ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 28, No. 4. 2022

Analysis of Hard Point Mechanical Behaviour Due to Variations of Potting Agent Volume on a Composite Sandwich Panel

Mohamad MALI [1], Ahmad Kamil HUSSAIN [1], Mohd Bokhari HASSAN [2], Jamaluddin MAHMUD [1] *

[1] *College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*
[2] *Edgenta Mediserve Sdn. Bhd., Hospital Seberang Jaya, Jalan Tun Hussein Onn, Pulau Pinang, Malaysia*

crossref http://dx.doi.org/10.5755/j02.ms.29937

Received 18 October 2021; accepted 25 January 2022

Composite sandwich panels are widely used in lightweight structures, especially in aerospace, automotive, and marine industries. They are chosen mainly because of the superiority of their specific stiffness as compared to solid panels. Stingray, a solar car designed by the UiTM Eco-photon team, applied this technology for its lightweight property. However, the honeycomb sandwich constructions were susceptible to localized load. Thus, load attachment points using metal inserts, also known as 'hard points', were introduced. In this study, the behaviour of hard points based on three volume variations of the potting agent was investigated. ESA recommended static pull-out tests to be conducted on the sandwich panels composed of Nomex honeycomb core, two laminates of carbon fibres/epoxy composite as the face-sheets to determine the failure load of the hard points. A finite element simulation using ANSYS was also performed to determine the displacement of the inserts in presence of normal-to-plane load. The results include load versus extension curves obtained by both methods. Potting agents were found to elevate the stiffness and the strength of the inserts by some degree. Therefore, the application of these hard points on the solar car was found to be effective.
Keywords: hard point, pull-out test, finite element analysis, potting agent, composite sandwich panel.

1. INTRODUCTION

Composite sandwich panels using honeycomb core are preferred in structural applications in aerospace, automotive, and marine industries due to their high specific stiffness and strength to weight ratio in comparison to solid panels. Without additional weight, the flexural rigidity of the sandwich is enhanced with the employment of a honeycomb sandwich core [1]. This is one of the main reasons for choosing the honeycomb sandwich panel as a Stingray of UiTM Eco-photon car body structure (Fig. 1 and Fig. 2).

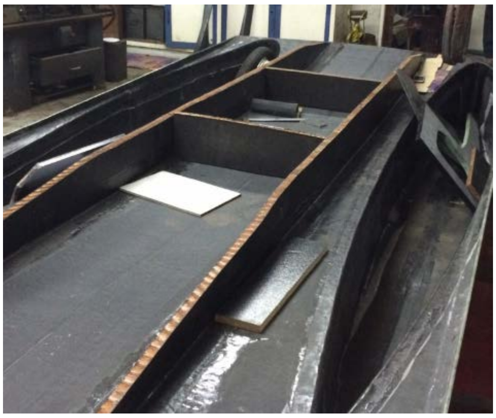

Fig. 1. Application of honeycomb sandwich panel on stingray

However, when a load is applied on the surface of the sandwich panel, the area of loading applied to the surface needs to be reinforced to prevent local failure, degradation, delamination or buckling of the sandwich [2–5].

Fig. 2. Stingray in action

This is because honeycomb sandwich panels are usually designed to be integrated into this type of applications. In the solar car fabrication, the suspension system is attached directly to the sandwich panel. Since reinforcement is needed, aircraft manufacturers are designing and employing various methods to reinforce the load attachment point [6]. The most common method is metal insert reinforcement. There are 3 types of the basic metal insert reinforcement methods which are 'through the thickness' insert, partially potted insert and fully potted insert [7].

The Stingray utilized the 'through the thickness' insert technology to create the hard points on its monocoque chassis made of composite sandwich panel. Therefore, this became the main focus of this study to analyse its effectiveness.

* Corresponding author. Tel.: +603-55436257, fax: +603-55435160.
E-mail address: *jm@uitm.edu.my* (J. Mahmud)

Several works have been focused on the analysis of reliability and characteristic of the metal insert reinforcement. For example, Lee D. G. and Kim B. J. investigated the characteristics of partially insert type [1], Heimbs S. and Pein M. investigated the failure behaviour of partial insert on honeycomb sandwich panel [8]. The analysis of the same type of insert was also done by Smith B. and Banerjee B. using a numerical approach [9]. Other researchers have also focused on the effects of changing the element or feature of the hard point. There have been experimental studies that investigated the effect of changing the core thickness, lamination scheme, types, and shape of the insert on the mechanical behaviour of the hard point [10 – 13]. However, the effect of potting agent volume on the mechanical behaviour of the sandwich panel has not been discussed thoroughly. Based on current literature, it was discovered that only Raghu, Southward and Battley have examined the effect of the potting element on the strength of the sandwich panel [14].

In discussing the mechanical test, the common methods used were a static pull-out test, dynamic pull out test, impact test, shear test and buckling test [15 – 18]. For example, Kim B. J. and Lee D. G. tested the effect of insert shape on the mechanical behaviour of the sandwich panel by using the static and dynamic pull out tests [1]. Next, Song K. L., and his associates conducted static pull out test and shear test to determine the strength of the sandwich structure with insert reinforcement [11]. Since the static pull-out test was the most common method used, this research will only focus on the static pull out test.

In discussing the finite element simulation approach from previous studies, the study from Heimbs and Pein used LS-DYNA to analyse the insert reinforcement strength [8]. They also discussed the effect of meso and macro meshing on the results. Moreover, Thomsen et al. numerically solved a through the thickness insert using a non-linear model and multi-segment method of integration [19, 20]. Next, the properties of the material used in the research were based on the technical data from the manufacturer. Indeed, the honeycomb type used was PK2 Kevlar® N636 Para-Aramid Fiber Honeycomb. The properties of the core refer to the technical datasheet from Hexcel Composites [21]. In addition, the Carbon Fiber Reinforced Plastic (CFRP) pre-preg used was also from Hexcel Composites which is HexPly® 8552 [22].

From reviewed literature, it was found the mechanical behaviour of a solar car hard points on a composite sandwich panel due to volume variations of potting agent has not been investigated thoroughly. Nevertheless, this knowledge is very important in designing the attachment between the solar car monocoque and its mechanical system. Hence, this paper for the first time investigated the mechanical behaviour of the hard points on a composite sandwich panel due to the volume variations of the potting agent.

2. METHODOLOGY

2.1. Experimental methods

In testing the useability of hard points as the load attachment points, a static pull-out test was conducted based on the recommendation from European Space Agency (ESA) taken from the society's Insert Design Handbook [15]. The test specimens were 80 × 80 mm square CFRP honeycomb sandwich panels with a core thickness of 10 mm. The hard points were inserted at the centre of the square of the sandwich panel as shown in Fig. 3. The standard testing method used was the pull-out test using a universal testing machine (Instron 5890) on a fastener that was attached to a composite plate. The standard code which has a similar testing method is ASTM D7332/D7332M-15a [16].

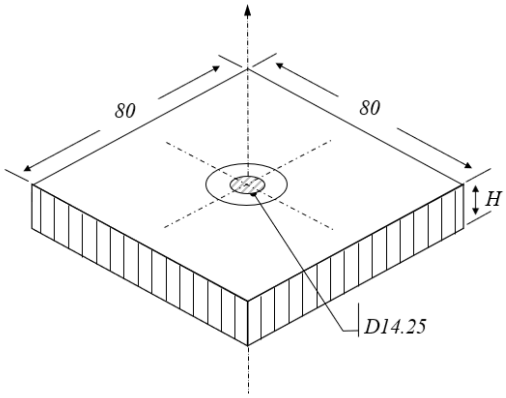

Fig. 3. The geometry of the specimen based on ESA insert design handbook (all dimensions in mm).

2.1.1. Specimen preparation

The 80 × 80 mm test specimen was comprised of 10 mm Nomex honeycomb core (PK2 Kevlar® N636 Para-Aramid Fiber Honeycomb) in the middle, sandwiched between pre-impregnated CFRP (HexPly® 8552) face-sheets. In the centre of the honeycomb core, a metal insert was inserted into a hole. Then, the potting agent, which was thick epoxy mixed with aerosil reinforcement, was pre-injected to bond the metal insert with the honeycomb core, as shown in Fig. 4. An adhesive film was used to attach each layer of CFRP face-sheet to the Nomex core. The specimens were fabricated via vacuum bagging process and cured at 120 °C for 3 hours.

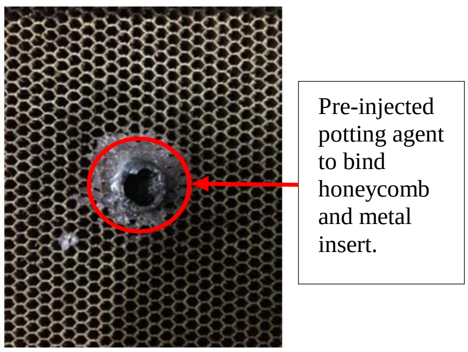

Fig. 4. Insert bonded with epoxy in honeycomb core. The cell size of the honeycomb is 3.2 mm, and the insert diameter is 14.25 mm

Nine test specimens were prepared, three sets for each type of hard point or insert. Type A, B, and C inserts were bonded using 0 ml (without a potting agent), 0.2 ml and

1.4 ml potting volumes, respectively. The three variations of potting agent volume are summarized in Table 1.

Table 1. Through-the-thickness inserts with various potting volumes

Variation	Diameter, mm	Volume, ml	Remarks
Type A	0	0	Without potting agent
Type B	16	0.2	With potting for bonding of insert to core
Type C	30	1.4	With potting volume as applied on stingray body

2.1.2. Jig and fixture preparation

The jig was designed and fabricated to be attached to the tensile testing machine (Instron 5890) and was fixed to the bottom of the fixture. The specimen was slotted in-between the top and bottom of the fixture. Hence, the fixture would not deform at a big margin until the sandwich honeycomb panel failed. Too much deformation on the jig would increase the error of the experimental results. The jig was designed based on the ESA Insert Design Handbook [15] where the circular hole diameter on the upper part of the jig is 70 mm. The specification of the test fixture is shown in Fig. 5.

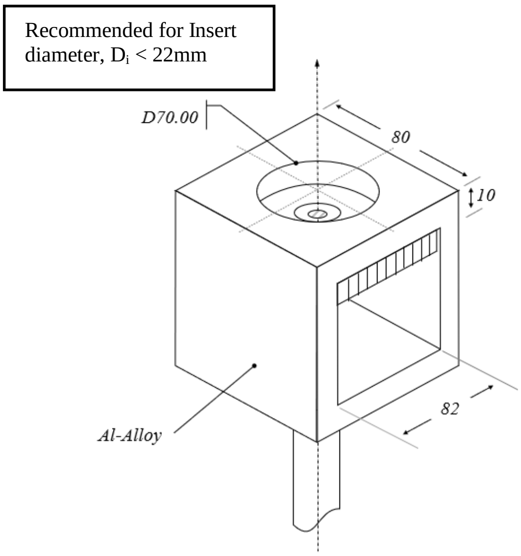

Fig. 5. The specification of the test fixture as recommended by ESA Insert Design Handbook (all dimension in mm)

2.1.3. Testing method

The pull-out test was conducted by applying load normal to the sandwich panel surface. In other words, the force was applied to the fastener at the centre of the specimen to pull the fasteners upwards. Fig. 6 shows the experiment setup. All the test parameters were kept constant except for the potting volume. The test speed rate set on the Instron machine was 3 mm/min.

2.2. Finite element simulation

Simulations based on the experiment set up were also performed using a commercial Finite Element Analysis Software, ANSYS.

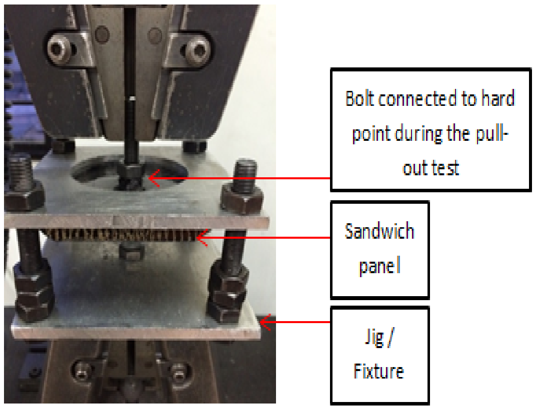

Fig. 6. Pull-out test on CFRP honeycomb sandwich panel

The basic finite element simulation procedure and analysis followed the previous research [23]. Any result of the deformation behaviour of the sandwich panel was also obtained through the software simulation. In performing the simulation, the parametric modelling was preferred since it would yield a faster computation than a discrete model and yield a reasonable result. However, parametric modelling would disregard the honeycomb shape effect on the rigidity of the sandwich panel.

The entire element was set as 3D solid. All the elements chosen were SOLID186 elements. The adhesive films were ignored since their function was just as a binder of the face sheet and the honeycomb core. Moreover, in the ANSYS model, the core and face sheet was assumed to be in contact and perfectly bonded. The contact surfaces are defined as CONTA174 and TARGE170 elements.

2.2.1. Pre-processor

In the first stages, the modelling of the honeycomb sandwich panel was done by using CATIA. Only a quarter models were made in the modelling process. All the components of the panels were modelled (Core, face sheets, aluminium insert, potting agent volume and fasteners) to be quarter models. Next, the element type was chosen. The entire geometries were analysed by using a 3D solid element (Brick 20 node 186). After that, the material properties of each constituent element were set in the material models. All the elements were considered isotropic except for the face sheet where the orthotropic property was defined on the layup. Next, the meshing was done to all the components once the element attributes were set accordingly. Lastly, the contacting surfaces were set using the contact manager.

Before solving, the loads and constraint were set first, where the boundary conditions were applied as followed:

1. All nodes on the top face sheet beyond the diameter D = 70 mm (Fig. 5), all DOF = 0;
2. Load on the top fastener, Psim.

Psim is defined as the load input for the analysis. The simulation on each type of hard point is comprised of different load inputs to generate the load-extension data for the sandwich panels. The load was the control parameter with the extension as the output. The loads were set at 1.0 kN with 1.0 kN increment giving the corresponding extension of not more than 4 mm. The limiting extension of 4 mm was considered because according to ESA Insert Design Handbook [15], the ultimate load should have been reached at around 2 mm deflection for most sandwich conditions

2.2.2. Post-processor

After solving, the results were interpreted and represented by nodal displacement (in the z-direction) of the sandwich panel. The shear stress and strain distribution throughout the panel were also obtained.

The data collected was then analysed and represented in graphical methods. The load-extension curve for the three types of sandwich panels with different potting volume were then illustrated. By doing this, the results from the simulations were able to be compared to the corresponding results from the simulations.

3. RESULTS AND DISCUSSION

3.1. Experimental results and discussion

The load-displacement curves of the static pull-out test for the hard point on sandwich panels are shown in Fig. 7. Each series of the lines represents the mean of three repeated tests for each potting volume variation. Each curve showcased varying results.

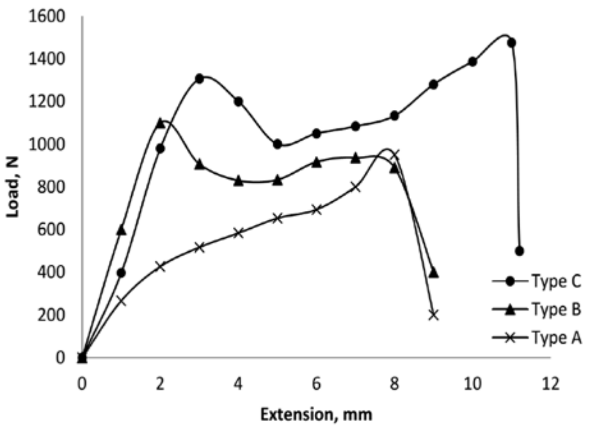

Fig. 7. Load (mean)-extension curves (from experiment)

It can be observed from the curves that Type A specimen without the potting agent is the weakest. Its curve behaves nonlinearly in the beginning stage of the test which is probably due to local slippage between the metal insert and the sandwich panel. The curve then shows a nearly linear behaviour suggesting that elastic deformation is taking place within the core material. With the absence of a potting agent, the pull-out insert was supported directly by the shear strength of the honeycomb cells and CFRP face-sheet. In the last stage, a slight nonlinear behaviour took place during the development of high strains in the plastic deformation stage of the core material. Failure load was recorded at 700 N which was established at the beginning of the plastic deformation stage and the failure load was measured at 905 N, just before the load was drastically dropped at the extension of 8 mm. Fig. 8 shows the failure loads of the hard points for all three types. The upper and lower whiskers show the maximum and the minimum loads, with the mean values represented by the lines on top of the bars.

The behaviour of the curves for Type B and Type C specimens with different quantity of potting agent showed a similar trend in the first and second stages but varied in the last stage.

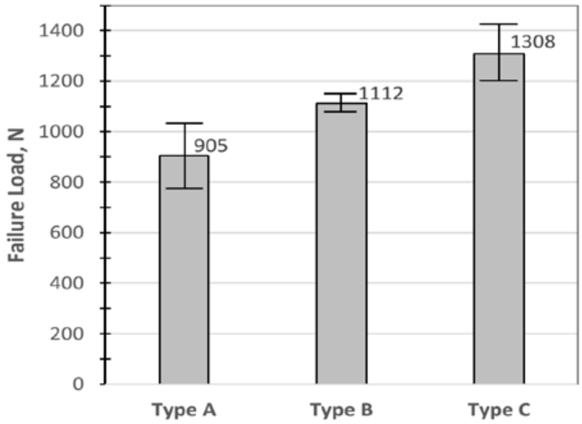

Fig. 8. Failure load of hard points (from experiment)

In the first stage, both curves were almost linear. The quasi-linear behaviour is attributed to the elastic deformation of the core and during this stage no considerable damage is taking place. At the end of this stage, the pull-out loads reached peak values and then started to slowly drop. These peak values were considered as the failure loads of the specimens [11 – 15], and they were measured at 1112 N and 1308 N, respectively for Type B and Type C specimens. In the second stage it can be observed that the loads were slowly decreasing and then levelling on over significant displacements, which is an indicator of plastic deformation occurring within the core material. In the final stage, the Type C curve increased slightly to a maximum load of 1500 N. The Type B curve, however, did not exhibit this trend. Since the potting volume was larger in Type C specimen, the insert was fully embedded in the core materials and had more ability for the potting to hold the inserts, hence the specimen could provide additional support to the load beyond the previous stages. Contrarily, due to the lack of potting agent in Type B specimen, the damage significantly progressed during the plastic deformation, causing it to have less strength to support the load further.

The three-stage behaviour of the load–displacement curve with two-peak load values, as exhibited by Type C specimen is typical for normal-to-plane tensile load test. Similar trend was observed by Ge et al., in [11], and Song et al., in [24] and among other research. In the present experiments, all six metal inserts were found to be detached from the sandwich panel. The typical insert failure is shown in Fig. 9. Damage of inserts by pull-out load is predominantly caused by shear buckling of the honeycomb core surrounding the potting [15]. Several other failure regimes, such as tensile breaking of the core, rupture of the potting, and debonding of the potting/skin interface were also reported [14, 15, 24 – 27] and they could have occurred beyond the first stage of the load–displacement curve. The stiffness of the CFRP face-sheet of the sandwich panel can also play important role in supporting the inserts after the strength of the honeycomb material has degraded. It is possible that the increase of loads in the final stage of the experiments for Type C and Type A was due to this reason. Smith et al., in [11], performed a reliability analysis on inserts and concluded that even if the first failure was caused by the buckling of the honeycomb core cells, the skin's strength still commanded significantly.

The experimental evidence also showed that the variations of potting volume also changed the stiffness of the insert system or the hard point. As can be observed from Fig. 7, considering the linear part of the curves, Type A specimen has the least stiffness. The slopes of both Type B and Type C curves are seen to be comparable, and steeper which indicate that both types of the specimens can resist more pull-out loads with the same deflections in comparison to Type A specimen.

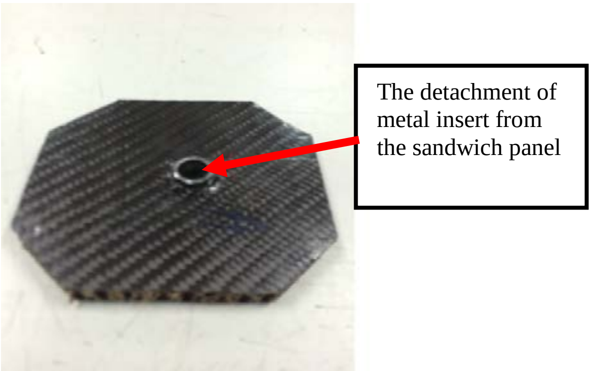

Fig. 9. The detachment of metal insert (diameter 14.25 mm) from the sandwich panel specimen

3.2. Simulation results and discussion

The results from the finite element simulation were plotted to give the load versus nodal displacement graph shown in Fig. 10.

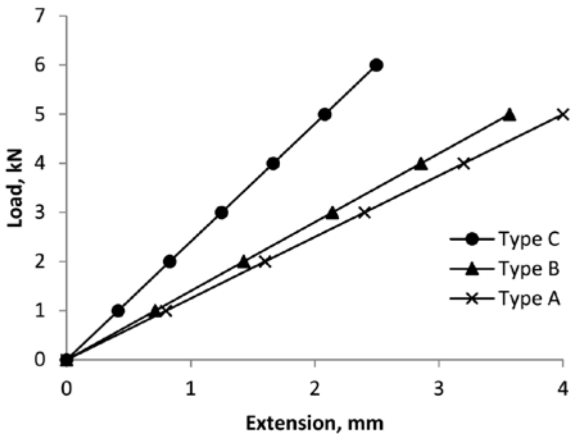

Fig. 10. Load-extension curves (from simulation)

Type C line has the steepest gradient followed by Type B and Type A lines. This indicates that the hard point on Type C specimen will deform less compared to Type B and Type A specimens with the same loading. This condition is more practical for load attachment point. It can be said that that the addition of potting agent to the sandwich panel will make the honeycomb core more rigid, yielding to a stiffer sandwich panel.

In general, the finite element simulation results in the present work did not provide a good prediction for the experimental results. All numerical load values were very much higher than the load experimental values, for all three cases. For example, referring to Type A line in Fig. 10, at 2 mm extension the corresponding load is 5 kN, which is 5 times higher than was measured experimentally. The gradients of lines for Type A and Type B are closer to each other in simulation, but the gradients of the straight portion of the curves are almost the same for Type C and Type B, as observed experimentally. In addition, the pull-out strengths of the hard points were unsuccessfully determined by the numerical prediction. Despite all the drawbacks, the simulation has supported the finding from previous experiments that the inclusion of the potting agent can make the hard point stiffer.

Variations in results between the common analytical approaches and experimental evaluations are well known among the sandwich structure community [12, 15]. As pointed out by Rodríguez-Ramírez et al., in [27], the lack of accuracy was an accumulation of errors related to insert defects, the testing methodology, along with the way analytical and experimental results were interpreted. Furthermore, over-simplification in the finite element model when conducting the simulation, as in the present case, had contributed most to the errors. The deficiencies in the present model include disregarding intrinsic rigidity property due to honeycomb shape and assuming the core and face-sheet to be in contact and perfectly bonded, among others. In addition, the main reason is linear finite element analysis was used which cannot adequately simulate the true effects of various sandwich components, non-linearity of Nomex honeycomb cells [28], and material degradations especially involving material yielding and large deformations. Thomsen [20] used the high-order theory to accurately estimate stress distribution in the core, face-sheet, and more currently, Rodríguez-Ramírez et al., in [25] proposed advanced nonlinear numerical simulation methods that can provide accurate pull-out strength estimations. Time and cost were the main factors when performing similar non-linear analyses.

As mentioned, the hard point for the present study was intended to be used on the Stingray solar car body. It was to be used to mount the suspension system of the car, which carried the most load. Following the calculation process given in [29], the weight of all components (chassis, battery, and mechanical systems and electronics) was 35 kg, and the driver was 50 kg, and together with 3 g acceleration yielding a load of approximately 1000 N. Therefore, Type C hard point with failure load measured at 1300 N can be used to safely support the load of 1000 N.

4. CONCLUSIONS

The main objective of this paper was to investigate the mechanical behaviour of the hard points on a composite sandwich panel due to volume variations of a potting agent. The major findings that could be drawn from this study are:

1. The strength and the stiffness of the hard points increase with the increment of potting agent volume. Consequently, the potting materials will add weight to

the Stingray chassis, hence increasing the car payload. The amount of 1.4 ml potting was found to provide adequate strength to the hard point to support the car's suspension load.

2. Curing potting resin provides high resistance for the inserts from pulling out of the test specimens. The potting also acts as a filler material that distributed the loads from the insert to the surrounding sandwich structure especially the honeycomb core. The evidence from the experiment showed the ultimate failure of metal inserts were due to the detachment from the potting agent and its surrounding. Hence the strength of the hard point can be improved with the better fabrication of inserts or replacing the inserts with metallic threaded fasteners or spindle type inserts and taking advantages of cold- or hot-bonded installation procedure.

As a conclusion, it can be highlighted that the current study is useful and has provided a data base for designing the attachment between Stingray's composite monocoque car structure and its mechanical system, which in general, improves the design and fabrication of the next generation of UiTM Eco-Photon solar car.

Acknowledgments

This work is supported by Universiti Teknologi MARA (UiTM) and Ministry of Higher Education (MOHE) Malaysia under the Fundamental Research Grant Scheme (grant no FRGS/1/2018/TK03/UITM/02/8 and 600-IRMI/FRGS 5/3 (165/2019)).

REFERENCES

1. **Kim, B.J., Lee, D.G.** Characteristics of Joining Inserts for Composites Sandwich Panels *Composite Structures* 86 (1 – 3) 2008: pp. 55 – 60. https://doi.org/10.1016/j.compstruct.2008.03.020
2. **Ramdzam, N.A., Mahmud, J.** Investigating the Shear Behaviour of Hard Points on Honeycomb Sandwich Panels *Journal of Mechanical Engineering* 4 (4) 2017: pp. 197 – 210.
3. **Vizentin, G., Vukelic, G.** Degradation and Damage of Composite Materials in Marine Environment *Materials Science (Medžiagotyra)* 26 (3) 2020: pp. 337 – 342. https://doi.org/10.5755/j01.ms.26.3.22950
4. **Herranen, H., Pabut, O., Eerme, M., Majak, J., Pohlak, M., Kers, J., Saarna, M., Allikas, G., Aruniit, A.** Design and Testing of Sandwich Structures with Different Core Materials *Materials Science (Medžiagotyra)* 18 (1) 2012: pp. 45 – 50. https://doi.org/10.5755/j01.ms.18.1.1340
5. **Abd Ghani, A.F., Mahmud, J.** Characterisation of Hybrid Carbon Glass Fiber Reinforced Polymer (C/GFRP) of Balanced Cross Ply and Quasi Isotropic under Tensile and Flexural Loading *International Journal of Automotive and Mechanical Engineering* 17 (1) 2020: pp. 7792 – 7804. https://doi.org/10.15282/ijame.17.1.2020.25.0580
6. US Military Handbook 23A, Design of Flat Circular Sandwich Panel Loaded at an Insert 1974.
7. **Slimane, S., Kebdani, S., Boudjemai, A., Slimane, A**. Effect of position of tension-loaded inserts on honeycomb panels used for space applications, *International Journal on Interactive Design and Manufacturing* 12, 2018: pp. 393–408. https://doi.org/10.1007/s12008-017-0383-2.
8. **Heimbs, S., Pein, M.** Failure Behaviour of Honeycomb Sandwich Corner Joints and Inserts *Composite Structures* 86 (4) 2009: pp. 575 – 588. https://doi.org/10.1016/j.compstruct.2008.11.013
9. **Smith, B., Banerjee, B.** Reliability of Insert in Sandwich Composite Panels *Composite Structures* 94 2012: pp. 820 – 829. https://doi.org/10.1016/j.compstruct.2011.10.018
10. **Roy, R., Nguyen, K.H., Park, Y.B., Kweon, J.H., Choi, J.H.** Testing and Modelling of Nomex^{TM} Honeycomb Sandwich Panels with Bolt Insert *Composites Part B* 56 2014: pp. 762 – 769. https://doi.org/10.1016/j.compositesb.2013.09.006
11. **Ge, Q., Li, M., Wang, S.Y.** Modelling and Reliability of Insert in Composite Pyramidal Lattice Truss Core Sandwich Panels *Composite Structures* 221 2019: pp. 110888. https://doi.org/10.1016/j.compstruct.2019.04.060
12. **Wolff, J., Brysch, M., Hühne, C.** Validity Check of an Analytical Dimensioning Approach for Potted Insert Load Introductions in Honeycomb Sandwich Panels *Composite Structures* 202 2018: pp. 1195 – 1215. https://doi.org/10.1016/j.compstruct.2018.05.105
13. **Giglio, M., Manes, A., Gilioli, A.** Investigations on Sandwich Core Properties through an Experimental-Numerical Approach *Composites: Part B* 43 2012: pp. 361 – 374. https://doi.org/10.1016/j.compositesb.2011.08.016
14. **Raghu, N., Battley, M., Southward, T.** Strength Variability of Inserts in Sandwich Panels *Journal of Sandwich Structures and Materials* 11 (6) 2009: pp. 501 – 517. https://doi.org/10.1177/1099636209104524
15. Insert Design Handbook. European Space Agency, ESA PSS-03-1202, 1987.
16. ASTM D7332/D7332M-15a. Standard Test Method for Measuring the Fastener Pull-Through Resistance of a Fiber-Reinforced Polymer Matric Composite, ASTM International, West Conshohocken, PA, 2015.
17. Space Engineering; Insert Design Handbook, ECSS-E-HB-32-22A; 2011
18. **Zenkert, D.** The Handbook of Sandwich Construction. EMAS Publishing; 1997.
19. **Thomsen, O.T.** Sandwich Plates with Through-the-Thickness and Fully Potted Inserts: Evaluation of Differences in Structural Performance *Composite Structures* 40 (2) 2008: pp. 159 – 174. https://doi.org/10.1016/S0263-8223(98)00017-8
20. **Thomsen, O.T., Rits, W.** Analysis and Design of Sandwich Plates with Inserts – A Higher Order Sandwich Plate Theory *Composites Part B: Engineering* 29B 1998: pp. 795 – 807. https://doi.org/10.1016/S1359-8368(98)00019-5
21. PK2 Kevlar® N636 Para-Aramid Fiber Honeycomb; Technical Datasheet.
22. HexPly® 8552; Technical Datasheet.
23. **Rahimi, N., Hussain, A.K., Meon, M.S., Mahmud, J.** Capability Assessment of Finite Element Software in Predicting the Last Ply Failure of Composite Laminate *Procedia Engineering* 41 2012: pp. 1647 – 1653. https://doi.org/10.1016/j.proeng.2012.07.363
24. **Song, K.I., Choi, J.Y., Kweon, J.H., Choi, J.H., Kim, K.S.** An Experimental Study of the Insert Joint Strength of Composite Sandwich Structures *Composite Structures*

86 (1 – 3) 2008: pp. 107 – 113. https://doi.org/10.1016/j.compstruct.2008.03.027

25. **Rodríguez Ramírez, J.D., Castanié, B., Bouvet, C.** Insert of Sandwich Panels Sizing through a Failure Mode Map *Composite Structures* 234 2020: pp. 111724. https://doi.org/10.1016/j.compstruct.2019.111724

26. **Bianchi, G., Aglietti, G.S., Richardson, G.** Static Performance of Hot Bonded and Cold Bonded Inserts in Honeycomb Panels *Journal of Sandwich Structures and Materials* 13 (1) 2011: pp. 59 – 82. https://doi.org/10.1177/1099636209359840

27. **Rodríguez Ramírez, J.D., Castanié, B., Bouvet, C.** On the Potting Failure of Inserts for Sandwich Panels: Review of Defects and Experimental Analysis *Mechanics of Advanced Materials and Structures* 28 (21) 2021: pp. 2210 – 2228. https://doi.org/10.1080/15376494.2020.1724352

28. **Bunyawanichakul, P., Castanié, B., Barrau, J.J.** Non-Linear Finite Element Analysis of Inserts in Composite Sandwich Structures *Composite:* Part B Engineering 39 (7 – 8) 2008: pp. 1077 – 1092. https://doi.org/10.1016/j.compositesb.2008.05.004

29. **Denny, J., Veale, K., Leverone, F.** Conceptual Design and Numerical Validation of a Composite Monocoque Solar Passenger Vehicle Chassis *Engineering Science and Technology, an International Journal* 21 (5) 2018: pp. 1067 – 1077. https://doi.org/10.1016/j.jestch.2018.07.014