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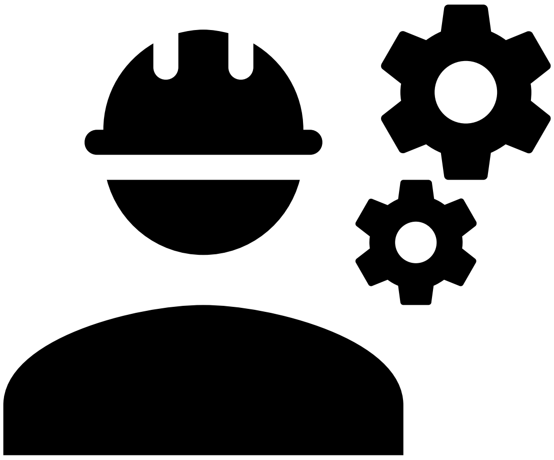
Practice
Practice article



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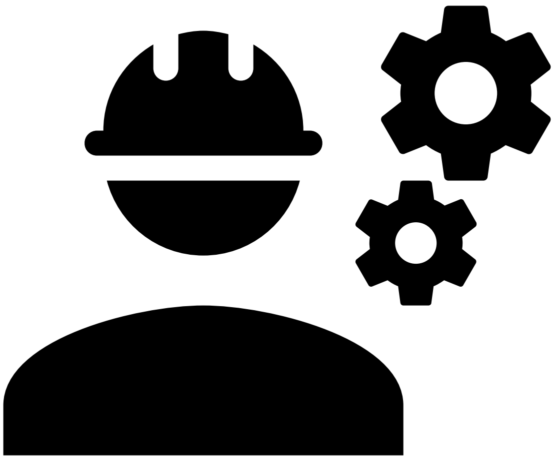
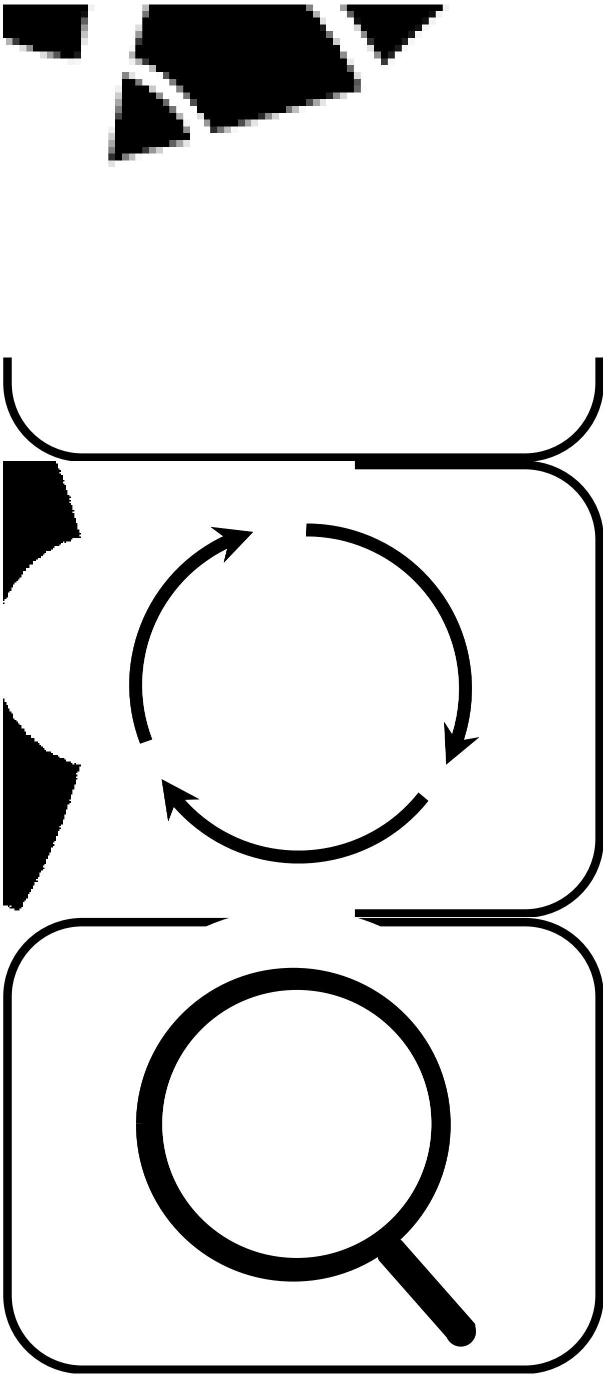


Welcome to the Practice volume. This volume contains a collection of practice documents providing guidance and step-by-step workflows on composite materials design and manufacturing. By clicking the links below, you can access the state-of-the-art practice to develop, optimize and troubleshoot a part, a process or a factory.

Want to learn more about the Practice volume? Refer to the Level I view to navigate the Practice volume quickly and learn more about the different type of workflows. Refer to the Level II view to learn more about the Practice volume and the underlying concepts of this volume.

Level I
Level II



Integrated Product Development
Production Optimization
Production Troubleshooting
Read more

Are you deciding on your part design/manufacturing process and need some guidance? This section of the KPC provides guidance on designing your composite product from deciding functional requirements to developing a complete factory. You will be guided from a blank page to conceptual and then detailed production design, and into production. You will also find detailed information on laying out your factory and the equipment and tooling you will need. Click here to explore the integrated product development practice documents.

Do you have an existing manufacturing process but would like to improve your part quality, increase throughput rate, or reduce cost? This section helps you optimize your process and factory by using quality, rate, and cost as the objective functions. Click here to explore the product optimization practice documents.

Is your manufacturing process failing to meet requirements? This may be the result of a single process step, or a combination of several process steps not meeting specifications. It may be due to the layout of the process steps themselves. This section provides troubleshooting assistance using the following outcomes as guidance: thermal management, material deposition, flow and consolidation, residual stress and dimensional control and assembly. Click here to explore the product troubleshooting practice documents.

How to use this volume[edit | edit source]

Volume Framework[edit | edit source]

Practice is where engineers spend most of their time and where a substantial amount of value and cost can be gained or lost. Good decision-making when putting knowledge into practice means that little rework needs to be done on the physical parts and the processes used to make the parts. This leads to efficient factories with minimal downtime, rework & intervention, non-conformances, scrapped parts, etc. The Practice volume consists of a number of practice documents that provide guidance on design analysis steps within each of three workflows:

1. Integrated product development
2. Production optimization
3. Production troubleshooting

The guidelines are presented with the goal of assisting you, the knowledge user, with understanding what steps are best taken in order to make sound decisions while navigating these workflows. The practice documents rely on Foundational knowledge, Systems knowledge and information from the Systems catalogue when describing how and why certain steps should be taken. Method documents are particularly important and referenced throughout the practice documents since a given practice consists of executing the relevant methods. While practices for different factory layouts may have different high-level content, it is important to note that much of the low-level content (method documents, foundational knowledge and systems knowledge) is identical throughout, and that the same physics and interactions apply in all cases, even though some aspects may be more important to certain manufacturing processes than others.

As discussed in Systems Knowledge, there are four classes of objects that interact with each other as a system to fully define a (sub-)process: Material, Shape, Tooling and consumables, and Equipment (MSTE collectively). In this practice volume we utilize the concept of design-gate indices to describe the state of each of the MSTE object classes. The four possible design-gate indices are shown in the table below:

Design-gate Index	Design-gate Index Name	Design-gate Index Meaning
–	Blank page	No decisions or commitments have been made yet.
1	Conceptual screening	Conceptual decisions have been made. You have screened the type(s) of your manufacturing (MSTE) system but nothing has been purchased yet. At this stage you have significant freedom to make changes because the cost of change is low.
2	Preliminary selection	Design choices are being evaluated and options down-selected. You have selected and specified all the objects of your manufacturing (MSTE) system. MSTE objects are fully specified and some may be purchased, but they can still be modified to alter their effect on the system. There is some freedom to make changes; the cost of change is high, but reasonable.
3	Detailed finalization	The manufacturing (MSTE) system is now ready for production. You have finalized and qualified your manufacturing (MSTE) system and have met all specifications. You have essentially no freedom to change anything about your process. At a minimum, any changes will come with substantial cost.

In this context, Integrated product development workflows are workflows that have a goal of progressing forwards in production design, towards full production (design-gate index = 3). Production optimization workflows have a goal of finding a better combination of design choices to improve the production configuration. In that sense the design indices always start and end at 3 (production) for an optimization workflow. Production troubleshooting workflows seek to answer the question "why?". When a production configuration is not working properly it is important to understand what has caused this to happen and understand why the systems in your manufacturing process are lacking robustness. Troubleshooting workflows assist you in moving backwards through the development process (towards 1) to find the root cause so that the root cause can be corrected by following the appropriate Integrated product development workflow.

The table below describes the MSTE outcomes after completing design-gate index 1 for conceptual screening. This is covered in the integrated product development under specifically Product Development. Moving from state 1 to 2 is the development of each process step, which is the second section of integrated product development:

Object Class	Meaning
Material (M)	You have selected the types of matrix (thermoset vs thermoplastic, polyester/vinylester/epoxy, etc), reinforcement material (glass fibre, carbon fibre, aramid fibre, etc) and reinforcement architecture (unidirectional, woven, braided, NCF, nonwoven, knitted, etc) based on the main process/factory workflow, cost, rate and quality considerations.
Shape (S)	You have a defined functional structure and working principles. The overall size, shape and interactions with other parts is defined.
Tooling & consumables (T)	Considering the equipment and process/factory workflow(s) selected, you have some idea of the type of tooling and consumables you would like to use (one-sided tool/multi-sided tool, heated tool/passive tool, flow media, etc.
Equipment (E)	You have selected the main processes/factory workflows that you would like to consider for the part based on considerations such as cost, rate, quality, existing equipment, part geometry, etc.

Volume Features[edit | edit source]

Coming soon.

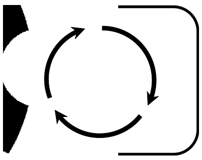
Content[edit | edit source]

Integrated product development workflows[edit | edit source]

Integrated product development is the process of advancing the part and process configurations beginning at anywhere from a conceptual state up to the production state. The integrated product development process begins with the design process initializations steps of defining the functional requirements, before moving on to selecting shape and materials. This is followed by an iterative process where the factory cells are identified, developed and subsequently assessed for feasibility. The assessments are done for both individual cells and for the factory as a whole (considering all cells). This loop is iterated over until the factory is fully defined with all its cells and process steps at a production state and the assessment of the part and process against the functional requirements is passed. Click here to explore the integrated product development workflows.

Learn more about how to develop:
- your product
- your process
- your equipment and tool
- your factory

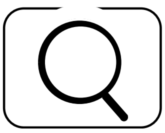
Production optimization workflows[edit | edit source]



Production optimization focusses on an existing manufacturing process where the goal is to achieve a lower cost, higher rate and/or higher quality for the parts. The optimization process is done by focusing on materials, shape, equipment or tooling to improve a process. Click here to explore the production optimization workflows.

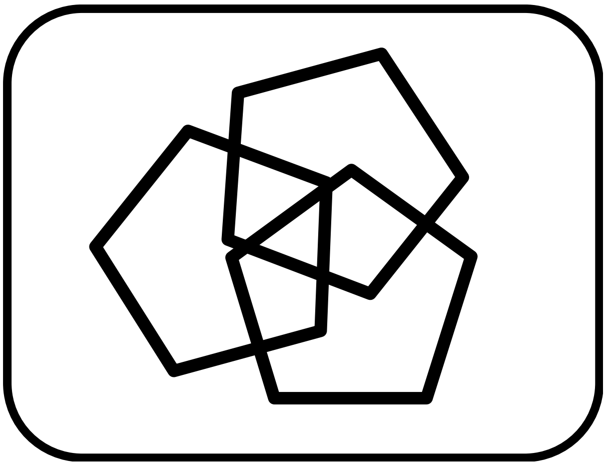
Learn more about how to optimize:
- your product
- your process
- your equipment and tool
- your factory

Production troubleshooting workflows[edit | edit source]

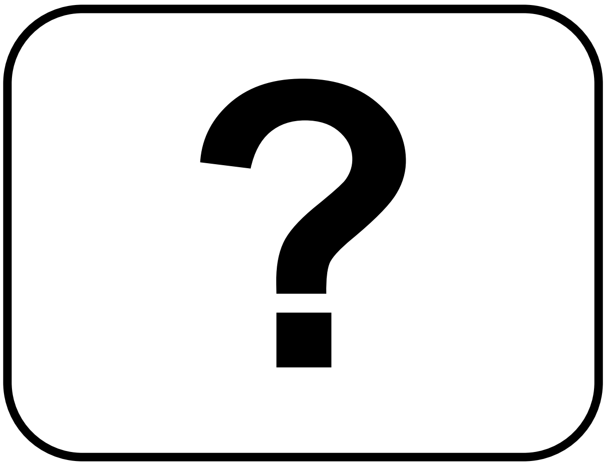


Production troubleshooting is the process of identifying problems in the manufacturability of a part and then taking steps to trace and correct the root cause of these problems by re-developing aspects of the part and/or process. A good integrated product development workflow should result in a process that is robust and not prone to producing bad parts given the expected variability in the system objects. If this is not the case, then additional controls or modification of the process will need to be made, and the production troubleshooting workflows provided here are intended to guide you through to find the most common problems. Click here to explore the production troubleshooting workflows.

Learn more about how to troubleshoot:
- your product
- your process
- your equipment and tool
- your factory



About



Help

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.

A set of steps/procedures that are intended to provide guidance in manufacturing and/or decision making activities.

There are two types of workflows:

- *Standard workflows* are intended to formalize practices where the manufacturing science base exists. The focus is to provide guidance using manufacturing simulation as an enabling tool (e.g. design activities/decisions relating to thermal management).
- *Complex workflows* are intended to reduce the level of effort in practices where the existing manufacturing science base is not sufficiently mature to support production scale problems. The focus is to provide guidance using simulation based thinking and/or checklists (e.g. design activities/decisions relating to porosity management).

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 act of combining reinforcement fibre, resin to shape on a mould (tool).

There are three main methods to combine resin and fibre to deposit onto a tool (i.e. material deposition):

- Wet Processes: Mixing liquid resin and dry fibre directly in the mould, e.g. Wet Compression

Moulding process for parts in BMW 7 series

- Liquid Composite Moulding (LCM) processes: Infusing dry fabric with resin using a pressure gradient, e.g. High Pressure Resin Transfer Moulding process (HP RTM) for parts in BMW i3
- Prepreg Processes: Laying up using prepreg where resin and fibre are already combined, e.g. Automated Tape Laying (ATL) process for some of the parts in Boeing 787.

In the context of knowledge in practice, knowledge refers to the systematic use of science based knowledge in composites manufacturing practice.

There is a distinction between experience based knowledge and science based knowledge:

- Experience based knowledge ('know-how') is an understanding of potential outcomes and their relationships that is founded on pragmatism and experience accumulated over time in individual programs, companies and in the industry more broadly.
- Science based knowledge ('know-why') is an understanding of potential outcomes and their relationships, based on the important processing physics, that is mature enough to be codified using the appropriate governing laws and constitutive equations.

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

Thermosets are a class of polymer that undergo polymerization and crosslinking during curing with the aid of a hardening agent and heating or promoter. Initially they behave like a viscous fluid. During curing, they change from viscous fluid to rubbery gel (viscoelastic material) and finally glassy solid.

If heated after curing, initially they become soft and rubbery at high temperatures. If further heated, they do not melt but decompose (burn)

Comes in two parts: part A (resin) and B (hardener). When mixed, curing reaction starts and is not reversible.

Examples include epoxy or polyester.

A class of polymer, some common examples include polypropylene and polyethylene.

They soften and melt upon heating (i.e. potentially recyclable), high viscosity when melted, therefore difficult to saturate fibres. Usually needs a lot of pressure and heat to process.

Carbon fibres are composed of large aromatic sheets similar to those in graphite. These graphitic layers form the basic structural units in the shape of ribbons. The structure of carbon fibre ribbon is believed to be a columnar arrangement of disoriented graphite crystallites parallel to the ribbon length. The idealized tetragonal crystallites are stacked above one another, with slight disorientation between the crystals in the direction of fibre axis, trapping sharp needle like voids, where the boundaries between the stacks represent the disordered regions.

Generic name for fibres composed of aromatic polyamide. Best known fibre is Kevlar, introduced by DuPont (USA) in early 1970s. Also, Technora (Japan), and Twaron (Europe). Originally developed to replace steel belts in radial tires, increased durability and increased strength.