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Investigating The Shear Behaviour of Hard Points on Honeycomb Sandwich Panels

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ABSTRACT

Honeycomb sandwich panels which act as the main structure of UiTM solar car, namely Stingray, are exposed to the localize load due to the weight of the handling system components attached to it. Therefore, hard points were introduced to strengthen the structure. Nevertheless, studies pertaining to the shear behaviour of hard points have not been well established. Therefore, this study was aimed to investigate the shear behaviour of hard points on honeycomb sandwich panels due to variations of potting agent volume. The samples, which are panels with hard points were fabricated with variations of potting agent volume (1ml, 2ml and 3ml). Apart from that, panels with hard points made of commercial metal insert (NAS1834) were also fabricated for benchmarking purposes. Shear tests were conducted on the samples to observe the failure mode, where the procedure was based on a published work. Stress-strain diagrams were plotted to determine the Modulus of Rigidity, $G_{ave,1ml}$, $G_{ave,2ml}$, $G_{ave,3ml}$ *and* $G_{ave,NAS1834}$ *and shear strength (the maximum load which the panel could withstand). As an alternative solution, finite element analysis was performed for the same specification. Initially, the panels with hard points were modelled using SOLIDWORKS and then assembled in CATIA. A commercial finite element analysis software, HyperWorks, was used to simulate the deformation behaviour of the panels under shear, according to the conducted tests set up. The experiments results are found to produce similar curves trend to other researchers. The simulated results for shear properties were compared with all the samples from physical tests. In general, the results show that the shear strength of the panels could be increased by increasing the volume of the*

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potting agent. The panels with hard points with 3ml of potting agent volume have the highest shear strength as compared to the other three variations. It can be concluded that the research related to the application of the hard points on the solar car is important and found to be very useful for improving the next UiTM Eco-Photon solar car.

Keywords: *Hard point, NAS1834, shear test, honeycomb sandwich panel, potting agent.*

Introduction

This study was related to the development of a car namely ‘Stingray’ by UiTM Eco-Photon Solar Team that applied the composite sandwich panel in the construction of the monocoque with honeycomb sandwich panels as its main body structure. Figure 1 shows (a) the application of honeycomb sandwich panel on Stingray and (b) Stingray on the road during competition.

(a) (b)

Figure 1: (a) The application of honeycomb sandwich panel on Stingray (b) Stingray on the road during competition

Sandwich structures consist of a pair of thin skin, core, and the attachment of adhesives [1]. The properties of these structures might be affected by many factors such as the orientations of fiber, number of layer or ply, types of adhesives used and many other things. In order to prevent local failure and/or delamination or buckling of the sandwich panel due to the force subjected to the sandwich panel surface, the area of the sandwich panel needed to be reinforced [2][3]. This is because CFRP honeycomb sandwich panels are designed to be continuous in application in order to obtain its full and high strength capability. Discontinuous of CFRP honeycomb sandwich panels exists when other components need to be attached to the CFRP honeycomb using mechanical joint such as bolted joints. There are few different methods that have been designed by the aircraft manufacturer to reinforce the attachment point to prevent the local failure, delamination or buckling [4][5]. This reinforced attachment point is called hard point. This can be seen in the solar car where the suspension system attached to the external car structure (Figure 2). Hence, mechanical joint were used as the connectors where it is the best option compared to other types of joints. In addition, mechanical joints are inexpensive and reliable. As stated earlier, when there is a presence of discontinuities at the composite panel due to holes and attachment, the superiority of the panel in terms of strength will reduce. As a result, this could induce local failure around the area of the load applied. For Stingray, Figure 2 shows the location of the attachment of handling system components which need hard points.

To aid the design process, this study was aimed to investigate the shear behaviour of hard points on honeycomb sandwich panels due to variations of potting agent volume

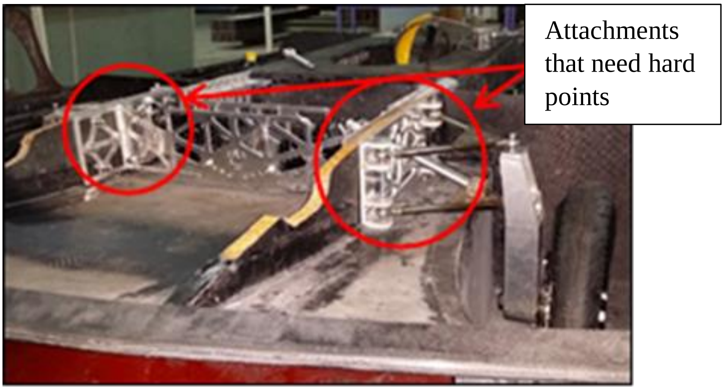

Figure 2: Attachment to the Stingray's composite sandwich panel

Methodology

In this study mechanical tests (shear tests) and finite element analysis has been performed to investigate the shear behaviour of hard points. The overall flow of the study is shown in Figure 3.

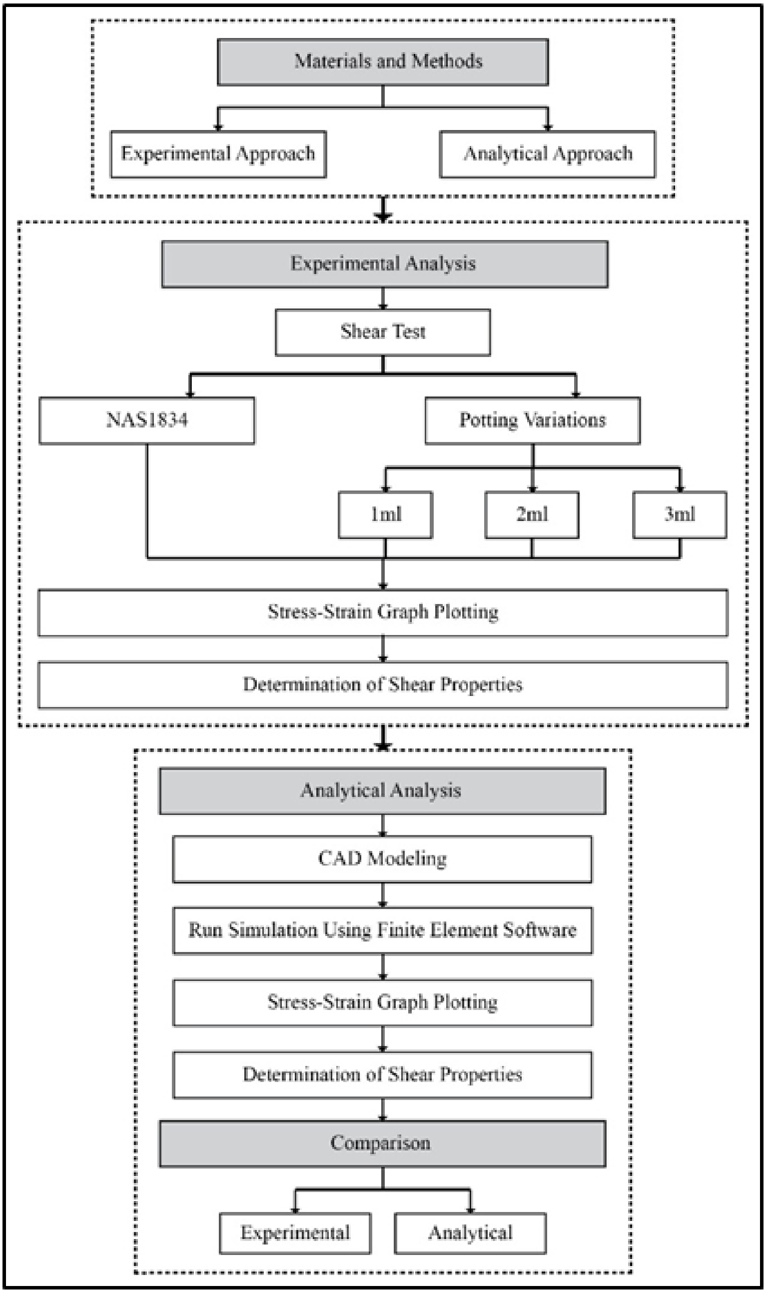

Figure 3: Overall Flow of Study

Shear Test

In testing the capability of the attachment points, two different types of metal insert were tested; which are the commercial metal insert NAS 1834 [6]-[8] and the metal insert designed and used in Stingray. Metal insert with 3 different volume variations of potting agent (1ml, 2ml, and 3ml) were tested. There was a total of 20 samples of which 5 samples were used for each variation. The shear test procedure was adopted from Song et al. [9].

a) Sample preparation

The dimension of the samples is shown in Figure 4. The length and width were 120 x 60 mm (length x width) made of CFRP honeycomb sandwich panel. It consisted of Nomex honeycomb core with the thickness of 10mm (PK2 Kevlar® N636 Para-Aramid Fibre Honeycomb), 4 layers of 2x2 Plain Weave Carbon Fiber Fabric (Fiber Glast) with 2 layers on top and 2 layers on bottom side, and epoxy resin (7893A) with hardener (7893B). The samples has undergone vacuum bagging process after the wet layup process. All samples were cured under room temperature for 16 hours [9].

There were two holes drilled on the sandwich panel and the metal insert were placed into the holes as shown in Figure 4 and the process flow for samples preparation is shown in Figure 5. Next, the potting agent which was epoxy thick mixed with aerosil reinforcement was injected using syringe to bond the metal insert with the sandwich panel. The potting agent was cured for 16 hours under room temperature.

For the NAS1834 metal insert, series, NAS1834-6-430 was selected for this study.

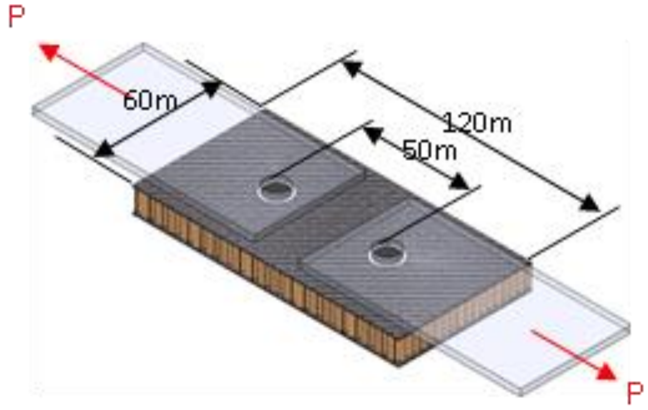

Figure 4: Sample specification [9]

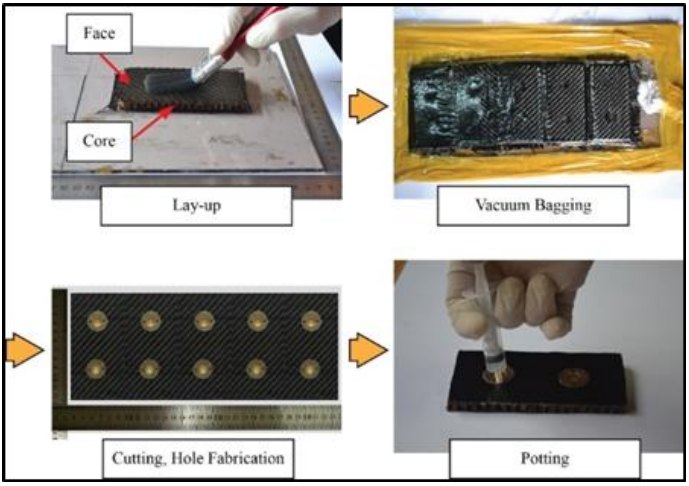

Figure 5: Process Flow for Sample Preparation

b) Jig/fixture preparation

For jig preparation, the design of the test jig was based on the fixture of universal machine (Instron 3382). The test jig is called steel strap. One of the steel strap was fixed at the bottom of the fixture and another one was connected to the upper fixture which it moved upward to create the load. The sample was fastened to the steel strap by using bolts and nuts to ensure that the test jig does not deform at a big margin until the honeycomb sandwich panel fails. There was an increase in error of the testing results as the jig also deformed increasingly. The jig design was fabricated by using mild steel. The test jig is as shown in Figure 6.

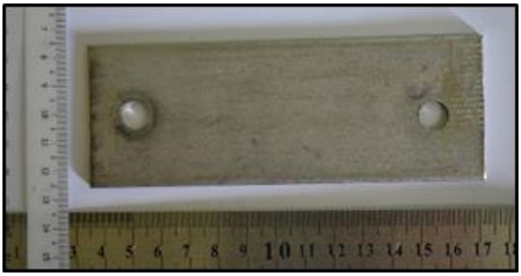

Figure 6: Jig used in the test

(c) Testing procedure

Load parallel to the sandwich panel surface was applied [9]. The force applied on the top hard point was pulled upward by the steel strap that was connected by fastener to the sandwich panels; while the bottom hard point was exposed to the shear force as the steel strap fixed to the fixture at the bottom (Figure 7).

During tests, all parameters were kept constant except for the metal insert design used and volume of potting agent. There was 5 samples for each variations (1ml, 2ml, 3ml, NAS1834 [6]). For all tests, the speed rate was 1mm/min [9].

Figure 7: Shear test on hard point of CFRP honeycomb sandwich panel

Finite Element Analysis and Simulation

Three commercial software have been used (SOLIDWORKS, CATIA and HyperWorks). The Finite Element (FE) software used for modeling are SOLIDWORKS (SOLIDWORKS® Premium 2015 x64 Edition) was used for modelling and CATIA (CATIA® Version 5.20) was used for parts assembly. FE analysis and simulation was performed using commercial software, HyperMesh and HyperView (Altair® HyperWorks® Version 13.0).

a) Modeling parts using SOLIDWORKS

SOLIDWORKS was used to model honeycomb and potting agent because it was easier to model the parts since the discrete model chosen produced more accurate results compared to parametric model [10]. The model of honeycomb and potting agent are as shown in Figure 8. Then the model was converted into STEP AP214 to assemble in CATIA.

Table 1: The material properties for the FE model

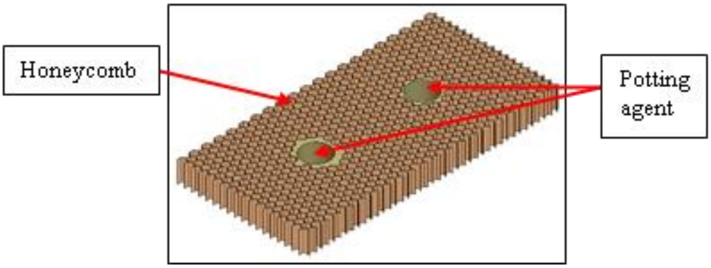

Figure 8: The model of honeycomb and potting agent

b) Modelling and parts assembly using CATIA

Other components such as face sheets, metal inserts and fasteners were modeled using CATIA. The assembly process of all of the parts was done in CATIA. The assembled model of the sample for (a) the model with metal inserts used in Eco-Photon and (b) the model with metal inserts NAS1834 are shown in Figure 9.

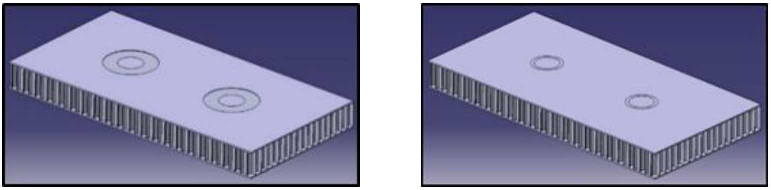
(a) (b)

Figure 9: (a) The model with metal inserts used in Eco-Photon (b) The model with metal inserts NAS1834

c) Finite Element Analysis and Simulation using HyperMesh

In HyperWorks, HyperMesh and HyperView were used. HyperMesh was used to import the geometry, set the materials properties, meshing, and applying boundary condition and load while HyperView was used to display the results (by Optistruct solver). The assembly geometry from CATIA was imported into HyperMesh. The core and face sheet were assumed to be in contact and perfectly bonded in the HyperMesh model. The material properties of FE model samples are shown in Table 1.

Materials	Properties	Value
PK2 Kevlar® N636 Para-Aramid Fibre Honeycomb [11]	Young's Modulus, E_h	4 GPa
	Poisson's Ratio, ν_h	0.25
2x2 Plain Weave Carbon Fiber Fabric [12]	Young's Modulus, E_f	141 GPa
	Poisson's Ratio, ν_f	0.10
Potting agent	Young's Modulus, E_p	3.5 GPa
	Poisson's Ratio, ν_p	0.25
Metal Insert (Eco-Photon and NAS1834)	Young's Modulus, $E_{Eco\text{-}Photon}$	210 GPa
	Poisson's Ratio, $\nu_{Eco\text{-}Photon}$	0.29
	Young's Modulus, $E_{NAS1834}$	210 GPa
	Poisson's Ratio, $\nu_{NAS1834}$	0.30

The model was then meshed using 5 mm element size. Figure 10 shows the meshed model. Constraints and forces in this study was applied on each nodes (115 nodes) at top face of the fasteners in order to apply shear force to the hard points. The total forces were divided with no of nodes in order to obtain the value of force to apply on each nodes. For constraints, it was set at bottom part of the sample while forces were applied at the top part of the hard point just like the set up for test. The maximum limit value of forces applied in FEA was based on the maximum load from the test. The applied constraints and forces for all samples are as shown in Figure 11. The results were interpreted and represented in contour plot of the panel using HyperView. The displacement and maximum stress distribution throughout the panel were obtained.

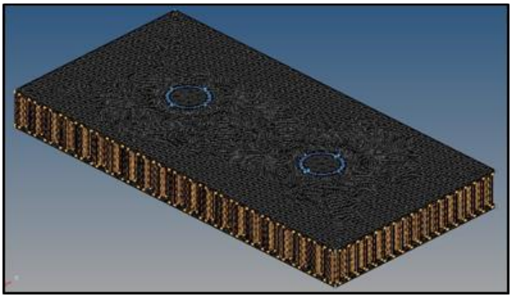

Figure 10: Meshed model

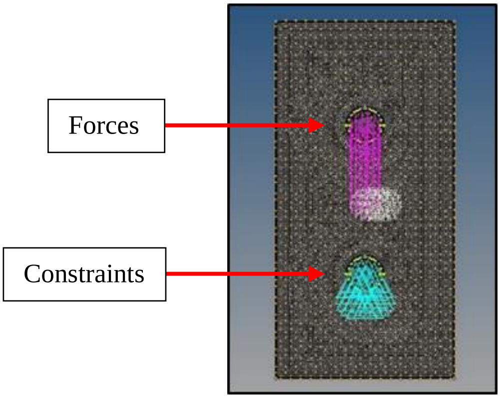

Figure 11: Force and constraints applied to the hard points

3.0 Results and Discussion

There are two types of results obtained in this study. One is the results from the test and another one is from the FEA using HyperWorks. For the FE model, discrete model was chosen over parametric model, especially for honeycomb part as to obtain a more accurate result. For test, there was a total of 20 samples with 5 samples for each of the variation (NAS1834, 1ml, 2ml, and 3ml potting agent volume) and they were tested for shear force. The main reason of applying 5 samples for each type was to find the average data. The results for shear force that was applied on the hard points of the composite sandwich panels were interpreted in graph forms for all the samples. Graph of stress-strain for all the samples obtained from the shear test was plotted are shown in Figure 12. It could be observed that the trend of the curves are found similar to the typical curves obtained by Roy et al [3] and Song et al [9].

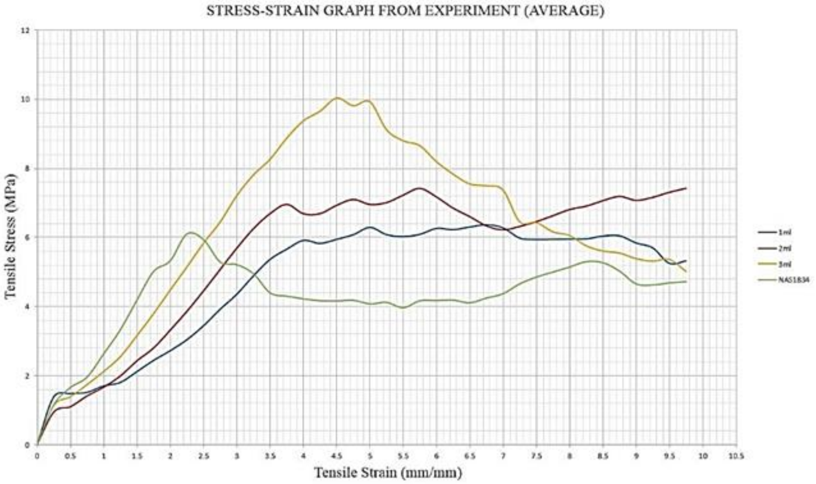

Figure 12: The stress-strain graph from the shear test (average)

It could be observed from Figure 12 that the metal insert with potting agent volume of 1ml, exhibits the smallest value of strain compared to other samples but has the highest value of stress. The metal insert with potting agent volume of 2ml exhibits the highest value of strain but has the lowest stress. At the starting of the graph between the 0 to 0.5 mm/mm, the stress for all samples were between 1MPa to 2MPa. Eco-Photon, 3ml has the highest value of maximum stress among the others which are 10.032 MPa. This means that 3ml can withstand more stress. The higher the volume of potting agent, the stronger the sample can withstand due to shear force. For NAS1834, it can be compared with Eco-Photon, 2ml, because NAS1834 has the same volume of potting agent. Based on the graph in Figure 12, the strength of NAS1834 wax better than Eco-Photon, 2ml due to shear force.

The common properties obtained from shear test were Modulus of Rigidity. From the stress-strain graph in Figure 12, the average Modulus of Rigidity, $G_{ave,1ml}$, $G_{ave,2ml}$, $G_{ave,3ml}$ and $G_{ave,NAS1834,}$ are 1.176 MPa, 1.659 MPa, 2.006 MPa, and 1.867MPa respectively.

For FEA, the average Modulus of Rigidity, $G_{ave,1ml}$, $G_{ave,2ml}$, $G_{ave,3ml}$ and $G_{ave,NAS1834,}$ from the shear test were used in order to compare the results obtained with the test results. This is important in order to validate FEA. A good FEA can be used in the future as it saves money and time, and it is much easier compared to performing the test again, to validate it. The stress-strain graph from the FEA are shown in Figure 13.

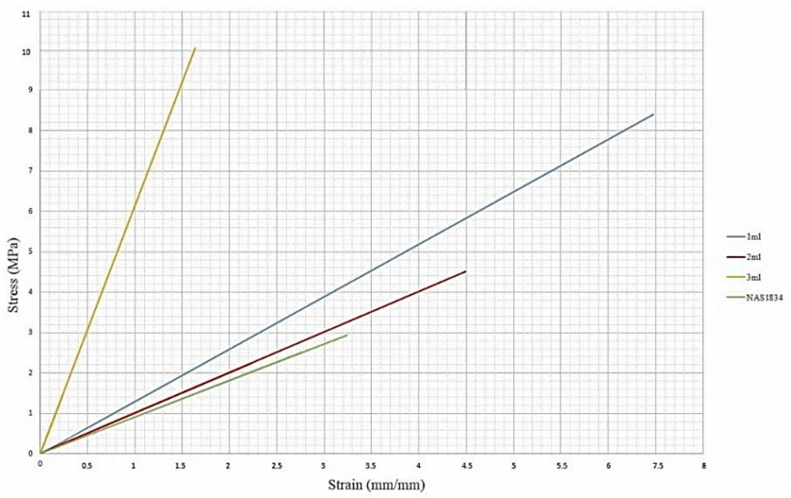

Figure 13: The stress-strain graph from FEA

Based on Figure 13, the highest Eco-Photon, 3ml has the highest shear strength and Eco-Photon, 1ml has the lowest shear strength. Eco-Photon, 3ml can withstand the highest stress which is 10.308 MPa. The shear strength for NAS1834 is higher compared to Eco-Photon, 2ml but the maximum load that it can withstand is lower than Eco-Photon, 2ml. The combination of both stress-strain graph from test and FEA are shown in Figure 14.

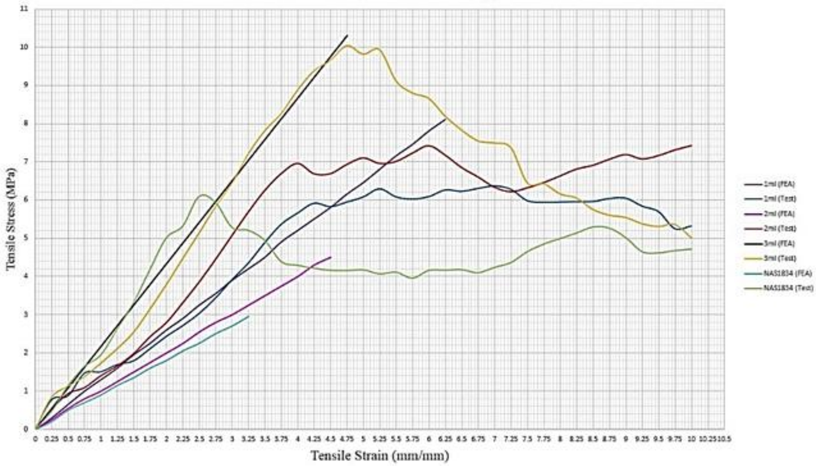

Figure 14: The stress-strain graph of tests and FEA

Based on Figure 14, the stress-strain curves that describes the shear behaviour from both tests and FEA were compared. For Eco-Photon, 1ml, 2ml, and 3ml from FEA, the results were acceptable because the difference between tests and FEA was not too far. Nevertheless, for NAS1834, the difference was quite large. Probably, there were some errors during the modeling phase of the model. Thus, the model of NAS1834 should be improved.

From the results obtained, it shows that the shear strength of the panels could be increased by increasing the volume of the potting agent. The failure modes due to shear force to the hard points can be observed on the panel itself. The effects of shear force was mixed mode where it has bearing/ tension/ shear out as shown in Figure 15.

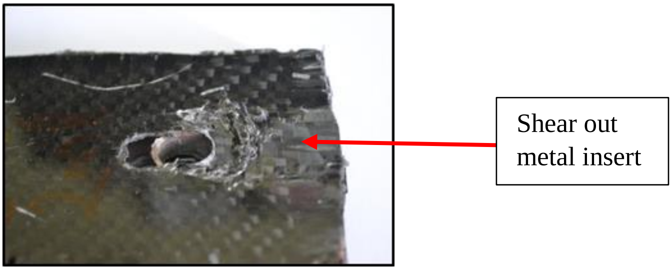

Figure 15: Shear force effects to the sandwich panel

Conclusion

The main objective of this research was to investigate the shear behaviour of hard points on honeycomb sandwich panels due to variations and the results proved that this objective has been achieved successfully. The knowledge of the hard points is important in order to design the attachment between composite sandwich panel and the mechanical system. The data obtained from this study has been used as a reference in improving the design of Stingray. Therefore, it can be concluded that this study has enhanced the knowledge pertaining to the shear behaviour of the hard points on honeycomb sandwich panels.

Acknowledgement

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