Research Progress in Mechanical and Manufacturing Engineering Vol. 2 No. 2 (2021) 788-802
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RPMME

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Behavioural Investigation on Table Tennis Blade Structure using Finite Element Analysis

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DOI: https://doi.org/10.30880/rpmme.2021.02.02.085
Received 15 July 2021; Accepted 28 Nov. 2021; Available online 25 December 2021

Abstract: Table tennis is one of the sports that well known around the world. It is comprised of 2 players facing each other in single or 4 players facing each other in doubles. The table tennis was first regulated in 1926 by the International Table Tennis Federation (ITTF). Later on, table tennis is one of the recognized as an Olympic Sport in 1988. In this particular indoor sport, the most essential equipment is the table tennis blades. Table tennis has well known history of using the woods as its main equipment for utilizing the sport to its finest. The purpose of the study is to identify behavioural structure of kenaf natural fibre as the material of table tennis blade. The utilization of questionnaires for verification of characteristics behaviour on table tennis structure as well as input for simulations. The questionnaire resulting 62.5% out of 96 respondents strongly agree that weight of blade is affecting the playstyles in their game. In the future, the result from this study might be references for further study in kenaf natural fibre.

Keywords: Kenaf, Table Tennis, Natural Fibre

1. Introduction

The table tennis structure has been advanced after a several decades of years. By today, the materials of the table tennis blade are somehow made of carbon fibre, aluminium or kevlar, comparing to standard materials which is wood base. The invention of the table tennis blade is started with wood extends throughout the handle and blade with a coating of dimple rubber, foam rubber. But in requirement of the table tennis blade, the structure must be lightweight, high strength and good rebound resonance. Lemke Jr [1] also said that in case of the foresaid aluminium bat with or without plastics honeycomb, the rebound resonance is too great, and in the case of the usual wooden table tennis blade it is again not correct. For these reasons, todays blades are still made of plywood, the plywood being glued in three or five layers usually which

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are provided with rubber, dimple rubber or a foam rubber coating and having particularly compact rubber foundation. Usually the table tennis blade is comprised of plywood with layered rubber glued pads that made of at least 85% natural wood and also can include composite materials such as graphite [2]. Most of the table tennis blade is about the size of 15.0 cm (5.9 inches) across and 26.6 to 27 cm (10.47- 10.63 inches) long with including the handle measurement. Table tennis blade is consisting with a shape with flat oval plywood with a handle as shown in Figures 1.1.

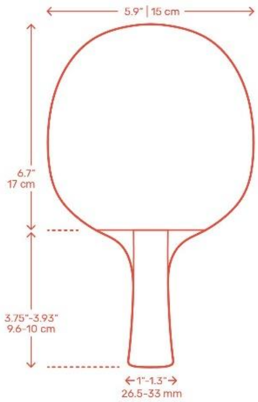


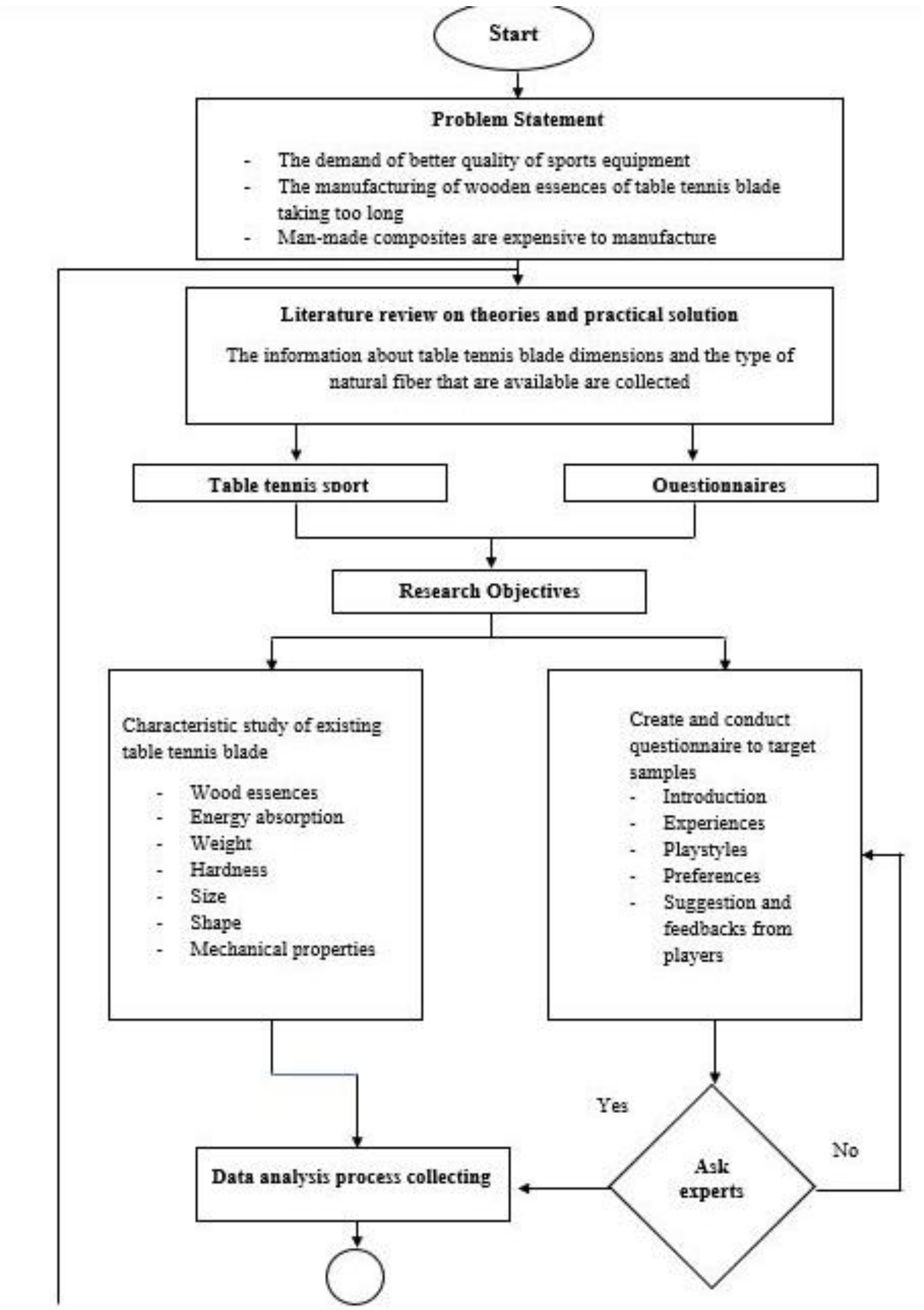
Figure 1: Table tennis blade (dimensions.com)

The trend of using natural fibre composites is rapidly increasing is due to its mechanical properties, low cost, processing advantages and low density as stated by [3]. This is due to the natural fibre composites have many advantages compared to synthetic fibres, such as low tool wear [4] low density, cheaper cost, availability and biodegradability [5]. Many of the researchers and manufacturers are growing their interest on natural fibre due to its properties. A. K. Bledzki et. al[6] stated that natural fibre has a higher specific strength than glass fibre and have a similar modulus. The natural fibre an advantage, which providing the renewable, better formability, cost effectiveness and safe towards wellbeing [7] .

There was no study of using kenaf natural fibre as replacement material for table tennis blade[8].The mechanical properties of kenaf natural fibre had make kenaf as most suitable material compared with other natural fibre such as sisal, jute, hemp and flax [8]. With density of 1.45 g/cm^3, tensile strength of 930 MPa and elastic modulus of 53 GPa, kenaf natural fibre is lightweight material that beneficially suitable for table tennis blade structure. From the brief of literature review, the purpose for this study is to identify the structural behaviour of table tennis blade using kenaf natural fibre. Hence, the method that used in the study are using finite element analysis (FEA) and the series of questionnaires for table tennis clubs as respondents for input to simulate the analysis.

2. Methodology

The study conducted with two ways to obtain the results. First and foremost, the series of questionnaires were distributed among table tennis clubs about table tennis blade preferences and characteristic that correlates with playstyles. The questionnaires were conducted online using Google Form for simplicity for gathering the data as inputs. The inputs from the questionnaires will be applied to the simulations. A flow chart of the study shown in Fig. 2.


Start
Problem Statement
- The demand of better quality of sports equipment
- The manufacturing of wooden essences of table tennis blade taking too long
- Man-made composites are expensive to manufacture
Literature review on theories and practical solution
The information about table tennis blade dimensions and the type of natural fiber that are available are collected
Table tennis sport
Questionnaires
Research Objectives
Characteristic study of existing table tennis blade
- Wood essences
- Energy absorption
- Weight
- Hardness
- Size
- Shape
- Mechanical properties
Create and conduct questionnaire to target samples
- Introduction
- Experiences
- Playstyles
- Preferences
- Suggestion and feedbacks from players
Yes
No
Ask experts
Data analysis process collecting

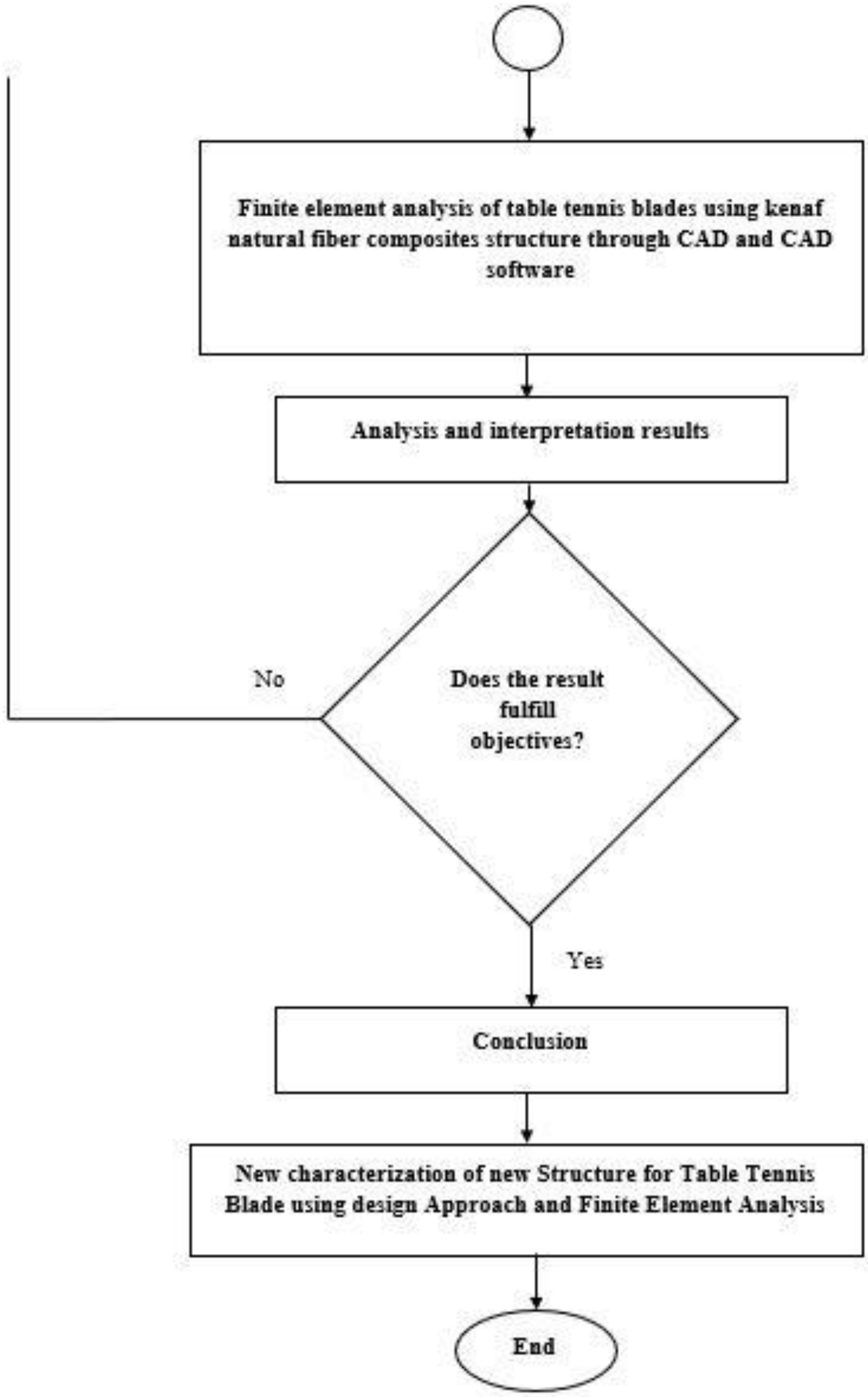


Figure 2: Flow chart of methodology study

2.1 Questionnaire

The questionnaire has a few part which consisting of the respondents' demography in first part. The second part consisting of their own table tennis blade data with their playstyles. Onto the last part of questionnaire is to verify and identify of some criterion that for characteristic of blade. The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.2 Simulation

The simulation of table tennis blade with material of kenaf natural fibre inputted into the Computer Aided Design (CAD) software which is SolidWorks 2018. The model of table tennis blade structure was generated with the arrangement of blade and table tennis ball aligned with each other. The distance between both of model are 300 mm with a few contact points set up for collision. The force applied from the table tennis ball is 10N.

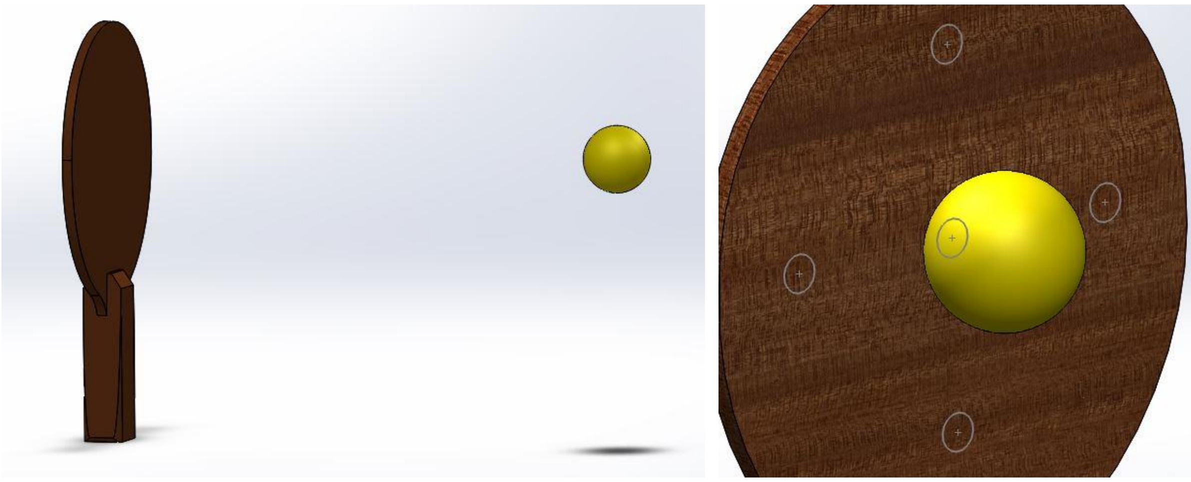


Figure 3: Arrangement of table tennis blade and ball; The contact points of ball collision

The table tennis blade model was constrained by the fixtures at other side that not facing the ball. The contact points between ball and the blade surface must be aligned to prevent the any non-uniform movement from the ball. It is must have step for guiding the ball hitting the blade. The collision set up with no penetration for the ball not pass through surface of blade. The result of ball after hitting the table tennis blade will discussed in next chapter.

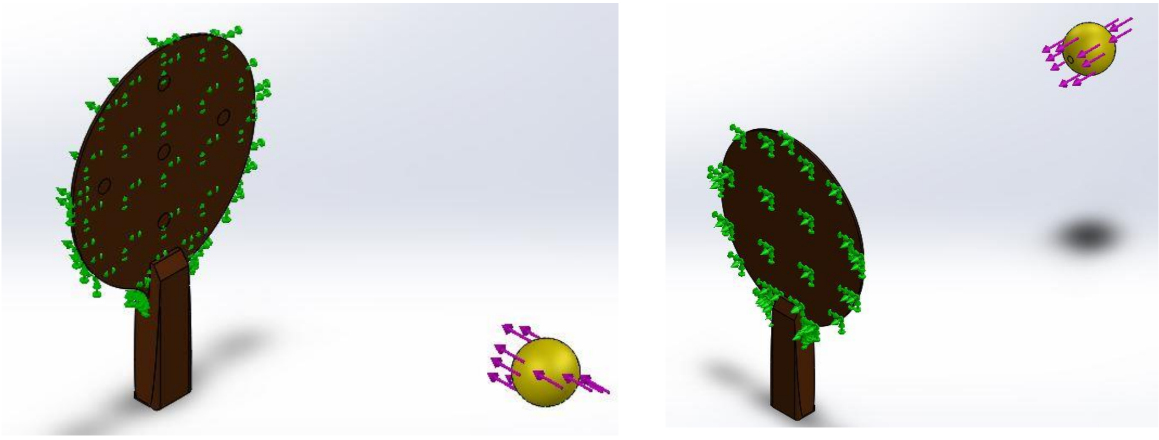


Figure 4: Fixture of table tennis blade model conditions

3. Results and Discussion

3.1 Questionnaire Summary

The obtained result from both questionnaire and simulation are valued in this study. The questionnaire was success with engagement from respondent with total of 96 respondent. In the first part of questionnaire, the percentage of male answering the questionnaire is 77.1% while the female respondent was 22.9%. Following up by the age range, most of the respondent are a more than 40 years old (46.9%) and 25 to 40 years old (44.8%) and 19 to 25 years old (8.3%). As for the experiences wise, most of them are veteran players in table tennis sport that have experience for more than 5 years (65.6%), second by 3 to 5 years (19.8%) and 1 to 3 years (14.6%) followed by no new player (0%). Out of 96 players, majority have offensive playstyles (59.4%), followed by controller playstyles (50%), defensive (22.9%), blockers (8.3%) and choppers (3.1%). As the table tennis sports are evolving, some of the players has two playstyles for their own preferences. The shape of blade used by the respondent heavily dominated by regular or standard shape table tennis blade (77.1%), semi large shape (17.7%), compact shape (5.2%) and large size shape as the smallest user percentage in this questionnaire sample (1%).

The secondary part of the questionnaire concluding with majority of the respondents used the normal-weight table tennis blade (61.5%), second by light-weight (30.2%) and heavy-weight (8.3%). The overall thickness of table tennis blade that currently used by the respondent with various thickness; 2mm-4mm (4.2%), 4mm-5mm (9.4%), 5mm-5.5mm (26%), followed by 5.5mm-6mm (41.7%) at majority, 6mm-6.5mm (14.6%), 6.5mm-7.5mm (9.4%). The 7mm-7.5mm, 7.5mm-8mm and 8mm-9mm are at 1% respectively. Questionnaires carried on by asking respondent on how many layers that currently the players used, as results, three layers and five layers dominating with 38.5% and 39.6% respectively. Subsequently, one layer (10.4%) and seven layers (11.5%).

Last but not least in third questionnaire parts, linear scale was applied to ask respondent on their opinions and knowledge on few proposed questions. As the indicator, scale '1' showing as 'Strongly Disagree' and increasing to scale '2' as 'Disagree', '3' as Neutral, '4' as 'Agree' and '5' as 'Strongly Agree' opinion. Figure 2 below shown the result of third part of questionnaire.

Table 1: The third part of questionnaire result

No	Questions	1	2	3	4	5
1	More layers of ply make the blade stiffer	1 (1.1%)	3 (3.1%)	9 (9.4%)	54 (66.7%)	13 (19.8%)
2	Weight of blade affecting playstyles	0 (0%)	0 (0%)	3 (4.2%)	28 (33.3%)	49 (62.5%)
3	Willing to try new lightweight kenaf blade	2 (2.1%)	0 (0%)	6 (6.3%)	19 (21.9%)	55 (69.8%)
4	Thickness of blade affecting hitting ball speed	1 (1%)	2 (2.1%)	8 (10.4%)	50 (66.7%)	19 (19.8%)
5	Thickness of blade affecting control serve of hitting ball	2 (2.1%)	2 (2.1%)	17 (21.9%)	40 (51%)	19 (22.9%)
6	Thickness of rubber affecting hitting ball speed	0 (0%)	0 (0%)	6 (6.3%)	25 (34.7%)	48 (58.9%)
7	Thickness of blade affecting reflection of served ball	1 (1.1%)	1 (1.1%)	8 (9.5%)	47 (64.2%)	22 (24.2%)

8	Type of handle affecting speed of hitting ball	5 (5.7%)	4 (4.2%)	11 (13.5%)	42 (54.2%)	18 (22.9%)
9	Type of handle affecting hitting ball control	1 (1%)	7 (7.3%)	7 (8.3%)	40 (51%)	25 (32.3%)
10	Material affecting playstyles	0 (0%)	0 (0%)	7 (8.3%)	27 (35.4%)	46 (56.3%)
11	Sound produced by hitting ball affecting feeling of gameplay experience	1 (1.1%)	3 (3.2%)	22 (27.4%)	29 (38.4%)	24 (29.5%)

The result of the third part of questionnaire was mainly the focus for the respondent to answer based on the scale linear method. The first question was about the more layers of ply make the blade stiffer, majority of them are agreeing to statement, in fact the more layers for constructing the blade are effective in more speed and power for the offensive players. The weight of the blade is one of the crucial factors for the players for their own playstyles. Each player has their own feeling to sensory feel and perception to their blades weight. More than half of the respondent are strongly agreeing to this statement. The question number 3 and 10 scoping on materials are affecting to playstyles. As mention by a table tennis article writer [9], he said pure wood offering the feel and spin support in play while carbon composite giving the better speed with sacrificing for less spin, less feel as well as less control. The vibration that produced by the composite carbon also more comparing to pure wood blade. The sound produced by hitting the ball relating to the vibration upon contact between the ball and the blade surface area. Due to every person have their own unique perception to their sensory feel at their hand, it can be understandable that the opinions were quite array. It can be same as the type of handle giving the comfortable handle to their hand feeling. Hence, the questionnaire result obtained will be as the inputs to the simulation testing of table tennis blade structure. The layers of plywood, the thickness of blade, the displacement produced from contact point between ball and the blade, also the vibration of the blades as the input that can be gathered furthering the process of simulation for the table tennis blade structure.

Table 2: Criterion from questionnaire

Criterion	**1**	**2**	**3**	**4**	**5**	
Layers of plywood (Q1)	1.1%	3.1%	9.4%	66.7%	19.8%	
Weight (Q2)	0%	0%	3%	33.3%	62.5%	**62.5%**
Thickness of blade only (Q4, Q5, Q7)	1%	2.1%	10.4%	66.7%	19.8%	
	2.1%	2.1%	21.9%	51%	22.9%	
	1.1%	1.1%	9.5%	64.2%	24.2%	
Thickness of rubber (Q6)	0%	0%	6.3%	34.7%	58.9%	**58.9%**
Type of handle (Q8, Q9)	5.7%	4.2%	13.5%	54.2%	22.9%	
	1%	7.3%	8.3%	51%	32.3%	
Material (Q3, Q10)	2.1%	0%	6.3%	21.9%	69.8%	**69.8%**
	0%	0%	8.3%	35.4%	56.3%	**56.3%**
Sound (Q11)	1.1%	3.2%	27.4%	38.4%	29.5%	

The criterion obtained from the questionnaire are the aspect that put into simulations. The linear scale of '5' that indicates 'Strongly Agree'. The scale of 5 are certainly voted from respondents about a few promising characteristics that can be used for developing table tennis using kenaf fibre. The weightage of first criterion that will be focus on are the weight of the blade. Since the kenaf natural fibre are lightweight material, the weight is heavily impact on table tennis blade in offensive playstyles that make use of lightweight blade. Secondly, the thickness of rubber also important aspect especially to the loopers and choppers player that make used of spin power. However, in this study where the rubber characteristic was not conducted. As the last criterion with promising criteria, the material of table tennis blade is crucial for every type of table tennis player. The kenaf natural fibre as in wood categories material are might be promising to line up as other wooden material that had been manufactured the table tennis blade.

3.2 Simulation Study

There are a few criteria of result obtained from the simulations. The expected result from the simulations are stress value that applied from the force of the table tennis ball to the surface of the table tennis blade. Next result that expected to be obtained is the deflection due to impact from ball hitting the blade surface. The deflection of table tennis blade is the result of the displacements at contact points and the whole structure with constraint at the back of the table tennis blade surface. The next expected result shall be obtained is the total strain energy as well as energy absorption. The variable that controlled for the simulation was the thickness of blade. Therefore, the relationship between thickness and stresses at contact points shown in Fig below.

3.2.1 Stress

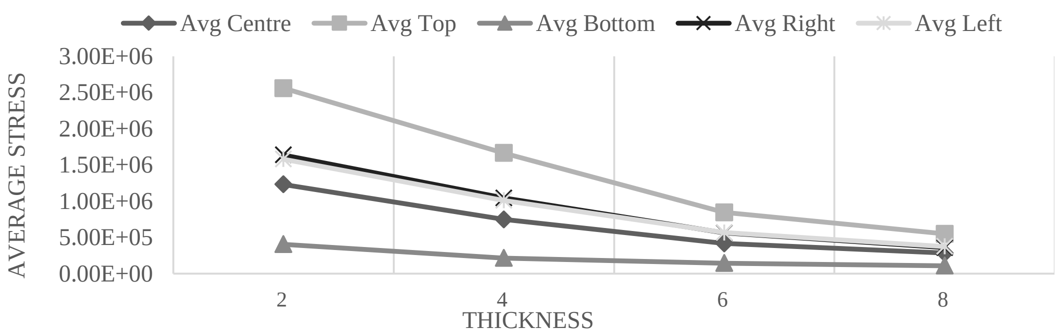


Figure 5: Relationship between thickness and average stress at contact points

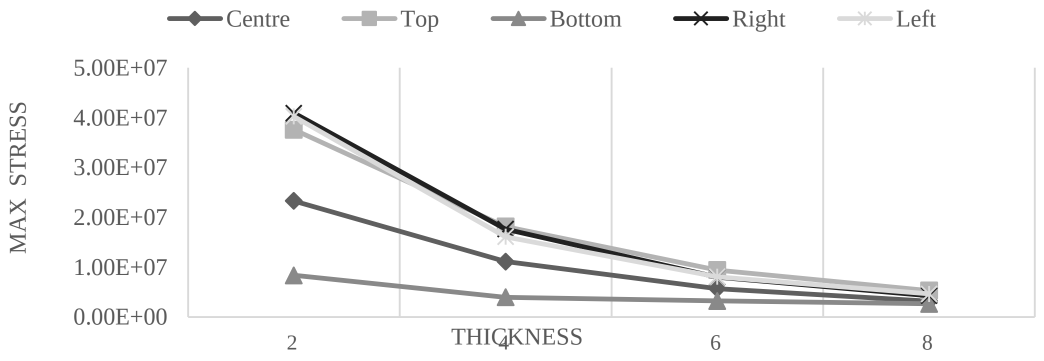


Figure 6: Relationship between thickness and average stress at contact points

3.2.2 Displacement

The deflections of the blade are visible in the simulation testing. The deflection of the deformed blade model projected by the displacement from the initial point to the final point after the period of time. The deflection is higher depending how far the nodal points moving from initial points. The displacement on the thickest blade, 8mm have least displacement due to the sturdiness of model. thickness differentiating the moment of inertia of a body. The higher the thickness of body means the more density and mass throughout the body. As the position of centre of mass also changed and changing the moment of inertia respectively. The displacement of the blade are towards to the z-axis as the constraint are bound to z-axis.

Table 3: Average displacement at all contact points

Thickness	Centre	Top	Bottom	Right	Left
2mm	1.54×10^{-5}	1.56×10^{-5}	1.59×10^{-5}	1.58×10^{-5}	1.59×10^{-5}
4mm	1.37×10^{-5}	1.34×10^{-5}	1.44×10^{-5}	1.34×10^{-5}	1.43×10^{-5}
6mm	9.26×10^{-6}	9.10×10^{-6}	9.17×10^{-6}	9.38×10^{-6}	9.33×10^{-6}
8mm	4.44×10^{-6}	4.02×10^{-6}	4.20×10^{-6}	4.47×10^{-6}	4.25×10^{-6}

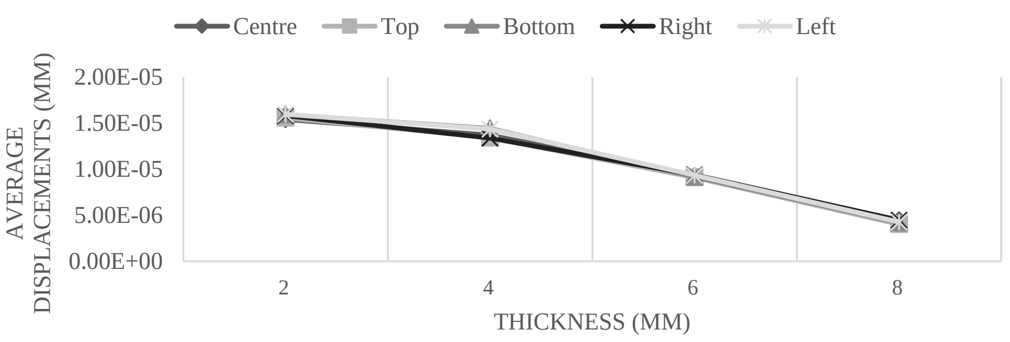


Figure 7: Relationship between thickness and average displacements at contact points

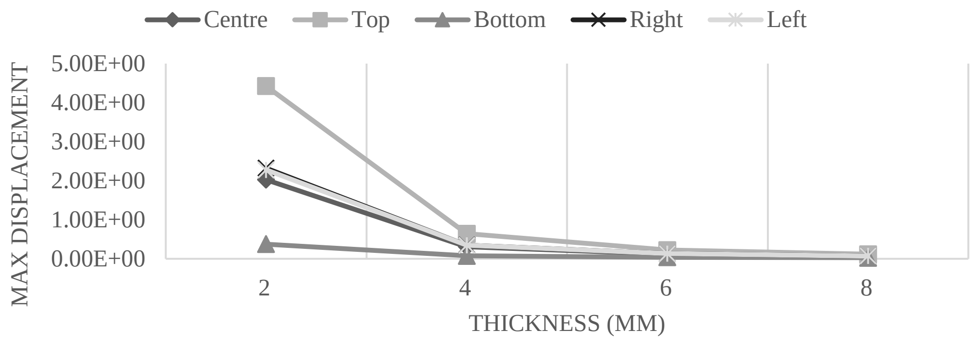


Figure 8: Relationship between thickness and maximum displacements at contact points

3.2.3 Energy absorption

The expected result from total strain energy are the energy absorption upon tested by ball as well at contact point and the whole model. Total strain energy is the area under stress-strain curve of a material body upon deformation. The strain energy is an energy that stored in a body during deformation. The strain energy density heavily valued on contact points and some of critical point of blade model.

Table 4: Total strain energy at contact points

Thickness (mm)		2	4	6	8
Centre	Avg	9.21×10^{-9}	1.14×10^{-8}	1.98×10^{-8}	4.72×10^{-8}
	Max	1.12×10^{-7}	1.45×10^{-7}	2.69×10^{-7}	5.61×10^{-7}
Top	Avg	2.17×10^{-8}	2.63×10^{-8}	3.98Ex 10^{-8}	3.34×10^{-8}
	Max	3.16×10^{-7}	3.26×10^{-7}	5.24×10^{-7}	6.24×10^{-7}
Bottom	Avg	1.37×10^{-8}	2.38×10^{-8}	2.01×10^{-8}	3.10×10^{-8}
	Max	2.08×10^{-7}	1.81×10^{-8}	3.10×10^{-7}	3.92Ex 10^{-7}
Right	Avg	9.26×10^{-9}	1.81×10^{-8}	4.59×10^{-7}	4.92×10^{-7}
	Max	7.22×10^{-8}	2.49×10^{-7}	4.59×10^{-7}	4.92×10^{-7}
Left	Avg	7.27×10^{-9}	9.86×10^{-9}	1.59×10^{-8}	2.42×10^{-8}
	Max	6.26×10^{-8}	8.04×10^{-8}	2.17×10^{-7}	2.82×10^{-7}

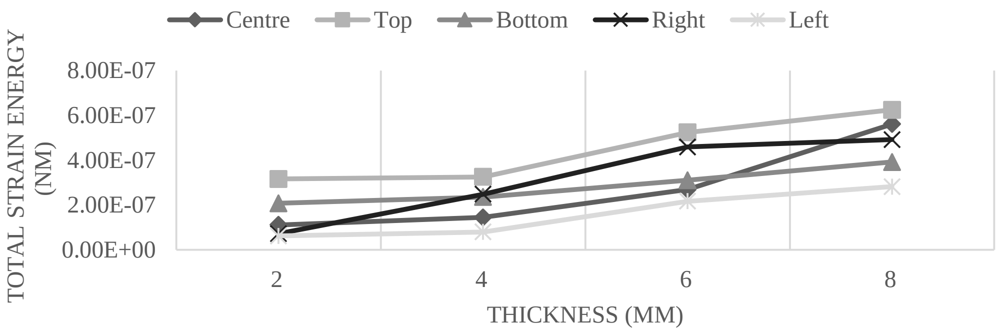


Figure 9: Relationship between thickness and total strain energy at contact points

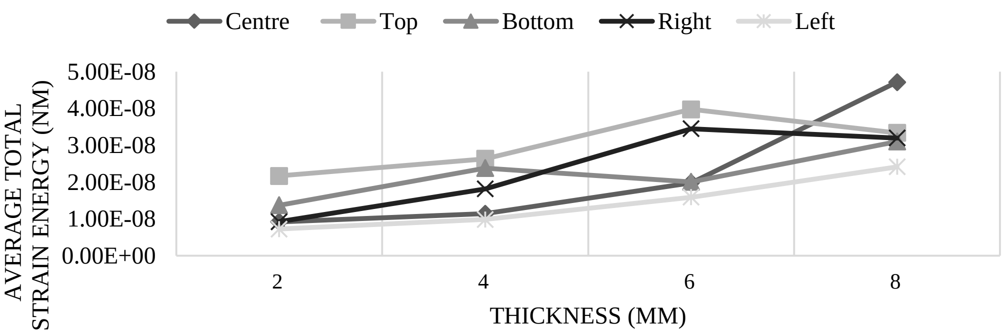


Figure 10: Relationship between thickness and average total strain energy at contact points

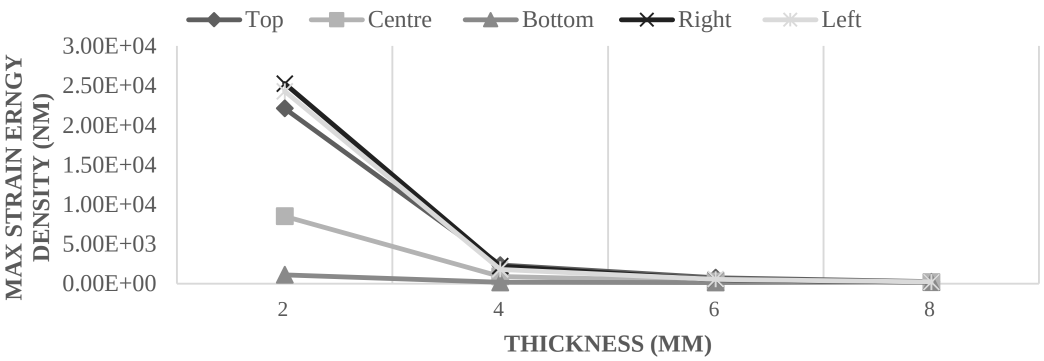


Figure 11: Relationship between thickness and maximum total strain energy at contact points

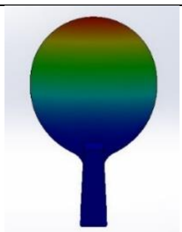
The maximum total strain energy hotspots are somehow detected at all contact points with ball. The findings of this simulation showed the maximum of total strain energy at the contact points and few critical spots. In actual match of table tennis sports, the blade always receiving high impact force within short time hitting the ball. Within a few certain spots, the total strain energy might be higher when ball hitting the blade surface area added with the full swing of forces from the hand controlling movement. Theoretically, the higher the speed of ball and swing force from players' hand, the strain energy density received to the blade also increases. However, the various rubber glued to the blade are able to absorb strain energy which can be investigate in further study later on.

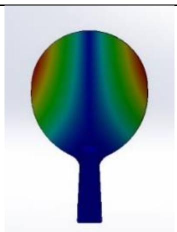
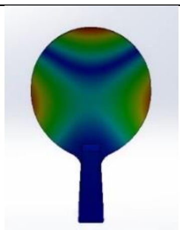
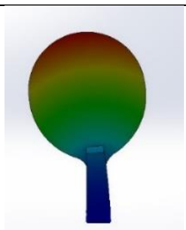
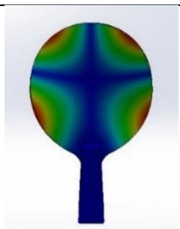
The absorption of energy can be identified with total strain energy density cause by the deflection of blade upon contact of the table tennis ball. In fact, the ball will be reflected to other direction of hitting the blade due to absorbed from the ball then transferred to ball. The reflection of ball impact force might not damping due to inelasticity of the material of blade model.

3.2.4 Frequency Analysis

The frequency test simulation also tested on the blade model to identify its natural frequency of vibration. Every structure will be damaged and deformed badly if the body exposed to the its natural frequency or exceeding it. The different thickness of blade model had such effect in natural frequency. Mode of vibration are difference with difference amplitude applied causing a structure vibrate differently according to the mode type. The higher the mode, the higher the frequency the model exposed to.

Table 5: Result of Frequency Analysis of each thickness

Mode	Simulation	Thickness	Frequency (Hz)
1		2mm	268.56
		4mm	488.3
		6mm	656.03
		8mm	771.83

2		2mm	558.6
		4mm	1039.2
		6mm	1372.1
		8mm	1254.6
3		2mm	1303
		4mm	1568.9
		6mm	1441.1
		8mm	1746.5
4		2mm	1997
		4mm	2302.9
		6mm	2991.9
		8mm	3544.4
5		2mm	2157.4
		4mm	4096.2
		6mm	5812.6
		8mm	7310.6

The simulation had shown the result that the weight of the table tennis blade had taking considerations of table tennis playstyles. As mention by Warren Davies [9], lightweight are suitable for offensive play due to lighter blade helping to accelerate faster as the most of respondent have offensive and controller playstyles Majority of them are using normal weight of table tennis blade (Refer Appendix A) while the heavy weight blade are purposely used for controllers, blockers and defensive players due to the absorption of more energy to damp the speed of incoming ball [9].

4. Conclusion

The usage of kenaf fibre in industries are quite common and popular within the engineering field, textiles field as well as other fields. In this study, it can be said that kenaf fibre have potential to construct the table tennis blade as other type of woods. Kenaf fibres' mechanical properties are as well as good and suitable for various usages. As the country that can provided the source of kenaf fibres, the experimental test actually feasible to be constructed in prototype forms. However, the simulation testing that can be worked on using SolidWorks 2018 as Computer Aided Design (CAD) software. There were some limitations on how the simulation result can be obtained. Initially, the simulation had gave the advantages on initial projection on how the kenaf fibre works well in table tennis structure. To resemble the real-life situations, a few characteristics of table tennis blade must be considered as input of visualized simulations. Some of characteristic are not available to simulate due to some boundary restrictions. Therefore, the result from the performed simulation can be the stepping stone to this study.

As conclusion, the objectives of this study were achieved for identifying, evaluating and studying the characteristics of table tennis blade using kenaf fibre as new materials. Hopefully, this study might help for the future references and manufactured to add new collection for some table tennis playersThe conclusion should summarize the main findings of the study, and restate the key points inferred from trends observed and discussed regarding the data. Some suggestions should be included to encourage the continuation of the current research.

Acknowledgement

The authors would also like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for its support.

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