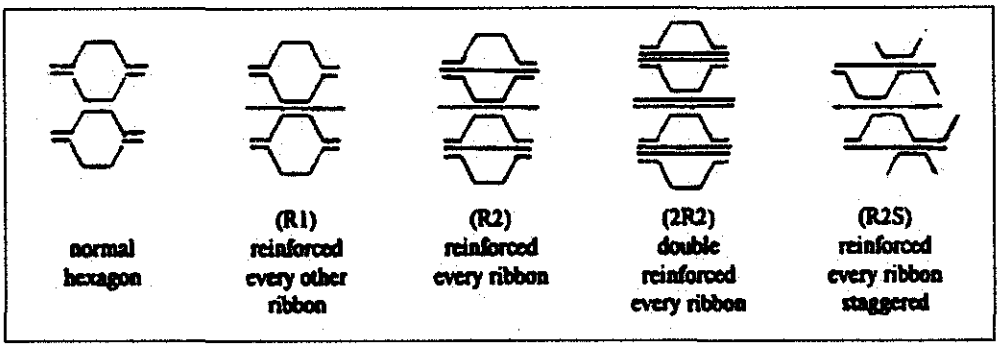


Figure 9 : Reinforced honeycomb[7]

- The reinforced honeycomb has a sheet or more substrate material placed along the nodes in the ribbon direction to increase the mechanical properties.

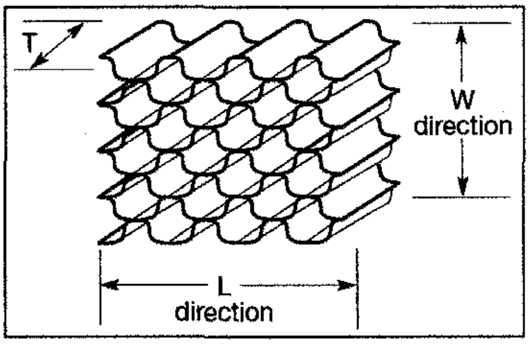


Figure 10 : Flex-Core ™[9]

The Flex-Core ™ cell configuration provides for exceptional formability in compound curvature and without buckling the cell walls. Curvature of very tight radii is easily formed.

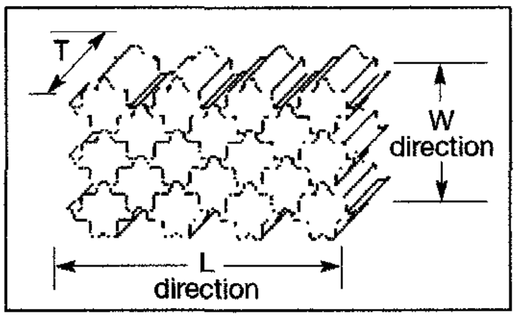


Figure 11: Double Flex[9]

Double Flex is a unique large cell Flex-Core for excellent formability and high specific compression. Double flex is the most formable cell configuration.

CHAPTER 3:

METHODOLOGY

3. METHODOLOGY

3.1 Material

3.1.1 Paper

- The main material is going to be used is waste paper which is an A4 paper. This material has been widely used and available in abundance in UTP specifically mechanical department. The paper grade may vary around 65 gsm to 80 gsm as we are aiming to use any available used A4 paper.

3.1.2 Paper glue

- The adhesive use for the node is paper glue (UHU) as it is very easy to handle and excellent bond between paper surface. UHU glue is Solvent-free and fast drying paper glue. It is environmental-friendly and bonds paper and cardboard without wrinkling paper

3.1.3 Shellac

- The shellac used for this FYP is GUITAR TONE 241 wood finisher which is available almost everywhere in hardware shop. It is a clear shellac used as the finisher of the last coating.

3.1.4 Wood (1x1/4x10 in)

- The woods were used to make the frame that acts as a temporary shape holder for the honeycomb core after the expansion process.

3.1.5 Steel nail (1 in)

- The nails were used as a place to hold the honeycomb core onto the jig set.

3.2 Project Planning- Gantt Chart (please refer to APPENDIX I and II)

3. 3 Testing Methods

3.3.1 Flat wise Compressive Test [10]

- The flat wise compressive strength and modulus are fundamental mechanical properties of sandwich cores that is used in designing sandwich a\panel. Deformation data can be obtained, and from a complete load-deformation curve it is possible to compute compressive stress at any load (such as compressive stress at proportional limit load or compressive strength at maximum load) and to compute the effective modulus of the core. Flat wise compression test ASTM C365-00 was being held in Block 17 using Universal Testing Machine (UTM) with the capacity of 5kN.

- **Test specimen**

According to ASTM, open-celled cores, having cores more than 6mm , minimum cross-sectional area is 5800mm^2. The numbers of samples are not less than 5. For this experiment, 5 samples are being used and the thickness of the cores is being preset as 1 cm. Below are the details of the honeycomb core:

Table 1: Honeycomb description

Specification	Description
Core material	Waste A4 paper
Bond adhesive	Paper glue
Coating	Shellac
Sample size	About $5800mm^2$

❖ **Specimen conditioning**

All the specimens were left in a conditioned room at 23 ⁰C at relative humidity of 65% for 24 hour before the test being carried out.

❖ **Procedure**

1. The length, width and thickness dimensions of the specimens were measured at the nearest 0.25mm using vernier calliper
2. Specimen weights were taken and specimen densities were calculated.
3. The UTM machine were being set as specification below

Table 2: UTM settings

Specification	Value
Preload	5N
Crosshead speed	0.5mm/min
Specimen height	About 10mm
Cross sectional area (sample)	About $5800mm^2$
Deflection stop at	4.0mm

4. Load-deflection curve were taken to determine the modulus of elasticity, proportional limit and maximum load.

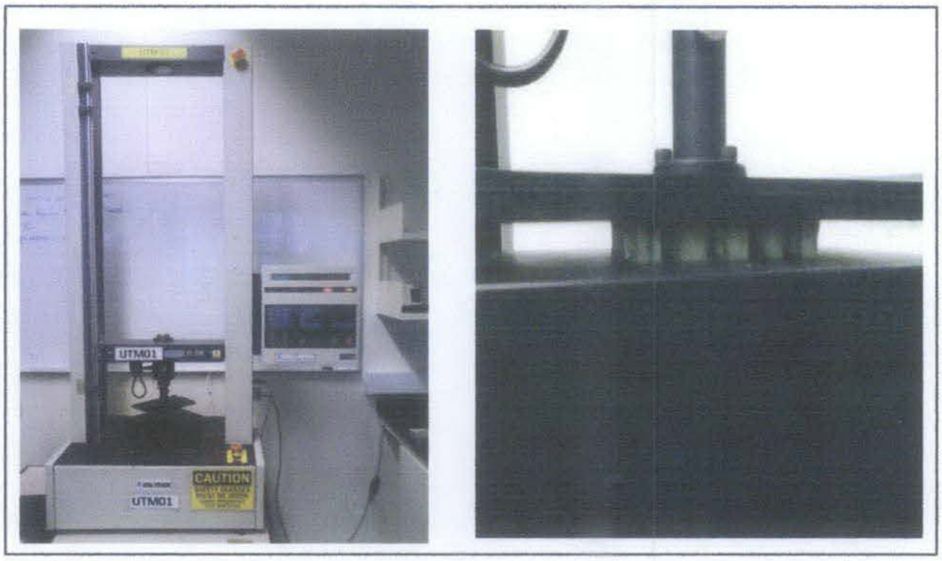


Figure 12: Compressive test

❖ **Calculation**

The flatwise compressive strength is calculated as follow:

$$\sigma = \frac{P}{A} \qquad (1)$$

Where:

σ = Core compressive strength, MPa (psi)

P = Ultimate load, N (lb)

A = Cross-sectional area, (mm^2)

The flatwise compressive moduli are calculated as follow:

$$E = \frac{St}{A} \qquad (2)$$

Where:

E = Core compressive modulus, MPA (psi)

S = (ΔP/Δu) slope of the initial linear portion of load-deflection curve, N/mm

U = displacement of loading block

T = core thickness, mm.

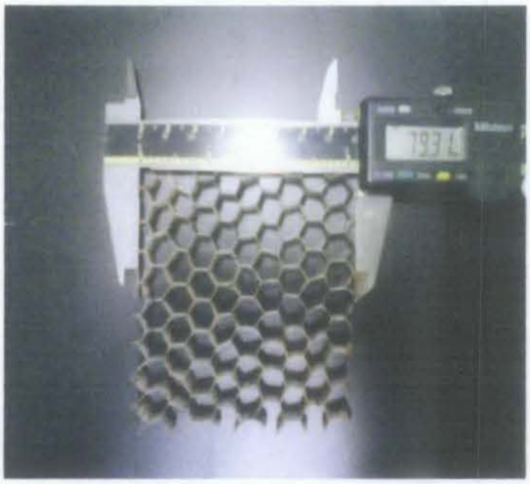


Figure 13: sample measurement

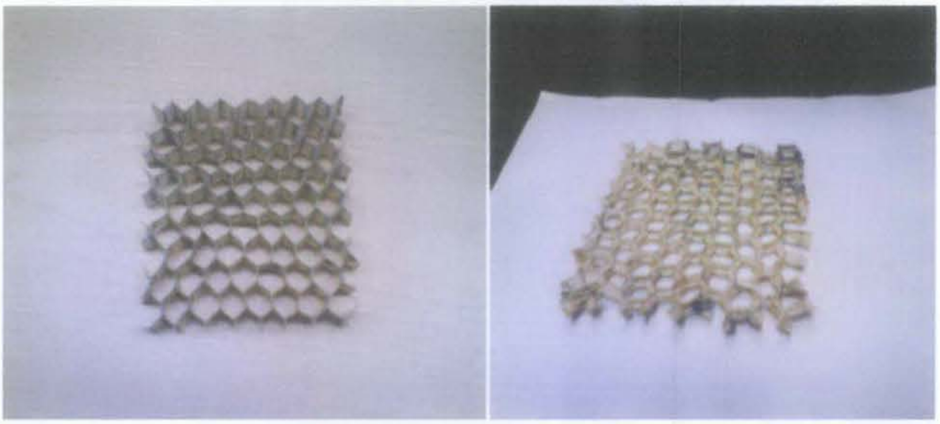


Figure 14: Sample before and after

Figure15: Sample weight in

3.4 Core development

- The core shape selected for this Final Year Project is hexagonal core. Hexagonal cells give minimum density for a given amount of material. **[11]** Besides that, hexagonal cells configuration can be produce using the expansion process which is the simplest way especially in the absence of proper automation and machinery. Other method maybe feasible and efficient to be done with proper tools as the university does not have that honeycomb machine, I am ought to choose the most feasible to create the core. With limited time, designing the machine or buying them would not be necessary.

3.4.1 Bare core trial 1 development

- The trial activity is using the expansion method where it is the simplest and easy. The trial development purpose was the test the adhesivity of the shellac towards the paper.

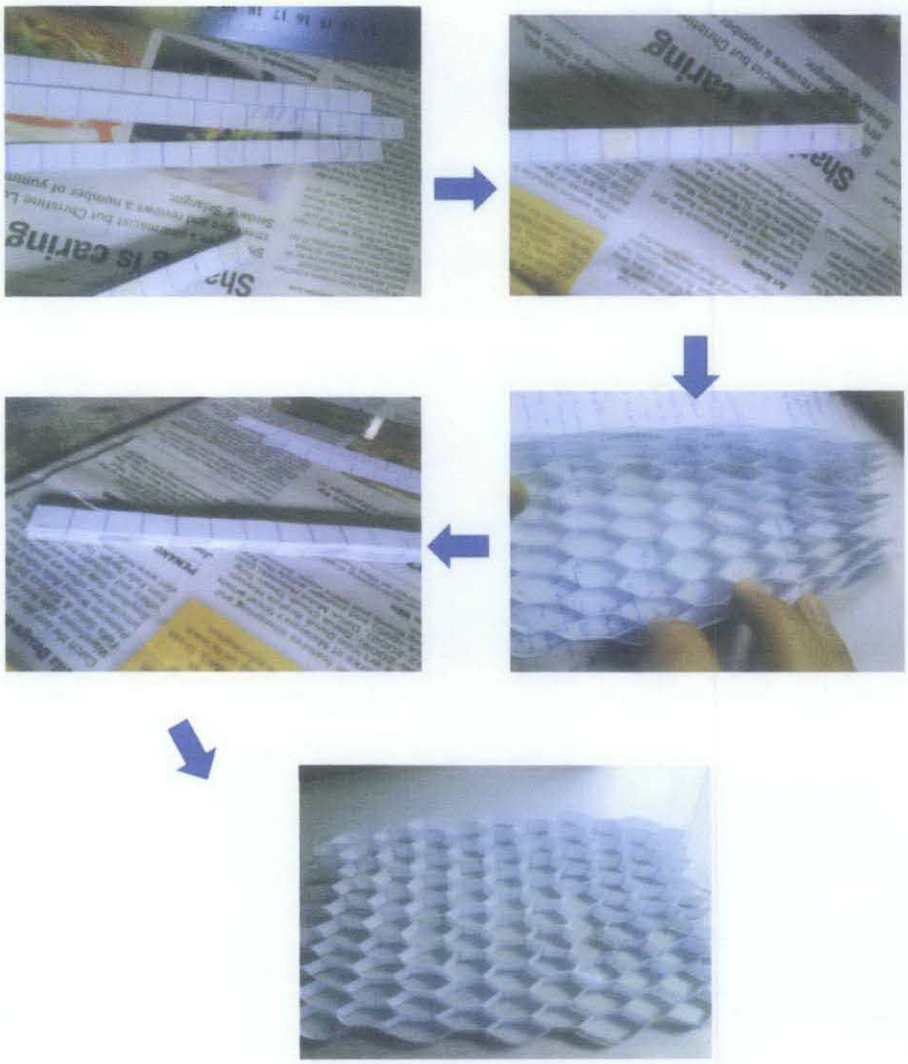


Figure 16: Trial development 1

Step 1- The paper is being cut to specific width.

Step 2- Adhesive is being applied at the marked node.

Step 3- The paper strips are being stacked together and cured.

Step 4 –The core is being expanded after it is fully cured.

3.4.2 Bare core trial 2 development

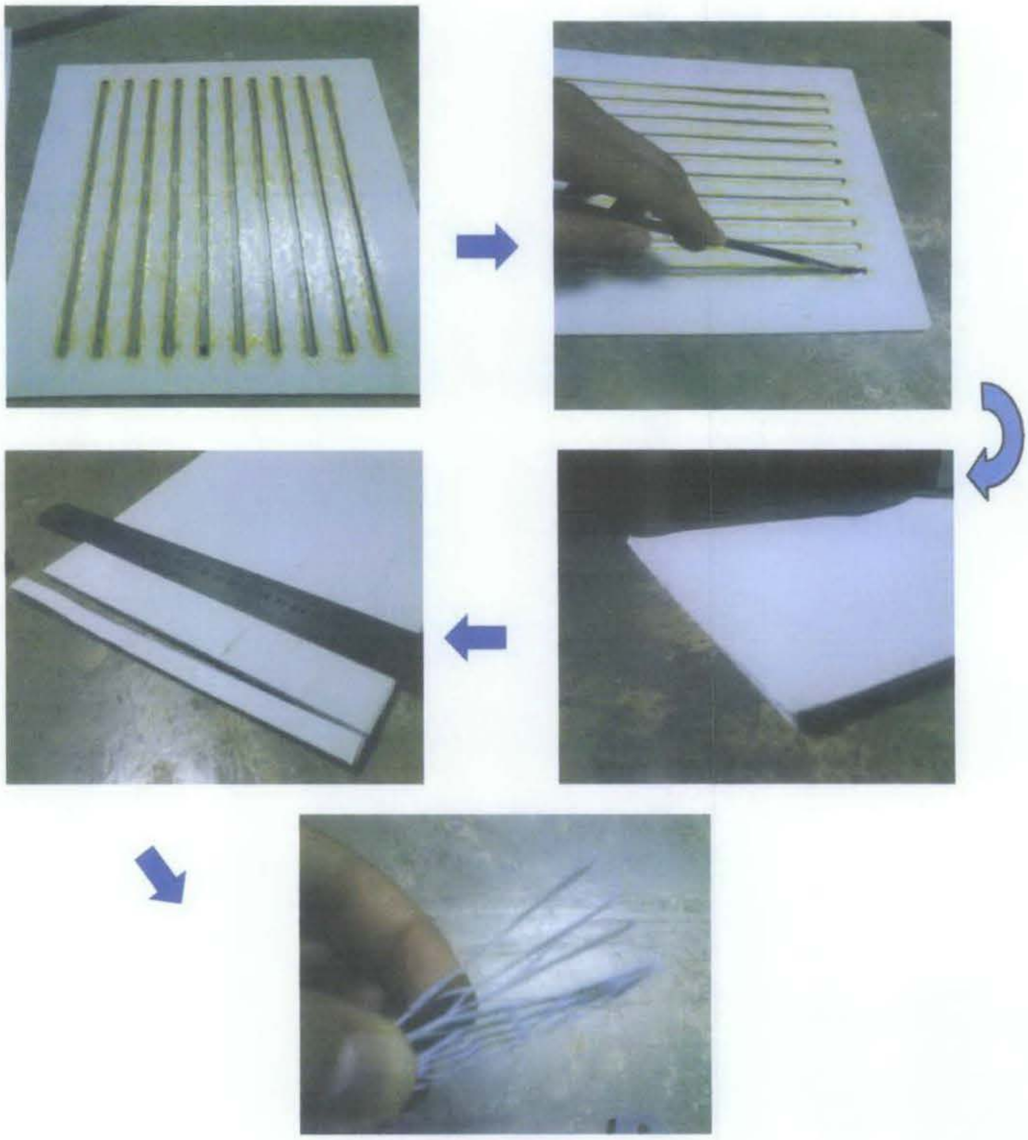


Figure 17 : Trial Development 2

Step 1- Two sets of gluing frame is being made

Step 2- A4 paper being put under the frame and shellac is being applies through the clearance.

Step 3- The glued A4 paper is being stacked together and cured.

Step 4 –Desired length of core is being cut out

Step 5- The core is expanded manually

3.4.3 Bare core trial 3 development

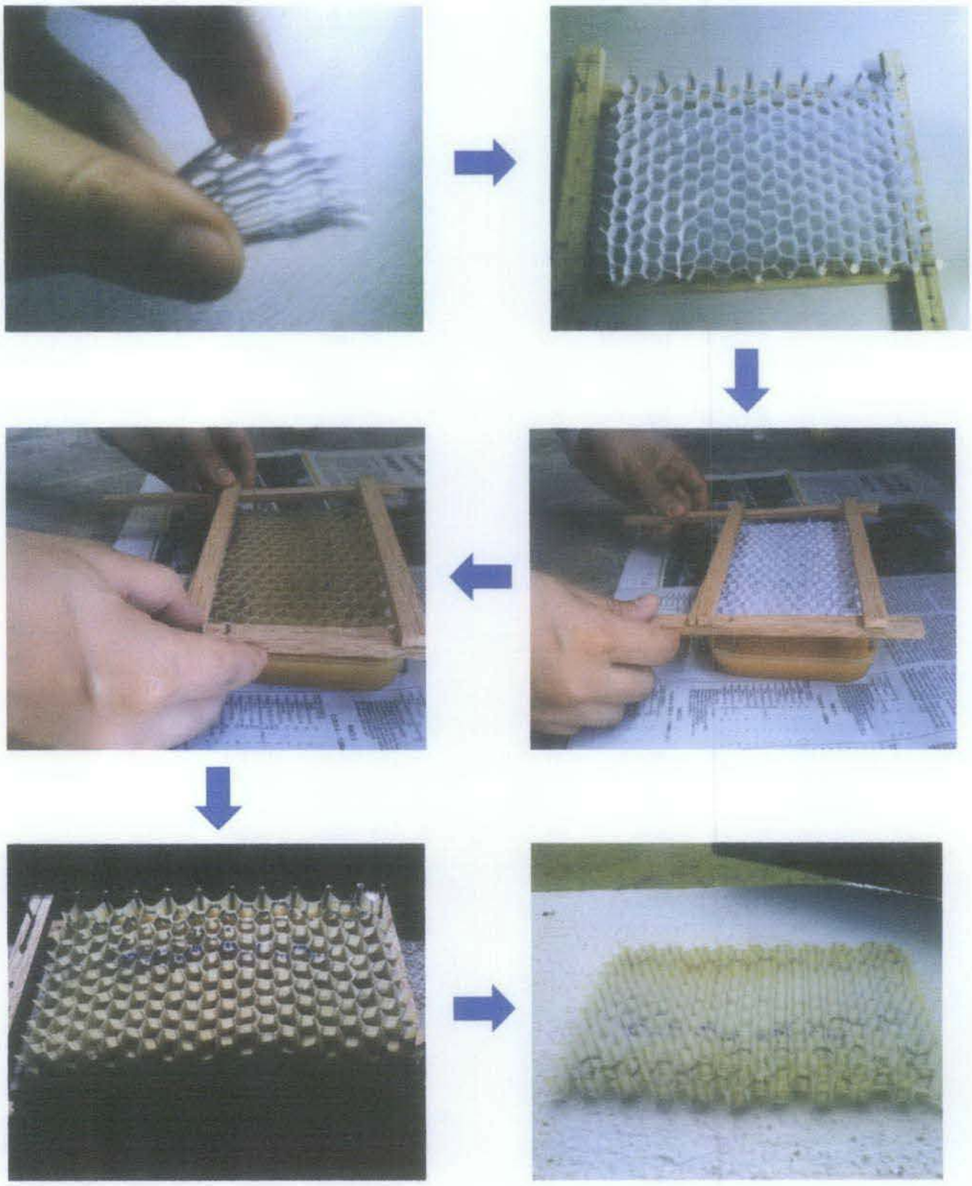


Figure 18: Trial Development 3

Step 1- A specific length of core is being cut out from the paper block

Step 2- The core is being expanded using designed jig to the calculated length

Step 3- The core is being dip into the shellac for coating

Step 4 – the shellac coating is being cure under the sun

Step 5- The core was detached from the frame jig.

❖ **Frame jig**

In order to evenly expand and create a proper hexagonal core, a expansion jig need to be design. In making this jig, many calculation is being made before hand to ensure an even core expansion. The jig is being made from wood and nails which assist in holding the core during the expansion process. Below are the calculation and consideration done:

Assumption:
The core is being made using the width of a normal A4 size paper which is 21 cm. Other parameters are being assumed to ease the initial calculation.

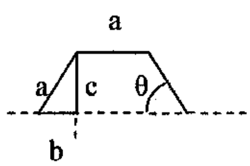
- Node/section length = 5 mm
- Cell width : 15 mm
- Thickness(t) : 0.097 mm (from table)
- Gap between cells = 5 mm
- $\theta = 60$
- a = 5 mm

Theoretical calculation (before expansion):

Thickness (T) = numbers of layers x paper thickness (3)

Theoretical calculation (after expansion);

Width



$b = \cos\theta\, a$ (4)

one cell width after expansion:

$w = 2b + a$ (5)

Core width after expansion:

W= 10(number of cells) x 5(numbers of gaps) (6)

Height

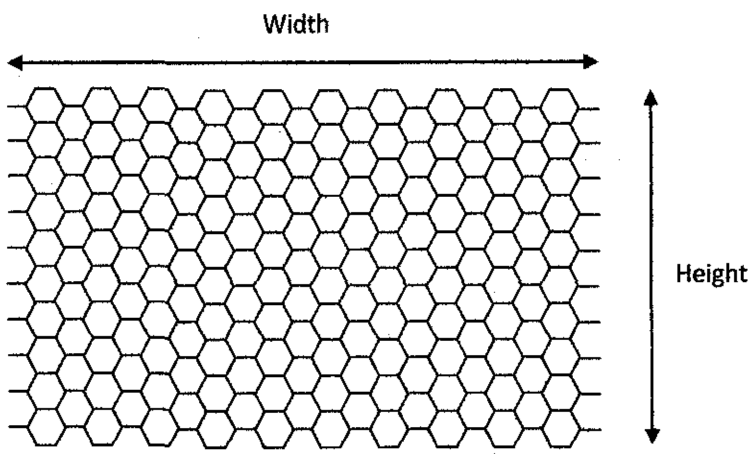
$c = \sin\theta\, a$ (7)

single cell height (2 layer):

$h = (c \times 2)$ (8)

overall core height:

H= (c x numbers of layers) + (t x num of layers) (9)



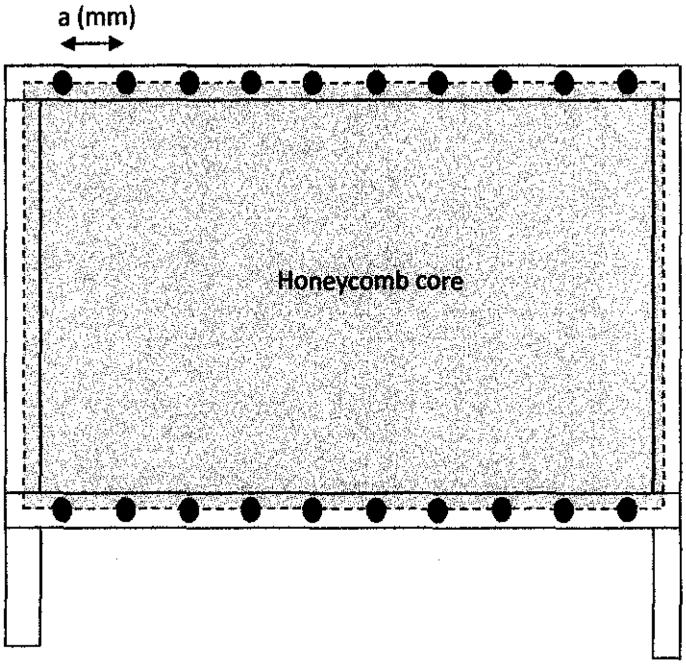
❖ **Jig design**

The frame jig is made from wood and nails. The nails functions as the holder for the honeycomb core. The nails are being placed accordingly at the centre of the node as being calculated.

The distance between nails:

a = expanded width/ num of node (10)

Jig assembly



- **Honeycomb Density (HD)**

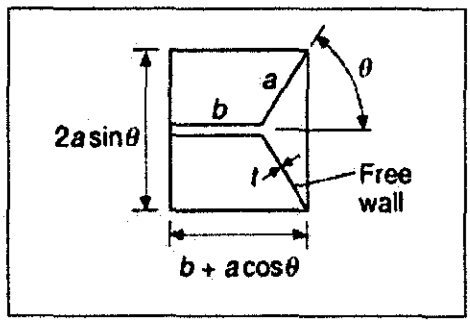


Figure 19: Honeycomb density [12]

a = free wall length

b = node width

θ = expansion angle

t = web thickness

ρ = web density

$$HD = \frac{2(b+a)t\rho}{(b+acos\theta)(2asin\theta)} \quad (11)$$

3.4.4 Final development

- **Core making**

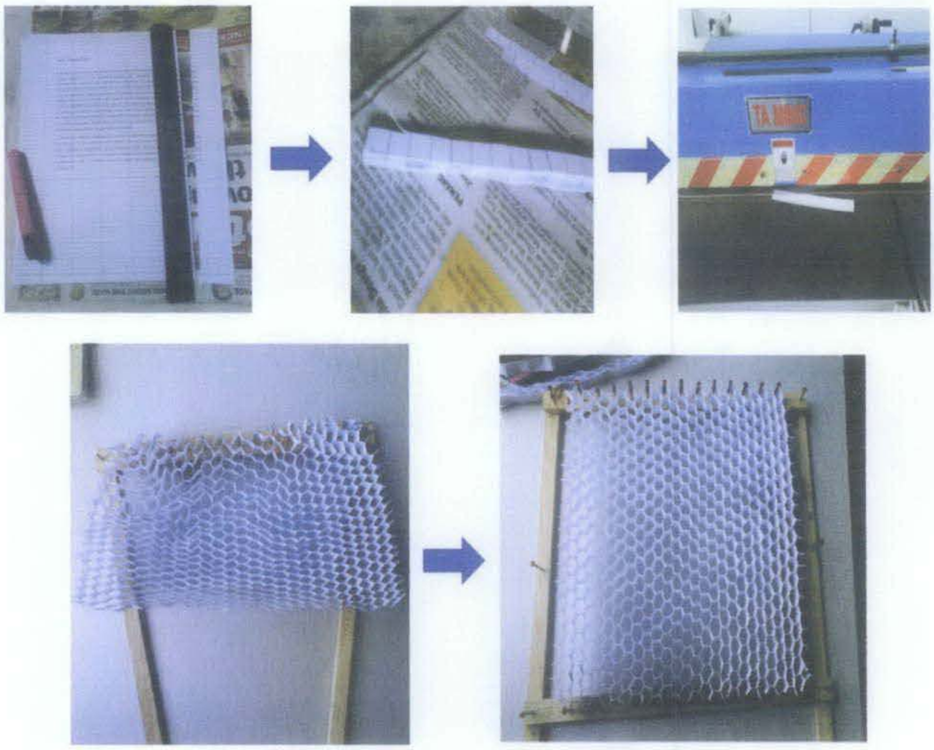


Figure 20 : Final core making

1. Paper is being outlined and **cut**
2. Strips of paper being **glued** at specific nodes ,**stacked up** and being cured.
3. Using pressing machine, the paper block being **cut** to specific width.
4. The core is being **expanded** onto the designed jig.
5. Both sides of the jig being assembled and fix into place.

❖ **Coating**

Figure 21: Coating process

1. The expanded core being coated with resin (shellac)

❖ **Drying**

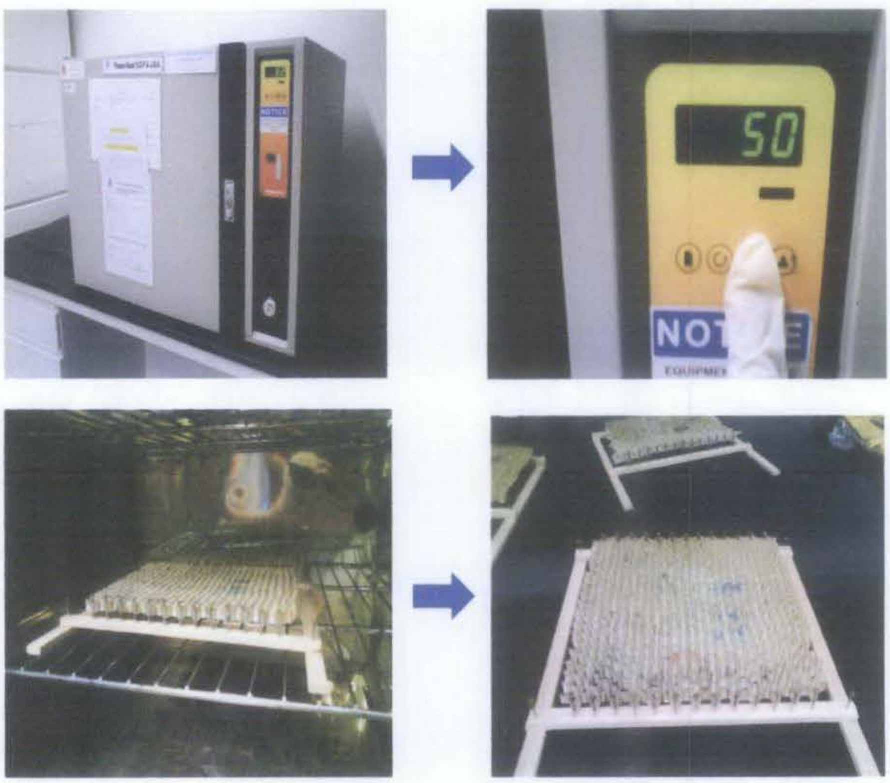


Figure 22: Dring process

1. Oven in block 17 is being used for drying process
2. Three different temperatures is being set.
3. Few samples are being cure at the same time
4. The sample is ready

CHAPTER 4:

RESULT AND DISCUSSION

4. 1 RESULT

4.1.1 Honeycomb core dimensions (theoretical):

- Based on the first trial development using formulae:

Table 3: Honeycomb core dimension

Trial	Initial width (cm)	Final width (cm) (6)	Numbers of layers	Initial height (mm) (3)	Final height (mm) (9)
Third	21	15.5	20	1.94	87.94
Final	29.7	20	40	3.88	175.88

- Based on formula (8) and (11), we were able to calculate the cell size honeycomb density (HD) Which are 8.6mm,23.8 kg/m^3 respectively.

4.1.2 Honeycomb drying temperature and time

Table 4: Drying temperature and time

Temperature (^{0}C)	Time (minute)
40	35
50	25
60	15

4.1.3 Flatwise compressive testing results (refer APPENDIX III)

Table 5: Standard deviation compressive strength

Standard deviation compressive strength			
Sample	HC40	HC50	HC60
1	0.348645	0.349429	0.356562
2	0.33975	0.303908	0.332578
3	0.347515	0.348942	0.285009
4	0.3281	0.358471	0.399797
5	0.310036	0.32619	0.385324
Average	0.334809	0.337388	0.351854
Standard deviation	0.016093	0.022188	0.045499

Table 6: Standard deviation compressive modulus

Standard deviation compressive modulus			
Sample	HC40	HC50	HC60
1	5.759985	6.198079	5.350464
2	4.789651	4.442623	5.659798
3	4.778046	5.999903	4.762981
4	5.584883	6.571992	10.90979
5	6.499136	6.121467	7.237372
Average	5.48234	5.866813	6.784081
Standard deviation	0.724107	0.824302	2.481484

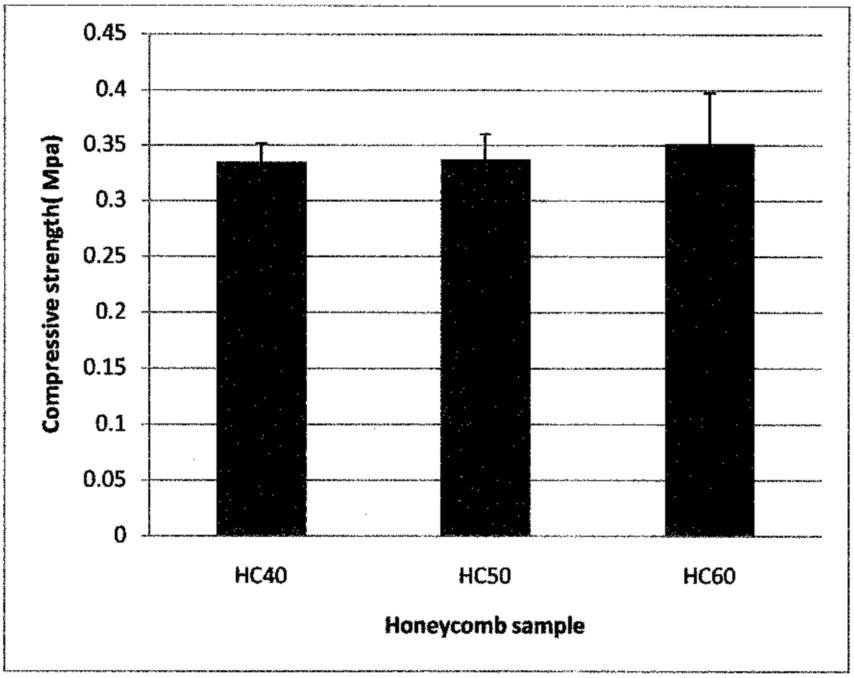


Figure 23: Standard deviation (compressive strength)

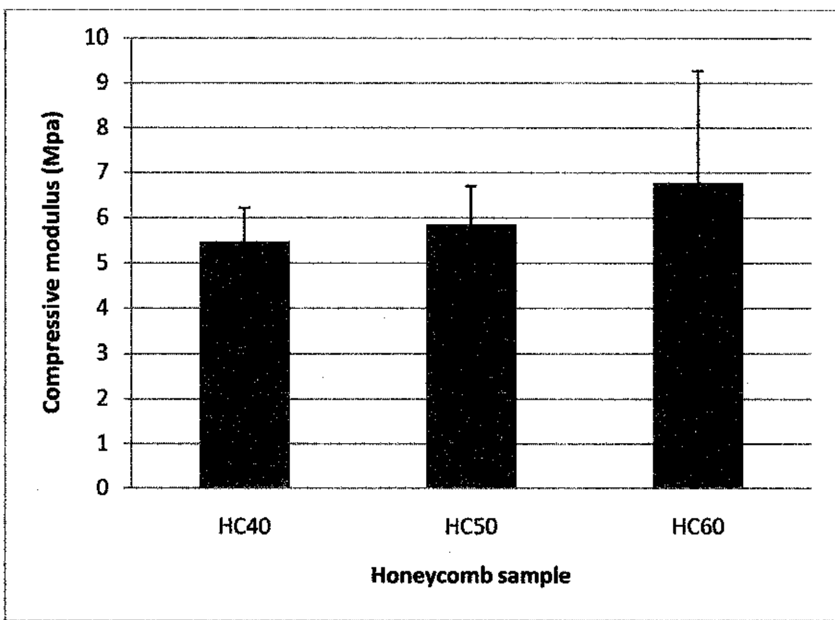


Figure24: Standard deviation compressive modulus

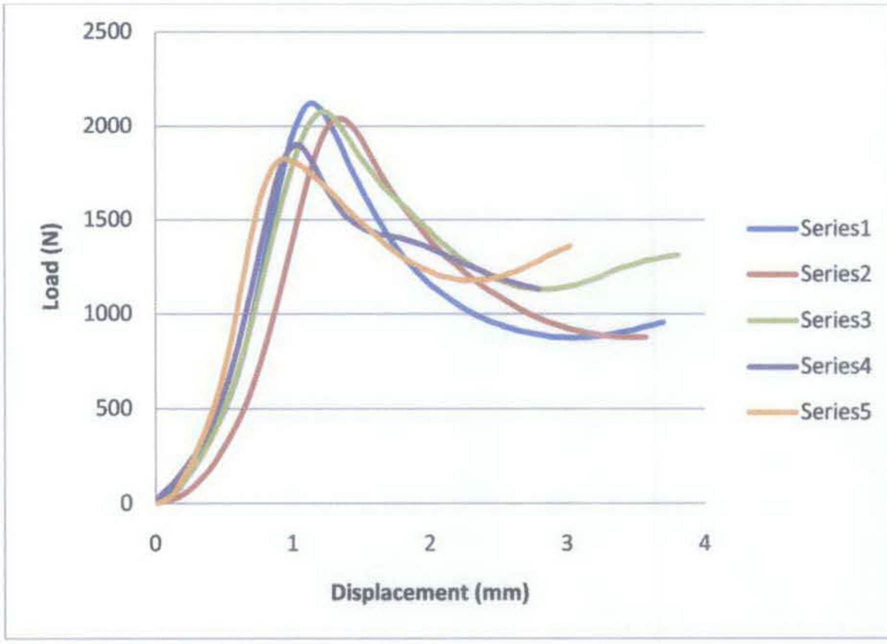


Figure 25: Load versus displacement (HC40)

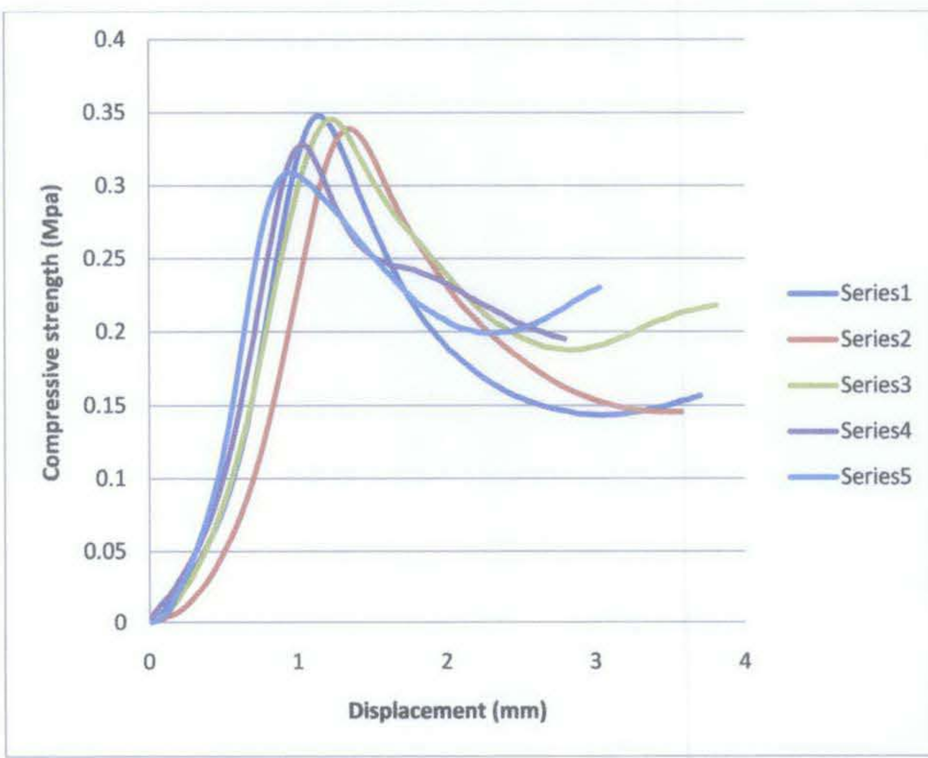


Figure 26: Compressive strength versus displacement (HC40)

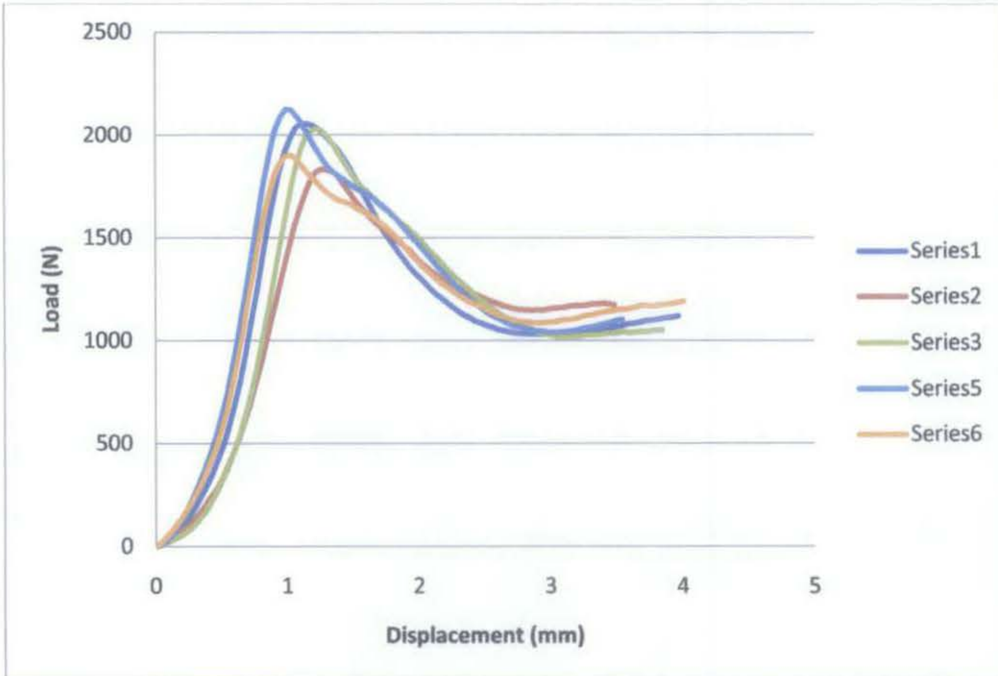


Figure 27: Load versus displacement (HC50)

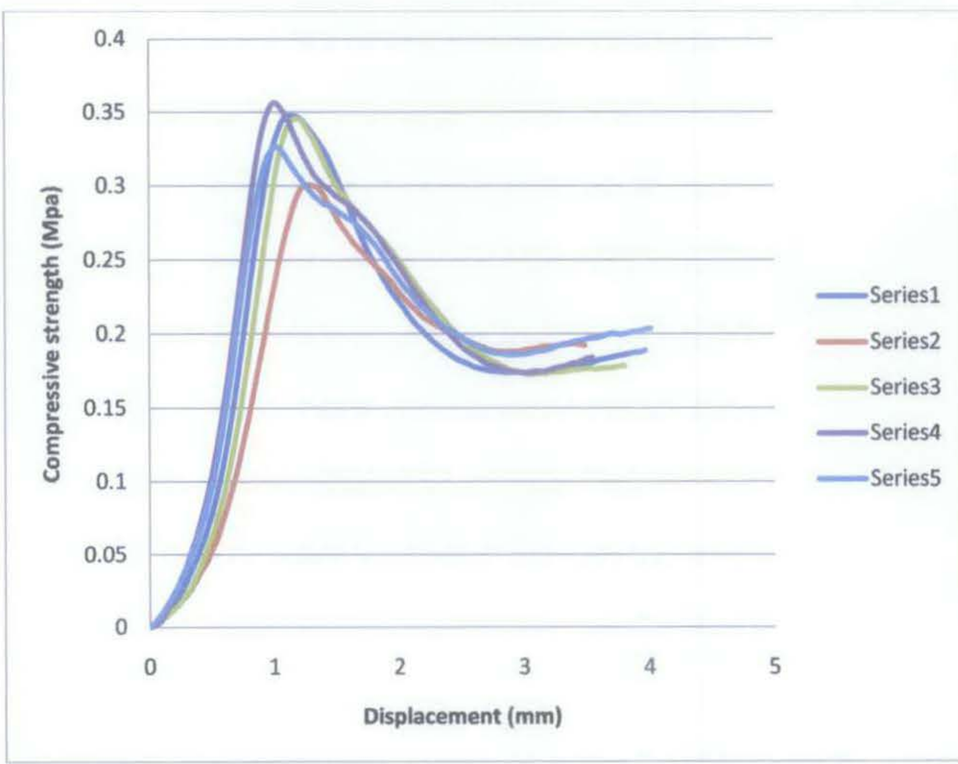


Figure 28: Compressive strength versus displacement (HC50)

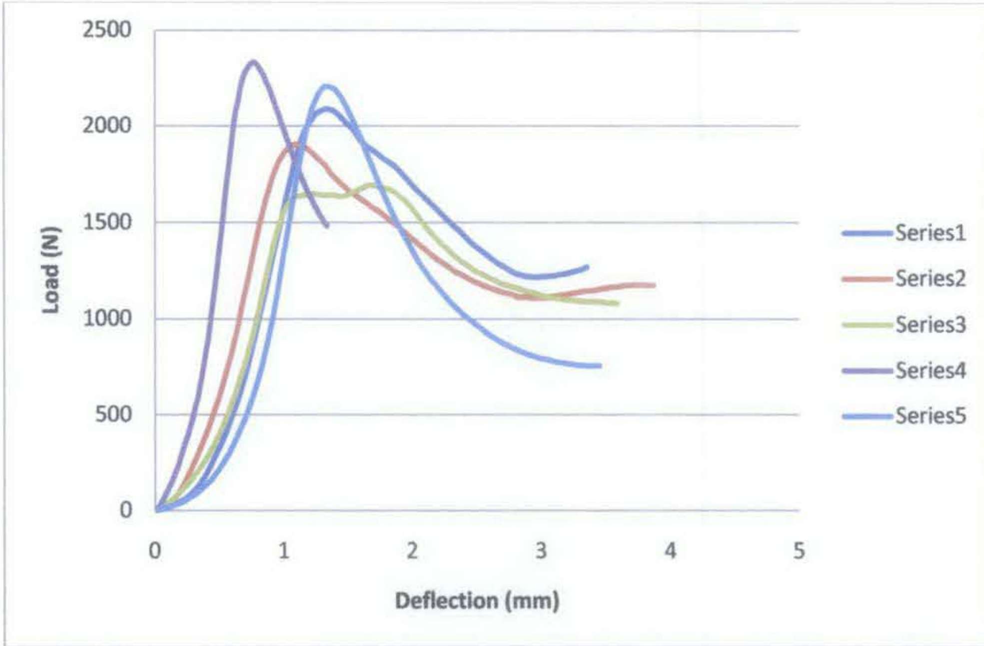


Figure 29: Load versus displacement (HC60)

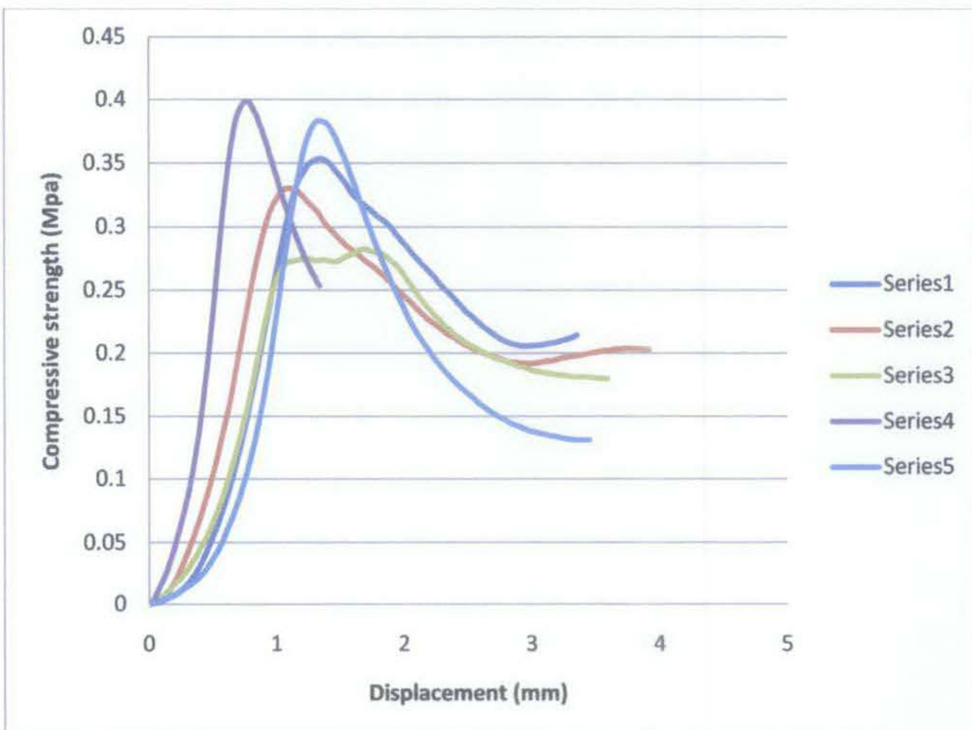


Figure 30: Compressive strength versus displacement (HC60)

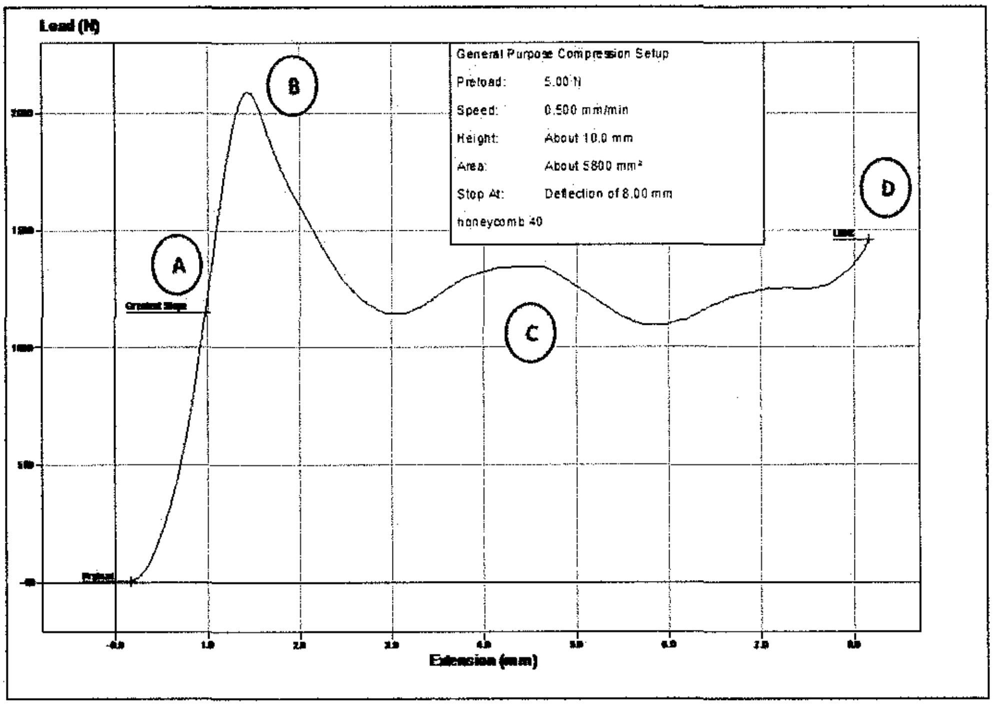


Figure 31: Load versus Displacement

Table 7: Comparison data

Type	Compressive strength (MPa)	Compressive modulus (MPa)
HC40	0.334809	5.48234
HC50	0.337388	5.866813
HC60	0.351854	6.784081
A1-23-6 **[13]**	0.7	41
ATL paper core **[14]**	0.9	-
PK2-1/8-3.0**[15]**	2.17	-

4.2 DISCUSSION

4.2.1 Core development

Trial development1

- An A4 paper is being outline with pen to create a specific row in order to create a border area for gluing purposes. After that, the paper is being cut into specific length which is 1 cm. For this trial, only one A4 paper is being used. These paper strips were then being glued with shellac using paint brush on specific node pattern which will be alternate on the next strips. These strips were then being stacked together and cured. Finally, the core is expanded manually.

- Throughout the process, there are several problems faced especially in handling the shellac. This is due to the viscosity of the shellac which varies with time when exposed to open air. As a result, the nodes were glued unevenly and resulted in producing uneven hexagonal honeycomb core when expanded. The gluing methods were to be improved in the future trials.

Trial development 2

- A set of gluing frame was being made in order to introduce automation and to increase the accuracy of the node. This can be done as the gap between the slots are being measured which will allow the gluing process in a certain area. In addition, the frame also eases the process of determining the distance of each node. After that, an A4 paper is being placed under the frame accordingly. This trial also uses the whole A4 paper without cutting it into a specific length. Next, the shellac is being applied onto the paper using brushes through the gap. The sets continue alternately with a different frame. The glued A4 paper are being stacked together and cured. Later, desired thickness can be cut out from the paper block and expanded manually.

- ❖ This new technique raise another problem where the shellac tends to spread out trough the paper as the shellac has a lighter viscosity at first. The problem faced is similar to the previous trial problem. The shellac consists of solvent and resin. The solvent will evaporate when given enough time leaving the resin to create bond between surfaces. Thus, in the first contact of the low viscosity shellac, the solvent will absorb inside the paper and leave only small amount of resins on the surface. As a result, weak bond between nodes are created which causes it to fail. Another problem that rises was that when the gluing process of the last slot end, the first slots dries out. This also contributed to the failure of the nodes when the core being expanded.

Trial development 3

- ❖ The method of gluing is similar to trial 1 and the only difference is the node size and the paper strips. Firstly, the A4 paper is being outlined before being cut out into 3 cm paper strips. Next, the shellac is being applied onto specific nodes as the same procedure in trial 1. After that, the paper strips is being stacked and cured. A desired length which is 1cm is being cut out from the stacked paper block. Using the designed jig, the core is being expanded and secured in place. The core is being heat treated by exposing to the sun to reduce the stress on the paper during the expansion process. The core is being dipped into the shellac once and cure under the sun. Finally, the core is being detached from the frame jig.

Final development

- ❖ The procedure for this trial is maintained as per trial development 3 except that instead of the width of the paper, the height of the paper being used to produce the honeycomb core. Referring to table 3, this will provide maximum width possible to produce the core without extending or modifying the size of the A4 paper. A bigger frame jig also being made to match the size of the honeycomb core.

- Another improvement that being used in this final development is the use of paper glue in bonding the nodes as it is easier to handle paper glue in the gluing process. However, the coating material is maintained, as shellac provides excellent coating which will improves and seals the paper core.

- The flatness of the surface of the core is vital during the flatwise compression test because the uneven surface may lead to stress point of the core which will cause failure in the future. The core was made with a certain thickness which needs to be cut out layer by layer in order to produce a flat surface. The cutting process was done using cutter machine in Block 21

- A more consistent method of drying being used instead of normal aspirated atmospheric drying method. Oven is being heated to a set of temperature and the coated samples were placed in it for drying process. The dying time improves significantly compared to the normal drying method.

Honeycomb core size

- As mentioned before in the improvement from trial development 3 to final development, the height if the paper is being used instead of the width of the paper. Thus, the maximum width of honeycomb core producible without modifying the original A4 paper is 20 cm. The height of the core can be extended to desired height as it is continuous in that direction.

Core drying temperature and time

- From table 4, the curing time varies for each temperature. The fastest drying time is with 60^{0}C. Proper curing will affect the strength of the coating. The effects of the curing temperatures were observed.

4.2.2 Experimental Data

Load versus displacement graph

- Based on the figure 31, the label A show the area where the compression slope is. This is where the compression load increases with displacement. The load increases until the peak value or maximum load at label B. Once the core losses its strength, it will start buckle and fail with displacement. However, at label C, there is a fluctuation value of load occurs. This is due to the buckling and crushing effect of the core. It will to continue to fluctuate until its buckling limit at label D. This is where the load will continue to increases exponentially indicating it is already fail. This usually happens after 70-80% of the thickness displacement.

Honeycomb core 40°C

- Table 6 indicated the maximum compressive strength for Honeycomb 40°C batch is 0.348 MPa and the average is about 0.335 MPa which is the lowest amongst the batches. The maximum compressive modulus is about 6.50 MPa with an average of 5.48MPa The graph (figure 26) shows the variation of compressive strength with displacement of each sample. The standard deviation for honeycomb 40 is smaller when compare to other batches. This indicates that the samples compressive strength are rather consistent.

Honeycomb core 50°C

- The maximum compressive strength of honeycomb 50°C batch is about 0.36 MPa with an average of about 0.34MPa which is higher compare to honeycomb batch 40°C. Table 7 also indicates the maximum compressive modulus value achieved which is 6.57 MPa with an average of about 5.87MPa which further clarify that these batches have higher strength compared to honeycomb 40°C batch. Figure 28 shows the detailed graph for each specimen for the batch. The standard deviation of this batch also small and consistent which means that the data gained are reliable.

Honeycomb core 60^oC

- These batches have the highest maximum compressive strength which is about 0.4 MPa with an average of 0.35MPa. Furthermore, these batches have the highest compressive modulus 10.9 MPa with an average of 6.78MPa. Figure 30 shows the compressive versus displacement graph for each sample. The graphs shows that the samples graph curves varies more compare to other batches. This is being confirmed with the higher value if standard deviation in figure 23,24. The batches may have higher strength, but the data gained are less consistent compare to others.

Result comparison

- Based on the product datasheet ([12],[13],[14]), we compare the compressive strength and compressive modulus to the nearest matching specification. The strength of the paper core is either half or a third from reaching the commercial product strength. Further improvement must be done in the future.

CHAPTER 5:

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

- Honeycomb development and testing project has been successful. Base on the data gained, we can conclude that higher drying temperature can produce higher strength core. However, honeycomb 60^{0}C batches are inconsistent and there is a possibility that the sample strength are equivalent with the other two batches. Despite that, honeycomb core 60^{0}C batches still requires less time to cure which makes it the best candidates for future improvement.

- The comparison between data in table 8 shows that the honeycomb core made from used A4 paper is yet need to be improved to meet the commercial standard grade.

5.2 RECOMMENDATION

- Automation should be introduced to the process in the future to produce a better product and to ease mass production. Automation can be introduced especially in gluing and stacking process where the precision of a robot is needed to produce precise hexagonal honeycomb core.

- Resin coating can be further improved in the future. This can be done by coating the paper core with different types of resins. Shellac coating can also be improve by using a thinner shellac to evenly coats the paper surface and double coat the paper core to further strengthen the core.

- ❖ More testing such as delamination test, tensile test and water absorption test should be done in the future to further investigate more on the paper honeycomb core properties.

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APPENDIX I

FYP I

Task	1	2	3	4	5	6		7	8	9	10	11	12	13	14
Selection of topics															
Preliminary research work															
Submission of preliminary report				★											
Development bare core															
Submission of progress report									★						
Seminar									★						
Apply testing on bare core															
Development of coated core															
Submission of the Internim Report															★
Oral presentation								During Study Week							

Current progress   Future progress

APPENDIX II

FYP 2

Development of coated core															
Submission of Progress Report 1				★											
Apply testing on coated cores															
Submission on Progress Report 2									★						
Seminar (compulsory)									★						
Improvement of the developed cores															
Final testing															
Poster exhibition												★			
Submission of the dissertion (final)															★
Oral Presentation								During Study Week							
Submission of the dissertion (hard bound)								7 days after oral presentation							

Current progress   Future progress

APPENDIX III

Sample	Batch	Weight (g)	Area (mm^2)	Thickness (mm)	Volume (mm^3)	slope (N/mm)	max load (N)	compressive strength (MPa)	compressive modulus (MPa)	Density (kg/m^3)
40	1	3.071	6100.257	9.97	60819.56229	3524.312	2126.824	0.348644983	5.759985	50.49362219
	2	2.7055	6024.816	9.93	59826.42288	2906.019	2046.932	0.339750127	4.789651	45.22249317
	3	2.975	6015.98	9.99	60099.6402	2877.34	2090.643	0.347514989	4.778046	49.50112829
	4	3.046	5794.56	10.2	59104.512	3172.739	1901.193	0.328099584	5.584883	51.5358286
	5	2.98	5905.904	10.15	59944.9256	3781.603	1831.045	0.310036311	6.499136	49.71229792
50	6	2.7408	5918.211	9.92	58708.65312	3697.736	2067.997	0.349429387	6.198079	46.68477055
	7	2.6348	6090.86	10.45	63649.487	2589.416	1851.059	0.303907634	4.442623	41.39546325
	8	2.7742	5884.184	10.33	60783.62072	3417.67	2053.238	0.34894178	5.999903	45.64058487
	9	2.7738	5976.675	9.99	59706.98325	3931.798	2142.464	0.358470889	6.571992	46.45687739
	10	2.855	5834.792	9.85	57472.7012	3626.141	1903.25	0.32618992	6.121467	49.67575806
60	11	3.163	5911.801	10.69	63197.15269	2958.922	2107.923	0.356561921	5.350464	50.04972321
	12	2.8179	5766.465	10.73	61874.16945	3041.661	1917.799	0.332577997	5.659798	45.5424295
	13	2.8571	5999.136	10.11	60651.26496	2826.288	1709.81	0.285009351	4.762981	47.1070142
	14	3.44	5849.004	10.65	62291.8926	5991.68	2338.414	0.399797028	10.90979	55.22387997
	15	3.07	5762.318	10.44	60158.59992	3994.64	2220.361	0.385324316	7.237372	51.03177275

APPENDIX IV

-- Bond Ledger	- Offset Text	- Cover -	-- Tag --	- Index -	- Points -	- *Caliper (inches)	-- millimeters --	- Metric (grams/sq meter)
16	40	22	37	33	3.2	.0032	0.081	60.2 gsm
18	45	24	41	37	3.6	.0036	0.092	67.72 gsm
20	50	28	46	42	3.8	.0038	0.097	75.2 gsm
24	60	33	56	50	4.8	.0048	0.12	90.3 gsm
28	70	39	64	58	5.8	.0058	0.147	105.35 gsm
29	73	40	62	60	6	.0060	0.152	109.11 gsm
31	81	45	73	66	6.1	.0061	0.155	116.63 gsm
35	90	48	80	74	6.2	.0062	0.157	131.68 gsm
36	90	50	82	75	6.8	.0068	0.173	135.45 gsm
39	100	54	90	81	7.2	.0072	0.183	146.73 gsm
40	100	56	93	83	7.3	.0073	0.185	150.5 gsm
43	110	60	100	90	7.4	.0074	0.188	161.78 gsm
44	110	61	102	92	7.6	.0076	0.193	165.55 gsm
47	120	65	108	97	8	.0078	0.198	176.83 gsm
53	135	74	122	110	9	.0085	0.216	199.41 gsm
54	137	75	125	113	9	.009	0.229	203.17 gsm
58	146	80	134	120	9.5	.0092	0.234	218.22 gsm
65	165	90	150	135	10	.0095	0.241	244.56 gsm
67	170	93	156	140	10.5	.010	0.25	252.08 gsm
72	183	100	166	150	11	.011	0.289	270.9 gsm
76	192	105	175	158	13	.013	0.33	285.95 gsm
82	208	114	189	170	14	.014	0.356	308.52 gsm
87	220	120	200	180	15	.015	0.38	312 gsm
105	267	146	244	220	18	.0175	0.445	385.06 gsm