TOWARDS MANUFACTURING OF FULL SCALE WOOD VENEER AUTOMOTIVE PANEL

Matt Jennings[1], Mahbube Subhani[2], Johannes Reiner[3], Giovanni Piazza[4], David Heyner[5]

ABSTRACT: This study investigates replacing the carbon fibre composite rear panel of the Deakin University Solar Car with a wood veneer alternative to increase sustainability. The approach to the project is informed by the framework put forward by North American Automotive OEMs in the 1990s: Advanced Product Quality Planning (APQP), which was created to ensure customer satisfaction with new products and/or processes. The project focuses on manufacturing feasibility, with the goal of understanding the limitations and opportunities when developing a lay-up process that forms wood veneers to the complex curvature of the solar car's rear panel mold. By temporarily increasing moisture content via heated water and steam, the veneers' bending limits were increased and were able to be formed then dried in shape as a preform before applying adhesive to layup. Results demonstrate that while the technique used to manufacture the panel for this study has to be improved further, the findings support the feasibility of wood veneer panels as a lightweight, sustainable replacement for carbon fibre composites in automotive applications, while highlighting the need for further research on such subjects as material properties, relief cuts, and veneer overlap.

KEYWORDS: veneer, forming, large-scale manufacturing, preforming

1 – INTRODUCTION

This study investigates the feasibility of manufacturing automotive body panels out of wood veneer as a sustainable alternative to traditional materials. Utilizing a pre-existing mould provided by the Deakin University Solar Car Team (DUST), this research examines the capacity of wood veneers to conform to complex geometries, including tight radii and a surface area of approximately 3 m² (Figure 1).

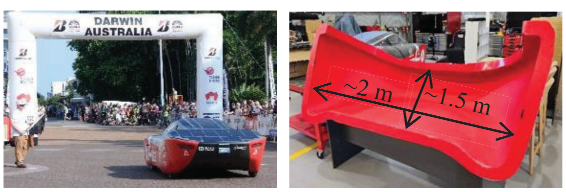

Figure 1. Figure 1. The Deakin University ASCEND Solar Car with its hand laminated carbon fibre composites rear bumper leaving Darwin (left) and the mould used to make the carbon fibre composite bumper that is also used to protype wood veneer alternatives (right).

Automobiles have traditionally been constructed using metals, plastics, and glass components [1]. However, increasing pressure on manufacturers to improve environmental sustainability and to reduce carbon emissions has accelerated the search for alternative, eco-friendly materials [2]. Wood laminates present a promising solution, offering significant reductions in embodied energy and carbon. Compared to steel, wood laminates reduce embodied energy (MJ/kg) by approximately 52%, and by 48% when compared to aluminium [3]. The benefits are even more substantial in terms of embodied carbon ($kgCO_2/kg$), with reductions of 68% relative to steel and 87% relative to aluminium [3].

While the use of wood veneer in automotive applications is not entirely new, recent advancements in processing have made it possible to produce thinner and more durable veneers suitable for structural and semi-structural components [4]. Moving forward, automotive manufacturers must consider how to integrate these materials using conventional techniques—without compromising safety, performance, or production efficiency [5].

The research aims to influence the automotive industry by demonstrating that wood veneer panels are possible to manufacture, and highlight the further research required to enable cost effective and high-quality components.

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2 – BACKGROUND

The current body of literature on large-scale manufacturing of composite panels with complex geometries is relatively sparse, especially when it comes to wood veneer composites. While there has been substantial research into the theoretical replacement of steel with wood-based materials in structural contexts [6], practical methods for forming large-scale, thin wood composites with intricate curvatures remain underdeveloped. Advances in manufacturing have enabled modern automotive designers to explore wood veneers as lightweight alternatives that can maintain structural performance [7]. Nonetheless, the integration of wood veneers in automotive applications presents considerable challenges, including not only mechanical performance and process compatibility but also critical factors such as reliability, repeatability, and integration into existing workflows [8].

Wood veneers offer an efficient use of natural resources, as their production allows for better quality control compared to thicker lumber. Additionally, combining different wood species reduces reliance on a single type, supporting biodiversity [9]. Veneers can also be produced from smaller logs, unlike traditional boards that require large-diameter logs, contributing to a higher recovery rate from natural forests [10].

Research into structural applications of veneers remains limited and typically focuses on a narrow range of species, including European beech [11], poplar [12], oak, and birch [13] within automotive contexts. Adhesives commonly used include polyurethane (PUR) and resorcinol formaldehyde, known for their bonding effectiveness but also for their toxicity—particularly the latter—raising sustainability concerns. This study proposes a bio-epoxy alternative, previously shown to be effective in bonding fibre-reinforced polymer composites [14].

During the layup process, alternating grain directions are typically used to counteract natural wood movement due to moisture fluctuations, improving dimensional stability and reducing warping risk [15]. Information on precise layup procedures and controls is limited, often due to proprietary constraints. However, studies of equipment providers such as Raute suggest these automated systems achieve precise alignment and positioning of veneers, while integrated quality control—such as vision systems—helps identify and reject defective sheets prior to layup [16].

Pasquier et al. [17] explored forming techniques using wood pulp, identifying thick-wall, transfer, and thin-wall moulding as key methods. The thin-wall approach, similar to plastic thermoforming [18], forms the basis of this study. By applying heat and moisture, the flexibility of thin wood veneers is increased, allowing them to adapt to complex moulds with reduced springback.

Existing literature demonstrates that wood veneers can meet performance requirements. When combined with techniques refined in furniture manufacturing [19–21], this suggests a viable path forward—highlighting the value of further research into controlled, large-scale production methods.

3 – PROJECT DESCRIPTION

A process flow chart was created and used to design discrete experiments to understand the limits and best practice for the steps throughout the manufacturing process (Figure 2). The experiments focused on optimizing veneer lay-up, adhesive application, and forming techniques to achieve structural integrity while accommodating the complex geometries of automotive components, always aiming to mimic the large scale part manufacture techniques. A critical aspect of the methodology involved analysing the impact of moisture content and resin penetration on springback and dimensional stability post-curing.

Once a basic understanding of the limits and techniques needed to enable forming and drying was achieved, sections of the body panel were made and lessons learned during that process were integrated to the process design for the full scale manufacture. The use of process flow charts and focusing on individual steps for quality improvements and cost reduction is taken from the APQP approach, the American Automotive guide to quality assurance [22].

The wood veneers used for this study were:

- Rotary cut European Beech with an average density of 720 kg/m^3. The veneers were provided by Metz & Co, Germany with an average thickness of 0.6 mm.
- Rotary cut European Birch (660 kg/m^3) and Quarter Cut Hoop Pine (530 kg/m^3) were provided by Briggs Veneer, Australia, with thickness of 0.6 mm.

The adhesive used was a laminating resin, Bypoxy, (CCBE-5) a bio-based epoxy supplied by Change Climate Pty Ltd. The mixing ratio between Part A and Part B was 71.5 to 28.5 by volume. The mixed density was 1150 kg/m3 with viscosity of 2,300 mPa·s. It was selected as the adhesive due to its sustainability and long working time, which allowed precise lay-up adjustments before curing. The adhesive application target was 180 g/m^2 between each veneer layer to ensure uniform bonding and prevent excessive resin absorption.

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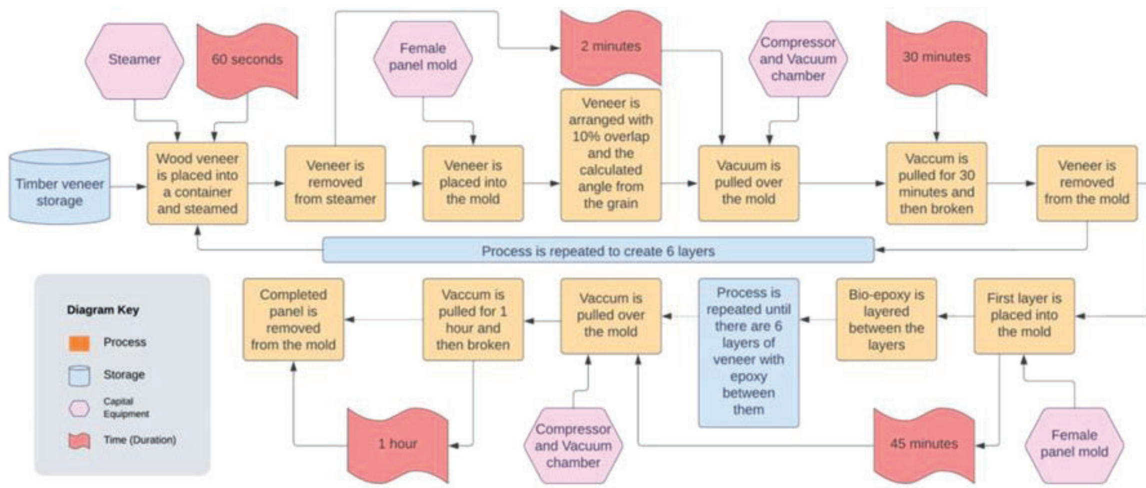

Figure 2. Process flow chart for the manufacturing of a complex shaped body panel made from wood veneers.

4 – EXPERIMENTAL SETUP

4.1 – TWO-DIMENSIONAL BEND LIMITS

The maximum bend radius of the rear bumper mould was mimicked with a 3D printed 25 mm bend radius and 75 mm width. Specimens of beech veneer were cut into 200 mm x 75 mm with 11 different grain directions, 0° to 90° in 10° increments, as well as 45°. The specimens were cut from areas in the leaves with no knots that would negatively affect the accuracy of the bend testing experiments.

The bend testing radius was then placed under the veneer. A clamp held either side of the veneer onto the bend tester, ensuring that excessive pressure was not applied to avoid the sample from cracking. The test was deemed a failure if cracking was heard and seen. A set of specimens were measured dry, then another set steamed for 60 seconds then measured in the bending rig, with a final set wet with cold water only to see if forming actually requires heat with moisture.

4.2 – VENEER PREFORM SPRINGBACK

The springback of single veneers was measured by first wetting the 500 mm long veneer leaves with boiling water to enable faster (30 second) softening than steaming. One leaf was completely submerged, while the other was only submerged where it needed forming into a complex curve. One layer of veneer was then laid in to the mould, and vacuum bagged as per typical composite vacuum bagging. Breather cloth was laid on the veneer then covered and sealed with sealant tape and vacuum bagging. A port was added and the vacuum pulled within the bag over 6 hours to dry out the stack and apply pressure to keep the veneer to the shape of the mould.

The springback of the veneers was measured by taking initial measurements, tip to tip, while still in the mould. Once the panels were taken out of the mould, measurements were immediately taken. The distance from the top edge to the bottom edge of both preforms was measured every 24 hours for two weeks, to determine the time in which a preform had to be used after forming.

4.3 – LAMINATE SPRINGBACK

Preforms were created as described in Section 4.2. Three different lay-up orientations were used, all with three layers of veneers in the laminate. Laminates with grain orientation of [0,0,0], [90,90,90] and [0,45,-45] to determine the effect of extreme orientations and a multi orientation layup that could be the full scale layup.

Once dried, the preforms were layed into the mould with Bypoxy spread across the surfaces of the first and second layer at approximately 180 gsm. A PTFE release film was placed on the veneers, then the layup was vacuum bagged as described when drying preforms. Vacuum was applied for 24 hours as recommended for curing of Bypoxy before the laminate was removed from the mould. This was completed for each layup. These panels were measured from the left-hand side, tip to tip, and these measurements were recorded for 21 days. These 21 days include the specified seven day curing cycle of the Bypoxy.

4.4 – FULL SCALE MANUFACTURE

Two sections of the panel were manufactured as per the process flow in Figure 2. The middle section, which is mainly a 2D curvature, and the side section, which has large radius yet complex curvature. This helped understand some of the limits when laying up with and without preforming, to understand limits and how relief cuts may be used. When manufacturing the full-scale bumper panel, the steps in Table 1 were followed, which also captured the limitations and opportunities for further research to increase the quality of a wood veneer body panel. The table is based on a Process Failure Mode Effect Analysis (PFMEA), with only the relevant columns presented in this paper.

The mould was first prepared using three coats of Zyvax Sealer GP, with 30-minute intervals between applications to ensure proper curing. This was followed by three coats of Zyvax Enviroshield release agent, again allowing 30 minutes time between coats. After final curing, the mould was ready for layup and forming trials.

European Beech was used for the two section layups, with the central section using a unidirectional layup, and the side section using a [0,-45,+45,0] layup. The full body panel layup was asymmetric quasi-isotropic: [0,-45,+45, 90]. Three species were used, Beech for the 0° layer, Birch for the 45° layers, and Pine for the 90° layer. These layups and specie combination may not be ideal from a design standpoint, but the goal of this study is to learn as much about the feasibility of manufacture, therefore all choices were geared to learn the most about the materials, forming, and epoxy application to ensure as much learning took place as possible.

To enable the wood veneer to conform to the complex mould geometry, its flexibility was increased by raising its moisture content. This was achieved by submerging each veneer sheet in boiling water for 30 seconds, ensuring even wetting on both sides. Immediately after conditioning, the veneer was removed and placed into the mould while still pliable.

The Bypoxy resin was mixed in batches in attempt to reach 180-250 gsm application rate, with each layer the required amount was calculated, mixed, then applied, with a new mix for each layer. For the full-scale panel, the first layer may have gelled prior to applying pressure via vacuum (5 hours) which may affect results (and surface finish, as seen in Figure 8) and therefore the panel will not be relied upon in service, just used as a demonstrator.

5 – RESULTS

4.1 – TWO-DIMENSIONAL BEND LIMITS

It was found that the 0.6 mm beech veneer was limited to a 60° grain orientation when bending over the 25 mm radius when dry, while all grain orientations could bend over the radius after steaming for 60 seconds (Figure 3*Figure 3*). Cold water conditioning did not improve the veneers' ability to bend, meaning that heat is required when forming and the softening of the lignin in the wood is a contributor to increasing the ability to form wood veneer.

4.2 – VENEER PREFORM SPRINGBACK

Springback of the preforms was not affected by local wetting vs full leave wetting, and the springback can be described as manageable over a reasonable period of time for manufacturers to batch-produced preforms and store prior to applying adhesive for laminate manufacture (Figure 4). An interesting result was found during this test which was that the leave that had only local wetting had failures occur in the section that was left dry: any natural moisture was removed when drying out the formed section. This means that control is required to not dry out areas of the material excessively during the preforming phase.

4.3 – LAMINATE SPRINGBACK

As shown in Figure 5, the asymmetric panel exhibits the highest initial springback but ultimately recovers closest to the mould shape. The 0° unidirectional (UD) panel shows no springback but instead shrinks. This occurs because the grain direction, aligned with the mould (0°), follows the path of least resistance, allowing the bio-epoxy to draw the panel inward during curing.

In contrast, the 90° UD panel displays significant and sustained springback with no shrinkage. This is due to the high resistance encountered when bending the veneer perpendicular to the grain. As shown in Figure 5, this panel reaches just under 20 % springback—approaching the failure threshold identified in the literature.

These results highlight the importance of varying grain direction within laminated wood stacks to balance internal forces, improve dimensional stability, and reduce springback. Additionally, tight mould radii restrict feasible grain orientations, reinforcing the need to design moulds with grain direction in mind. This approach can enhance lay-up efficiency and reduce the risk of distortion in wood composite components.

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Figure 3. Comparison between bending the dry beech veneer around a 25 mm radius where it fails at 60° grain orientation and above (left), and the successful bending of the same set up when steamed for 60 seconds (right).

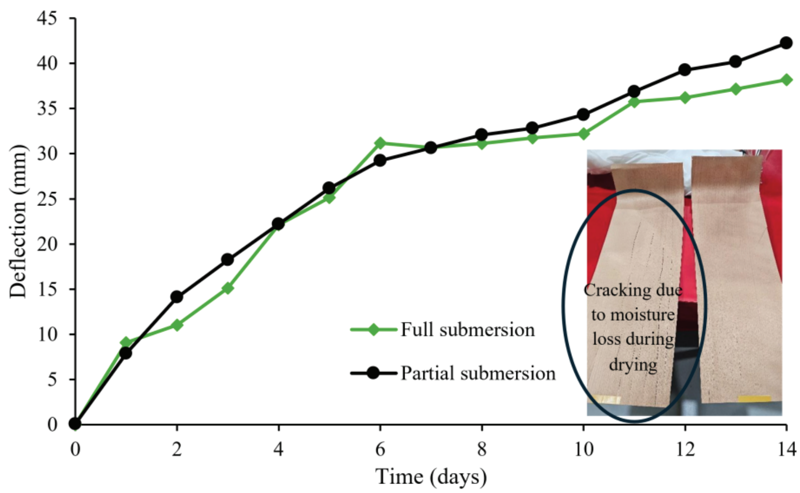

Figure 4. Springback was minimal over days and not affected by localised wetting vs total leaf wetting. Localised wetting caused excessive drying out of the wood, leading to the recommendation of full leaf wetting when preforming the wood veneer.

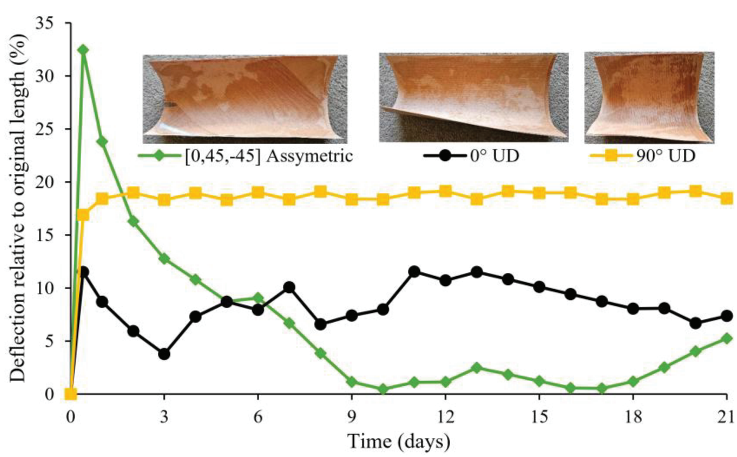

Figure 5. Springback of the laminates with different layups showed initial springback then stability over time for unidirectional layups, while the asymmetric layup showed the most initial spring back then relaxed to its moulded dimensions after about 9 days, similar to the recommended cure time at room temperature of the Bypoxy resin.

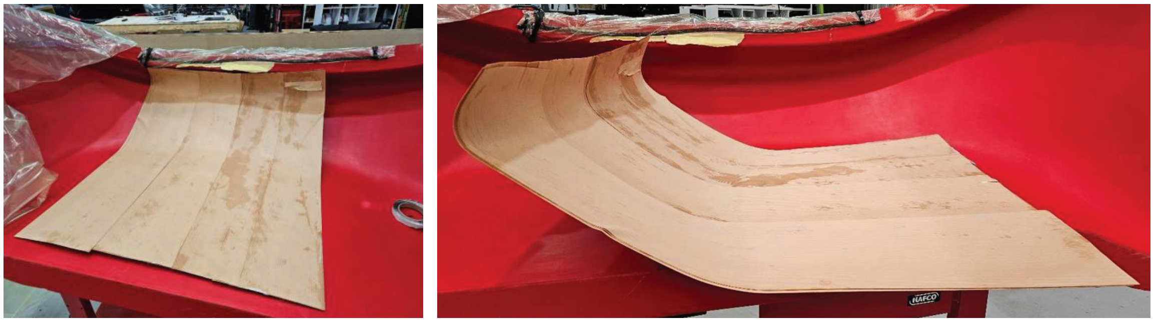

Figure 6. Section manufacture of the middle of the body panel was proved to be relatively simple with good conformance to the mould, minimal relief cuts required and a good surface finish.

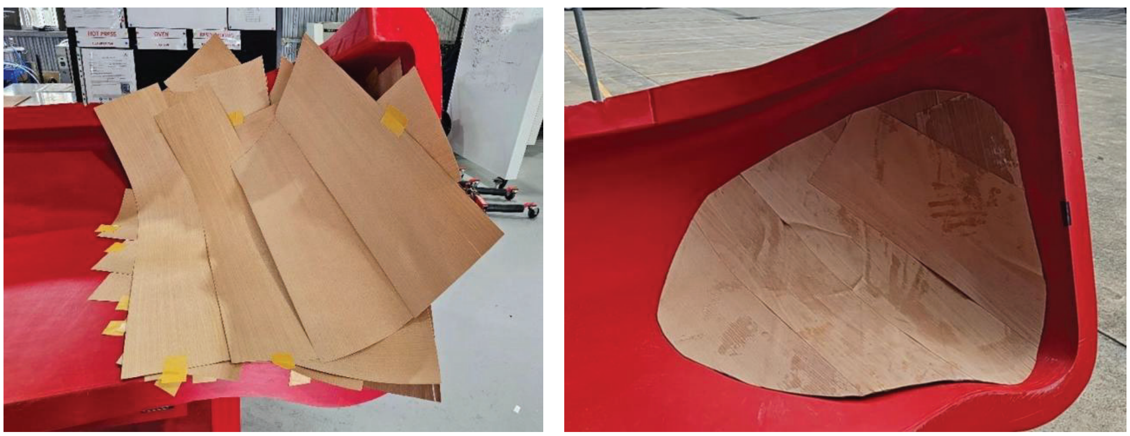

Figure 7. Section manufacture of the side of the panel with complex curvature showed the many relief cuts will be required but feasibility of full panel manufacture will be possible with methodical preforming and relief cuts prior to applying resin.

Figure 8. The full scale manufacture of the bumper panel proved that it is feasible to manufacture a large scale parge from wood veneers but requires different mould design and more research in to temperature and moisture control during forming, as detailed in Table 1.

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4.4 – FULL SCALE MANUFACTURE

The process and results are discussed in Table 1.

Table 1. The key steps involved in laying up a large panel from wood veneer leaves with the limitations discussed in the failure mode effects and cause columns, and potential solutions and further research recommendations presented to address them

Process Step #	Description	Potential Process Failure Mode Effect and Cause	Recommendation to minimise failure mode
1	Soften each veneer leaf by submerging in hot water	Lignin in wood leaches out with heated water/ steam which could lower performance of the wood. Wood expands excessively due to moisture content and won't be the correct shape when dry. Wood is not wet enough for forming and will crack during preforming.	A study that can find the optimal balance of moisture, temperature and exposure time that allows the most formability of the veneers while minimising expansion and lignin loss. Understanding the extent of formality of the lignin: can veneer be stretched at all, like thermoforming?
2	Veneer placed into mould layer by layer at correct grain angle with 20-50 mm overlap of each leaf Repeat these 2 steps for each veneer leaf placed into mould.	Relief cuts may affect performance due to breaking of fibres and increasing layer overlap. Overlap of each leaf is inconsistent over complex geometries, combined with relief cuts this causes varying thickness across the panel potentially affecting performance and aesthetics. Excess overlap increases overall panel weight. Veneer doesn't stay in place due to gravity and shrinkage/warping as it dries.	The effect of the overlap to find the best way to join the veneer leaves that minimises any effect in performance while also not increasing weight needs to be understood. This can drive precutting leaves to be the correct size prior to forming. A study on the impact on performance of relief cut angle with respect to grain orientation is required to assist in defining the best leaf preforms shape. Preform mould design: Investigating use of male mould and staples or magnets to hold each leaf in place. A solution could also be to use male and female moulds for forming, but the moulds require airflow to the preform for the veneer leaf to dry. A study on if bending veneer fibres causes microcracking and/or loss of performance via other means, to determine how to translate specimen testing to formed part performance.
3	Veneer lay-up left to dry in mould	Insufficient drying time leads to high moisture content remaining in wood causing reduction in effectiveness of adhesive. Over drying can lead to veneers cracking and losing their mechanical properties. Wood veneer shrinks over time that can cause dimension inaccuracies and imperfections in the part and on the surface.	Preform mould design needs to await inputs from the study that finds the ideal preforming moisture content and temperature which will have shrinkage data. The preform moulds can then be designed to compensate for the expected shrinkage. Ideal drying time at the correct environment needs to be understood. A balance of speed of drying and ensuring overdying does not occur is key.
4	Veneer removed from mould	Excessive handling of veneers increases risk of damage as dry veneer cracks and splits along the grain very easily.	Correct storage and movement should be incorporated into production line design.
5	Apply resin into mould for a surface coating (~180gsm)	Uneven application may cause poor surface finish.	This is dependent on the shape of the part: in this case the visible layer will be on the outside if a male mould is used. Final laminating coats could be applied, or post processing of the part be conducted, as per other materials.
6	Place first layer of veneer into mould	Veneer misalignment or movement after placement.	Refer to Step 2: male mould shapes combined with clamping mechanisms.
7	Repeat adhesive application and veneer placement for each layer	Uneven application may cause poor adhesion if too little and an increase in mass if too much.	The use of adhesive films, pre-coating with resin and/or spraying resin on the wood veneer prior to layup will dramatically decrease manufacturing time.
8	Place consumables and vacuum bag and pull vacuum for resin cure time.	Composite bagging consumables used.	Investigation on alternative and more sustainable pressing options required. Female mould pushed into male mould to apply pressure is a more expensive but repeatable and more sustainable solution.
9	Remove panel from mould	Panel sticking to mould causing damage during removal.	Ensure the appropriate release is applied to the mould for the resin/adhesive used, typical of composite manufacture.

6 – CONCLUSION

This study has explored the feasibility of manufacturing a full-scale automotive panel using wood veneers as a sustainable alternative to traditional materials. Through iterative testing, a number of key process variables have been identified—including veneer grain direction, moisture conditioning, adhesive application, and preforming technique—that significantly affect the outcome of forming complex geometries. The project has shown that it is possible to manufacture a veneer-based panel over a large and curved mould, but also makes clear that doing so in a repeatable and high-quality manner requires further investigation.

The work contributes to the limited body of knowledge on large-scale wood veneer forming by presenting practical insights into springback behaviour, moisture sensitivity, and challenges associated with relief cuts, veneer overlap, and preforming. While the outcomes are promising, the current process is not yet optimised for performance or production efficiency and should not be considered ready for end-use applications.

Future research should focus on refining preforming methods, quantifying the impact of relief cuts and overlap on performance, and better understanding the interaction between veneer properties, moisture content, and adhesive cure cycles. Further development of mould design and automation strategies will also be critical to move this approach toward scalable and reliable manufacturing.

7 – REFERENCES

[1] M. K. Gupta and V. Singhal, 'Review on materials for making lightweight vehicles', Materials Today Proceedings, vol. 56, pp. 868–872, 2022, doi: 10.1016/j.matpr.2022.02.517.

[2] J. Ross, 'Why Auto Giants Are Betting on Wood for the Next-Gen of EVs', Wood Central Australia. Accessed: Mar. 13, 2024. [Online]. Available: https://woodcentral.com.au/why-auto-giants-are-betting-on-wood-for-the-next-gen-of-evs/

[3] G. P. Hammond and C. I. Jones, 'Embodied energy and carbon in construction materials', Proceedings of the Institution of Civil Engineers - Energy, vol. 161, no. 2, pp. 87–98, 2008, doi: 10.1680/ener.2008.161.2.87

[4] B. Castanié, A. Peignon, C. Marc, F. Eyma, A. Cantarel, J. Serra, R. Curti, H. Hadiji, L. Denaud, S. Girardon and B. Marcon, 'Wood and plywood as eco-materials for sustainable mobility: A review', Composite Structures, vol. 329, 2024, doi: 10.1016/j.compstruct.2023.117790

[5] U. Müller, F. Feist, T. Jost, C. Kurzböck, and W. Stadlmann, 'Crash simulation of wood and composite wood for future automotive engineering', Wood Material Science and Engineering, vol. 15, no. 5, pp. 312–324, 2020, doi: 10.1080/17480272.2019.1665581

[6] D. Dalalah, S.A. Khan, Y. Al-Ashram, S. Albeetar, Y.A. Ali and E. Alkhouli, 'An integrated framework for the assessment of environmental sustainability in wood supply chains', Environmental Technology & Innovation, vol. 27, 2022, doi: 10.1016/j.eti.2022.102429

[7] D. B. Heyner, G. Piazza, E. Beeh, G. Seidel, H.E. Friedrich, D. Kohl, H. Nguyen, C. Burgold, and D. Berthold, 'Innovative concepts for the usage of veneer-based hybrid materials in vehicle structures', Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, vol. 235, no. 6, pp. 1302–1311, 2021, doi: 10.1177/1464420721998398

[8] D. Kohl, P. Link, and S. Böhm, 'Wood as a Technical Material for Structural Vehicle Components', Procedia CIRP, vol. 40, pp. 557–561, 2016, doi: 10.1016/j.procir.2016.01.133

[9] B.P. Gilbert, H. Bailleres, H. Zhang, and R.L. McGavin, 'Strength modelling of laminated veneer lumber (LVL) beams', Construction and Building Materials, vol. 149, pp. 763-777, 2017, doi: 10.1016/j.conbuildmat.2017.05.153

[10] B.P. Gilbert, I.D. Underhill, D. Fernando, H. Bailleres, and D. Miller, 'Structural behaviour of hardwood veneer-based circular hollow sections of different compactness', Construction and Building Materials, vol. 170, pp. 557-569, 2018, doi: 10.1016/j.conbuildmat.2018.03.105

[11] S. Orellana, K. Hadi, D. Narain, M. Jennings, M. Subhani, and J. Reiner, 'Effects of manufacturing parameters on mechanical interface properties of thin wood veneer laminates', International Journal of Adhesion and Adhesives, vol. 130, pp. 103614, 2024, doi: 10.1016/j.ijadhadh.2023.103614

[12] R. Guélou, F. Eyma, A. Cantarel, S. Rivallant, and B. Castanié, 'Crashworthiness of poplar wood veneer tubes', International Journal of Impact Engineering. 147: pp. 103738, 2021, doi: 10.1016/j.ijimpeng.2020.103738

[13] R. Guélou, F. Eyma, A. Cantarel, S. Rivallant, and B. Castanié, 'A comparison of three wood species (poplar, birch and oak) for crash application', European Journal of Wood and Wood Products, vol. 81, no. 1, pp. 125-141, 2023, doi: 10.1007/s00107-022-01871-x

[14] D.K. Don, J. Reiner, M. Jennings, and M. Subhani, 'Basalt fibre-reinforced polymer laminates with eco-friendly bio resin: a comparative study of mechanical and fracture properties', Polymers, vol. 16, no 14, pp. 2056, 2024, doi: 10.3390/polym16142056

[15] J. Reiner, S. O. Pizarro, K. Hadi, D. Narain, P. Zhang, M. Jennings and M. Subhani, 'Damage resistance and open-hole strength of thin veneer laminates:

 https://doi.org/10.52202/080513-0334

Adopting design and testing principles from fibre-reinforced polymers', Engineering Failure Analysis, vol. 143, pp. 106880, 2023, doi: 10.1016/j.engfailanal.2022.106880

[16] Raute, 'Raute Lines & Machines'. Accessed: May 07, 2024. [Online]. Available: https://www.raute.com/lines-and-machines/

[17] E. Pasquier, R. Skunde and J. Ruwoldt, 'Influence of temperature and pressure during thermoforming of softwood pulp', Journal of Bioresources and Bioproducts, vol. 8 no. 4, pp. 408-420, 2023, doi: 10.1016/j.jobab.2023.10.001

[18] M. Farajollah Pour, H. Edalat, M. V. Kiamahalleh, and K. D. Hoseini, 'Microwave-assisted laminated veneer lumber (LVL): Investigation on the effect of preheating time and moisture content on resin penetration and bonding quality', Construction and Building Materials, vol. 304, pp. 124677, 2021, doi: 10.1016/j.conbuildmat.2021.124677

[19] Becker Brakel, 'Molded wood'. Accessed: February 2025. [Online]. Available: https://www.becker-brakel.de/en/molded-wood/

[20] Danzer, 'Wood veneer in a new form', Danzer Hardwood Excellence. Accessed: February 2025. [Online]. Available: https://www.danzer.com/en/products/sliced-wood/3d-veneer

[21] Freshape, 'HiWood: Wood Redefined for High Performance'. Accessed: February 2025. [Online]. Available: https://www.freshape.com/hiwood/

[22] Quality-One International, 'Advanced Product Quality Planning (APQP)'. Accessed: March, 2024. [Online]. Available: https://quality-one.com/apqp/