

Composite Tooling Design

Training Objective

After watching the program and reviewing this printed material, the viewer will learn and become aware of the many elements to be considered in the design of composite tools.

- The steps for composite tooling design are outlined
- Types of composite tooling are shown
- Tooling materials are discussed
- Composite tool support structuring is explored

Composite Manufacturing

The manufacture of fiber-reinforced thermosetting polymer, or composite, parts requires strict quality control in every step of the production. This begins with the use of CAD software for design of the composite tooling, a working knowledge of the materials involved, and an understanding of the various methods used to process composites, including:

- Wet layup
- Spray-up
- Prepreg layup
- Vacuum resin infusion
- Resin transfer molding
- Compression & matched press molding
- Pultrusion
- Filament winding
- Automated fiber placement
- Secondary processes, such as drilling, sawing, & milling

Composite Tooling

There are many different types of tools required to support composite manufacturing:

- Ply & core kit-cutting templates used to support pre-layup operations.
- Ply & core locator templates, which supports layup of composite material in either a mold or mandrel. These templates often have machined, color-coded 'eyebrow' cutouts along the ply or core locations to facilitate marking these locations on the laminate during layup.
- Layup molds/mandrels, which provide the basic shape of the composite part to be produced. They can range from being a simple flat plate to a complex configuration. Hollow parts will have cores that collapse or dissolve to facilitate part removal.
- Trim jigs & fixtures – most parts require trimming of excess material. There may be a knife flange incorporated into the tool design or a more complex trim fixture or jig can be used that locates and holds the part in position for processing.

Tooling Materials

Choice of a tooling material may be determined by two factors: production requirements with respect to the life of the tool and maximum service temperatures that the tool will be subjected to. Service temperature is a concern because of material expansion when heated. The value given to a material indicating how it reacts during a change in temperature is referred to as the coefficient of thermal expansion or 'CTE' value. The higher the CTE value, the more a tool expands.

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Materials typically used in composite tool creation include:

- Glass reinforced polyester or vinyl-ester laminate – very low temperature capability and used for room-temperature molding.
- Carbon fiber reinforced epoxy or bismaleimide laminate – can endure severe temperatures up to 350° F/177°C, has a very low CTE value, and is light weight.
- Glass fiber epoxy or bismaleimide laminate – tools made of these materials are heavier and less rigid than carbon tools. Thus they require three times the laminate thickness to match the stiffness of carbon tooling.
- Invar – A nickel and iron alloy used in very high temperature molds and mandrels because it has a low CTE value. This material is very heavy and requires more time and energy to heat and cool. Invar tooling can be created by forming, machining, and welding.
- Invar coated carbon fiber – a relatively new tooling material, which is lightweight with a low CTE value. Its principal advantage is in its long tool life.
- Steel – A useful material with a fairly high CTE value. The stainless variety is preferred for molding and resisting oxidation, but is also very expensive.

Tooling Design

Primary design considerations are to provide for the layup, the compaction, and the curing of parts all within the tool itself. All designs should include sufficient draft angle to facilitate part removal. With complex geometries, multi-piece tooling might be required. Additionally, tension and part shrinkage can contribute to a condition known as ‘spring-in’ with cured parts, requiring an angular compensation in the tool design.

Hand Layup

Tooling used for hand layup with no vacuum bag or at high temperatures can be made of a wide range of materials using part surface quality as the primary requirement. In contrast, molds designed for vacuum bagging at high temperatures require careful material selection and perhaps dimensional offsets to mitigate the effects of thermal expansion.

Vacuum Infusion

Single-sided molds designed for vacuum infusion processing, or ‘VIP’, and vacuum assisted resin transfer molding, or ‘VARTM’, utilize a flexible vacuum bag. These molds commonly require additional flange area outside of the part area to support placement of the vacuum seals and/or resin injection plumbing. Some molds may be of two-piece designs with one half being a solid outer part and a flexible inner half with silicon rubber seals.

Resin Transfer Molding

Many resin transfer molding, or ‘RTM’, molds are similar to matching die sets and are used with a platen press to control internal pressures. Such tools can be made of composite materials but are normally made from selected metals, which can more readily be made to accommodate integral heating and cooling systems.

Automated Fiber Placement/Tape Laying

Tooling and mandrels for automated fiber placement and tape-laying processes typically are designed to provide the appropriate inner-most-loft or outer-most-loft surface. Tools and mandrels of this type may be designed to index on an automated trunnion or machine-bed platform for use with automated fiber placement or tape-laying equipment.

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Pultrusion

Pultrusion machines are designed to collimate pre-tensioned fibers, stitched mat and/or continuous filament mat, introduce resin to saturate and impregnate the materials, and process or cure these materials into a constant cross-section through a highly specialized die set and machine-molding process. Pultrusion dies may be single or multi-piece and are commonly made of special mold steel. Heating and cooling systems along with a cut-off saw to cut finished pieces to specific lengths are also utilized.

Composite Tool Laminates

When molding a composite tool laminate, a master or part model is required that is the opposite gender than that of the final mold. This model must include all of the various part features, flanges, and indexes that must be molded in the final laminated tool.

In an effort to minimize the effect of thermal expansion when molding the tool laminate from the model, designers tend to select materials that can be cured at low temperatures and then post-cured to perform at higher temperatures in service.

The design goal in the manufacture of composite tool laminates is a high fiber-to-resin ratio along with a very low void volume of less than one half percent (0.5%). Additionally, the tool surface should be resin rich to avoid fiber print transfer to the parts.

Many chop-spray-glass-mat reinforced polyester and vinyl-ester tools with heavily gel-coated surfaces almost always exhibit cracking in the gel coat after a few runs. This must be repaired by removing the cracks and bubbles in the damaged areas and repairing them with a mixture of milled fiberglass and gel coat.

Composite Tool Structuring

Composite tool design must also incorporate a strong, torsion-resistant substructure or frame that will be a rigid platform for the tool laminate during processing.

For elevated temperature service, substructures are usually made from the same material as the parent tool, but also can be made from dissimilar materials such as steel, Invar, or aluminum.

When a tool is not going to be subjected to elevated temperature, then dissimilar materials such as steel tubing can be used to produce a cradle or substructure to reinforce the tool laminate. Often with very large tools these structures can be adapted to a trunnion to allow the mold or fixture to be rotated into the best working position.

In addition to tooling support, transportation and handling features also must be considered part of the tool design. Tool lift lugs should be positioned in such a manner so as not to allow the lifting straps or chains to load or damage the tool. For large tools, forklift provisions should be designed so as not to allow the forklift's tines or rails to contact or damage the primary tool body or laminate.

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Review Questions

1. An 'eyebrow' is:
 - a. a flaw in a mold
 - b. the end part of a mandrel
 - c. a color-coded cutout
 - d. a template

2. Layup molds with cores that collapse or dissolve are used to create:
 - a. hollow parts
 - b. parts made on a mandrel
 - c. templates
 - d. round or spherical parts

3. To facilitate trimming, tools may incorporate:
 - a. ear hooks
 - b. knife flanges
 - c. reverse flanges
 - d. trim tabs

4. 'CTE' value refers to:
 - a. hardness of the composite material
 - b. surface density
 - c. tool shrinkage
 - d. thermal expansion of the tool

5. Carbon fiber reinforced epoxy or bismaleimide laminates can endure temperatures up to:
 - a. 750°F/399°C
 - b. 550°F/288°C
 - c. 350°F/177°C
 - d. 150°F/66°C

6. Many resin transfer molding molds resemble:
 - a. matching die sets
 - b. inflatable vacuum bags
 - c. elongated mandrels
 - d. layup molds

7. Pultrusion dies are commonly made of:
 - a. composite material
 - b. silicon rubber
 - c. Invar
 - d. mold steel

8. The targeted goal in designing laminate tools is:
 - a. void volume of less than 0.5%
 - b. high Brinell hardness
 - c. maximum stiffness
 - d. ease of assembly

9. A tool substructure is often needed to:
 - a. facilitate trimming
 - b. aid in part removal
 - c. resist torsional movements
 - d. provide for tool transportation

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Answers

1. c
2. a
3. b
4. d
5. c
6. a
7. d
8. a
9. c