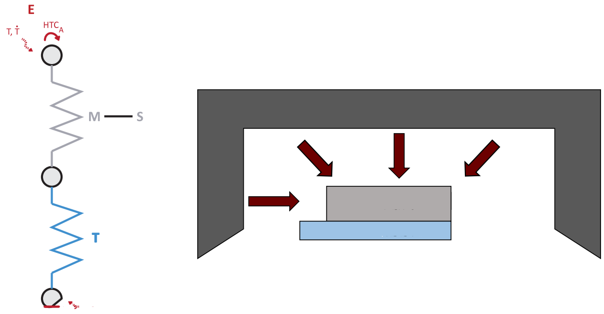
A109

System interactions

Systems knowledge article



System representation of a composite processing step.

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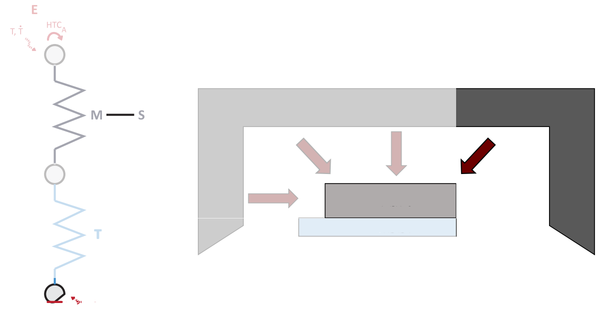
Overview[edit | edit source]

In composites manufacturing, each process occuring in the factory can thought of as a system of interactions between the part, tooling and consumables (T), and equipment (E)[1]. The part can be further broken into its constituent materials (M) and shape or geometry (S). In shorthand notation, this is collectively referred to as the MSTE system. The interactions between these components are what determine the outcomes of a given process step, such as final degree of cure (DOC) or porosity. These interactions are based on foundational science principles. In many cases, it is convenient to represent the system components as a simple resistance diagram. Take a heating scenario as depicted in the image on the right for example. In this schematic, the part - divided into material (M) and shape (S) - and tool (T) are represented by spring elements, each with their own thermal properties; while, E represents the environmental conditions of the equipment. Depending on the assembly, there may be multiple material systems in play, or the part may be surrounded by tooling on two sides (in a closed mould process for example). Moreover, if the consumables add significant thermal resistance to the process then they too should be considered and represented in the diagram (for example breather cloth in a vacuum bag assembly). In any case, representing the system as a series of elements with individual material properties under a given set of environmental conditions is a good way to deconstruct the problem.

Single interaction[edit | edit source]

At the simplest level, one system class interacts with one other system class. There are four practical and useful interactions to understand. They are described below.

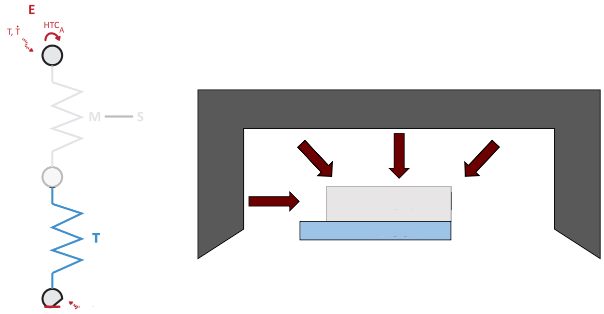
Interaction between material and shape (MS)[edit | edit source]



Resistance diagram for the interaction between M and S (left), and the physical representation in the system (right).

The material and shape together form the part. Therefore, the interaction between material and shape defines the outcome sensitivity for the system. That is, how the part will respond to the imposed boundary conditions. The part response is based on the physical dimensions and construction of the part as well as its material properties. The state of the part is what determines the final outcomes for the system.

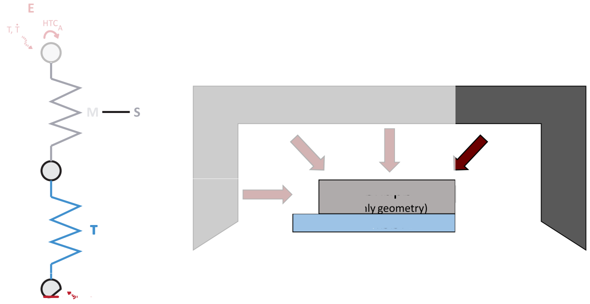
Interaction between the tooling and equipment (TE)[edit | edit source]



Resistance diagram for the interaction between T and E (left), and the physical representation in the system (right).

The interaction between tooling and equipment defines the system boundary conditions with respect to the part. Within any given cell, the equipment impose the environmental conditions that all other elements of the system assembly are subject to. The energy imposed by the equipment either interfaces directly with the part or indirectly by interfacing with the tooling/consumables adjacent to the part. For example, the temperature of a part in an oven is dependent on the interaction between the thermal conditions of the oven and the exposed surfaces of the part and/or between the thermal conditions of any tooling/consumables the part is in contact with. The latter scenario is significant, as during processing of composite materials there is almost always some form of tooling or consumable involved in the assembly which greatly affects heat transfer to and from the part. The thermal conditions of the tooling and consumables are themselves directly dependent on their interaction with the equipment.

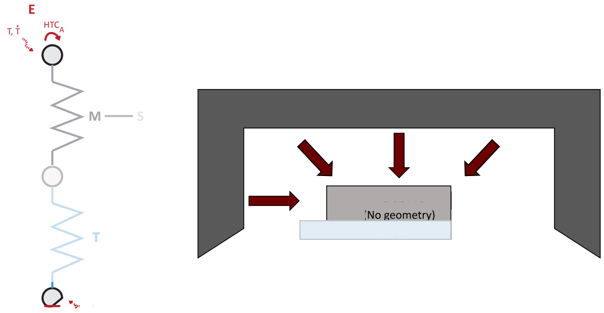
Interaction between shape and tool (ST)[edit | edit source]



Resistance diagram for the interaction between S and T (left), and the physical representation in the system (right).

The interaction between shape and tool define the dimensions of the tool-part assembly. This is useful from the perspective of understanding how impinging airflow may be redirected in a thermal system. Moreover, the geometry of the tool-part assembly must be considered when selecting equipment.

Interaction between the material and equipment (ME)[edit | edit source]



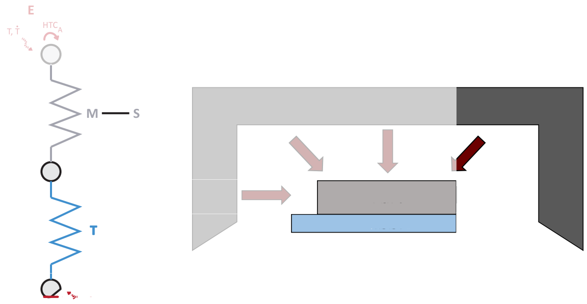
Resistance diagram for the interaction between M and E (left), and the physical representation in the system (right).

It is necessary that the part achieves its specifications as defined for the material system. Therefore, at a minimum, the equipment on its own should be able to provide the environmental conditions necessary to satisfy the material specs. Consider a thermal system. An empty piece of equipment (such as an oven) represents the best case scenario for achieving the thermal specifications of the material. For example, if a material must be processed at 180°C, it requires a heating environment that can achieve such a temperature. As soon as the tooling and part(s) are added, thermal resistances are introduced to the system, and the part may not achieve the intended thermal history. This method of thinking breaks down for thermosetting resins at low environmental temperatures, where the heat of reaction is considerably higher than the heat of the environment. Here, it is the exothermic nature of the material that drives the cure reaction, not the thermal conditions imposed by the equipment; although the ambient air temperature does play an important role. In either case, these interactions are important considerations when sourcing equipment and defining the manufacturing process.

Multiple interactions[edit | edit source]

In reality, within any given factory cell, multiple system classes interact with one another. The manner in which they interact is a combination of the single interactions listed above.

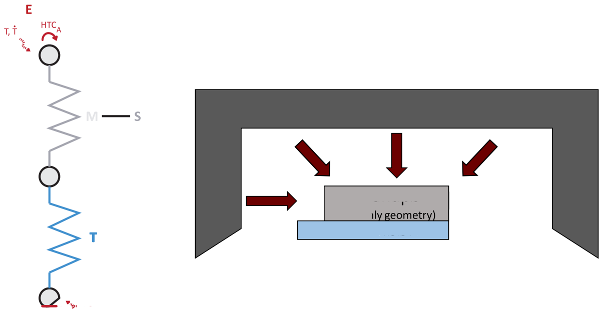
Interaction between material, shape, and tooling (MST)[edit | edit source]



Resistance diagram for the interaction between M, S, and T (left), and the physical representation in the system (right).

The material and shape together form the part. The interaction between tool and part defines how energy transfers through the tooling and consumables into the part and vice versa. In the case of thermal management it is the transfer of heat to and from the tool-part interface that is important. Changing the geometry or the materials of either tool or part will affect the transfer of energy between the two. In some cases, changing the tooling parameters may result in dramatically different outcomes for the part. This can be used to tailor the system design and, if not considered, may lead to unexpected failures. In the case of residual stress and dimensional control management, tool-part interaction is a common subject in composite processing literature. Here, the transfer of energy between tool and part occurs mechanically as the tool and part expand and contract differently under temperature, imposing stresses across the tool-part interface.

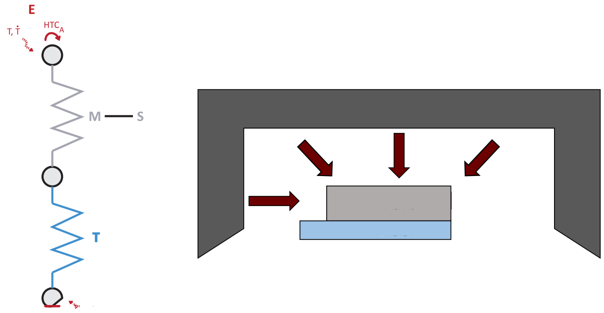
Interaction between shape, tool, and equipment (STE)[edit | edit source]



Resistance diagram for the interaction between S, T, and E (left), and the physical representation in the system (right).

As mentioned above, the interaction between shape and tooling define the physical dimensions of the tool-part assembly. When considered with equipment, the STE interaction represents the geometry of the entire system. Part shape, tooling dimensions, and equipment specifications must be considered together when qualifying the system. If the equipment is relatively small compared to the tool-part assembly, then a batch-load of several tools/parts may not be possible. Moreover, a large tool/part may block or redirect airflow around other tools/parts in a convective heating environment. Similarly, the local geometry of a given tool-part assembly may influence airflow across its own surface. All of this, in turn, changes the local heat transfer coefficient (HTC) across the part surface(s).

Interaction between material, shape, tooling, and equipment (MSTE)[edit | edit source]



Resistance diagram for the interaction between M, S, T, and E (left), and the physical representation in the system (right). This representation describes the entire system.

The interaction between M, S, T, and E captures the entire system response, including the boundary conditions of the tool-part assembly, and the internal energy transfer to and from the part. In order to understand the outcomes of a system, all MSTE interactions must be considered. In order to approach this, it is easiest to consider the individual contributions each class makes to the system and how they come together in the manner described above. The individual contributions of each system class are explored in detail in further pages for each of the processing themes.

For thermal management related interactions refer to the following pages:

- Effect of material in a thermal management system
- Effect of shape in a thermal management system
- Effect of tooling in a thermal management system
- Effect of equipment in a thermal management system

Related pages

Page type	Links
Introduction to Composites Articles	
Foundational Knowledge Articles	
Foundational Knowledge Method Documents	
Foundational Knowledge Worked Examples	
Systems Knowledge Articles	• System interactions - A109 • System parameters - inputs and outcomes - A108
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. ↑ [Ref] Fabris, Janna Noemi (2018). *A Framework for Formalizing Science Based Composites Manufacturing Practice* (Thesis). The University of British Columbia, Vancouver. doi:10.14288/1.0372787.

About **Help**

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.

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

Degree of cure (DOC) is an indication of how far the chemical curing reaction (crosslinking process) has advanced in a thermoset resin.

DOC is defined with a number between 0 and 1 (or 0% and 100%) where 100% is a fully cured resin. It does not have to fully reach 100% for the resin to become solid or the part to be used. In some aerospace applications, resins are only cured to about 90%. Higher the degree of cure, higher the mechanical properties.

Polymerization of thermoset resins is an exothermic reaction and heat is generated during the curing process. A thermosetting resin has the potential to release a certain amount of energy while curing. This is called the total heat of reaction, H_R, with a unit of J/g (SI units).

The heat of reaction during polymerization is measured using a Differential Scanning Calorimeter (DSC) equipment measuring much energy/heat comes out of the reaction for a small resin sample.

An individual station within a factory where a given set of tasks are accomplished (also known as a "work cell"). Some cells may directly add value to the product (e.g. deposition), while others may serve support roles that are critical to maintaining part quality (e.g. receiving, storage, inspection & shipping).

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.

A central processing theme in the manufacturing cycle. This theme relates to management of internal stresses that occur as the material undergoes differential thermal and physical phase change volume changes and viscoelastic property development.

Key components of all composite manufacturing processes. Collectively, the four themes represent the time-temperature-pressure-vacuum history, which is traditionally used to define a manufacturing cycle.

The four processing themes are:

- Thermal management
- Material deposition management
- Flow and consolidation management
- Residual stress and dimensional control management

(Same as "Theme")