# Parameter Design Optimization Of Straight Bow Limb By Implementing Honeycomb Sandwich Structure To Increase Projecting Performance Using The Taguchi Method

1st Farras Burhanuddin Prihandoko
*Telkom University*
*Faculty of Industrial Engineering*
Bandung, Indonesia
farrasbp@student.telkomuniversity.ac.id

2nd Rino Andias Anugraha
*Telkom University*
*Faculty of Industrial Engineering*
Bandung, Indonesia
rinoandias@telkomuniversity.ac.id

3rd Teddy Sjafrizal
*Telkom University*
*Faculty of Industrial Engineering*
Bandung, Indonesia
teddysjafrizal@telkomuniversity.ac.id

**Abstract**

**Good performance bow limb can be acknowledge by the ability of the limb to store energy that will be transforms into kinetic energy for the arrow to be projected. Bow limb structure that made of sandwich of layered structures desired to be light in weight but also high in strength because it is use by human and bends every time and it can not break while it being used. In search for an alternative design for a bow limb, recent studies in Bio-inspired design of honeycomb shows remarkable mechanical performance of the hexagonal honeycomb that promotes a lighter structure while high in strength and have good energy absorption ability that already vastly used in many engineering applications. Hence, honeycomb sandwich structure limbs were made with several variety of parameter factors and levels. Using Taguchi method as an optimization method in order to design and to know the optimized design of honeycomb setup of honeycomb sandwich structure bow limb. Strain energy of each 18 samples were obtained using a 3-Point Bending Test simulation using ASTM D7250 as testing reference on ANSYS static structural. Non-Parametric statistical test was done to obtain which factors is the most significance to the design and use to determine. The results of this study may eventually contribute to the alternative bow limb designs.**

**Keywords: Bow Limb, Honeycomb Sandwich Structure, Taguchi Method, 3-Point Bending, Non-Parametric Test**

## I. INTRODUCTION

Recent developments in the field of athletic sports have led to a renewed interest in advancing the technology of designing sport equipment. Over the past decade there have seen a growing trend in archery and it followed by the development of bow and arrow[1]. Along with the development in the industry of bow manufacturing increasingly competing to make bow designs with better quality. Another reason that development of the bow is always need an improvement is that for many years of the invention of bow and arrows, these equipment were used by human to hunt and sport by hands. Hence, human ability to draw the bow is the only primary input to operate the bow and the fact that human is projecting an arrow using the whole body function as an energy source is turned into causing several injuries and health problem such as blisters on fingers, wrist injuries, shoulder injuries, hand injuries, neck and back injuries [2]. Since archery is a sports that requires strength and endurance of the upper body, arms, and shoulder girdle the typical movement need to executed with high precision in order to get the perfect quality of projecting performance result [3]. This can be caused by several factor it can be human factor and the tool factor or in this case the bow itself[4]. Since the rule of archery competition is every athlete must use the same specification of the bow so it can be said that the use of the bow is essential for this sport[5]. Hence, the bow can always be improve in order to ease the athlete and minimize the injury factor from the archery sport and competition. To dig more about what and how a bow can be improve, there are several problem statement of a bow product design. Performance goal of the bow and arrow are the ability of the bow limb to store the maximum energy during the draw of the bow string. Smoothness of the draw is indicated by the draw weight material, therefore the bow expected to be strong enough to hold the weight of its own draw. Stability is one of the key factor of bow draw success, stiffness roles on the aspect of maintaining the stability of the draw. Physical weight of the whole set of bow and arrow are affecting the easiness to use the bow, and lastly lower stress distribution is indicating a good robustness and durability of the bow arrow product[6]. As such, projecting performance of a bow is characterized by its ability to store energy. It is difficult to find a single material that provides sufficient strength under high degrees of both tension and compression. The use of reinforcement in the limb part has been shown to be able to increase the projecting a of a bow, coupled with the selection of the right material and the right manufacturing method can also produce good quality bow and increase the projecting performance. However, the use of reinforcement in the limb is limited and one of the major problem with the application is that there lacks of study on what parameters can be used to improve the reinforced limb design. Honeycomb sandwich structure is one of the most broadly used bio-inspired design, countless study on mechanical advantages, improved structure properties, and the successful applications of the design itself creates a promising alternatives to even developing the honeycomb sandwich structure even more. The needs for improvement on bow limb reinforced design met with the characteristic advantages of the honeycomb sandwich structure. The use of honeycomb structures are known to be able to enhance the need of a lightweight, more effective efficient structural structures that provide high strength and rigidity in tandem with low structural weight. The aim of this study is to find out more about geometry design parameters to maximize the projecting performance of bow limb using honeycomb sandwich structure.

## II. RESEARCH METHODOLOGY

### a. Procedure

The conceptual model is a diagram that illustrates a number of relationships between some factors affecting or leading to a target condition. The aim of creating this model is to include guidelines for the implementation of standardized studies. Figure 1 shows that the study's focus is on finding design factors that are of significant value and finding the best combination of parameters. The studies begin with generating the scenario of simulation experimental design to determine the study requirement and objective. Followed by specifying the parameter, and controlled parameter, setup simulation to generating the value of strain energy, calculated quantitatively with Taguchi method and ANOVA to support the Taguchi method result statistically.

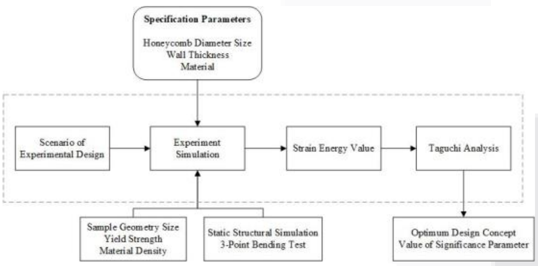



**Figure 1**. Model of Conceptual Study

### b. Point Bending Simulation Setup

Designing each of the samples were done in order to be used as an input to the simulation software, this process were done using a CAD software Solidworks 18. In this study, the data collection for the bending test was done using simulation of static structural on ANSYS. Therefore each of the 18 samples were run into the simulation through the procedure that has determined. The procedures for the simulation were determined to achieve the desired result output which was the energy strain. In this study the experimental design of honeycomb sandwich structure bow limb will be look for the energy strain of the sample could hold when it bended. Hence, it needed to be set up for the bending test on ANSYS static structural. According to ASTM D790-17, the setup for bending test were the mid-span length and test support-nose size. The sample length were 380mm long, the ratio used to calculate the placement of the support-nose was 16:1 to the thickness value of the sample. Next the support-nose size used was 10mm, the concept are shown in Figure 2

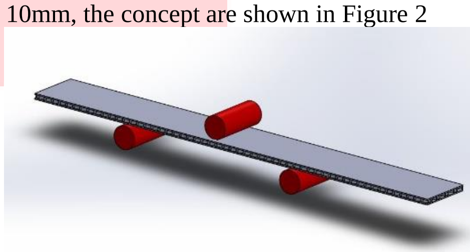
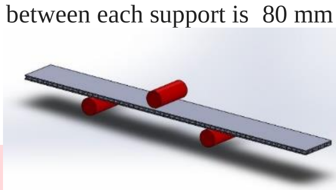
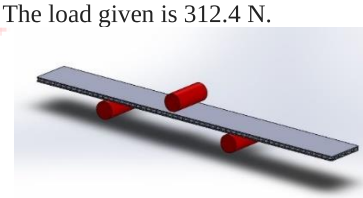


**Figure 2**. 3-Point Bending Setup

After creating the model and the setup the next thing to be determined was the force applied, according to the past study the average bow drawn mass were around 50lbs – 70lbs (converted into force and became 222.4N – 312.4N), therefore it was determined to use 70lbs or 312.4N as the maximum force human can draw a bow to be use in the bending test. the bending simulation was run on ANSYS static structural with the setup as seen on Table 1. Where the information to be included in the study in the section of engineering details, simulation feedback, meshing settings, and research settings need to be defined to get the wanted value in the section on solution.

**Table 1**. Simulation Setup

| No | Display | | Description |
|---|---|---|---|
| 1 | Engineering Data | | Select and enter material properties for the three materials specified in the design parameters, namely Aluminum 6061 Alloy, Oak Wood, Composite. |
| 2 | Geometry | | Insert 3D models that have been created using CAD software. |
| 3 | Model | Mesh | Meshing by arranging the mesh that will be applied to the geometry. The accuracy of the use of mesh is the initial foundation of engineering simulation. Set the meshing: Tetrahedron, set the meshing size 0.8mm |

<table>
<tr><td rowspan="2"></td><td rowspan="2"></td><td>Analysis Settings</td><td>Determine the steps to be taken during the simulation in the step controls section and adjust the solver controls.
<table>
<tr><th colspan="2">Step Controls</th></tr>
<tr><td>Number Of Steps</td><td>1.</td></tr>
<tr><td>Current Step Number</td><td>1.</td></tr>
<tr><td>Step End Time</td><td>1. s</td></tr>
<tr><td>Auto Time Stepping</td><td>On</td></tr>
<tr><td>Define By</td><td>Substeps</td></tr>
<tr><td>Initial Substeps</td><td>20.</td></tr>
<tr><td>Minimum Substeps</td><td>20.</td></tr>
<tr><td>Maximum Substeps</td><td>100.</td></tr>
</table></td></tr>
<tr><td>Fixed Support</td><td>Determine and select two straight lines from the support location as a geometry that serves as fixed support. With the distance between each support is 80 mm
</td></tr>
<tr><td></td><td>Model</td><td>Force</td><td>Set the load value (Force) for the nose given to the geometry with a load centred on a line found on the surface of the upper layer across the centre of the specimen. The load given is 312.4 N.
</td></tr>
<tr><td>4</td><td colspan="2">Solution</td><td>Determine the strain energy as the output</td></tr>
<tr><td>5</td><td colspan="2">Setup</td><td>This section will be automatically done when running simulation and all the set-up needs are met.</td></tr>
<tr><td>6</td><td colspan="2">Solution</td><td>This section will be automatically done. Consists of the setup of solutions carried out at the model stage.</td></tr>
<tr><td>7</td><td colspan="2">Results</td><td>Shows the final results of the analysis and report preview of the simulation carried out.</td></tr>
</table>

c. Taguchi Method

Calculate the S/N Ratio for each level using Minitab statistical software. The objective was to obtain the optimum value for each response. The optimum value was used to be the reference point on parameter selection. According to Taguchi method there are 3 quality index which are the best value is nominal, the best value is minimal (smaller is better) and the best value is maximum (larger is better). Signal to ratio (S/N ratio) is a value that stating on how much is the controlled factor towards the quality of the product resulted and calculating the product variance obtained and mapped on how close the targeted quality achieved on the experiment

d. Statistic Test

ANOVA test is done to estimate the significant contribution of each factor towards the experiment. There are several type of ANOVA test which are ANOVA One-way and ANOVA two-way. On ANOVA One-way the only consideration is to seek for the uncontrolled variable towards the controlled variable respond. However on ANOVA Two-way, it identify each of uncontrolled variable interaction that have affect towards the controlled variable from the value of another uncontrolled variable. Kruskal-Wallis Test is one of the non-parametric tests based on the rank test. This test functions generally to carry out non-parametric tests that compare more than 2 sample variables. Where this test does not have or require assumptions about the normality of the data, but it is assumed that the observations of each group come from populations with the same form of distribution and the samples are independent and random. When carrying out the Kruskal-Wallis test the following assumptions are needed

## III. RESULT AND DISCUSSION

### a. Point Bending Simulation Result

Simulation results are compiled into Table 2. Simulation were conducted to the all 18 samples using ANSYS Static Structural 3-Point Bending Test in order to obtain the output which was the strain energy value. As seen that there are different gap between strain energy result of each material. Strain energy varies between each material with lowest energy strain obtained on Alumunium Alloy 6061 material with honeycomb size of 6.78mm and wall thickness 0.5mm with 83e-03 J strain energy value. The highest energy strain obtained on Oak wood material with honeycomb size of 10.39mm and wall thickness 0.1mm with 353e-03 J strain energy value

**Table 2**. Simulation Results

| Input | | | Response |
|---|---|---|---|
| Honeycomb Size | Wall Thickness | Material | Strain Energy |
| mm | mm | | J |
| 6.78 | 0.1 | Alumunium Alloy 6061 | 97e-03 |
| 6.78 | 0.3 | Alumunium Alloy 6061 | 87e-03 |
| 6.78 | 0.5 | Alumunium Alloy 6061 | 83e-03 |
| 10.39 | 0.1 | Alumunium Alloy 6061 | 117e-03 |
| 10.39 | 0.3 | Alumunium Alloy 6061 | 93.3e-03 |
| 10.39 | 0.5 | Alumunium Alloy 6061 | 87.8e-03 |
| 6.78 | 0.1 | Oak Wood | 290.8e-03 |
| 6.78 | 0.3 | Oak Wood | 260.8e-03 |
| 6.78 | 0.5 | Oak Wood | 247.8e-03 |
| 10.39 | 0.1 | Oak Wood | 353e-03 |
| 10.39 | 0.3 | Oak Wood | 280e-03 |
| 10.39 | 0.5 | Oak Wood | 263e-03 |
| 6.78 | 0.1 | Epoxy Resin Carbon Fiber Composite | 248.5e-03 |
| 6.78 | 0.3 | Epoxy Resin Carbon Fiber Composite | 224.8e-03 |
| 6.78 | 0.5 | Epoxy Resin Carbon Fiber Composite | 215e-03 |
| 10.39 | 0.1 | Epoxy Resin Carbon Fiber Composite | 292.7e-03 |
| 10.39 | 0.3 | Epoxy Resin Carbon Fiber Composite | 239e-03 |
| 10.39 | 0.5 | Epoxy Resin Carbon Fiber Composite | 226.8e-03 |

### b. Optimization by Taguchi Method

After the results were obtained, the further process was to construct a Taguchi model on Minitab18 software. From the study before, the steps to build the model was first to set the orthogonal array according to the set of the data obtained. Orthogonal array that used was L18 with 3 factors and several levels. After the Taguchi has been designed, the next step was to calculate the S/N Ratio or Signal to Noise Ratio in order to acknowledge which level and factor resulting a significant value that obtained. In this study the S/N Ratio formula that being used was "Larger is better" because the larger energy strained made the larger kinetic energy that will be used to draw the bow.

### c. Statistic Test Result

Firstly on the data identification distribution, normality test was conducted beforehand in order to acknowledge the distribution of the data were normally distributed or the data was taken from normal population. Using Minitab18 the normality test was conducted using Kolgomorov-Smirnov method in order to done valid test with small number sample.

H0 : Data is normally distributed

H1 : Data is not normally distributed

Critical Region : H0 is rejected if P value ≤ α, where α used is 0.05

After testing the normality, the result were shown in Figure 3. From the figure it can be seen that the P value of strain energy is <0.05 so it is concluded that the data is not normally distributed.

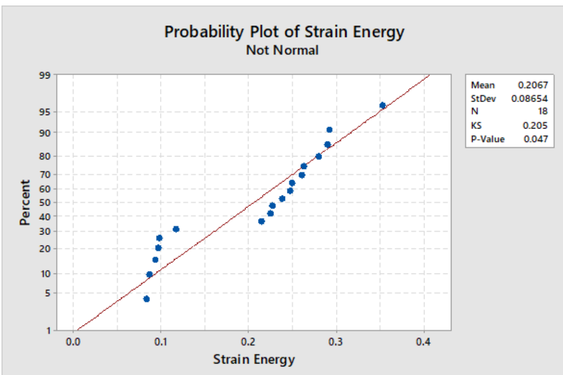



**Figure 3**. Normality Test Result

Hence, the result was assumed not normally distributed then it was continued to Non-Parametric Test which was Kruskal-Wallis Test. Before entering the Kruskal-Wallis test, assumptions regarding H0 and H1 must be determined. This assumption will use a confidence level of 95% so that the value of $\alpha = 0.05$.

H0 : These three factors do not have a significant effect on energy strain under 3-Point Bending Test

H1 : There is at least one factor that significantly influences to the energy strain under 3-Point Bending Test

Critical Area : H0 rejected if P-Value$\leq\alpha$,where $\alpha$=0.05.

In Table 3 are the results of the Kruskal-Wallis test on Honeycomb size factor

**Table 3**. Kruskal-Wallis test on Honeycomb Size Factor

| Honeycomb Size (mm) | N | Median | Mean Rank | Z-Value |
|---|---|---|---|---|
| 6.78 | 9 | 0.225 | 8.2 | -1.02 |
| 10.39 | 9 | 0.239 | 10.8 | 1.02 |
| Overall | 18 | | 9.5 | |

H =1.03 DF = 1 *P-Value* = 0.31

Table 3 shows the significant value of the independent variable honeycomb size factor to the dependent variable of the strain energy value with P-Value = 0.31. So it is known that the P-Value form factor 0.31 > α 0.05. And based on the average value of the honeycomb size ranking which has the highest median value is the honeycomb size of 10.39mm.

In Table 4 are the results of the Kruskal-Wallis test on Wall Thickness factor

**Table 4**. Kruskal-Wallis test on Wall Thickness Factor

| Wall Thickness (mm) | N | Median | Mean Rank | Z-Value |
|---|---|---|---|---|
| 0.1 | 6 | 0.2705 | 12.2 | 1.5 |
| 0.3 | 6 | 0.2320 | 8.5 | -0.56 |
| 0.5 | 6 | 0.2210 | 7.8 | -0.94 |
| Overall | 18 | | 9.5 | |

H = 2.29 DF = 2 P-Value = 0.318

Table 4 shows the significant value of the independent variable wall thickness factor to the dependent variable of the strain energy value with P-Value = 0.148. So it is known that the P-Value form factor 0.318 > α 0.05. And based on the average value of the wall thickness ranking which has the highest median value is the wall thickness of 0.1mm

In table 5 are the results of the Kruskal-Wallis test on Material factor

**Table 5.** Kruskal-Wallis test on Material Factor

| Wall Thickness (mm) | N | Median | Mean Rank | Z-Value |
|---|---|---|---|---|
| Alumunium | 6 | 0.0951 | 3.5 | -3.37 |
| Oak | 6 | 0.2715 | 14.5 | 2.81 |
| Composite | 6 | 0.233 | 10.5 | 0.56 |
| Overall | 18 | | 9.5 | |

H = 13.05 DF = 2 P-Value = 0.001

Table 5 shows the significant value of the independent variable material factor to the dependent variable of the strain energy value with P-Value = 0.001. So it is known that the P-Value form factor 0.001 < α 0.05. And based on the average value of the wall thickness ranking which has the highest median value is the Material Oak Wood.

d. Selected Design and Significant Parameter

S/N Ratio calculation for each level shown the optimum parameter for strain energy obtained. On the graph of S/N Ratio, optimum parameter are shown on each peak point of each factor. This is caused the smaller S/N Ratio value then the less variance are occurs from the data it is more desired value for Taguchi method. And also the same if the S/N Ratio is bigger then the more variance occurs in the data results it is less desired value for Taguchi method. From Table.6 it is shown that the optimum level for Honeycomb size factor is level 2 with 10.39 mm, optimum level for Wall thickness is level 1 with 0.1 mm, and lastly optimum material to be use is Oak wood. The result is aligned and fit to be accept due to the highest strain energy obtain from the simulation was exactly the run number 10 with 0.355 J. To be compared with the regular bow limb with no honeycomb design, in Table IV.2 it can be seen that Oak wood regular bow limb obtained 0.153 J with the exact same 3 Point Bending Simulation setup, so there is an increasing of 132% strain energy by implementing honeycomb sandwich structure into bow limb and to get a better view of this increasing strain energy it can be seen on Figure V.3. Hence, the acknowledgement of honeycomb sandwich structure promote a high strength and more energy absorption is correct and proven in this study.

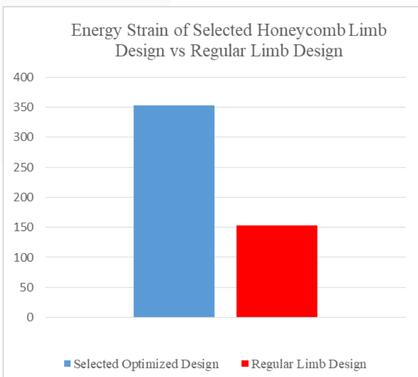



**Figure 4** Increasing strain energy by implementing Honeycomb Sandwich Structure into Regular Bow design

The response value is the largest value of energy strain among all the results this is count that the result of the simulation is acceptable and the method of using Taguchi as optimization method is counts as fit because the trend for the results is aligned with the criteria needed which are the higher the strain energy obtained the more desired it will become as the selected optimized sample, and since the chosen optimum design of honeycomb is the largest size on this study then it gave more flexibility to the design which desired for the mechanic dynamic that happened on bow limb when it used. Thicker wall thickness can also improves the stress distribution of the cell wall[7] and it is also desired for the better design of bow limb, with 10.39 mm wall thickness it is also makes it easier to be manufacture with less waste and machining process. Oak wood as the chosen material is also act as benefit for the further study beside the mechanical properties of it that used in many applications.

**Table 6**. Optimum Design Result of Taguchi

| **Factor** | **Unit** | **Level** | **Value** |
|---|---|---|---|
| Honeycomb Size | mm | 2 | 10.39 |
| Wall Thickness | mm | 1 | 0.1 |
| Material | - | 2 | Oak Wood |

In this study, it was found that the data of abnormal distribution values, the statistical test conducted was the Kruskal-Wallis test. From the Table. 7 it is know that Material is the most significant factor affecting the strain energy with P-Value of 0.001 < α=0.05. While the wall thickness and honeycomb size did not have a significant effect on strain energy because they had a P-Value greater than α 0.05. So it can be concluded that Wall Thickness and Honeycomb Size needs to be studied more to find its effect on strain energy in order to find a significant value

**Table 7.** Kruskal-Wallis Test Result of the study

| Factor | *P-Value* | Toward α = 0.05 | Status |
|---|---|---|---|
| Honeycomb Size | 0.310 | > | Not Significant to strain energy during 3-Point Bending Test Simulation |
| Wall Thickness | 0.318 | > | Not Significant to strain energy during 3-Point Bending Test Simulation |
| Material | 0.001 | < | **Significant to strain energy during 3-Point Bending Test Simulation** |

## V. CONCLUSSION

The optimum value according to strain energy that could be stored during the 3-Point Bending Test simulation on ANSYS Static Structural is on Run number 10 with 10.39mm Honeycomb size, 0.1mm Wall thickness, and Oak Wood material with increasing 132% of Strain energy compared to the Regular bow design. The only significant factor to the honeycomb sandwich structure experimental limb design is Honeycomb size according to the Krukal-Wallis test. For further study it can be validate with real field experiment. The aim is to being able to compare simulation results with the actual results

.

REFERENCES

[1] H. Pontzer, B. M. Wood, D. A. Raichlen, T. Basdeo, J. A. Harris, and A. Z. P. Mabulla, “Journal of Archaeological Science : Reports Mechanics of archery among Hadza hunter-gatherers,” *J. Archaeol. Sci. Reports*, vol. 16, no. August, pp. 57–64, 2017.

[2] H. Ertan and M. Tüzün, “Injury Patterns among Turkish Archers,” vol. 13, no. 1985, p. 1990, 1996.

[3] E. M. Medica, “Acute and overuse injuries in elite archers,” vol. 58, no. 7, pp. 1063–1070, 2018.

[4] R. Article, “Injuries in archers,” pp. 168–170, 2016.

[5] J. L. Park, “Winning major international target archery competitions,” pp. 1–9, 2015.

[6] M. Pagitz and K. Bletzinger, “Shape optimization of a bow,” vol. 76, pp. 73–76, 2004.

[7] L. Z. B. Liu and Y. G. X. H. Xu, “Modelling and characterization of mechanical properties of optimized honeycomb structure,” vol. 0, no. 15, 2019.