DOI: http://dx.doi.org/10.15282/ijets.2014.1.10.1017

Characterization of Light Weight Composite Panels for Table Tennis Table

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Abstract: Light weight composite panels (LWCPs) have attracted interest in various applications such as in building and transportation sectors. However, their usage in constructing sports equipment has not been fully explored due to the novelty of the materials and, sometimes, cost or manufacturing issues. Although traditional table tennis tables (TTT) have shown consistent performance, but due to the weight of the materials, commonly medium density fibreboards (MDF) used, the table movability is often limited. In this study, various composite panels using wood veneers and fibre reinforced polymers as face sheets incorporating different core structures have been developed for the purpose of prototyping a full-size standard TTT. In order to comply with the international standard for such a piece of sports equipment, the effects of various material parameters on the coefficient of restitution have been investigated. Such parameters include the types of core material and configuration, the types of face sheet and its thickness. From the study, the composite surfaces have displayed better restitution properties, i.e. bounce of ball is better, compared to the veneer surfaces. The bounce behaviour of the ball is also much closer to that on the standard TTT made from MDF. The findings from this study have demonstrated the potential of using LWCPs for the construction of TTTs to improve the mobility of this sport without compromising the quality of play.

Keywords: Light weight composite panels, restitution, dynamic coefficient of friction

I. INTRODUCTION

The use of composite sandwich panel in sport applications is growing rapidly because of the advantageous features such as high strength to weight ratio and low maintenance cost [1]. Table tennis is one of the mainstream sports that manipulate the composite technology, in which most commonly to make the table tennis bet. However, very little research has been undertaken into the development of a light weight, strong and competitive table tennis surface from laminated veneer lumber (LVL) composite panel (plywood), fibreglass and foam. Plywood is a man-made composite combining natural and synthetic material. Thin layers of wood veneer are bonded together with adhesive to form flat sheets of laminated wood that are stronger than natural wood [2]. Pine is one of the favoured plywood materials as it is easy to saw, treat, nail and glued [3].

The most common material of table tennis table is high density fibre (HDF) and high density press board (HDPB). Radiata pine wood veneer is thought to be a good alternative due to its low density (460 – 560 kg/m^3) as compared to HDF and HDPB (between 800 – 1040 kg/m^3) [5]. The main issue that comes along with Radiata pine is its relatively high equilibrium moisture content (EMC) compared to HDF and HDPB. HDF and HDPB have an EMC of 10.9% at 80% relative humidity [6]. This is relatively low when compared to the EMC of the untreated pine at around 16% [7]. However, the hygroscopic of wood, defined as the trait of the wood ability to absorb and desorb moisture depending on the humidity of the environment compared to the wood moisture content (MC), can be minimised when wood is heat-treated [8]. Heat-treatment recommended is done with dry air at temperature of 230 degrees for 2 hours for the decrease in physical properties such as shrinkage, swelling and EMC [9].

This research attempts to compare the performance of the prototyped sandwich panel developed with new types of sandwich panel of different core configuration and different types of face sheet. The effect on the panel restitution has been investigated for different core configurations, using honey comb, foam and combination of these two; as well as different face sheets, using wood veneer, two layers and three layers fibreglass. Fibreglass is a fibre-reinforced composite made of a plastic matrix reinforced by fine fibers of glass. Fibreglass is a lightweight, extremely strong stiff material, with Young's Modulus of around 17.2 GPa [10]. Stiffness of the skin is thought to influence the restitution property of a sandwich panel. Fibreglass also exhibits very low moisture absorption, with the moisture content of almost 0% [11]. Meanwhile foam is a strong, lightweight material that is widely employed as the core material in sandwich structure due to its isotropic property hence providing more uniform property across the panel [12]. This will reduce the variability of the result from the restitution test. However, it is likely that impact loaded sandwich structures will absorb significant energy in contact deformations local to the point of impact [13]. Therefore it is of an interest to study how this energy dissipation will effect on the restitution property of the sandwich panel constructed with foam as the core.

II. EXPERIMENTAL DETAILS

Two main variables being assessed are the cores and the face sheets of the panels. Four types of panels with different cores but the same face sheets (3 Plies Veneer) were manufactured to see the effect of the cores on the properties of the panels, while three different kinds of panels of different face sheets but the same core (honeycomb) were constructed to investigate the face sheet effect on the properties of the panels. 6 types of panels were manufactured to look at the effect of various parameters on the properties of the panels as shown in Table 1. All the panels have a same size (300x200mm) and thickness of 40mm.

Table 1: Manufactured Panel

Panel	Core Type	Face Sheet Type
1	Honeycomb	3 Plies Veneer
2	Foam	3 Plies Veneer
3	Combination of honeycomb and foam, honeycomb on top	3 Plies Veneer
4	Combination of honeycomb and foam, foam on top	3 Plies Veneer
5	Honeycomb	2-Layers Fibreglass
6	Honeycomb	2-Layers Fibreglass

Untrimmed 3 plies Radiata pine veneer sheets of size 2450 mm by 1250 mm were used to manufacture the honeycomb cores. The sheets were preglued with the stacking sequence of [0/90/0] to decrease the probability of warping during the thermoforming process, as corrugated sheet with grain directions normal to the corrugation direction tends to have lower bending stiffness and easily warped [8].

Veneer Honeycomb Panel

Using thermo-forming process, veneer sheets were formed into corrugations with dimension as shown in Figure 1 (reproduced from [14]) to be used as the core of the panels. To make honeycomb structure, the corrugated sheets were trimmed to 40 mm strips. These strips were glued between the peaks by crosslink PVA and clamped together under the pressure for 24 hours during curing. Once the honeycomb was within acceptable tolerance (1 mm), cross-link PVA was applied to the sides of the face sheet to create a bond at the intersection of the face sheet and the honeycomb core. Borders were added to the panel sides to provide more stability by reinforcing weak supports around the edges.

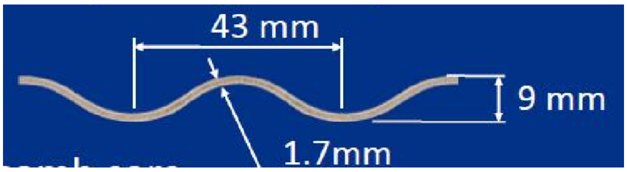


Figure 1: Corrugation dimension

Foam Core Panel

The foam used was M80 Corecell MFoam supplied by SP-High Modulus ™ with the density of 81 – 89 kg/m3 and the thickness of 38 - 40 mm [10]. The foam was carefully cut to 300 mm by 200 mm. Cross-link PVA was applied to both sides of the foam fitted with 3 plies veneer face sheet to create a strong bond between the surfaces of foam and the face sheets and left to fully cured under load. Borders were added to the panel sides and the panels protruding features and sharp corners were sanded flush.

Combination of Honeycomb and Foam Core Panel

To make the core with a combination of honeycomb and foam, each honeycomb and foam was manufactured separately earlier. The procedures of manufacturing the honeycomb and foam core parts are similar to the one used to make the honeycomb and foam core panel. However, the thickness was halved to be 20 mm instead of 40 mm. Once the honeycomb and foam were readied, they were combined together by using the cross-link PVA to form a combined honeycomb-foam core panel of thickness 40 mm. Similar to other panels, 3 plies veneer face sheets were applied with cross-linked PVA to both the refined honeycomb and foam core at regions of contacts and cured under evenly distributed loads and borders were glued to the panel sides to provide more stability by reinforcing weak supports around the edges.

Fibreglass Face Sheet Panel

The fibreglass face sheets were manufactured using the resin infusion technique. High clamping pressure of the vacuum (approximately 1 ton/sq.ft.) helps to fuse the material together with any air voids being replaced by resin, therefore results in a weight saving of over 30% over traditional cored fibreglass laminate while improving its properties. Two thicknesses were produced, by using 2 layers and 3 layers of fibreglass fabric. The sandwich panels were made up of layers of EU450-1270, a unidirectional stitched fibreglass fabric with a density of 480 grams per square metre. The polymer matrix utilised during the experimental procedures for this project was epoxy thermosetting resin R300 which is characterised by low viscosity and low exotherm [16]. The resin was used in combination with a fast hardener at a ratio of 80% resin and 20% hardener. The hardener used was R310 Infusion. The resulting mixture permit a faster infusion rate by lowering the viscosity of the resin, hence permitting the resin mixture to infuse the glass fibre more quickly. This was especially favourable when the temperature in the infusion chamber was low.

III. PANEL CHARACTERISATION

International standards set up by ITTF were used as a guideline to characterise the panels. The required testing to get approved by ITTF is the restitution test. The tests were conducted using ITTF approved table tennis ball, Butterfly brand, which is 3 stars, a rating system used to describe the quality of a ball [17].

Restitution Testing

In order to get approved by the ITTF, a standard table tennis ball needs to display a rebound of within the range of 230 - 260 mm when it is dropped from a height of 300 mm. The consistency of the ball bounce is also assessed, where the difference of the maximum and minimum bounce height observed during the approval testing of at least 16 systematically chosen points must be less than 10mm [17]. There were 120 testing points on each panel, placed in equal length between each other. The distance between the testing points in y-direction is 20 mm and the distance between the testing points in x-direction is 26 mm. Each of the testing point restitution property was tested by dropping the table tennis ball from a fixed height of 300 mm. The bouncing motion of the ball was recorded with a high speed digital camera that captures 60 frames per second of the motion to determine the maximum rebound height. The measured maximum height of rebound was measured at the bottom-most side of the ball at its maximum height. For all the testing panels, each testing point was tested once and the result was recorded. 10 random testing points on each panel was selected to validate the consistency of the rebound height. This is done by repeating the test for five times at each point and the average was recorded.

IV. RESULTS AND DISCUSSION

Restitution Property

Restitution vs Type of Cores

The plots compare the restitution amplitudes based on different types of core, which are honeycomb, foam and the combination of both honeycomb and foam with both sided being tested. From the result in Figure 2, it is apparent that the 40 mm honeycomb core panel has the highest restitution with an average of 227 mm, while the foam core panel has the lowest restitution with an average of 220 mm. This suggests that the foam core gives more damping effect to the bounce of the table tennis ball as compared to the honeycomb core. However, the foam core panel has smaller spread compared to the honeycomb core panel. This is expected as the foam has a very uniform surface in contact with the face sheet, therefore the effect on the restitution is also uniform throughout the panel. The geometry of honeycomb core in the other hand gives supported and unsupported region underneath the face sheet, hence create variation in the restitution property throughout the panel. Meanwhile, the combination of foam and honeycomb core panel exhibits a restitution property in between that of honeycomb core and foam core. The combined core panel does not show much variation in terms of the average amplitude when honeycomb or foam were put as the panel top. However, the spread by the panel when foam was placed as the panel top shows slight reduction, suggesting that the foam contributes an effect in giving a more uniform restitution throughout the panel. This is expected due to the surface of the foam being much more uniform compared to the honeycomb core.

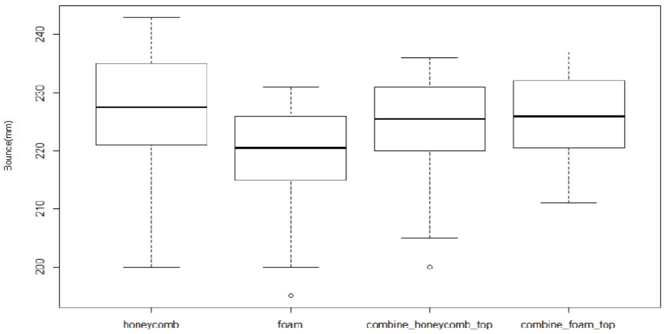
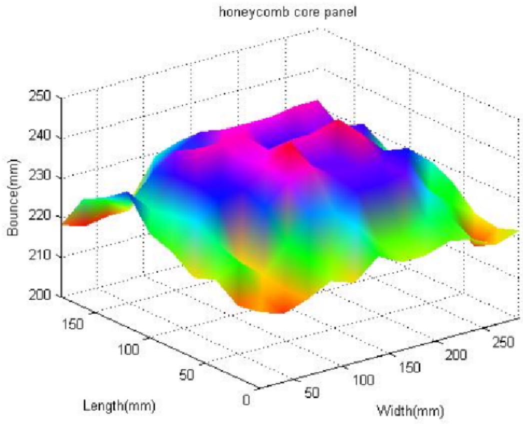
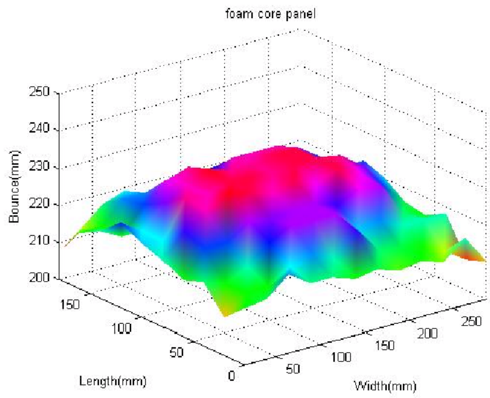
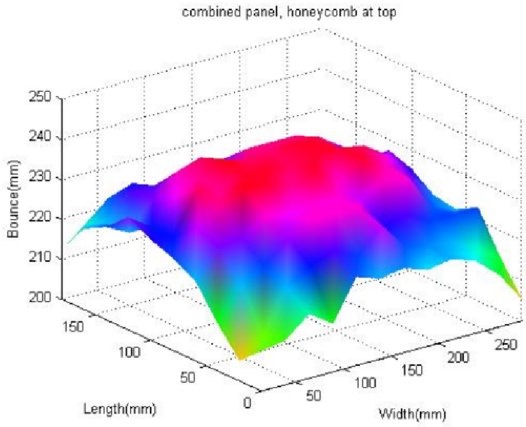


Figure 2: Bounce vs Type of Cores of LWCP

Matlab code was generated to create a surface plot of the restitution over the tested panel area. Taking the length as the X-axis and Width as the Y-axis, the (0mm, 0mm), (0mm, 300mm), (200mm, 0mm) and (200mm, 300mm) coordinates represent the corner of the panel while (100mm, 150mm) coordinate represents the middle of the top of the panel.







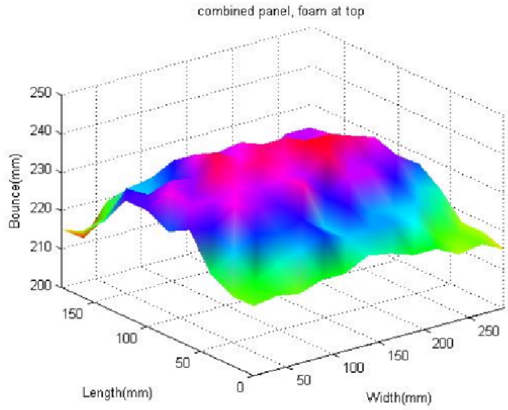


Figure 3: Variation of restitution amplitude based for different types of core

From the surface plots in Figure 3, the variation of restitution amplitude is more noticeable for the panels with honeycomb core. This strengthens the deduction made earlier that the geometry of the honeycomb structure creates the variation in the restitution property. There is also a noticeable increasing trend in the restitution amplitude as it approaches the centre for all panels being compared above. This concludes that all the panels has a high reliance on the core configuration and the mechanical properties of the panel, rather than the supporting structure, like the panel borders, and sub-structure, like the loads on the panels during the testing.

Restitution vs. Type of Face Sheet

From the previous comparison, an early conclusion can be drawn that the core with the best restitution bounce is the honeycomb. Hence in further testing, honeycomb core has been used in comparing the effect of different face sheet to the restitution property. In this comparison, face sheets were varied by using 3 plies veneer face sheet, 2 layers fibreglass face sheet and 3 layers fibreglass face sheet.

From the plots in Figure 4, the average restitution amplitude for the panel with two layers fibreglass face sheet does not vary much with the 3 plies veneer face sheet panel. This suggests the local flexural stiffness of the two layers face sheet is nearly the same as the 3 plies veneer face sheet. However, there is a noticeable increase in the restitution property for the three layers fibreglass face sheet panel. This is thought due to the three layers fibreglass face sheet having a higher global flexural stiffness therefore contributing to a higher bouncing of the table tennis ball.

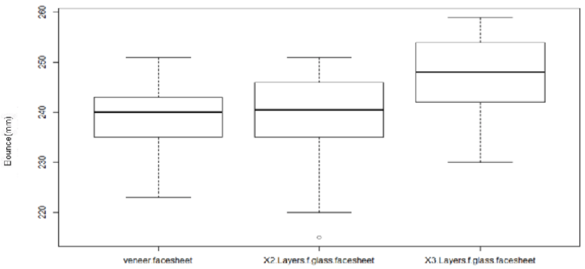
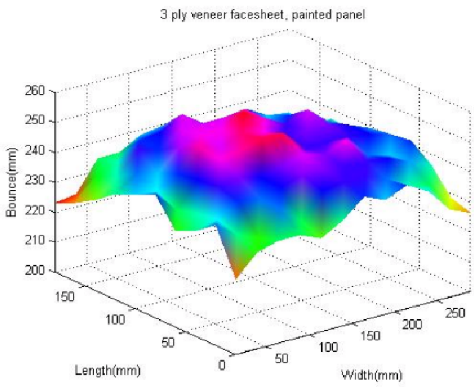
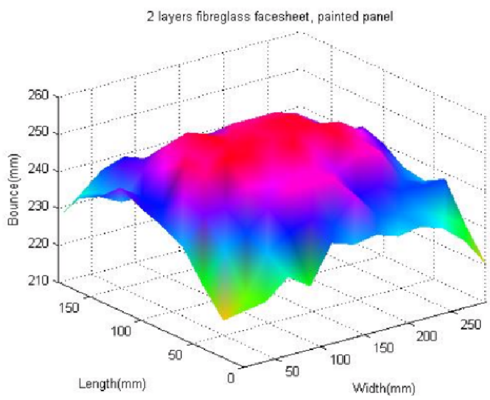


Figure 4: Bounce vs Face Sheet Type of LWCP





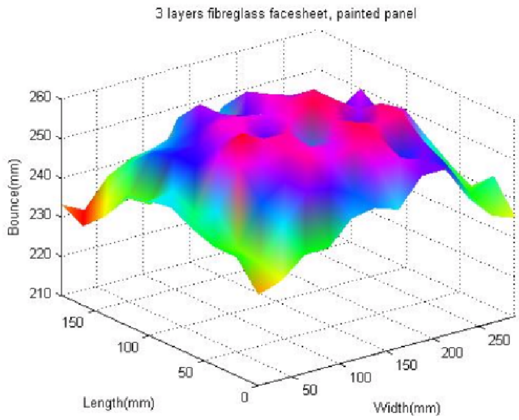


Figure 5: Variation of Restitution Amplitudes for different types of face sheet

From the Matlab 3-D surface plots in Figure 5, there was significant variation in the restitution property of both fibreglass face sheet panels, as compared to the 3 plies veneer face sheet panel. A factor that could contribute to this is that the presence of the fibre may affect the restitution at a local testing point, while the fibre presence or the local percentage of fibre can vary between the testing points [18]. This could also be the contributing factor as to why the 2 layers fibreglass result is relatively less varied than its 3 layers fibreglass counterpart. This also suggests that the restitution on the fibreglass face sheet is heavily dependent on the face sheet configuration rather than the core.

Industrial Feasibility Study

Weight Comparison

Table 2: Weight comparison among the manufactured panel

Panel	Core	Face Sheet	Weight (per panel)	Density (kg/m^3)
1	Honeycomb	3 Plies Veneer	482.0 g	200.8
2	Foam	3 Plies Veneer	411.0 g	171.3
3	Combination Honeycomb and Foam	3 Plies Veneer	513.5 g	214.0
4	Honeycomb	2 Layers Fibreglass	431.0 g	179.6
5	Honeycomb	3 Layers Fibreglass	511.0 g	212.9

From the weight comparison shown in Table 2, the panel with combination of honeycomb and foam core has the highest density, due to the use of extensive amount of cross-link PVA in the manufacturing of the panel as compared to the other panels. Meanwhile the foam core panel has the lowest density, due to the lightweight and porous nature of the foam structure. Typically, the density of hardboard ranging between 800 - 1040 kg/m^3 and the MDF is approximately 500 kg/m^3 [5]. Therefore, the weight saving of the panels ranges between 70% and 80% compared to hardboard and up to 65% compared to MDF.

Operation Time Comparison

Table 3: Operation time comparison among the manufactured panel

Panel	Core	Face Sheet	Operation Time (per panel)
1	Honeycomb	3 Plies Veneer	100 minutes
2	Foam	3 Plies Veneer	35 minutes
3	Combination Honeycomb and Foam	3 Plies Veneer	125 minutes
4	Honeycomb	2 Layers Fibreglass	230 minutes
5	Honeycomb	3 Layers Fibreglass	230 minutes

The panels with fibreglass face sheets equally took the longest operational time to be manufactured (230 minutes), while the panel with foam as the core consumed the shortest time (35 minutes). Meanwhile, honeycomb core panel took a moderate operational time (100 minutes) and the panel with core of honeycomb and foam combination took slightly longer time than that (125 minutes). The resin infusion process to make fibreglass face sheet is a complicated process, time consuming and is the biggest fraction of time taken to manufacture. If fibreglass sheets were to be used to manufacture the table tennis table in a mass production, it will require very high labour cost, as the labour needs to be skilful and working for a long hour. Although the fibreglass yields a better restitution property, fibre glass also has an exceptionally high strength, which is an unnecessary aspect for a table tennis table. Therefore, it can be deduced that using fibreglass is not feasible to be manufactured as the table tennis table in mass production. 3 plies veneer sheet made of honeycomb core can be used to manufacture the table tennis table due to its low manufacturing time, its easiness to prepare and acceptable restitution property.

V. Conclusion

In comparison of different cores while keeping the face sheets to be 3 plies wood veneers, the 40 mm honeycomb core panel has the highest restitution, while the foam core panel has the lowest restitution. The foam core panel has smaller spread compared to the honeycomb core panel due to the foam has a very uniform surface in contact with the face sheet. The combination of foam and honeycomb core panel exhibits a restitution property in between that of honeycomb core and foam core. The combined core panel does not show much variation in terms of the average amplitude when either honeycomb or foam were put as the panel top. However, the spread by the panel when foam was placed as the panel top shows slight reduction, suggesting that the foam contributes in giving a more uniform restitution throughout the panel.

In comparison of different face sheets while keeping the cores to be honeycomb cores, three layers fibreglass face sheet panel exhibits highest restitution profile, at the expense of consistency. Meanwhile, the average restitution amplitude for the panel with two layers fibreglass face sheet does not vary much with the 3 plies veneer face sheet panel. There was significant variation in the restitution profiles of both fibreglass face sheet panels as compared to the 3 plies veneer face sheet panel.

The panel with combination of honeycomb and foam core has the highest density, while the foam core panel has the lowest density. The honeycomb core panel has density in between that of these two aforementioned panels. The weight saving the panels give ranges between 70% and 80% when comparing to hardboard, and up to 65% when comparing to MDF.

The panels with fibreglass face sheets equally took the longest operational time, while the panel with foam as the core consumed the shortest operational time to manufacture. The honeycomb core panel operation time is in between that of these two panels. 40 mm honeycomb panel would be suitable for casual table tennis table and could be viable alternative for a competition tables with further research.

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