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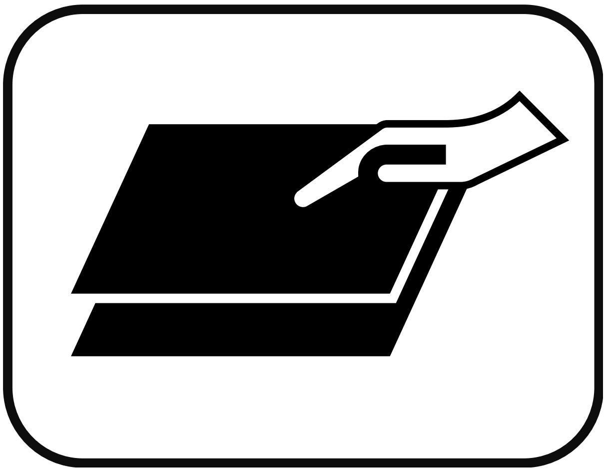
A157

Materials deposition and consolidation management (MDCM)

Systems knowledge article



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Prerequisites	• Systems Knowledge

Introduction[edit | edit source]

Material deposition and consolidation management (MDCM) is concerned with knowing, understanding, and managing how the constituent materials of a composite part are placed and consolidated onto the tooling. Whereas the thermal management is relatively independent of process, material deposition and consolidation management is highly dependent on the process, which is likely why most processes are colloquially named after their MDCM step. Material deposition processes can be broadly separated into two categories:

- Deposition of the reinforcement onto the tool followed by the deposition of matrix (Tool + Reinforcement + Matrix)
- Reinforcement and Matrix combined, then deposited onto the tool ((Reinforcement + Matrix) + Tool)

Regardless of the manufacturing process, material deposition and consolidation have direct impact on cost and final part quality. Depending on the process, material form and part shape, deposition and consolidation can consume a huge amount of time and resources in a manufacturing system, especially for complex and high performance applications. The combined effect of the material deposition and consolidation and the subsequent thermal transformation steps will determine local porosity, resin volume fraction leading to either resin rich or resin starved areas, and fibre misalignment.

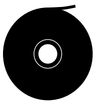
Significance[edit | edit source]

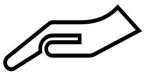
Link to the outcome matrix

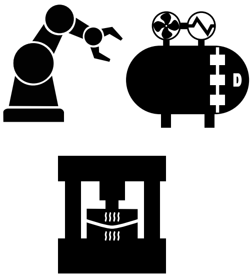
Material deposition and consolidation is a major cost driver in composite manufacturing. The capital and overhead cost of MDCM accounts for 40 - 60 % of the total cost depending on part complexity and production volume[1]. Several manufacturing outcomes are directly related to MDCM. This includes wrinkling, fibre waviness, Fibre volume fraction, porosity (void content), residual stress and others. Further, material deposition rate can directly impact throughput. Choosing the correct manufacturing process and appropriate processing parameters is essential to a composite manufacturing system.

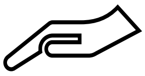
Scope[edit | edit source]

This page describes MDCM from a systems level perspective. Since material deposition and consolidation is heavily process dependent, the section is expanded into a comprehensive list of composite manufacturing processes. Two representative processes, vacuum assisted resin transfer moulding (VARTM) from liquid composite moulding and hand layup pre-preg/autoclave are discussed in detail. These two examples demonstrate using the MSTE approach to categorize processing parameter which can affect the MDCM outcomes. Following this approach, the effects of each MSTE parameter class on the MDCM outcomes are analyzed and illustrated in the following subpages:









Effect of material in a materials deposition and consolidation management system
Effect of shape in a materials deposition and consolidation management system
Effect of tooling in a materials deposition and consolidation management system
Effect of equipment in a materials deposition and consolidation management system

Systems level approach[edit | edit source]

Overview[edit | edit source]

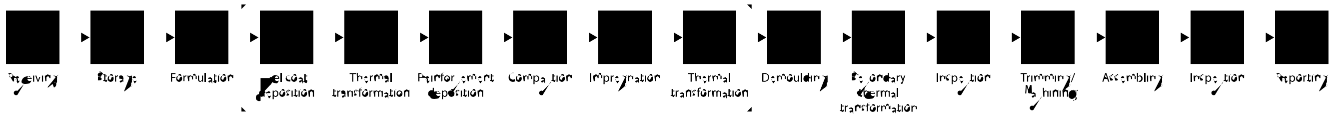
Material deposition and consolidation management is highly dependent on the material deposition process. Material deposition processes can be broadly separated into two categories:

- Deposition of the reinforcement onto the tool followed by the deposition of matrix (Tool + Reinforcement + Matrix). Some typical processes in this category include:
  - Vacuum assisted resin transfer moulding (VARTM)/resin infusion (VARI)
  - Light resin transfer moulding (Light RTM)
  - Resin transfer moulding (RTM)
  - Forming (dry charge)
  - Resin injection moulding (RIM)
- Reinforcement and matrix combined, then deposited onto the tool ((Reinforcement + Matrix) + Tool). Some typical processes in this category include:
  - Wet layup
  - Spray-up
  - Pultrusion
  - Filament winding (wet winding)

    - Filament winding (Towpreg winding)
    - Forming (Pre-preg)
    - Compression moulding (SMC/BMC)
    - Hand layup prepreg (Autoclave/Out-of-autoclave) processing - A291
    - Automated fibre placement (AFP)
    - Automated tape layup (ATL)
    - Bladder moulding
    - Tube Rolling
    - Centrifugal casting
    - Continuous Lamination

[Explain the physics in relation to the outcomes in two phases: first one only for first category, second true for both] and link to the example below (replace ex. 2 with autoclave process).

Example 1: Vacuum assisted resin transfer moulding (VARTM)/resin infusion (VARI)[edit | edit source]



MSTE under the context of MDCM for Vacuum assisted resin transfer moulding (VARTM)/resin infusion (VARI) are:

Material[edit | edit source]

- Material Structure
    - +Reinforcement sizing - sizing serves the interface between the reinforcement and the matrix. Sizing can affect how the reinforcement is impregnated *NOTE: in this case, the term sizing has nothing to do with the physical size of the fibre
    - +Reinforcement architecture - tow size can affect the impregnation. Large tow size, potential porosity within the tow. Small tow size, potential porosity between the tows (Ask Casey for figure/schematic)
- Material properties
    - Fibre-bed drapability - how well fibre will conform to the shape of the tool. Plays a role in fibre waviness
    - Fibre-bed permeability - Along with Viscosity (resin) and pressure differential, determines the rate at which resin infused the fibre
    - Viscosity (resin) - Along with Fibre-bed permeability and pressure differential, determines the resin deposition rate
- Consumables

Vacuum bags, spiral tubing, peel ply, flow media and other consumables play crucial roles in VARTM. Consolidation of VARTM is solely provided by vacuum pressure via the vacuum bag. Spiral tubing and flow media assist the resin deposition (flow) to fully impregnate the reinforcement.

Shape[edit | edit source]

- Geometry - VARTM can adopt a wide range of size and shape complexities. In theory, a shape is achievable if the reinforcement can be deposited and resin flow can reach. In practice,

sharp/tight turns and undercuts are difficult to fully infuse. Reinforcement is typically deposited manually if the shape is simple. A small amount of adhesive (often 'spray glue') is sometimes used to stop the consumables and reinforcements from shifting. For complex shapes, reinforcement preforms can be used.
  - Thickness - affects the through thickness resin flow front profile
  - Corners and curvature - tight convex corners raises pressure, leading to thinner part. Tight concave corner can potentially cause resin pooling and resin rich areas

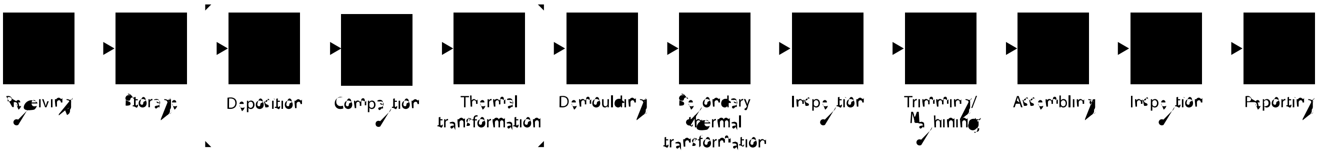
Tool[edit | edit source]

- Tool determines the shape

Equipment[edit | edit source]

- Fibre cutting equipment - potentially cause fibre waviness
- Fibre handling equipment - potentially cause fibre waviness and misalignment
- Vacuum pump - determines the vacuum level and consolidation force exerted on the part

Example 2: Hand layup prepreg (Autoclave/Out-of-autoclave) processing[edit | edit source]



Depositing pre-preg material using hand layup is intrinsically slower and more prone to errors and uncertainties comparing to Automated fibre placement (AFP) or Automated tape layup (ATL). However, for small and intricate parts, hand layup can be a lot more robust for manipulating the pre-preg sheet onto complex contours. MSTE under the context of MDCM for Hand layup prepreg (Autoclave/Out-of-autoclave) processing - A291 are:

Material[edit | edit source]

- Material Structure
  - Reinforcement architecture - Unidirectional or woven; tow size and deposition rate
  - Inserts - The use of inserts complicates the MDCM, depending on the insert type, sealant or other insert associated consumables are potential required. Potential cure in multiple stages.
- Material properties
  - Fibre-bed drapability - how well fibre will conform to the shape of the tool. Plays a role in fibre waviness
  - Viscosity (resin) - Along with Fibre-bed permeability, determines the resin deposition rate. Function of temperature, warming up the pre-preg softens the resin, making hand layup easier.
- Consumables

Vacuum bags, breather cloth and release films are used during de-bulking and curing. The layup is typically debulked every three to five layers depending on the shape complexity. Debulking compacts the layup and removes entrapped air between the pre-preg layers. Debulking can also be perform at elevated temperatures (65.5°C to 93.3 °C or 150 °F to 200 °F) to soften the resin for better consolidation[1].

Shape[edit | edit source]

- Thickness - The thicker the part, the more layers of pre-preg required, longer it takes to complete layup
- Layup - more complex the layup, lower the deposition rate, higher uncertainties and chance for error
- Corners and curvature - tight convex corners raises pressure, leading to thinner part. Tight concave corner can potentially cause resin pooling and resin rich areas
- Gapping - when gapping is required, hand layup can be inaccurate which may cause resin rich areas or other defects

Tool[edit | edit source]

- Tool determines the shape

Equipment[edit | edit source]

- Fibre cutting equipment - potentially cause fibre waviness
- Fibre handling equipment - potentially cause fibre waviness and misalignment
- Vacuum pump - determines the vacuum level and consolidation force exerted on the part
- Autoclave - As temperature increases initially Viscosity (resin) decrease, along with the autoclave pressure, part is consolidated

Manufacturing outcomes/MDCM outcomes[edit | edit source]

- Fibre waviness
- Fibre misalignment
- Wrinkles
- Variation in Fibre volume fraction
- Porosity (void content)

Related pages

Page type	Links
Introduction to Composites Articles	
Foundational Knowledge Articles	
Foundational Knowledge Method Documents	
Foundational Knowledge Worked Examples	

Systems Knowledge Articles	• Machining and assembly management (MAM) - A287 • Materials deposition and consolidation management (MDCM) - A157 • Quality/inspection management (QIM) - A288 • Residual stress and dimensional control management (RSDM) - A165 • Thermal and cure/crystallization management (TM) - A107
Systems Knowledge Method Documents	
Systems Knowledge Worked Examples	
Systems Catalogue Articles	
Systems Catalogue Objects – Material	
Systems Catalogue Objects – Shape	
Systems Catalogue Objects – Tooling and consumables	
Systems Catalogue Objects – Equipment	
Practice Documents	
Case Studies	
Perspectives Articles	

References

1. ↑ [1.0] [1.1] [Ref] Campbell, F.C. (2004). *Manufacturing Processes for Advanced Composites*. Elsevier. doi:10.1016/B978-1-85617-415-2.X5000-X. ISBN 9781856174152.

About **Help**

The individual materials that combine to form the composite material. The constituent materials are separate and distinct on a macroscopic level.

Engineered materials (designed to have specific properties) made from two or more constituent materials with different physical or chemical properties. The constituents remain separate and distinct on a macroscopic level within the finished structure.

A central processing theme in the manufacturing cycle. This theme is concerned with managing the thermal response of materials during storage and handling or parts/tools when they are subsequently heated.

The continuous material phase that binds the reinforcement together, maintains shape, transfers load, protects the reinforcement from environment and damage, and provides the composite support in compression.

Desirable characteristics:

- Moisture/chemical resistance
- Low density
- Processability

For polymer matrix composites (PMCs), resin refers to the matrix; the continuous material phase that binds the reinforcement together, maintains shape, and transfers load. Resins are divided into two main groups: thermosets and thermoplastics.

Volume fraction of either matrix or fibres with respect to total composite volume (matrix + fibre).

Outcomes represent the range of response/sensitivity to factory system attributes. Those that fail to satisfy manufacturing requirements are known as defects. Examples of manufacturing outcomes include process parameter outcomes, material structure outcomes, and material performance outcomes.

Vacuum assisted resin transfer moulding (VARTM) - also known as vacuum assisted resin infusion (VARI), vacuum infusion process (VIP) or often just resin infusion. VARTM is a liquid composite moulding (LCM) closed mould process with a single side tool and vacuum bag where the resin is drawn through the preform using vacuum.

Vacuum assisted resin infusion (VARI) - also known as vacuum assisted resin transfer moulding (VARTM), vacuum infusion process (VIP) or often just resin infusion. VARI is a liquid composite moulding (LCM) closed mould process with a single side tool and vacuum bag where the resin is drawn through the preform using vacuum.

Sizing or fibre sizing refers to a coating that is applied to fibre during manufacturing. Highly proprietary (formulation and process).

Sizing serves two functions:

- Protects and aids fibre during processing
- Aids in the bonding of fibre and matrix

A tow is a bundle or yarn of individual fibres. The tow size is inherent to the fibre manufacturing process (i.e. a tow is manufactured in one process, rather than each fibre individually then bundled together after).

Typically, smaller tows are better because they result in a more homogeneous material.

The larger the tow:

- The faster it is to deposit material
- The easier is it for resin to flow between tows
- Harder for resin to saturate

Typical tow sizes:

- 1k (thousand)
- 3k
- 6k
- 12k
- 24k
- 50k

Permeability refers to the resistance to fluid flow through a porous material.

- Resin flow through fibre
- Gas flow through prepreg

Any manufacturing and/or decision making activity that occurs during any stage of the development design cycle (e.g. conceptual design to production).

In the context of Knowledge in Practice, practice refers to the systematic use of science based knowledge to reduce composites manufacturing risk, cost, and development time.

Flow front refers to the leading edge of the resin as it is flowing into and through the fibre preform.

Pre-impregnated (prepreg) material refers to fibre that is already combined with resin. It is the most common material form used in aerospace.

During prepreg production, (e.g. fibres are run through a resin bath), prepreg is heated and partially cured to B Stage (< 5 % degree of cure). Thermoset prepregs (e.g. epoxy prepreg) have to be kept in a freezer at around -20 °C. At room temperature, the epoxy starts to cure.