

TCO G Module – Perform a Bonded Composite Repair

G1: Demonstrate/apply common drying and surface preparation techniques, and how to inspect for acceptability

Proper drying and surface preparation are essential for a successful bonded composite repair. This is due to the sensitivity of adhesives and resins to degradation when exposed to moisture and contamination prior to cure.

Drying of Composites Demonstration: Contaminates and water are removed from the component using vacuum and heat. The area being dried must extend well beyond the area of damage per the approved repair documentation and 8110 specifications.

- a) Remove the protective coating (e.g. conductive coating if present, paint enamel and primer) using the prescribed method such as abrading or sanding. Remove the coatings over an area that will more than encompass the repair per the approved repair documentation and 8110 specifications. Take care not to damage any composite fiber material. Use protective eye ware and a facemask and remove dust with a vacuum
- b) If the damaged part is of sandwich construction first open up the honeycomb cells (sand off any adhesive covering the cells)
- c) Lay down a glass fabric screen over the entire damaged area
- d) Place a thermocouple (T/P) in the center of the damage
- e) Place a breather cloth over the entire area, use masking tape to hold cloth in position.
- f) Place the heat blanket in position over the breather cloth, making sure that the vacuum probe is above the breather cloth
- g) Place the vacuum bag over the entire area, and seal in place
- h) Apply a minimum vacuum of 22 inches of mercury to the damaged area
- i) Operate the Heat blanket to apply heat to the area being dried at the heat-up, hold and cool-down rates and temperatures specified in the approved repair documentation and 8110 specifications.
- j) Remove the vacuum bag, heat blanket, breather cloth and screen
- k) Moisture and contaminate removal can take up to 24 hours, depending on whether the damaged part is of sandwich construction or solid laminate. Since practical

methods to verify moisture removal are not yet available, the drying process must be followed stringently. After drying the repair area, ensure that the area is protected from further moisture exposure by covering the area with waterproof film and adhesive tape or sealant.

Scarfig of Laminate Demonstration: In all processes, the approved repair documentation and 8110 specifications must be followed explicitly.

- l) Make the necessary taper to the damaged plies for the bonded scarfed repair, using a taper ration per the approved repair documentation and 8110 specifications. (Remove any damaged core, if present, to the same size as the cutout in the face sheet. Be careful not to damage the backside face sheet). Again use protective eye ware and a facemask and remove dust with a vacuum.
- m) Surface Preparation and Cleaning Demonstration: In all process the approved repair documentation and 8110 specifications must be followed explicitly.
- n) Remove any remaining dust and debris from the repair area with a vacuum cleaner.
- o) Solvent wipe the scarfed surface and surrounding surfaces per the approved repair documentation and 8110 specifications. Care must be taken to avoid smearing contamination from unclean adjacent surfaces onto the repair area. Use further clean dry cloths to remove solvent until final cloth wipe shows completely dry

G2: Demonstrate and apply material lay down and compaction processes for a simple laminate panel repair

Prepreg Ply Layup for Scarfed Laminate Demonstration: In all process the approved repair documentation and 8110 specifications must be followed explicitly.

- 1) Trace Scarf contours onto ply templates. Ply count and orientation must be in accordance with SRM and 8110 requirements. Mark the orientation, ply number and crosshairs on each template to facilitate lay up. Use these to cut out the adhesive film, and repair plies.
- 2) Cut adhesive and repair plies using ply templates. Make sure that each replacement ply fit and orientation is in accordance with the approved repair documentation and 8110 specifications.
- 3) Layup adhesive and repair plies into scarfed per the approved repair documentation and 8110 specifications. In most prepreg repairs, film adhesive will be placed between the scarfed surface and the repair plied. Some approved repair documentation and 8110 specifications will require an additional ply to cover the entire repair. Sweep each ply after lay-down to remove any wrinkles and entrapped air from between the plies
- 4) Compact the repair plies as required by the approved repair documentation and 8110 specifications, using a temporary vacuum bag to remove any entrapped air from between the repair plies. Some prepreg materials may need a compaction cycle for each repair ply laid down, while others may allow a greater number of plies to be applied between compaction cycles.

Wet Layup Ply Layup for Scarfed Laminate Demonstration: In all process the approved repair documentation and 8110 specifications must be followed explicitly.

- 5) Trace the ply contours onto a transparent sheet such as vacuum bagging film to create a ply template sheet. Ply count and orientation must be in accordance with approved repair documentation and 8110 requirements. Mark the orientation, ply number and on each template to facilitate lay up.
- 6) Smooth one sheet of vacuum bagging film to the work surface. Place one layer of dry fabric as specified in the approved repair documentation and 8110 specifications onto this sheet. Cover the fabric with the ply template sheet having the notation facing outward.
- 7) Calculate the amount of resin required to impregnate the fabric as specified in the approved repair documentation and 8110 specifications.
- 8) Pour the resin over the entire surface of the fabric using a back and forth pattern to dispense evenly.
- 9) Replace the ply template sheet over the fabric. Use a squeegee to wet out and work the resin into the fabric as evenly as possible. Work the material until there is no air remaining between the vacuum bagging film and fabric taking care not to force the resin from the fabric edges. When the air is removed from between the ply template side, turn the parcel over and repeat the process to remove the air from between the fabric and the lower vacuum bagging film.
- 10) Turn the parcel over such that the ply template sheet is again facing up. Cut out the individual plies as marked on the ply template sheet. Verify the lay-up sequence by stacking the patch plies in numerical sequence prior to lay-up.
- 11) Layup repair plies into scarfed per the approved repair documentation and 8110 specifications. Sweep each ply after lay-down to remove any wrinkles and entrapped air from between the plies. Retain all backing film to verify that they have all been removed from the lay-up.
- 12) Compact the repair plies as required by the approved repair documentation and 8110 specifications, using a temporary vacuum bag to remove any entrapped air from between the repair plies.

G3: Demonstrate how to prepare and cure a simple bonded repair to a laminate panel, and explain the types of errors to avoid

Vacuum Bagging Demonstration:

- 13) Vacuum bag the repair for cure by applying perforated parting film, bleeder, parting film, caul sheet, thermocouples, heat blanket, breather, and vacuum bag per the approved repair documentation and 8110 specifications.

Repair Curing Demonstration:

- 14) Apply vacuum and cure using a hot bonder per the approved repair documentation and 8110 specifications. Care must be taken to ensure that the proper cure parameters are maintained including vacuum pressure, ramp rates and cure temperature ranges.
- 15) Visual Inspect, Tap test and NDI Repaired area per the approved repair documentation and 8110 specifications

Mistakes to Avoid: There are a number of repair process mistakes that are almost certain to lead to inadequate repairs that may, in service, disbond or even fall off. The following processing errors are described in more detail in TCO F5:

- *Incorrect or inadequate surface preparation:* It is essential that the protective coating (e.g. conductive coating if present, paint enamel and primer) is removed using a prescribed method such as abrading or sanding.
- *Failure to Track Backing Paper and Separator Film:* All pieces of backing paper or separator film must be accounted for during ply layup. If the piece count is less than required, the piece may still be present in the ply stack. Under these circumstances, the repair plies must be removed and the Layup process must be repeated.
- *Insufficient moisture or fluid removal and drying:* All fluids must be removed from the component using vacuum and heat, otherwise the repair may contain moisture or moisture may be present in the bondline resulting in poor strength or even loss of the repair during operations.
- *Insufficiently cleaned repair surface:* If the abraded surface and tapered area is not cleaned sufficiently with an approved solvent, contaminants (e.g. dust) may be present in the repair bondline.
- *Out-of-Date prepreg and adhesive materials:* Prepregs and adhesives that have exceeded their allowable out-time or are old and have expired must not be used, otherwise the resin may not wet out the fibers properly during cure, leading to less

than the desired strength, stiffness and durability. The use of old, “board” prepreg also can result in delaminations and bridging when used to repair curved parts.

- *Wet layup repair resin ingredients that have been incorrectly mixed:* It is essential that the correct measured amounts of the two parts of the resin be mixed correctly otherwise the repair may never reach the desired state of cure leading less than desired strength, stiffness and durability.
- *Poor vacuum bagging procedure leading to leaks during the cure cycle:* If there are any leaks in the vacuum bag, they can be detected by good in-process monitoring of the heating unit read-outs, otherwise the repaired patch and bondline may contain voids, excessive porosity and delaminations.
- *Incorrect in-process control:* If the cure process is not monitored closely, wide variations in thermocouple readings, incorrect heat-up rates and cure temperature, and loss of vacuum may result. If there is a lower, or higher than, acceptable thermocouple reading, then an unevenly cured repair may result.

G4: Describe process parameters which affect bonded repair quality, and in-process controls necessary to avoid defects

As stated above in D3, there are a number of repair processing parameters that can affect repair quality. The cure parameters that are critical to repair quality are:

- *Maintain Proper Vacuum Pressure:* After the vacuum bag has been installed over the repair and sealed, apply and maintain vacuum per the approved repair documentation and 8110 specifications.
- *Maintain Proper Cure Ramps and Hold Temperatures:* Increase the temperature of the heat blanket by the ramp rates specified in the approved repair documentation and 8110 specifications.

G6: Demonstrate critical in-process quality controls during laboratory bonded repair process trials

It is essential that during the entire bonded repair procedure, there are checks performed to ensure that the approved repair instructions are followed.

Checks should be performed to ensure that the appropriate repair materials are prepared and handled such that they are not contaminated. The ply lay-up (including adhesive film ply), ply size and orientation, must be checked as each repair ply is laid down.

If a debulk cycle is required, it must be performed per the approved repair instructions

The vacuum bagging sequence must be checked at each step, and the vacuum seal must be checked by applying vacuum and monitoring any vacuum loss.

The cure process must be monitored to ensure that the specified cure cycle proceeds correctly. The heating apparatus (e.g. dual zone hot bonders) have controls for temperature and vacuum measurement and control. Up to 10 thermocouples (T/C) can be monitored, the hottest and coldest can be automatically selected or an average of all T/Cs can be monitored. If the cure process is not monitored closely, wide variations in thermocouple readings, incorrect heat-up rates and cure temperature, and loss of vacuum may result. If there is a lower, or higher than, acceptable thermocouple reading, then an unevenly cured repair may result. A record of the cure vacuum and temperature profiles must be printed out for the post-repair approval procedure.

(The requirements of this TCO are detailed in the previous sections G1-G4 of this module.)

G7: Describe differences between 'wet layup' and 'prepreg' bonded repairs to sandwich and laminate parts

Advantages of prepreg repairs over wet layup repairs:

- Prepreg materials are easier to use, requiring no precise mixing of the resin parts
- Repairers can repair larger, deeper damages with prepregs
- Repairers using prepregs can process the repair with the same process (autoclave and higher temperature) used by the OEM for the original part fabrication. This allows, in some cases, replacing complete skins of secondary structural sandwich parts. One advantage of an autoclave prepreg repair is no need for additional repair plies due to the reduced strength and stiffness of wet layup or vacuum bag repairs. It is, however, customary to add one structure ply to the outside of any repair (wet layup, vacuum prepreg or autoclave prepreg repair) to ensure strength and stiffness in case of any error of orientation of repair plies.

In general, wet layup bonded repairs are useful for repairs to sandwich parts, thin laminate areas (e.g. edge bands for sandwich parts, and minor (partial thickness) repairs to laminate stiffened parts. Use of wet layup materials for the repair of thicker laminate stiffened components is usually limited to minor repairs due, in part to limited working life of the mixed wet layup resins, and partly due to reduced strength, stiffness and durability of the wet layup resins.

Wet Layup Repair Background: Wet layup repairs employ different types of materials than 'prepreg' repairs. Prepregs and film adhesive require special storage facilities (e.g. a zero degree freezer) and must be carefully monitored (each batch of prepreg has a 6 month freezer life, and must be either scrapped or re-tested for acceptance). Wet layup materials consist of a) fabric fiber mats which are stored at R/T, and b) two-part resin

systems that are stored in sealed cans and mixed to prescribed compounds upon use. These two parts are the actual resin and a catalyst that allows the mixed resin to cure. All of these wet layup materials have extensive storage lives compared to prepregs, but the resins, after mixing, must be applied to the repair immediately. Wet layup repair materials tend to be more convenient for repairers than prepregs when faced with small, infrequent damages. The use of prepregs requires special storage facilities and special monitoring for shelf and working lives. Cure temperatures of wet layup repairs typically range from R/T to 200oF. The strength, stiffness and durability of the lower (R/T to 150oF) cure temperatures are typically too low for permanent repairs, and are used mainly for temporary or time-limited repairs (see TCO E1). Wet layup bonded repairs cured at 180oF to 200oF result in a higher state of cure, and are used for permanent repairs (see TCO E1).

Advantages of wet layup repairs over prepreg repairs:

- Wet layup materials do not need special storage and working life monitoring
- Useful to repairers for repair of small, infrequent damages. Many repairers complain that they are unable to buy small quantities of prepregs, and are forced to perform acceptance tests and re-tests
- Wet layup materials can be cured at lower temperatures based on need and convenience

Prepreg Repair Background: The process for a ‘prepreg’ repair is basically the same as used for the original part bonding process. Differences may include: a) for a repair, each ply is cut out by hand and laid down by hand, whereas the plies are typically cut and laid down by machines. Another difference may be that the repair is cured with heat under vacuum pressure only, whereas the original bond assembly is typically cured with heat, vacuum and autoclave pressure. The main reason for this difference is that many composite components are difficult to remove from the aircraft; therefore most repairs are performed without autoclave pressure. The problem in using prepreg material without autoclave pressure is that typically more porosity is present in the repair patch and adhesive than in the original autoclaved part. Excess porosity can have the effect of reducing repair strength and stiffness with increased thickness. In order to reduce excessive porosity in prepreg repairs, in many cases a compaction or debulk cycle may be used. In a compaction cycle, after each ply, or a number of plies have been laid down, a vacuum bag is placed over the repair and sealed, and vacuum is drawn to compact the ply or plies. The difference between a compaction and a debulk cycle is heat is applied during the debulk process. This will produce gases and volatiles which are vented through a breather cloth under the vacuum bag.

For prepreg repairs to thicker laminates requiring many replacement plies, a compaction procedure called Double Vacuum Debulk (DVD) may be performed. This method employs a rigid aluminum chamber about 15 cm high and 61 cm square (6 inches high and 24 inches square). When a vacuum-bagged patch is placed inside the DVD tool's

chamber, the pressure inside the vacuum bag is equalized by removing the chamber's atmospheric pressure during the hot debulk cycle. Unlike a conventional compaction or debulk procedure, nothing is pressing down on the patch during the hot debulk cycle, so more gas and volatiles are removed. As a result, as an example, an 8-ply unidirectional carbon/epoxy patch experiences 15 percent greater ply-to-ply compaction than after a conventional vacuum only compaction cycle.

Prepreg bonded repairs can be used for repairs to thin faced sandwich parts and thicker laminate stiffened parts. Prepreg repair materials, which were originally designed for autoclave cure at high temperatures, are cured at temperatures ranging from 250oF to 350oF. Due to these higher curing temperatures, the resulting repairs exhibit higher states of cure and are suitable for permanent repairs and repairs to more highly loaded components. When using prepreg materials for repairs to sandwich parts it is essential to ensure that all water is eliminated from the part, otherwise during cure any water still present within the part will boil and may cause damage to the skin-to-core bondlines.

Advantages of prepreg repairs over wet layup repairs:

- Prepreg materials are easier to use, requiring no precise mixing of the resin parts
- Repairers can repair larger, deeper damages with prepregs
- Repairers using prepregs can process the repair with the same process (autoclave and higher temperature) used by the OEM for the original part fabrication. This allows, in some cases, replacing complete skins of secondary structural sandwich parts. One advantage of an autoclave prepreg repair is no need for additional repair plies due to the reduced strength and stiffness of wet layup or vacuum bag repairs. It is, however, customary to add one structure ply to the outside of any repair (wet layup, vacuum prepreg or autoclave prepreg repair) to ensure strength and stiffness in case of any error of orientation of repair plies.

G8: Describe metal bond repairs and differences from composite bonded repairs

Background: Metal bonded structures have been utilized in the aircraft industry for more than 60 years. Many aircraft still retain metal bonded parts. Early models of the 737 utilized metal bonding in the fuselage to increase skin thickness due to bending loads and at joints and stringer interfaces. The latter was done to effectively prevent 'knife-edge' conditions due to the use of countersink fasteners, and to lower the stresses at the joints for fatigue reasons. Current models of the 737 do not employ metal bonding in the fuselage skins, but do use it for the main flaps and engine cowls which are aluminum sandwich parts. A typical metal bond sandwich flap employs skins that have been chemically machined to increase or decrease thickness, epoxy adhesive and aluminum honeycomb core. The cure process for metal bonding at the OEM usually employs an

autoclave in order to apply pressure as well as vacuum and heat. Other current aircraft models which contain metal bonded parts include the 747, 757, and 767 models.

The repair of metal bonded parts such as the early model 737 skins was predominately performed by removing the damaged or more likely corroded piece of skin or doubler and fastening a repair plate in place. Repair of metal bonded sandwich parts usually employs a metal bonded repair plate, and usually replacement core, epoxy and foaming adhesives and vacuum bag cure.

Successful Metal Bond Processing Parameters: The most important parameters in effecting a good metal bond, be it for an original part or a repair, are surface preparation and environment. The reasons for failures of metal bonding on early model aircraft were that the original part bonding processes utilized poor surface preparation procedures. The following points are essential for affecting a successful metal bond repair.

- *Use Uncontaminated Solvents:* The surfaces must be solvent cleaned with a pure, contaminate free solvent per the approved repair documentation and 8110 specifications.
- *Verify Surface Cleanliness:* A water-break test is often required per the approved repair documentation and 8110 specifications.
- *Surface Preparation is Critical:* Surface preparation must be correctly applied per the approved repair documentation and 8110 specifications. Often, processes like Boeing's Sol-Gel and phosphoric acid anodizing are specified which are available in portable formats.
- *Surfaces Must be Dry:* Surface drying must be conducted per the approved repair documentation and 8110 specifications in a manner similar to that applied to composite structure.
- *Processing must be per Specification:* Cure vacuum pressure, ramp rates and temperatures must be maintained within the parameters of the approved repair documentation and 8110 specifications.

Differences between metal bonding and composite bonding:

- Primers are commonly used in metal bonding in order to 'wet' both of prepared/dried metal surfaces properly to ensure a good bond and ensure good bond durability. Primers reduce surface energy which helps to reduce the attraction of contaminants to the surfaces and also provides a surface which is highly compatible with the epoxy adhesives. Composite parts must be abraded, cleaned and dried, but do not need a coat of primer.
- Metal Bond requires chemical surface treatments such as Sol-Gel or phosphoric acid anodizing, where as composite surfaces simply require solvent cleaning.

- Metalbond repair surfaces usually require a shorter drying time than do those of composites.
- Metal bond and most prepreg repairs require the use of an epoxy adhesive to enable the bond. An adhesive layer is also required when performing a precured patch composite repair. Conversely, adhesives are not required for wet layup composite repair.

G5 [Lab]: Students will prepare a bonded repair for cure, including vacuum bag and heating apparatus installation, and cure (Two different types of bonded repairs: a) a 200°F wet layup bonded repair and b) a 250°F prepreg bonded repair)

Note: this Laboratory exercise is meant to serve as an example for how the indicated composite repair principles can be taught. Individual Trainers may choose different methods to convey the same underlying principles.

250°F Prepreg Bonded Repair Lab:

In teams of two, students will perform a 250°F prepreg bonded repair composite repair in a controlled laboratory environment. Process steps to be followed are detailed previously in G1 through G 4. Emphasis will be placed on following the work instruction in a step by step fashion to simulate a conforming repair process.

200°F Wet lay-up Bonded Repair Lab:

In teams of two, students will perform a 200°F Wet lay-up bonded repair composite repair in a controlled laboratory environment. Process steps to be followed are detailed previously in this document. Emphasis will be placed on following the work instruction in a step by step fashion to simulate a conforming repair process.