https://compositeskn.org/KPC/P153

P153

Material Selection

Practice document

Document Type	Practice
Document Identifier	153
Tags	• Integrated product development • Material
Objective functions	**Cost** Maintain **Rate** Maintain **Quality** Maintain
MSTE workflow	Development
Prerequisites	• Integrated Product Development • Practice • Practice for Developing a Product

It is assumed that you have already selected composites as your material of choice. This page will go into the specific constituent materials and how to select a suitable resin and matrix system for your application while keeping in mind manufacturability. The material must fulfil the requirements for your application, but it must also be able to be manufactured. Referring back to the MSTE framework keeps the developer aware of the interplay that the material system has on the other facets of the manufacturing system. When going through this process it is important to keep in mind there are hundreds of fibre and resin variations, as well as many adhesives, cores and ancillary materials to choose from. Material suppliers will be able to give specific information on what materials are available from them and their properties.

Considerations for Selecting Fibre Material Candidates[edit | edit source]

Fibre types dictate the inherent strength of the composite. They are the main contributor of strength as well as other other properties unique to the specific fibre. this section provides a guide through the three main decisions related to fibres. Firstly, the fibre family needs to be selected, ie. glass, carbon etc. Then the type of fibre within the family, eg. E-Glass. Lastly the architecture the fibre will have, eg fabric, braid etc.

The three common types of fibre are Glass, Carbon and Aramid. See Systems Catalogue on Reinforcement Material for more on fibre types. Below is a short summary of the fibre types and what to consider when selecting them, followed by a brief table comparing the three main options.

Glass Fibre[edit | edit source]

The most common fibre used in reinforcement of plastics is glass fibre. They have the lowest mechanical properties of common fibre, however, they are relatively inexpensive and have a very high resistance to corrosive and other harsh environments. Glass fibre usually has a diameter of 5 - 20μm [1]. The most commonly used type of glass is E-glass, which in turn has variations of itself for specific properties[2]. Another common type of glass fibre is C-glass, the C stands for chemical or corrosion, indicating that this fibre type has a high resistivity to harsh chemical environments relative to other glass fibres[3]. Other types of glass fibres such as S-glass have been developed and have 10-15% higher strength and are stable at higher temperatures, for harsh acidic environments and is more expensive. ECR-Glass is an improvement on the traditional E-glass with the added benefit of not using boron or fluorine in the manufacturing process. Z-glass has a high resistance to alkaline environments[4]. Moisture will reduce the strength of glass fibre and they are susceptible to damage when under constant load, this is due to crack growth when constantly loaded for and extended period of time[5].

Carbon Fibre[edit | edit source]

Carbon fibre has lower density and higher modulus than glass, due to the hexagonal arrangement of carbon atoms layered upon each other. Strong covalent bonds provide high strength and stiffness, but weaker van der Waals forces between the layers yield low transverse properties. The width of the tows, the number of graphene layers, i.e. diameter of fibre (usually 5 - 10µm [1], and the continuous length of fibre contribute to the mechanical, electrical and thermal properties of carbon fibre. There is a large variety of carbon fibre types to choose from with different filaments counts, densities, moduli and strain limits[6]. Carbon fibre is a proprietary product, with each manufacturer making their own types.

One of the advantages of carbon fibre is the high fatigue limits. Carbon fibre undergoes complete elastic recovery when unloaded and its high strength fibres are able to bridge to prevent propagation, see Fatigue Limits for more on this. It is also important to note that the coefficient of thermal expansion is negative for carbon fibre. It is possible to develop a product which has a CTE of zero by using the correct matrix and accounting for the internal stresses this will produce when the part sees elevated temperatures[7].

Aramid Fibre[edit | edit source]

This is a class of organic fibre consisting of aromatic polyamide fibre that have long-chain synthetic polyamide and amide linkages to aromatic rings. Well-known commercial examples of aramid fibre include Kevlar®, Technora®, Twaron®, or Nomex®. Like the other fibres discussed, aramid fibre has a high stiffness and a low density, however, they are especially poor in loading perpendicular to the fibres and the compressive strength is about one eighth of the tensile strength. Aramid is known for its high impact resistance and vibration damping, up to five times higher than glass fibre. Aramid fibre are particularly sensitive to UV light, which causes the fibre to go from yellow to brown and lose mechanical properties. This is due to UV light absorption by the polymer and breaking of chemical bonds. Aramid fibres are not usually suited for outdoor application, unless well protected[8].

Other Fibre Types[edit | edit source]

Boron fibre has similar density to glass fibre, but about six times higher strength. It is usually used as unidirectional fibre mats due to their relatively large diameter, which makes weaving challenging. The fibre has a highly complex production method and thus are very expensive. Polyethylene fibre is made from ultra-high molecular weight polyethylene. These types of fibre are very similar to aramid in their properties, but have a lower maximum operating temperature of about 130°C[8]. Well-known commercial examples include Dyneema® and Spectra®.

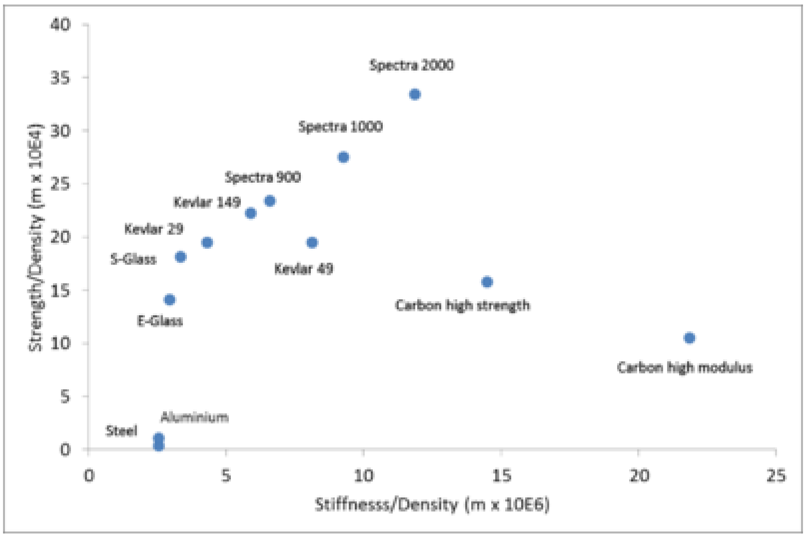
Selecting Fibre for an Application[edit | edit source]

Each fibre type has its own benefits and drawbacks. The selection of one or more will depend on the requirements of your application. The table below is made to assist in the initial selection of fibre material by comparing the three common fibre types to each other. Once the fibre type has been selected a more specific type and architecture can be selected.

Comparison of Fibres[edit | edit source]

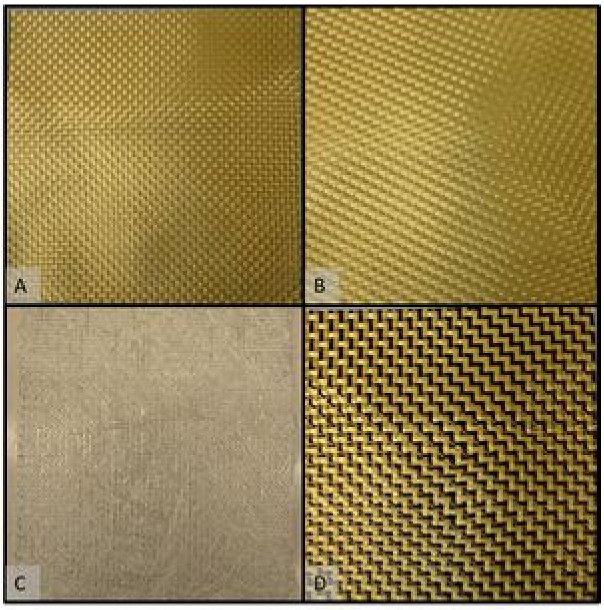
Below is a table roughly comparing the different properties of fibres relative to each other. This can be used as a guide to narrow down the search for fibre types. There is also a graph showing the specific strength vs stiffness for various fibre types, as well as steel and aluminum, to show how there is variation within the fibre types as well.

Table:Fibre reinforcement properties



Specific Strength vs Stiffness for Different Fibre Types Within the Same Fibre Class and a Comparison to Common Steel and Aluminum.

Considerations for Selecting Fibre Architecture and Ply Stacking[edit | edit source]



A: Plain weave aramid fibres. B: Satin weave aramid fibres C:Random glass fibre mat. D:Combined twill weave of carbon and aramid fibres.

Fibre is the component of the composite that carries most of the load. The main objective of laminate development is to select the right fibre material (type), orientation and architecture. In general, the mechanical properties of a laminate tend to increase with higher fibre content (volume fraction) relative to resin matrix content until there is insufficient resin to transfer the load between fibres. The theoretical limit is set by the cylindrical shape of the fibre, while the practical limit is set by processing limitations and the matrix's ability to transfer loads into and out of the fibres. There needs to be enough resin so that there are minimal voids in the laminate. Voids are a stress concentrator and will decrease the final strength of a laminate. In aerospace, for example, prepreg material has a fibre volume fraction of 50 - 60% with a 2% tolerance for voids in the cured laminate[1].

Now that fibre material is selected, considerations need to be made for how the fibres are going to be combined to form a laminate, ie their architecture and ply stacking needs to be considered. Firstly, the architecture needs to be selected (eg. woven E-glass) and then, if applicable, the sub type of architecture (eg. twill weave E-glass), before choosing the areal weight of the fibre (eg. 200 gsm twill weave E-glass).

See also the webinar on fiber architecture Fibre Architecture: Availability, pros and cons, and selection for my application.

Ply Type[edit | edit source]

Continuous unidirectional (UD) fibre is widely available and will produce the highest stiffness in the direction of the fibre. The strength of the fibre will reduce rapidly as the angle of load shifts away from the fibre axis. When the load is perpendicular to the fibre, it will be carried solely by the matrix. Combining layers of UD fibre at angles to each other will provide a quasi-isotropic material[9]. The thickness of a UD ply is 0.1 - 0.2 mm (0.004 - 0.008 inches)[1]. Usually, manufacturers will provide the thickness of the fibre in terms of areal weight. To find the ply thickness, use the following: $t=\frac{FAW}{V_f \rho_f}$

Fibre is also commonly available in woven mats or broad goods, commonly referred to as fabric. This is typically available with a thickness of 0.13 - 0.38mm (0.005 - 0.15inches)[1]. During fibre production, individual fibre is gathered into "tows", or "rovings", which are bundles of fibre that are used to weave a fabric. The amount of fibre in a tow is in the thousands and is categorized by how many thousands in each tow, indicated by 'K'. The common sizes are 3K, 6K, 12K and 48K[1]. The weave can be specified to provide more stiffness in a certain direction, this is done by having more fibre in either the warp or the waft direction. See figure for examples of types of fabric. Image A shows an example of aramid fibre in a plain weave, where the tows alternate going above and below each other. Image B shows a satin weave, one tow over and three under, providing more stiffness in a certain direction and good drapeability over curved surfaces. Image C shows a chopped strand mat, which is composed of short fibre that are randomly distributed and held together with a binder that is soluble to styrene. The stiffness properties will be lower due to the discontinuous fibre and lower fibre volume fraction, but the resulting product will be more or less fully isotropic in-plane. It is also possible to combine fibre types as seen in image D.

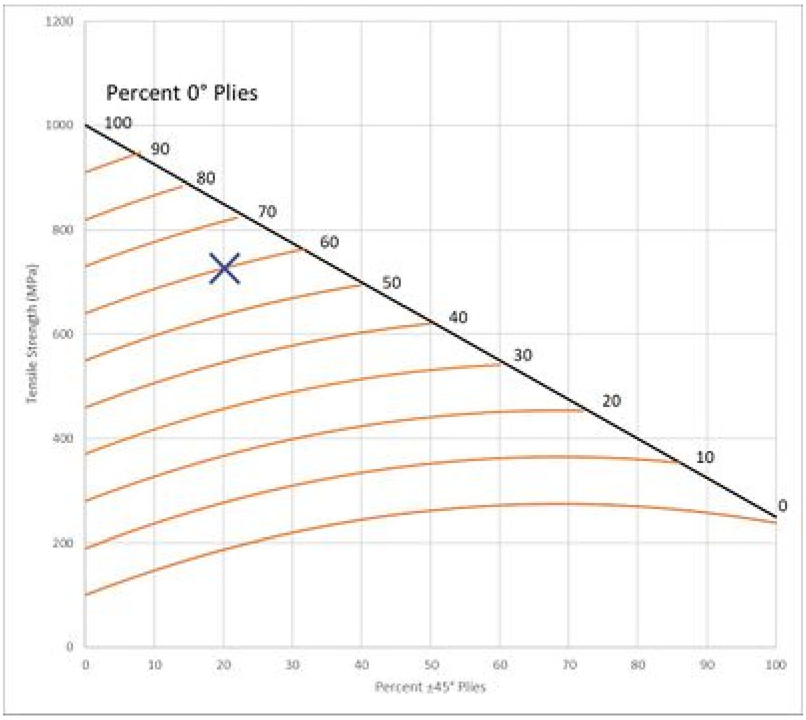
To choose between UD or fabric there are some key points to consider. Fabric tends to have lower strength and stiffness, this is due to the weaving of tows forcing the fibre to bend over and under each other (crimp). Fabric is generally more expensive, pound for pound, because of the weaving process being an additional step, but since fabric is generally thicker there may be less plies required to build up a thickness, thus reducing lay-up time/labor. Also, fabric is easier to handle by an operator due to the interlocked nature of woven tows, as well as the laminate being more damage resistant because of this[1].

Non-crimp fabric (NCF) is an architecture developed to address the shortcomings of woven fabric. NCF consists of tows that are laid down in a specific pattern then stitched together with thin polyester threads. This allows the fibers to remain un-bent (non-crimped) and the fabric is held together for ease of handling. The downside is that the polyester remains in the fabric after manufacturing leading to a lower fiber volume fraction and thus lower mechanical properties[10].

Lastly, it should be noted that the manufacturing process that will be selected may affect the fibre forms available as well. Also, there are many more specialty forms of fibre like: 3-D weaves, braids and CSM.

Ply Stacking[edit | edit source]

See Foundational Knowledge Page on Macro Mechanics



Example of a carpet plot for a 65% Vf carbon with epoxy composite. Made for a layup of 0°/±45°/90°. The cross marks properties for a 20% ±45°, 60% 0° and the remaining 20% 90°. Giving a tensile strength of around 720 MPa.

Composite product development needs to take into account the directional properties of the fibre, ie. the anisotropy of composites. For conventional materials like steel or aluminum the developer can find a single value for the properties of the material in every direction, but for composite layups the properties are different in different loading directions depending on the angles of the fibre. A useful tool to decide the ply stacking sequence is to use carpet plots or performance charts, see examples of a carpet plot to the right. The chart shows a specific type of layup with a certain fibre volume fraction[11].

A typical stacking sequence is [0°/±45°/90°], which will produce in-plane quasi-isotropic properties. Another option is to use a stacking of sequence [0°/±30°/±60°/90°][11], which yields an even more uniform distribution of properties to the composite. However, carpet plots work for three ply orientation combinations[12]. Laminated plate theory can be used to predict laminate properties as well. This theory can be implemented in a spreadsheet or code. There are also various commercial software packages that use it. They are typically designed to assist in this part of the development process. The user inputs a stacking sequence and the program will give the resulting properties, see the Systems Catalogue for some of the available software Resources.

As seen in the macro mechanics chapter of foundational knowledge composite laminates show coupling phenomena when unsymmetric and/or unbalanced layups are used. A balanced layup can be achieved by using a perpendicular ply for every ply used, for example a 90° ply for ever 0° ply. This sequence eliminates shear distortion as each layer compensates in an equal and opposite shear with each other. Symmetry refers to having a plane of symmetry at the midplane of the laminate. A symmetric laminate would have upper half mirrored from the bottom half. This effectively eliminates stretching-bending and bending torsion coupling. When selecting the layup sequence, it is important to keep in mind the edge effects of the laminate, where the free edges can experience out of plane tensile, compressive shear and/or bending stresses[12].

A benefit to using composites is that a combination of materials can be used, creating what is called a hybrid composite. This is where there is either more than one fibre type layered between each other, or a sandwich structure is used using a core material. For more on this see Shape Development.

Considerations for Selecting Matrix Polymer Material Candidates[edit | edit source]

See foundational knowledge on Polymer structure

The primary function of the matrix is to transfer loads between the fibres and hold the shape of the composite. However, the matrix has many other functions that it can contribute to the composite part, for example: protecting the fibre from environmental effects or visual qualities. There are two families of polymers to choose from. Thermoset polymers are the most commonly used. They start as a liquid and harden (cure) through a chemical reaction of crosslinking between the polymer chains. This reaction is irreversible, which means thermoset polymers will not melt (see Thermoset polymers). The second family is thermoplastic polymers. They harden due to a physical process similar to freezing and melting, which is usually reversible[13] (see Thermoplastic polymers).

Selecting for Performance[edit | edit source]

Operating Temperature[edit | edit source]

The polymer matrix system is typically the limiting factor on the operating temperatures of the composite part. For thermosets, a good indicator for service temperature is the glass transition temperature. When the polymer reaches its glass transition temperature (Tg) it will lose most of its structural capabilities and the composite will fail (see Glass transition temperature (Tg)). A simple way to screen thermoset polymers in the selection is to select polymers that have a Tg of at least 25°C higher than the maximum operating temperature of the part[1]. If the part will be operating in humid or wet environments, the absorption of moisture will lower the Tg and so it is good practice to screen for thermoset polymers that have a Tg of 50°C higher than the service temperature[14]. Selecting thermoset polymers with a higher Tg will usually come with a trade-off of higher brittleness and less fracture toughness as well as higher cost. Higher curing temperatures are also required, which may induce thermal stresses into the composite. There is the possibility of adding toughening agents to the resin, however this will increase cost and/or processing time of the composite part.

For thermoplastic polymers the operating temperature will depend on the crystallinity of the polymer, which will decide the operating temperature of the final part. A low crystallinity will have a Tg that can be used for reference, but for most thermoplastics with a semi-crystalline structure, it will depend on the application and the allowable reduction in strength (see Thermoplastic polymers). Some thermoplastics will have a Tg that is higher than thermosets and others have Tgs that are below 0°C [15]. This gives thermoplastics a wider range of theoretical applications where they can purposefully operate above Tg as a soft material.

Mechanical Properties[edit | edit source]

When considering the mechanical properties of a polymer, it depends on which are required/relevant to the application. This means that for composites that will see compressive stresses a high modulus matrix is preferable, whilst to control intraply cracking, a higher tensile strength in the matrix is required. For matrices that need to prevent crack propagation and delamination, selecting one that has a high fracture toughness is needed. The fibre needs to be able to transfer the mechanical loads. To do this, the fibre needs to be fully wet out by the resin and there needs to be compatibility between the sizing (a coating material applied to fibre, not the physical size of fibre) and the resin to ensure good bonding [16].

Selecting for Manufacturing[edit | edit source]

Processing Properties - Viscosity[edit | edit source]

Another property to consider is the viscosity of the polymer (see Viscosity (resin)). Lower viscosity will improve wettability, mentioned above, and aid in removing voids and entrapped air during processing. It is typically desirable to use a polymer with a low viscosity depending on the process. Viscosity is a function of temperature and degree of cure (in the case of thermosets). Heating the resin will lower the viscosity. There are additives that can be added to improve viscosity values during processing. Since the polymer will be considered gelled at 100 Pa-s or above it is also important to consider pot life and shelf life of the resin. The pot-life will dictate how long the resin is able to be worked before hardening reactions start to occur for thermosets and for thermoplastics it is comparable to how long the processing step is able to keep the polymer at an elevated temperature so that the resin can flow adequately. Shelf life is a consideration that may not affect the resin system chosen, but it will affect how the factory operates and how purchasing will function. For example, most prepregs have a shelf life of 6 to 12 months, whilst 2-part thermosets have a shelf life of two or more years[16].

Cure/Crystallization Time and Temperature[edit | edit source]

The cure profile is very important for thermoset polymers as this will influence a majority of tooling and equipment decisions further on in the development process. Having a polymer with a long cure time will allow for flexibility as it will typically have a long pot life, as mentioned above, as well. This will also dictate how long the moulds will be occupied for when creating a part, so choosing a polymer with a short cure time may be beneficial for freeing up equipment. The temperature that the polymer needs to cure is also a vital aspect, this will immediately dictate if an oven or other heat source is required and how much power is needed. When it comes to thermoplastic polymers, they will require a much higher temperature to melt and re-crystallize in order to shape the part than the typical thermoset. However, their re-crystallization time is generally much shorter than any cure time for a thermoset. These parameters are important to consider early on as they will impact the MSTEP decisions downstream.

Other considerations include, cooling rates and solvent resistance.

Below is a table of some of the properties of a select few thermoplastic and thermoset polymers that may be chosen for a composite product. The table is provided to show a range of values between polymer types and to give an idea of how they vary between the different types[17][18][19][20][21].

Table:General polymer properties

Click here to return to Practice for Developing a Product[edit | edit source]

Click here to return to Selecting Functional Requirements[edit | edit source]

To continue on to defining the shape of your product follow the link: Shape

Development[edit | edit source]

Related pages

Page type	Links
Introduction to Composites Articles	
Foundational Knowledge Articles	
Foundational Knowledge Method Documents	
Foundational Knowledge Worked Examples	
Systems Knowledge Articles	
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	• Composite Production Part Drawing - P169 • Material Selection - P153 • Practice for Developing a Deposition Step - P157 • Practice for Developing a Product - P111 • Practice for Identifying Process Steps - P102 • Process selection for production scale-up - P171 • Selecting Functional Requirements - P152.0 • Shape Development - P151.0
Case Studies	• Developing for Future Production Scale Up - C113 • Lack of Requirements in Product Development - C104 • Use of Right Sized Simulation to Aid Decision Making in Thermoplastic Composite Manufacturing Systems - C114
Perspectives Articles	• CKN’s Approach to Developing Products with Composite Materials - A332

References

1. ↑ [1.0] [1.1] [1.2] [1.3] [1.4] [1.5] [1.6] [1.7] [Ref] *Composite Materials Handbook 17 - Polymer Matrix Composites; Materials Usage, Design and Analysis*. **3**. SAE International on behalf of CMH-17, a division of Wichita State University. 2012. pp. 2–12. ISBN 978-1-68015-454-2.
2. ↑ [Ref] Eckold, Geoff (1994). *Design and Manufacture of Composite Structures*. Woodhead Publishing. p. 34. ISBN 9781845698560. Retrieved 25 May 2022.
3. ↑ [Ref] Chawla, Krishan K (2019). Chawla, Krishan K (ed.). *Composite Materials Science and Engineering*. Springer International Publishing. p. 12. doi:10.1007/978-3-030-28983-6.

ISBN 978-3-030-28983-6.
4. ↑ [Ref] Balasubramanian, M. (2013). *Composite materials and processing*. p. 43. doi:10.1201/b15551. ISBN 9781439880548.
5. ↑ [Ref] Chawla, Krishan K (2019). Chawla, Krishan K (ed.). *Composite Materials Science and Engineering*. Springer International Publishing. p. 16. doi:10.1007/978-3-030-28983-6. ISBN 978-3-030-28983-6.
6. ↑ [Ref] Balasubramanian, M. (2013). *Composite materials and processing*. p. 49. doi:10.1201/b15551. ISBN 9781439880548.
7. ↑ [Ref] Balasubramanian, M. (2013). *Composite materials and processing*. p. 50. doi:10.1201/b15551. ISBN 9781439880548.
8. ↑ 8.0 8.1 [Ref] Chawla, Krishan K (2019). Chawla, Krishan K (ed.). *Composite Materials Science and Engineering*. Springer International Publishing. p. 50. doi:10.1007/978-3-030-28983-6. ISBN 978-3-030-28983-6.
9. ↑ [Ref] Eckold, Geoff (1994). *Design and Manufacture of Composite Structures*. Woodhead Publishing. p. 30. ISBN 9781845698560. Retrieved 25 May 2022.
10. ↑ [Ref] Meola, Carosena et al. (2017). *Composite Materials in the Aeronautical Industry*. Elsevier. doi:10.1016/B978-1-78242-171-9.00001-2.
11. ↑ 11.0 11.1 [Ref] Chawla, Krishan K (2019). Chawla, Krishan K (ed.). *Composite Materials Science and Engineering*. Springer International Publishing. p. 494. doi:10.1007/978-3-030-28983-6. ISBN 978-3-030-28983-6.
12. ↑ 12.0 12.1 [Ref] Chawla, Krishan K (2019). Chawla, Krishan K (ed.). *Composite Materials Science and Engineering*. Springer International Publishing. p. 495. doi:10.1007/978-3-030-28983-6. ISBN 978-3-030-28983-6.
13. ↑ [Ref] Eckold, Geoff (1994). *Design and Manufacture of Composite Structures*. Woodhead Publishing. p. 21. ISBN 9781845698560. Retrieved 25 May 2022.
14. ↑ [Ref] Balasubramanian, M. (2013). *Composite materials and processing*. p. 139. doi:10.1201/b15551. ISBN 9781439880548.
15. ↑ [Ref] Hoa, S V (2018). *Principles of the Manufacturing of Composite Materials*. DEStech Publications, Incorporated. ISBN 9781605954219.
16. ↑ 16.0 16.1 [Ref] Balasubramanian, M. (2013). *Composite materials and processing*. p. 140. doi:10.1201/b15551. ISBN 9781439880548.
17. ↑ [Ref] Balasubramanian, M. (2013). *Composite materials and processing*. doi:10.1201/b15551. ISBN 9781439880548.
18. ↑ [Ref] Eckold, Geoff (1994). *Design and Manufacture of Composite Structures*. Woodhead Publishing. ISBN 9781845698560. Retrieved 25 May 2022.
19. ↑ [Ref] Chawla, Krishan K (2019). Chawla, Krishan K (ed.). *Composite Materials Science and Engineering*. Springer International Publishing. doi:10.1007/978-3-030-28983-6. ISBN 978-3-030-28983-6.
20. ↑ [Ref] Melton, George H. et al. (2011). *Engineering Thermoplastics*. Elsevier. doi:10.1016/B978-1-4377-3514-7.10002-9.
21. ↑ [Ref] Maier, Clive (1998). *Polypropylene: The Definitive User's Guide and Databook*. Plastics Design Library. ISBN 978-1-884207-58-7.

About

Help

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

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.

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

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.

Graphene is a one atom thick two dimensional honeycomb layer of bonded carbon atoms. When many graphene layers are stacked regularly in three dimensions and held together with weak forces, graphite is created.

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.

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

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.

Areal weight (or fibre areal weight, AW) refers to the mass/weight of fibre per unit area. (Typically in g/m^2 gsm) or $ounces/yard^2$ (often just called ounces). Areal weight depends on tow size and fibre architecture (weaving, density, etc.).

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

Drapeability refers to how well a material conforms to a complex shape (non developable surface).

Trade off: typically the more drapeable a fabric, the less dense the weave (lower V_f), and less stable during processing.

Chopped strand mat - A reinforcement material made of short, randomly oriented glass fibers bonded with a resin.

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.

The glass transition temperature (T_g) is the temperature region where the polymer transitions from a hard, glassy material to a soft, rubbery material. It is one of the most important properties of any amorphous polymer.

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 portion of the molecular polymer chains tend to ‘fold up’ into densely packed regions called crystals.

The failure mode characterized by a partial or full separation of adjacent laminae. Delamination is unique to laminated structures, and can be induced by impact load, fatigue load, and quasistatic load. (Also known as interlaminar separation)

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

In composites processing, viscosity is an indicator of how easily the resin matrix will mix with the reinforcement and how well it will stay in place during processing. The lower the viscosity, the more easily resin flows. Resin viscosity ranges considerably across chemistries and formulations.

By scientific definition, viscosity is a measure of a material’s resistance to deformation. For liquids, it is in response to imposed shear stresses.

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.

Material and process (M), Shape (S), Tooling and consumables (T) & Equipment (E) - all have an interlinked effect on the Process step (P). (See MSTE factory ontology)