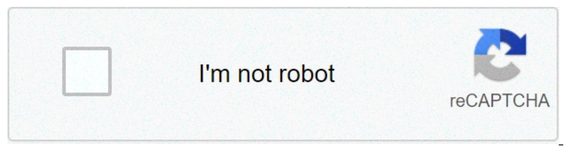

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Composite material manufacturing process pdf

There are three types of composite manufacturing processes: open molding, closed molding and cast polymer molding. There are a variety of processing methods within these molding categories, each with its own benefits.Composite materials (resin and fibers) are placed in an open mold, where they cure or harden while exposed to the air. Tooling cost for open molds is often inexpensive, making it possible to use this technique for prototype and short production runs.Composite materials are processed and cured inside a vacuum bag or a two-sided mold, closed to the atmosphere. Closed molding may be considered for two cases: first, if a two-sided finish is needed; and second, if high production volumes are required.A mixture of resin and fillers are poured into a mold (typically without reinforcements) and left to cure or harden. These molding methods sometimes use open molding and sometimes use closed molding. Taking composite materials as a whole, there are many different material options to choose from in the areas of resins, fibres and cores, all with their own unique set of properties such as strength, stiffness, toughness, heat resistance, cost, production rate, etc. However, the end properties of a composite part produced from these different materials is not only a function of the individual properties of the resin matrix and fibre (and in sandwich structures, the core as well), but is also a function of the way in which the materials themselves are designed into the part and also the way in which they are processed. This section compares a few of the commonly used composite production methods and presents some of the factors to be borne in mind with each different process, including the influence of each process on materials selection. Published courtesy of David Cripps, Gurit The process by which a liquid thermosetting pre-polymer is turned into a rigid solid is called ‘cure’. Learn more Describes the processes involved in spray lay-up.Learn more Describes the processes involved in wet or hand lay-up.Learn more Explains filament winding and highlights the main advantages and disadvantages.Learn more Covers the process of pultrusion and some of the material options.Learn more Describes the methods used in resin transfer.Learn more Covers various infusion processes including SCRIMP, RIFT and VARTM.Learn more Describes what prepregging is and explains the process.Learn more Covers the safety systems, temperature, pressurisation and vacuum controls, plus a look at future developments.Learn more Describes low temperature curing prepregs in relation to conventional prepregs.Learn more Explains the method involved in resin film infusion.Learn more Share this article Twitter Facebook LinkedIn Email Continue to Formulae Back to Repair Composite materials are a distinctive set of materials characterized by the combination of two or more individual components to achieve an enhanced material with substantially different properties, and that also exceeds the capabilities of the separate elements. Due to the unique properties of composites, this material class can… V.V. SILBERSCHMIDT, in Multi-Scale Modelling of Composite Material Systems, 2005Manufacturing composite materials from (at least) two components – fibres and matrix in case of cross-ply laminates – usually results in considerable heterogeneity of the obtained composite. Microstructural analysis of this system is usually concerned with manufacture-induced defects such as fibre/matrix debonding, interface cracks, microvoids, fibre ruptures and kinks, etc. Reifsnider and Case (2002) estimated that in any cross-sectional area one-tenth of fibres are broken in the manufacturing process. These defects not only result in deterioration of a material’s properties but also serve as stress concentrators and, hence, nuclei of macroscopic fracture initiation. Still, even neglecting their effect on the composites’ randomness, another source of spatial randomness in materials’s properties is important for many types of laminates, namely, a non-uniform distribution of their constituents.Micrographs of transverse cross-sections of unidirectional carbon/epoxy plies vividly demonstrate a considerable extent of non-uniformity in a spatial distribution of fibres. Still, due to a relative small diameter of individual carbon fibres (normally, 5–10 μm), a majority of mechanical approaches uses the average volume fraction of fibres vf as a single global parameter. But local fluctuations of vf lead to respective fluctuations in Young’s moduli that mean exposure of various parts of the composite to different levels of stresses even under the macroscopically uniform boundary conditions (forces and/or displacement). For instance, the effective axial modulus of the composite Ē11 can be presented aswhere E11RoM is the axial modulus calculated according to the linear rule of mixtures, and ΔE11 is a non-linear term that is negligibly small compared to E11RoM for unidirectional carbon/epoxy lamina. After rearranging the standard presentation of the linear rule of mixtures to the formproportionality of the local magnitude of the elasticity modulus to the local volume fraction of fibres becomes obvious. In eqn 6.2 ELf is the longitudinal module of fibres (transversely isotropic in the case of carbon ones) and Em is the Young’s modulus of the (isotropic) matrix.J. Schön, R. Starikov, in Fatigue in Composites, 2003Although advanced composite materials manufacturing techniques make it possible for the civil, shipbuilding, automobile, and aerospace industries to manufacture large structural components with complex shapes and geometry, they have to be joined together to create the desired structures. There are two main techniques of joining composite components: mechanical fastening and adhesive bonding. Since each method has its own special advantages and drawbacks, particular design criteria and preference are difficult to present unless the type of structure, material, service and loading conditions are specified. In order to make a short comparison Table 23.1 lists the general strong (+) and weak (–) points of each joining method.Table 23.1. Comparison of joining techniquesPropertyMechanical fasteningAdhesive bondingOverweight penalty–+Corrosion resistance–+Design of smooth surfaces–+Severity of stress concentrations–+Strength degradation of basic composite–+Manufacturing and life-cycle cost–+Joining of complex shapes–+Required surface preparation+–Sensitivity to peel stress and creep+–Disassembly and removeability+–Possibility of joining thick components+–Sensitivity to environmental attack+–In general, when relatively thick structures are used and designed to withstand high levels of loads in service life, or component disassembly is required for inspection and repair purposes, bolted joints are usually preferred. The major drawback of bolted joints is the concentration of high stresses at the bolt holes induced by the notch effect. The hole generation requires specific drilling techniques introducing the possibility of mechanically and thermally induced defects. Finally, the installation of thousands of fasteners results in a large weight penalty.The functioning principle of bolted joints is based on friction between the joined parts, shear or tensile stresses in fasteners, and contact forces between the fasteners and composite. Bolted joints are used extensively by industry to join metal components with composite structures. However, special care should be taken when materials with different electrode potential would be used in the joint. For instance, aluminium and stainless steel fasteners, being installed in carbon fibre/epoxy matrix composites, may result in galvanic corrosion.There are four basic failure modes, see Fig. 23.1, which may occur in composite bolted joints.Fig. 23.1. Failure modes of composite bolted joints: (a) net-section failure; (b) bearing failure; (c) shear-out failure; (d) bolt failure.Net-section failure is caused by tangential tensile or compressive stresses at the hole edge in the net-section plane. This mode primarily occurs when the ratio of hole diameter d to plate width w is high, or when the ratio of bypass load (i.e. the load applied to the plate) to bearing load (i.e. the load which passes through the bolt) is high. Net-section failure is common for joints with several bolt rows. Bearing failure mode is governed by compressive stresses acting on the hole surface. This failure occurs when the ratio d/w is low or when the ratio of bearing load to bypass load is high. Bearing failure is common for joints with one bolt row. Shear-out failure mode is caused by shear stresses acting in shear-out planes on the hole boundary in the principal load direction. This mode primarily occurs when the end distance e is short. Shear-out mode is quite common for highly orthotropic laminates. In this case the shear-out failure mode is independent of the end distance. Bolt failure mode is a result of high shear stresses acting in the bolt shank. This failure is governed by the properties of the bolt to support shear and tensile loading and depends on the plate and bolt geometry.Since the bearing failure usually develops slowly, giving plenty of warning before the ultimate failure occurs, it is recognized as a desirable failure mode in bolted laminates. The other failure modes, i.e., net section and shear out, usually occur suddenly and are therefore catastrophic. Despite the above description of the failure modes being usually associated with static failure of composite bolted joints, the same failure modes can take place during fatigue loading as well.Although there are many different joint configurations, they may be divided depending on their general geometry and load-transfer capability. Mechanically fastened joints may be implemented with either a single overlap or double lap configuration. The first configuration is recognized as prone to out-of-plane deflection, i.e. secondary bending, during loading. Secondary bending causes bending deflection of the bolt and joint plates which may result in non-uniform stress distributions through the thickness of the composite laminates and high contact forces localized at the top and bottom hole edges.Depending on the amount of load being transferred, composite joints may be divided into lightly and heavily loaded. The first group is usually realized in the form of single-row joints, whereas the latter type is implemented as multi-row joints. Although non-catastrophic bearing failures are quite common for single-row joints, net-section failure is common for multi-row joints. Another significant difference between single and multi-row bolted joints is distribution of applied load between the fasteners. In single-row joints all the fasteners transfer the same amount of load, whereas the outer bolt rows in multi-row joints usually transfer more load than the inner bolt rows.In the cases when thin composite parts or large area components are to be joined and service load levels are expected to be relatively low, adhesive bonding techniques are usually employed. Bonded joints possess the potential of weight saving in comparison to mechanical fastening methods, and make it possible to design smooth surfaces. On the other hand, surface pre-treatment and accurate matching the joint parts as well as the use of adhesives, requiring the time for heating and curing, drastically increase the cost of manufacturing. Despite this, the eventual cost of adhesive joining of large composite structures would still be lower than with mechanical joining.1 Adhesive joining of dissimilar materials with different coefficients of thermal expansion can cause problems. If the structure is subjected to large temperature variations, large thermal stresses can be introduced.Composite structures may be bonded by three different techniques: cocuring, cobonding, and secondary bonding. The present work addresses the last method of bonding. A connection by secondary bonding usually consists of an adhesive layer and parts to be joined, adherends. Since in adhesive joints the load transfer depends on chemical bonds between the adhesive and adherends, the adhesive/adherend interface plays an important role in the mechanical performance of the bonded structures under loading. The presence of voids, flaws and inhomogeneities as well as the quality of the interface affect the fatigue performance of the bonded joint, and make it a feature partially depending on the quality of the manufacturing process.1 −4Adhesive bonded joints may be classified into three main groups: laps, scarfs, and butts (see Fig. 23.2).Fig. 23.2. Examples of adhesive joint configurations: (a) single and double overlap joints; (b) stepped lap; (c) single scarf; (d) butt joint.Lap joints are the most frequently used configuration of adhesive composite joints in engineering applications. There are several basic types of this joint configuration, i.e. single or double overlap, and tubular lap. From a stability point of view, joints with the double overlap configuration would result in a better mechanical performance under loading than the single overlap joint. A modified configuration of the lap joints is a stepped lap configuration shown in Fig. 23.2(b). Bonded joints of this design are able to create bearing resistance to applied compressive loads. In addition, this configuration facilitates the assembly of the bonded joints as it allows the length of the joint overlap to be controlled, which eliminates the use of supporting fixtures. Tubular joints are widely used in the oil industry for joining composite pipes, which offer excellent corrosion resistance in the presence of severe service conditions.Scarf joints have a very distinguished advantage over other joint configurations being flush and collinear. This results in a better stability of the joint when axial loads are introduced. In scarf joints the normal and shear stresses are dependent on the adherend thickness and the angle of scarf. It is therefore obvious that the preferred joint configuration is when the joint strength would be higher than the strength of adherends and joint fracture would occur in the adherends. Scarf joints are frequently used in the repair of aircraft composite primary parts since aerodynamic smoothness remains intact as well as the higher load carrying capability that joints of this type give compared to other methods of repair.5In comparison to other configurations, butt joints are less complicated and time-consuming to prepare. This configuration of bonded joints is recognized as being relatively free of stress concentrations under axial loads. However, the adhesive layer is usually rather short and therefore the mechanical performance of such joints is limited under axial tensile loads. As a result, this configuration is rarely used by itself in engineering applications. In the case of compressive dominated loads, butt joints may fully utilize the compressive strength of the adherends.Despite the existence of modern manufacturing techniques and the long term experience in designing composite joints, they are considered as weak points in the structure and may be a source of service breakdown and even catastrophic failure. No matter which industry is considered, modern design philosophy gives the highest priority to safety of people. Almost all structures, such as aircraft bodies, aerospace vehicles, cars, boats and ships, experience a broad range of mechanical loads including fatigue. However, current design procedures are still often based on the well-established static approaches, which are often conservative leading to large safety margins and thus to a high degree of structural weight penalty. Therefore, a review of the state-of-the-art methodologies and achievements by industry and academia in studying the subject of fatigue applied to composite mechanical and adhesive joints would be a challenge.Pierpaolo Carlone, ... René M. Kent, in Comprehensive Composite Materials II, 2018In this chapter a summary of process control knowledge for composite material manufacturing has been reported. In particular, both process sensing systems and process control systems have been deeply discussed. Moreover, issues that can arise during processing have been illustrated. A correct cure cycle is fundamental for obtaining a defect-free composite product. Even if several tools, such as FEM-based simulations, are currently available to engineers to design the cure process, other innovative approaches seem promising to manage unpredicted events as well as for process optimization. Indeed, during the curing process, factors such as equipment malfunction or variation in material properties considered for process simulation may result in significant discrepancy between simulated and actual process. More advanced solutions involve process monitoring and control. Such systems are generally made with: a sensorial one to collect useful cure information, a calculation engine to analyze the information and an active control subsystem to feed the information back to the process tools.Hong Hu, ... Yanping Liu, in Auxetic Textiles, 2019One of the most important industrial applications of the auxetic textiles is manufacturing composite materials which have been specifically introduced in Chapter 9, Auxetic fibre–reinforced composites. The auxetic composites manufactured from auxetic fabrics or auxetic composites realised from structural design show enhanced mechanical properties in many areas, indicating that these composites can find various applications in industry such as making sensors, engine fine blades and vanes for gas turbine engine. In addition, there are other applications of auxetic materials in industry. One example is the auxetic fastener designed by Choi and Lakes [20]. The auxetic fastener can be installed more easily, but removal is more difficult than conventional materials. This auxetic fastener is designed a little larger than the hole within a tolerance in the radial dimension. When the fastener is being inserted to the hole, it will be pressed in axial direction; thus due to the auxetic effect the fastener will become smaller in the diameter, which makes it easy to be installed. After the fastener is installed and the compression force is removed from the fastener, the fastener will tend to expand in both axial and radial directions. This expansion effect locks the fastener in position tightly. When the fastener is needed to be removed from the hole, compressing it to make it decrease in the radial direction to achieve easy removal. The auxetic fastener has the advantage of simple press-fit insertion and easy removal.Jared A. Grauer, James E. HubbardJr., in Flight Dynamics and System Identification for Modern Feedback Control, 2013Unmanned air vehicles (UAVs), or aircraft without on-board pilots, are proliferating into many sectors of society and have the potential to significantly impact daily life. Enabled by advances in electronics miniaturization and composite material manufacturing, hobbyists, commercial companies, defense contractors, universities, and government research laboratories are currently developing small unmanned platforms. UAVs will play an important role in the future because in addition to the relatively low cost, they can un-man aircraft to perform “dull, dirty, and dangerous” work.In the civilian sector, UAVs are currently used as toys, hobby aircraft, and research flight platforms. They have been employed in such tasks as airport wildlife control and population monitoring, and are expected to contribute to autonomous crop surveying, atmospheric weather monitoring, and search and rescue missions. In the military sector, these vehicles are employed in intelligence, surveillance, and reconnaissance missions. It is envisioned that these vehicles will perform missions such as chemical substance detection and autonomous perimeter surveillance, as well as achieve multi-mission capabilities including perch and stare, robust long-duration outdoor flight, and agile flight through cluttered indoor environments.To accomplish such mission profiles autonomously, a flight control system, such as that shown Figure 1.1, must be implemented in order to stabilize the vehicle and achieve desired performance goals while attenuating the effects of noise, disturbances, and model uncertainty. The aircraft plant model contains a set of equations that evolve the vehicle position and velocity state variables as a function of the control inputs and disturbances. Sensors on board the aircraft provide measurements, which are used in an estimator to predict the aircraft state. The tracking error is supplied to the controller, which is designed to shape the inputs to achieve flight performance metrics.Figure 1.1. Flight control architecture block diagramFixed-wing aircraft remain the most prevalent type of UAV, as they are in general relatively simple aircraft and the dynamic models describing their motions are well known and understood [1, 2, 3]. However, as the vehicle size decreases and viscous effects become more pronounced, fixed-wing aircraft suffer from decreased lift to drag ratios that degrade flight performance [4]. Additionally, most fixed-wing aircraft require forward speed to generate aerodynamic forces, making it difficult for them to hover and fly slowly, which are abilities needed for indoor flight.Miniature rotary-wing vehicles present an alternative to fixed-wing designs. These vehicles are highly maneuverable and have the ability to hover, making them suitable for indoor reconnaissance and surveillance missions; however, rotorcraft have a number of drawbacks. As with fixed-wing aircraft, viscous effects reduce the aerodynamic efficiency of the vehicle [5]. The added complexity of the rotor and swash plate systems increases the vehicle cost and maintenance. Furthermore, these aircraft are noisy, open-loop unstable, and potentially hazardous to bystanders and operators, making them difficult for human operators to fly without training and closed-loop control.Although both conventional fixed-wing and rotary-wing vehicles fill niches in the design space of UAVs, a new vehicle design is needed to both fly in a robust manner outdoors and in an agile manner in cluttered environments.A. McIlhagger, ... R. McIlhagger, in Polymer Composites in the Aerospace Industry (Second Edition), 2020For the successful operation of civil aircraft, the main drivers currently are environmentally based. This implies that significant weight reductions are essential, and hence, a fundamental re-think of the materials and their manufacturing processes used has taken place over a number of years. For realizing the benefits offered by advanced composite materials, manufacturing processes must be able to produce economically large components with as few joints as possible. Also, in order to increase the robustness of primary structures in-service, there is a move toward cocuring monolithic components and elimination of cellular sandwich panels and multistage cures; this presents challenges regarding the complexity of tooling and control of the process. This chapter presents the key manufacturing processes used for composite aerospace applications, control of these processes, and some basic theory. Current applications of these processes on modern composite airframes are provided.J.P. Carey, C. Ayranci, in Handbook of Advances in Braided Composite Materials, 2017Braids are one of the oldest forms of textiles, originally using, among other base materials, animal hair and plants to produce ropes. Therefore the idea of renewable or green braiding is not new. The use of natural reinforcement dates back millennia, when straw was used to reinforce mud huts. Some composite material manufacturing processes and end-products, such as braided composites, are very versatile and are replacing traditional engineering materials such as steel. Braided composites have been used in air ducts, fuel lines, fan blades, and automotive shafts [1] and have been explored for orthopedic treatments [2] and for aircraft frames [3], as well as for concrete reinforcement and confinement [4]. The reasons for the increased use and adoption throughout the industry are many; first and foremost, composites are lightweight, stiff, and strong. Additionally, their corrosion and chemical-resistant nature increases their service life cycle time. Although many composites are expensive to produce, these advantages have led to significant cost reductions in other ways such as airplane fuel costs, less frequent bridge repairs (since they do not corrode), and many more. The objective of this chapter is to examine how greener braided composites could bridge the next step in their industrial and commercial usefulness and have a lower environmental impact.S. Agarwal, R.K. Gupta, in Thermosets (Second Edition), 2018Additional information on topics covered in this chapter may be obtained by consulting the following sources:S. Agarwal, R.K. Gupta, Plastics in building and construction (revised), in: M. Kurtz (Ed.), Applied Plastics Engineering Handbook: Processing and Materials, Elsevier, 2015.G. Akovali, Polymers in Construction, Rapra Technology Ltd., Shrewsbury, 2005.H.V.S. GangaRao, N. Taly, P.V. Vijay, Reinforced Concrete Design With FRP Composites, CRC Press, Boca Raton, 2007.S.H. Goodman, Handbook of Thermoset Plastics, second ed., Noyes Publications, Westwood, 1998.R.K. Gupta, E.B. Kennel, K.-J. Kim, Polymer Nanocomposites Handbook, CRC Press, New York, 2010.P.K. 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