

A new method for the treatment of delaminated plywood: vacuum infusion

■ Stephan de Vries

Introduction

In 1955 Arne Jacobsen designed the Butterfly chair, model 3107 in the 'Series 7'. This iconic chair combined functionality with aesthetics. The elegant design proved timeless and was perfect for mass production. The Series 7 evolved and more designs followed, such as the Mosquito chair, which was produced until 1965 by Fritz Hansen (model 3105, figure 1).¹ Over time, many of these chairs suffer from a similar type of damage: the moulded plywood in the waist area of the seat delaminates, ultimately resulting in a broken back, rendering the chair useless.

This article investigates the possibilities of re-gluing the beech veneers of the delaminated plywood using a technique new to furniture conservation, called vacuum infusion. With the help of a vacuum pump several types of adhesive are tested on mock-ups of delaminated plywood. The article concludes with a case study of re-gluing delaminated Mosquito chairs.

Vacuum infusion

Vacuum infusion is a method that is widely used in the car industry for making carbon frames. For this application the first step is to make a silicone mould for the carbon fabric. The next step is sealing the mould with polyethylene (PE) film. The vacuum compartment is connected on one side to a vacuum pump and on the other side to a reservoir containing the adhesive (epoxy resin). When the pump is activated the adhesive is sucked through the fabric. A catchpot is situated between the mould and the pump to catch excess adhesive before it enters the pump.

The use of vacuum for applying an adhesive works similarly: when the air is sucked out of the delaminated area, the atmospheric pressure rises to about 0.8 bar, which 'pulls' the adhesive through the delaminated area.² The vacuum ensures optimal penetration and wetting of the wood.³ For the vacuum infusion method to be applicable on delaminated plywood the delaminated area on the

Figure 1 Arne Jacobsen, circa 1965, Mosquito chair, model 3105.





Figure 2 Delaminated waist area, model 3105.

chair has to run from one side of the back seat to the other (figure 2), and the method needs some adjustments (figure 3).

Adhesive and vacuum compartments

The most important aspects of this research are the type of adhesive to be used and the design of the vacuum compartment. The adhesive needs to be of low viscosity. Also, it must be strong enough for the chair to be usable after treatment. This means the adhesive's shear strength should be high, almost as high as the wood itself.

The vacuum compartment seals the delaminated area from its surroundings - like a vacuum bag. For our purpose it also acts as a barrier for the excess adhesive. It has to be as small as possible in order to decrease the surface area between the compartment and the chair's finish.

Adhesive selection

The shear strength of the adhesive is an important factor for re-gluing the delaminated plywood veneers.⁴ A selection of adhesives with different shear forces are considered. These adhesives are selected from a study by Ellis & Heginbotham (2004) (table 1).⁵ When the shear strength of the adhesives is compared to the shear strength of American beech with a moisture content of 12% (142 KgF/cm²) it can be concluded that beech wood

is much stronger than the adhesives.⁶ This means that glue failure would occur before wood failure and therefore, in theory, limit the risk of new damage occurring.

Discussion of adhesives

The adhesives to be tested are: epoxy, fish glue and Paraloid B72 in three different solutions: acetone, acetone/ethanol mixture and Shellsol A.⁷

Epoxy is in many cases a taboo in conservation, because after curing the highly cross-linked polymer is insoluble. Mechanical removal of the adhesive is practically impossible when applied to moulded plywood veneers. A comparison could be made with the conservation and impregnation of archaeological wood.^{8,9} Ikjoo (2012) states that 'irreversible materials' may be used in conservation when there is no other way in preserving the object.¹⁰ In those cases the conservation of the object weighs higher than reversibility or retreatability. For furniture that is in (daily) use and for which no alternative treatment exists it can be argued that epoxy resin adhesive is justified.

Liquid fish glue is a water-soluble cold animal glue with positive processing properties: it has good wetting capacities and due to its formulation it has a fairly long open time. Spills are easily cleaned up with water, and re-dissolving it should be possible although this implies the use of moist and/or heat. It dries quickly to a rather hard and brittle film.

Paraloid B72 dissolved in an apolar solvent such as Shellsol A dries much slower than when dissolved in polar solvents. Due to the slow evaporation, especially so when applied in a vacuum system, effective drying becomes an issue. The adhesive stays flexible because the encapsulated solvent acts as a plasticiser.¹¹ A benefit of Paraloid B72 in Shellsol A is that it doesn't interact with the cellulose nitrate varnish of the chair.

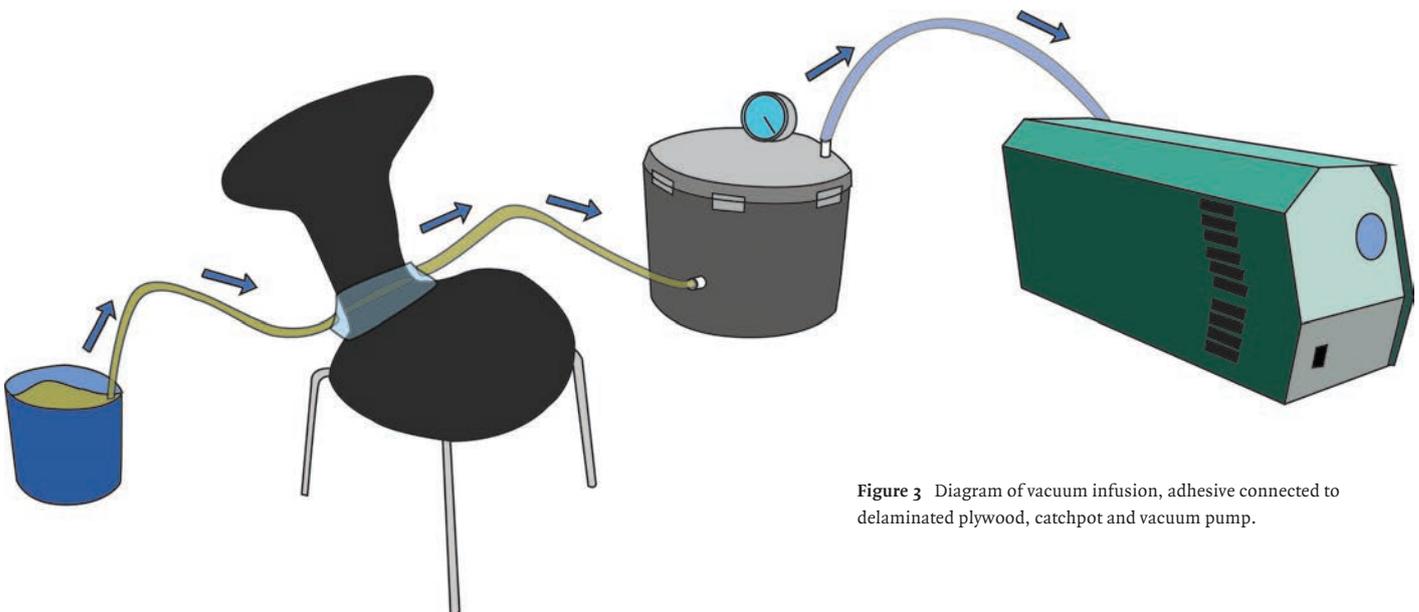


Figure 3 Diagram of vacuum infusion, adhesive connected to delaminated plywood, catchpot and vacuum pump.

Vacuum infusion tests

Mock-ups of delaminated plywood were prepared. With a bandsaw a cut was made through the centre of the boards, and the ends were glued back together (figure 4). The boards were wrapped in PE film with the help of airtight rubber tape and connectors for the tubes were added (figure 5). After infusion and drying, the mock-ups were cut into two-centimetre wide strips, running in the infusion direction. From the sides of these strips the bonds could be observed. The spread of the adhesive was drawn, resulting in flowcharts (figure 6).

Discussion results

After the experiment it became clear that for vacuum infusion the viscosity of the adhesive is preferred to be between water and maple syrup. The adhesive can be made thicker with phenolic microballoons, but this will lower the strength of the adhesive.

Both fish glue and epoxy worked well; they fully wetted the delaminated area. Paraloid B72 did not work well. When applied in acetone and acetone/ethanol air bubbles developed, when dissolved in Shellsol A the resin wouldn't dry due to insufficient evaporation.

Spillage of adhesive on the surface can occur directly during application, and via reverse migration or bleeding, when the adhesive migrates through the veneers to the surface of the plywood. The cellulose nitrate finish¹² of the chairs is very sensitive to acetone. The migrated adhesive might reactivate or solubilise the finish, or indirectly damage the finish when the surface has to be cleaned afterwards. In the case of fish glue this may not be so much of an issue although aged cellulose nitrate finishes are sensitive to water. Since epoxy hardens to an insoluble mass it can only be removed mechanically, causing damage.



Figure 4 Delaminated plywood mock-ups.



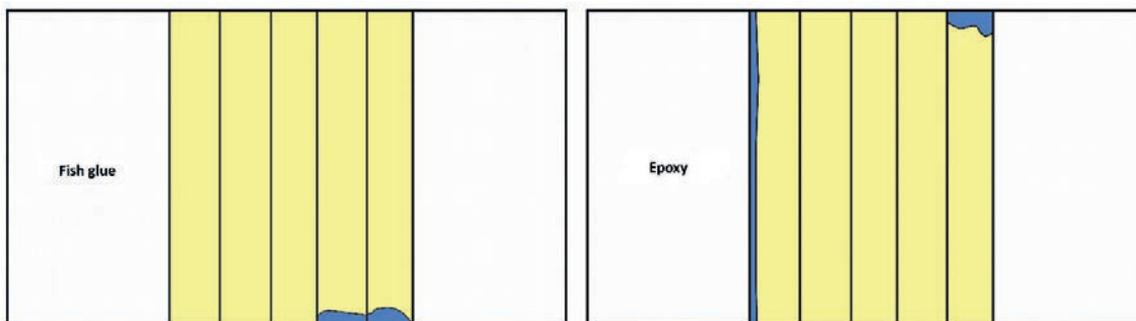
Figure 5 Vacuum compartment with mock-up, PE film, tube connectors and sealing tape.

Based on the above-mentioned test results and material properties fish glue was selected as the adhesive for the case study treatment of the Mosquito chairs.

Case study and alterations

The vacuum compartment had been altered during the testing process. After the first six tests a couple of disadvantages of the PE film compartment became clear. Firstly, it took a lot of time to make the compartment perfectly airtight. Secondly, the compartment is of single-use and is afterwards discarded. From these drawbacks it was clear that a new type of compartment had to be designed. The new compartment covered only the edges of

Figure 6 Flowcharts of fish glue and epoxy. Yellow: glue has spread; blue: gaps; white: plywood from the mock-up.



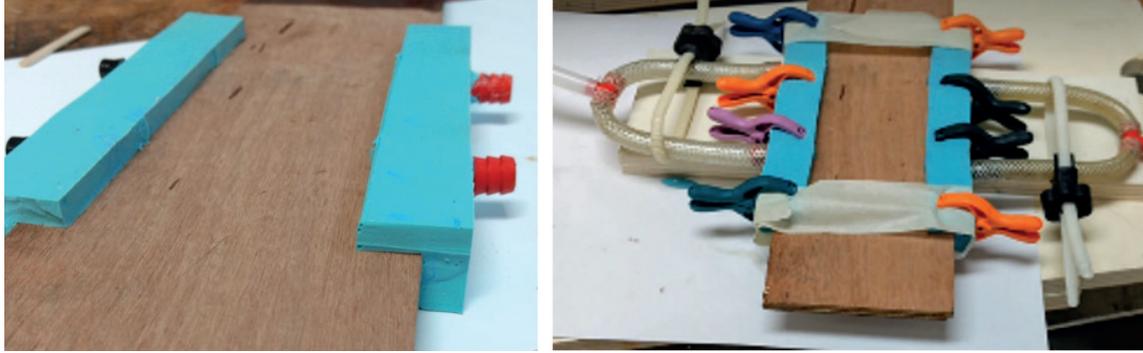


Figure 7a, 7b Re-usable cast silicone compartment on mock-up and chair.



the delaminated area (figures 7a, 7b). It is best described as a mouthpiece with an inlet and an outlet. The silicone rubber was cast and proved to be a re-usable and flexible component. This made it easier to set up the testing rig and to remove the components after infusion. With these silicone mouthpieces double-inlet and -outlet valves were tested. A better spread of the adhesive was expected but in practice it had the same results as with the previous vacuum compartment.

For the case study the procedure was altered a third time. Instead of the silicone mouthpiece, plasticine was used. This material is perfect for free forming a mouthpiece, and it seemed to be sufficiently airtight. With the first two methods the adhesive was transported from an adhesive tank through tubing into the inlet mouthpiece. This was altered, and only an outlet mouthpiece was fabricated, connected via tubing to the catchpot. The adhesive was applied with a syringe, which increased the adjust-



Figure 9 Scan the QR code for a short vacuum infusion video.

ability and controllability of the infusion (figure 8). After infusion the delaminated area was clamped in a mould until dry (figure 9).

The technique proved to be successful in bonding the delaminated veneers. Only where the inner veneers had also broken additional action had to be taken: for example, in case of a crack perpendicular to the veneer grain direction, resulting from continuous use of the chair after the veneers in the back had already started delaminating. As a test, a piece of carbon fibre-reinforced polyamide cloth was inserted in between the broken veneers using a spatula. The edges of the cloth were before-

Figure 8a, 8b Plasticine mouthpiece, fibre reinforcement and application of fish glue during infusion. Right: clamped chair after infusion.



hand sealed with fish glue so they wouldn't tear. Following the presentation at the 2018 symposium, suggestions were made for alternative fabrics for the polyamide, such as silk; future testing needs to prove if application of these fabrics is satisfactory. After infusion and drying the repairs were strong and the chairs could be sat on.

Conclusion

Vacuum infusion is a suitable technique for re-gluing delaminated plywood. Fish glue and epoxy showed good spread and gap-filling capacity. For the treatment of the Mosquito chairs fish glue was selected, because of its retreatability and the ease of removal of possible spills and bleeding of the adhesive. Future research should focus on adhesive performance and characteristics. Is a rigid or rather a flexible adhesive suitable for this specific purpose? These and other questions remain to be answered. However, this experiment has proven that vacuum infusion can be a promising aid for future conservation projects.

Acknowledgements

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Notes

¹ P.E. Tojner, K. Vindum, *Arne Jacobsen architect & designer*, Dansk Design Centre, 1996, p. 52.

² Y. Chastang, 'Het verlijmen van plakkages onder druk door middel van partieel vacuüm, een alternatief voor de traditionele technieken', in: *De problematiek van verlijmingstechnieken en materialen in de conservatie en restauratie*, BRK – APROA, Brussel, 2001, p. 48.

³ Y. Wang, A.P. Schniewind, 'Consolidation of deteriorated wood with soluble resins', in: *JAIC*, vol. 24, no. 2, 1985, pp. 77-91.

⁴ Personal communication Bill Wei, conservation specialist Cultural Heritage Agency, 16-10-2017.

⁵ L. Ellis, A. Heginbotham, 'An evaluation of four barrier-coating and epoxy combinations in the structural repair of wooden objects', in: *JAIC*, vol. 43, no. 3, 2004, pp. 23-37.

⁶ D. Green, J. Winandy, D. Kretschmann, *Wood handbook: wood as an engineering material*, USDA, Wisconsin, 2010, 5-5, Internet, 14-12-17 <https://www.google.nl/search?q=Wood+handbook%3A+wood+as+an+engineering+material&qs=chrome.69i57j69i59.850j0j4&sourceid=chrome&ie=UTF-8>.

⁷ Ellis & Heginbotham's (2004) research and strength tests form the base of the adhesive selection in this article. The type of adhesive is similar but trade names differ. The high temperature epoxy used in this article has a much higher viscosity than the Araldite 1253. Instead of Titebond the liquid fish glue from Kremer Pigmente is used, and the Paraloid B72 has a higher polymer concentration. For this research, in spite of their differences, conclusions are drawn on the base of similarities in material properties of the adhesives.

⁸ T. Nilsson, R. Rowell, 'Historical wood – structure and properties', in: *Journal of Cultural Heritage*, vol. 3, no. 3, supplement, 2012, p. 9.

⁹ Y. Wang, A.P. Schniewind, 'Consolidation of deteriorated wood with soluble resins', in: *JAIC*, vol. 24, no. 2, 1985, pp. 77-91.

¹⁰ K. Ikjoo, 'Damage to the wooden objects and the conservation treatment', in: *Conservation of wooden objects*, National research institute for cultural heritage, 2012.

¹¹ M. Opeña, E. Jägers, 'Extended Abstract— Effects of Solvents on the Physical Properties of Polymeric Films', in: *New insights into the cleaning of paintings: Proceedings from the cleaning 2010 international conference universidad politécnica de Valencia and museum conservation institute*, Smithsonian Institution Scholarly Press, Washington, 2013, pp. 165-167.

¹² A diphenylamine spot test proved positive for cellulose nitrate.

Materials

- Global vacuum presses GVP 170 industrial, vacuum pump
- Vacuum film, polyethylene, VAC000411 (www.polyestershoppen.nl)
- Sealent tape, tacky tape, VAC000355 (www.polyestershoppen.nl)
- Silicone rubber: OOMOO® 25 Tin-Cure Silicone Rubber (www.FormX.nl)
- High temperature epoxy 800C Part A + B (www.Polyestershoppen.nl)
- Fischleim, fluid, article nr.: 63550 (www.kremer-pigmente.com)
- Paraloid B72, ethyl methacrylate co-polymer, 67400 (www.kremer-pigmente.com)
- Phenolharz-hohlkugelchen, 0,005-0,127 mm, 59960 (www.kremer-pigmente.com)