

FIBER METAL LAMINATES MADE BY THE VARTM PROCESS

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ABSTRACT

Fiber metal laminates (FMLs) are multi-component materials utilizing metals, fibers and matrix resins. Tailoring their properties is readily achievable by varying one or more of these components. Established FMLs like GLARE utilize aluminum foils, glass fibers and epoxy matrices and are manufactured using an autoclave. Two new processes for manufacturing FMLs using vacuum assisted resin transfer molding (VARTM) have been developed at the NASA Langley Research Center (LaRC). A description of these processes and the resulting FMLs are presented.

Keywords: fiber metal laminate (FML), vacuum assisted resin transfer molding, VARTM, metal plasma deposition, GLARE.

INTRODUCTION

Fiber metal laminates (FMLs) are multicomponent materials utilizing metals, fibers and matrix resins. Typical FMLs are prepared by stacking alternating layers of metal foils and fiber/matrix resin prepreg followed by consolidation in a press or autoclave. FMLs consisting of aluminum sheets and aramid fiber/epoxy prepreg were first developed by Vogelsang et al. at the Technische Universiteit Delft together with ALCOA in the 1980s [1] and are known as ARALL (Aramid Reinforced ALuminum Laminate). GLARE (GLASS REinforced FML), which replaces aramid fibers with glass fibers, was introduced in 1991. Fiber metal laminates combine the best properties of the metal and the composite making them suitable for aerospace applications. For example and as shown in Figure 1, GLARE is used in the fuselage of the Airbus A380 and is being evaluated for use as blast resistant cargo containers due to the unique combination of properties.

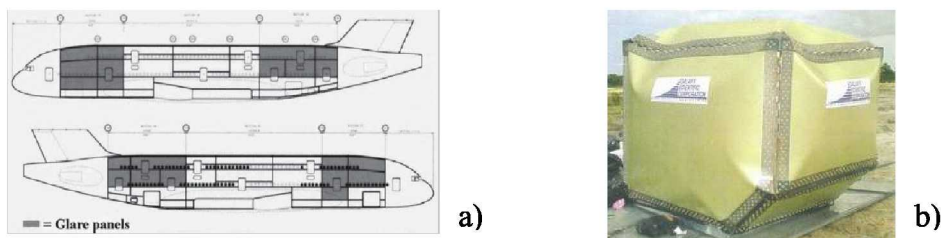


Figure 1. Current uses of GLARE: a) Airbus A380, b) Cargo Containers

However, GLARE is expensive to produce and part size is limited due to the required prepreg and use of an autoclave in consolidation. Traditionally, composites have also been fabricated by similar methods. However, infusing liquid resin into dry fabric layers solely by vacuum pressure to produce high quality materials has proven to be a more cost effective process for preparing composites [2, 3]. This process, known as vacuum assisted resin transfer molding (VARTM), utilizes a flow distribution media to allow the resin to proceed rapidly on the surface over the length of the part followed by the slower through the thickness infusion through the part, thereby decreasing infusion times. Figure 2 illustrates a typical VARTM set-up.

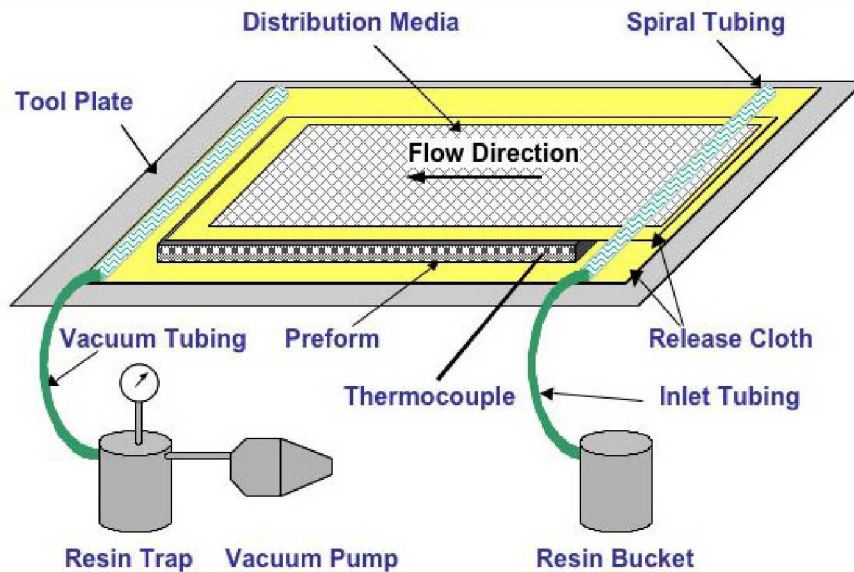


Figure 2. Illustration of a VARTM set-up.

NASA LaRC has developed a VARTM process for FML that utilizes flow pathways (perforations) in the metal layers to allow for through the thickness resin infusion [4]. The materials produced by this process will be referred to as VARTMFML. A second VARTM process developed at LaRC for FMLs utilizes porous metal-coated fabrics to allow through the thickness infusion. These laminates will be referred to as VARTMPCL.

EXPERIMENTAL

The processing of VARTMFML involves stacking alternate layers of the metal foil (same aluminum, 2024-T3, and surface treatment as GLARE) containing resin flow pathways (perforations) and fabric. This preform is then infused with a resin via a VARTM process as shown in Figure 3.

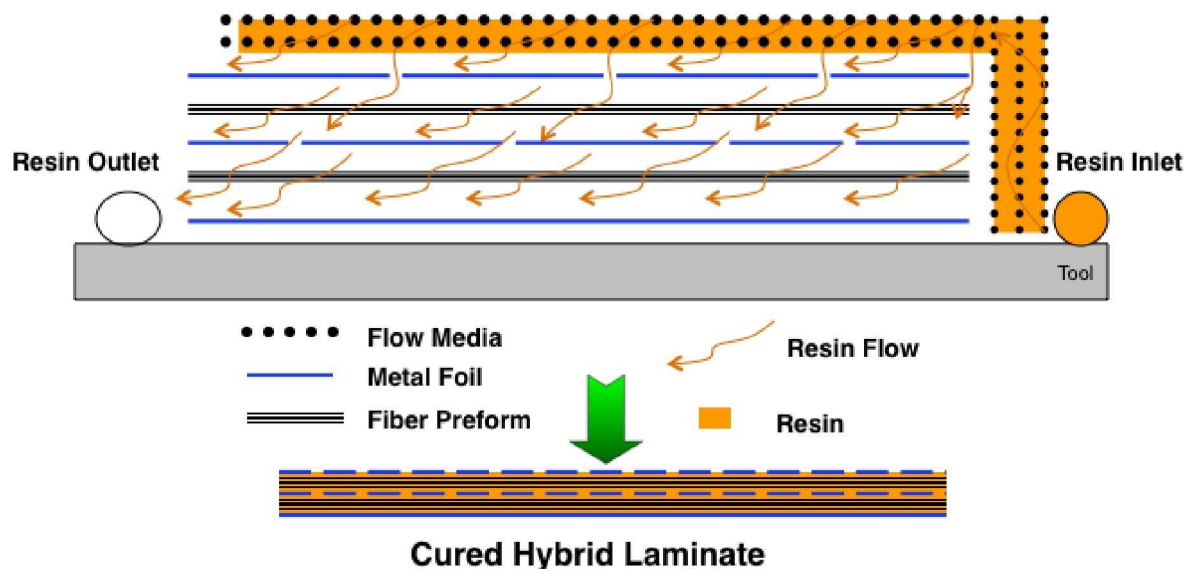


Figure 3. Illustration of the resin flow during VARTM of VARTMFMLs.

The insertion of the resin flow pathways has been accomplished by several different methods. Methods to insert flow pathways include 1) simply drilling with a 0.38 mm (0.015 in) drill bit using a Dremel tool mounted on a portable, table top press or 2) mounted on a precision drill press with speed control and improved bit positioning, 3) a laser drilling process using a Nd:YAG laser (Coherent AVIA model, 7 watt at a power setting of 90%) or 4) a water jet cutter (Flow Industries, Model #WMC24030, fifty thousand psi capability, 80 grit garnet). Photomicrographs of resin flow pathways produced by each process are shown in Figure 4.

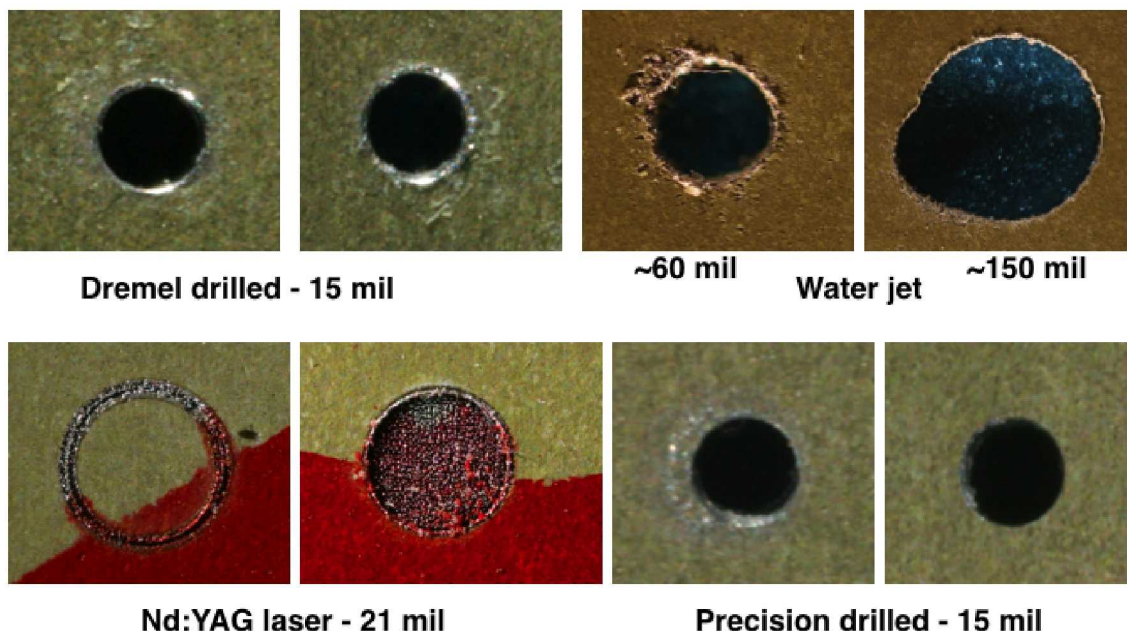


Figure 4. Resulting hole quality (two samples, 2024-T3, 0.38 mm) from various drilling methodologies. (1mil = 0.0254 mm).

The processing of VARTM infused plasma coated laminates (VARTMPCL) first requires the production of the metal-coated fabrics. The fabric is coated with a metal layer using a plasma deposition process [4]. The metal layer produced is porous so that stacked metal-coated fabric layers can be infused to produce novel FMLs. The equipment used for this process is shown in Figure 5. Metal powders are axially injected into inert Argon/Helium plasma at low pressures. As the particles pass through the plasma they become molten metal particles. The particles are accelerated and impinge onto the as-received fabric, rapidly cooling and forming a metal to fabric bond. A drum of 35 cm (14 in) diameter is previously wrapped in the desired fabric. The drum rotates and translates under the plasma and is coated by the deposition to provide a uniform thickness of desired metal. The process is illustrated in Figure 6. The fabrics can also be coated on both sides by simply turning the fabric over and replacing onto the drum, then repeating the deposition process.

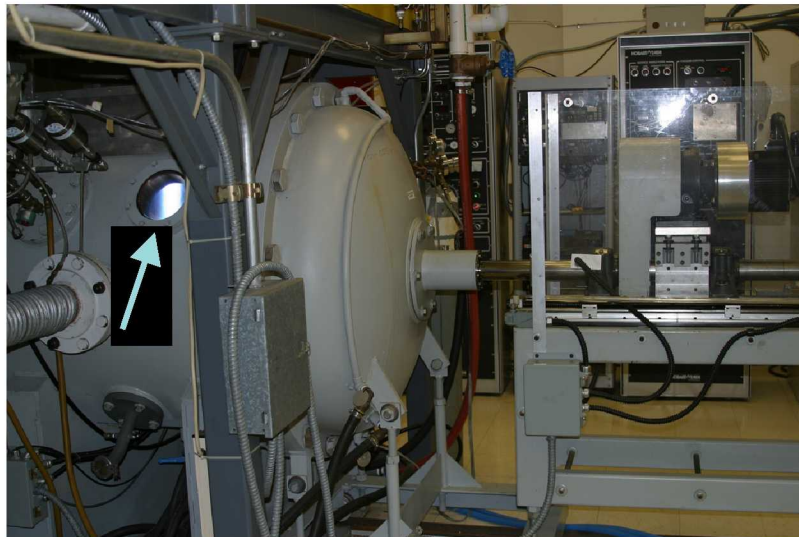


Figure 5. Plasma deposition chamber. Note plasma field through chamber window.

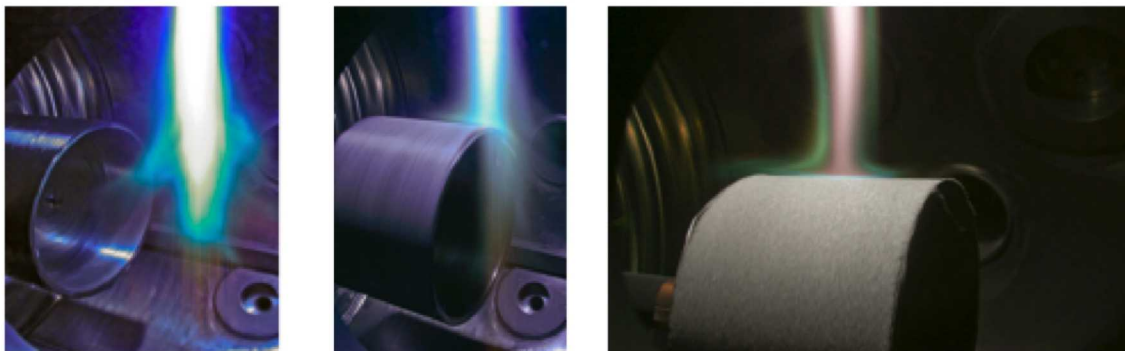


Figure 6. Photographs of plasma deposition process.

For each process, many combinations of metal, fiber and resin can be selected to tailor the material for specific applications. Metal-coated fabric combinations prepared so far include aluminum on glass, copper on glass and titanium on carbon. Figure 7 shows two examples of plasma metal-coated fabrics.

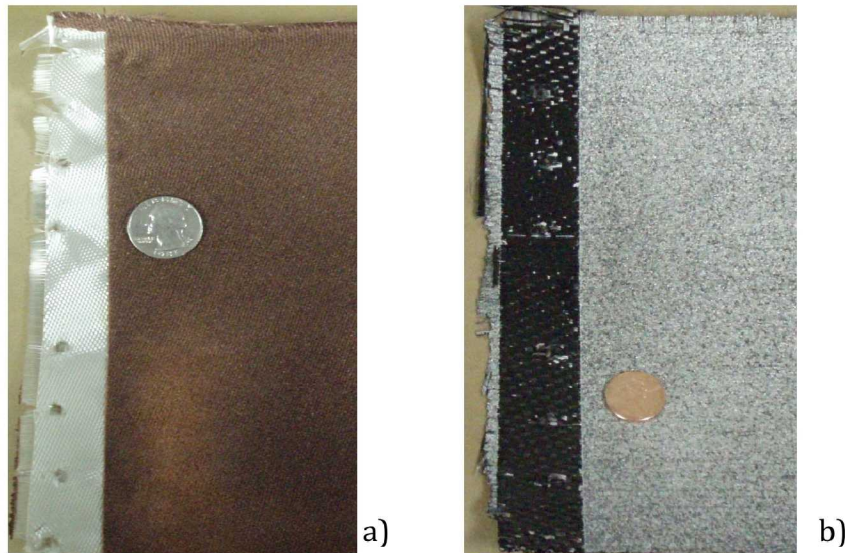


Figure 7. Photographs of glass fabric plasma-coated with copper (a) and carbon fabric plasma-coated with titanium (b).

RESULTS AND DISCUSSION

Both VARTMFMLs and VARTMPCLs with low void fractions and relatively high quality have been prepared. In addition, ongoing work uses a VARTM process simulation model and a flow visualization fixture to optimize the processing parameters and the arrangement and size of the resin pathways that are inserted into the metal layers. Other work has involved the mechanical testing of the laminates and modeling of their mechanical properties with various compositions. The modeling work [5, 6] and mechanical evaluations [7] are fully documented.

Preliminary testing on VARTMFMLs has shown that failure initiation occurs at the site of the resin flow pathways, as expected. This crack initiation from tension/ tension fatigue [7] is shown in Figure 8. Therefore, significant effort was made to insert perforations with low defects into the aluminum foils. The Nd:YAG laser was extremely slow and provided a rough, textured hole, essentially burning away the metal. The water jet cutting was incapable of producing holes as small as desired with a 1.52 mm (0.060 in) hole resulting from a single water jet blast. The precision drilling process proved to be the best method of inserting holes. All desired size drill bits are available and multiple aluminum sheets can be drilled at once. This process also lends itself to automation.

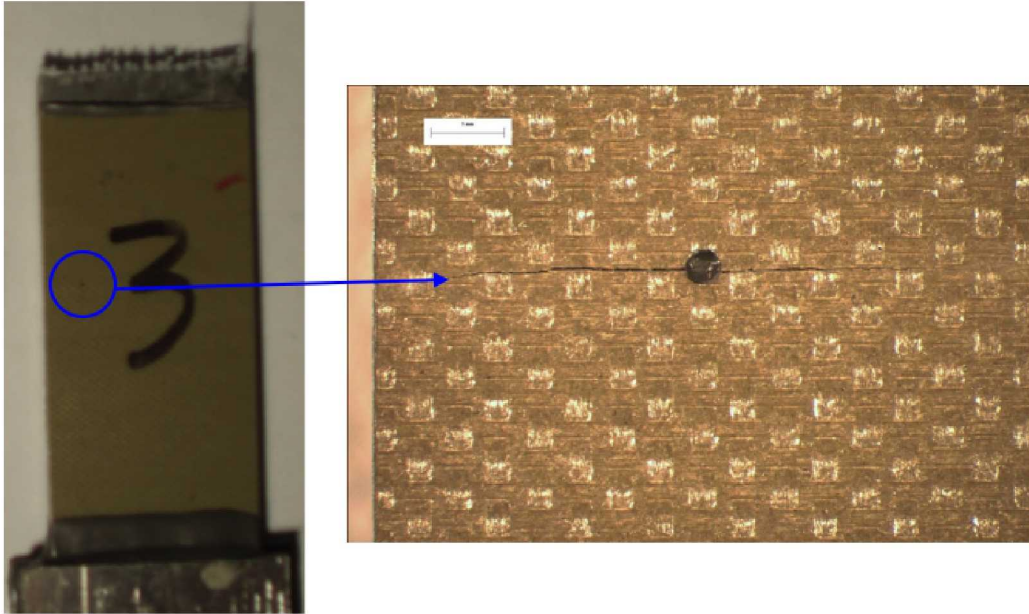
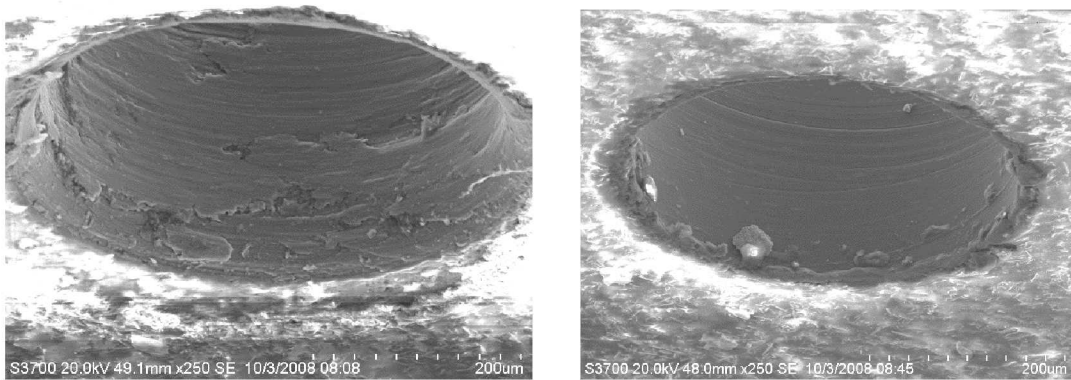


Figure 8. Photograph of typical crack propagation during tension/tension fatigue.

To compare hole quality and level of defects, SEM photomicrographs were taken for both the Dremel drilled and the precision-drilled holes with results shown in Figure 9. The precision drilling process produces a hole with better quality and fewer defects, so resistance to fatigue failure was expected to improve.



Dremel drilled

Precision drilled

Figure 9. SEM of Dremel and precision-dilled holes.

Therefore, single aluminum foils 2.54 cm wide were prepared and tested with three holes centered with respect to width and located 2.54 cm apart lengthwise. The results of this testing, shown in Figure 10, indicate that the precision-drilled holes do in fact resist fatigue failure longer than the Dremel drilled holes. However, holes inserted into the foils by either process adversely affect properties relative to foils with no holes.

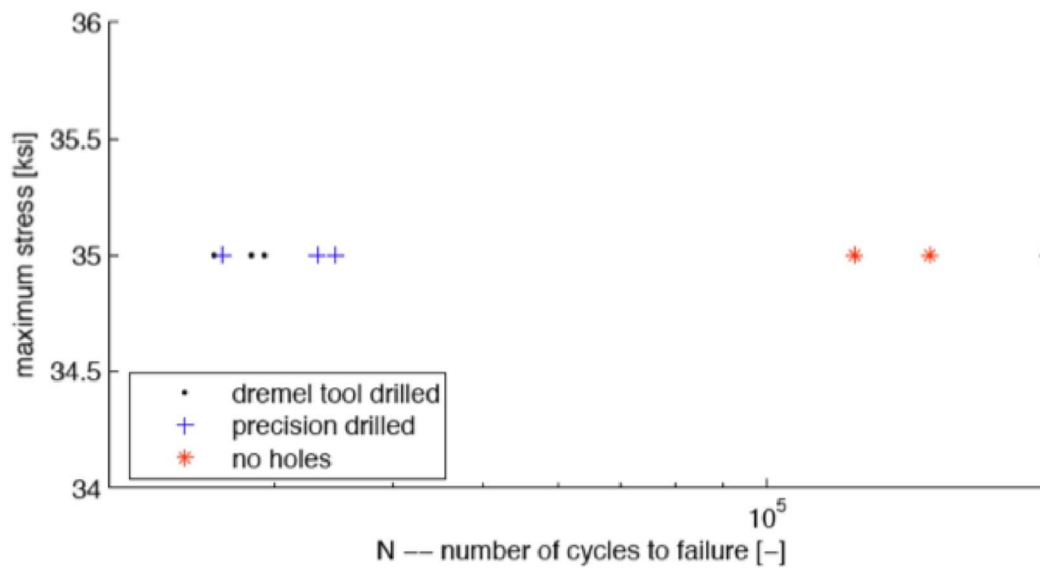


Figure 10. Tension/ tension fatigue ($R = 0.1$) of aluminum sheets (Reference 8).
(1 ksi = 6.897 MPa)

Initial mechanical property testing of the VARTMPCL panels indicates that the metal layers add little strength to the fiber layers in the final FML. While the metal layer is continuous, it is porous and not optimized by post treatment for mechanical properties after deposition. The advantage of the VARTMPCL is most likely an improvement in functional properties, including electrical conductivity (e.g. lightning strike protection) or thermal conductivity (e.g. heating for deicing) relative to the parent polymer matrix composite.

Photomicrographs of the edge of each type of hybrid laminate prepared in this research are shown in Figure 11. Not only do they look very different, they provide very different properties in the final form. The VARTMFML looks very much like the GLARE FML and provides similar properties. The VARTMPCL shows the highly textured, porous metal layers, however these FMLs provide less structural performance but are anticipated to yield improved functional properties relative to the polymer matrix composite alone.

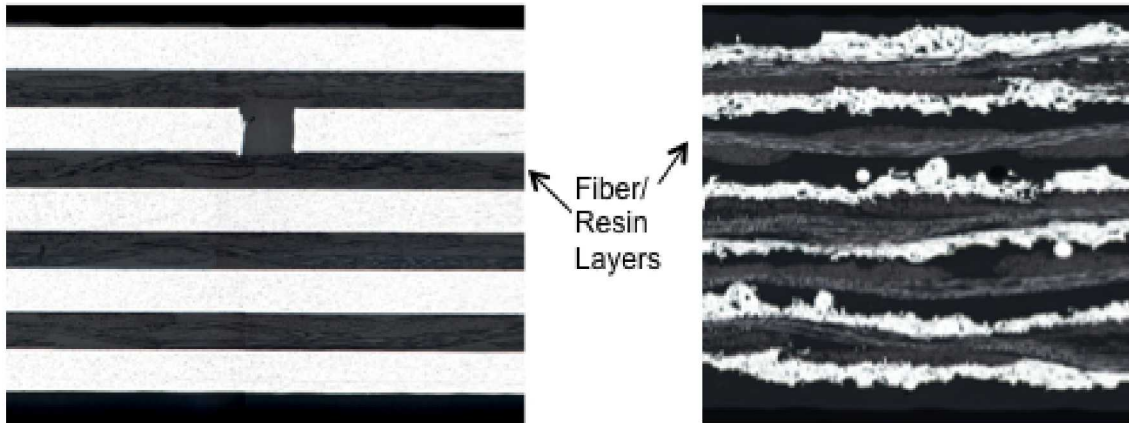


Figure 11. Photomicrographs of a) VARTMFML (0.38 mm foils) and b) VARTMPCL.

CONCLUSIONS

Two types of fiber metal laminates were prepared by vacuum assisted resin transfer molding. Both methods provide for through the thickness infusion by either the insertion of resin flow pathways or by utilizing a metal deposited layer with porosity. The VARTMFMLs provide good mechanical properties that can be optimized by proper selection of metal foil, fiber, resin and size and distribution of the pathways. The VARTMPCLs allow the incorporation of a plasma deposited metal layer that can improve functional properties like electrical and thermal conductivity.

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