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## Resin Matrix

The resin matrix of the PFC contained a mixture of urethane dimethacrylate and dimethacrylate comonomers.

From: [Biomedical Composites \(Second Edition\), 2017](#)

Related terms:

[Carbon Nanotubes](#), [Carbon Fiber](#), [Composite Materials](#), [Carbon-Fiber-Reinforced Plastic](#), [Fiber-Reinforced Polymer](#), [Glass Fibre](#), [Monomers](#), [Resin](#), [Tensile Strength](#)

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## Polymer Matrix Composites: Applications

Dodd H. Grande, ... Jason Daniel, in [Comprehensive Composite Materials II](#), 2018

### 3.18.4.3.1 High performance fishing rod resin systems

Resin matrices used for high performance fishing rods have transitioned from polyester to high performance epoxy resin matrices. This transition has occurred in part due to the utilization of carbon fiber in the designs as compared to the lower modulus and strength glass fibers. Most often, the epoxy resin system is impregnated into carbon fibers resulting in a [prepreg](#) material. This prepreg is then roll wrapped using a table rolling process onto steel [mandrels](#) and cured to form the final tubular product. Epoxy resin systems used as matrices for these applications are often combinations of diglycidyl ether of bisphenol-A (DGEBA) resins of various molecular weights and epoxy novolac resins, which are combined to provide the necessary properties and handling characteristics (i.e., tack and drape). These resins systems also often contain a toughness modifier, such as a [thermoplastic](#) or rubber material. Most resin systems used for fly rod development are cured with dicyandiamide, which is accelerated with a substituted urea. This [curing agent](#) and catalyst selection enables 120°C (250°F) cure cycles to be used in many of the processes. As new designs require higher performance, lighter weight rods, epoxy systems used as matrices in these prepreg systems have also advanced. These new resin systems have mainly come from changes in the epoxy resins with the curing agent system being the same. More recent [epoxy resin systems](#) utilize aerospace type epoxy resins or greater use of multifunctional epoxy resins to enhance compression strength of the resin systems, which is critical to improving the performance of the rod. Other methods to improve the compression strength have been through the use of [nanomaterials](#), such as nano-silica, but this has often resulted in higher resin density, offsetting performance improvements.

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## Polymer Matrix Composites: Fundamentals

G. Xian, Z. Wang, in *Comprehensive Composite Materials II*, 2018

### 2.17.5.1 Water Uptake of CFRP Without External Stress

Thermosetting resin matrices used for CFRPs generally exhibit strong hydrophilic characteristics, and tend to absorb amounts of water molecules. This will bring about a deterioration in mechanical properties.<sup>140</sup> The absorbed water acts as a very efficient plasticizer, strongly reducing the glass transition temperature ( $T_g$ ) of the resin matrices. Furthermore, if water absorption takes place at elevated temperatures and/or for prolonged time periods, a permanent damage of the structural network may ensue, giving rise to the formation of microcracks and catastrophic failures in the resin matrix.<sup>141–143</sup>

The diffusion of water into a glassy polymer is intrinsically related to its molecular structures, water–polymer interaction. Polymer matrices show Fickian or non-Fickian moisture absorption characteristics. The non-Fickian diffusion process can be simulated through a variety of models including the Langmuir dual-sorption model and the two-stage diffusion model, respectively.<sup>139,141,144–146</sup> Non-Fickian diffusion is inherently due to the non-equilibrium thermodynamic state of the glassy polymers which causes time-dependent behaviors. The diffusion process is further complicated by some other factors such as continuing chemical reactions (e.g., hydrolysis) and even advancing cure.

Regarding to CFRPs, the water uptake exhibits much complex compared to the resin matrix.<sup>70</sup> Poor wetting of the fiber by the matrix often results in open space at the interface, in which capillary effect causes fast diffusion along the fiber direction. Because of the filling of voids at the interface and extra spaces for water ingress due to fiber debonding, the normalized composite weight gain will be higher than that of the neat resin.<sup>139,147</sup> In addition, carbon fibers may restrict matrix segmental motions near the interface. As moisture transport in polymers is closely related to molecular motions, moisture uptake is expected to be low in this layer. Finally, an interphase region is often formed around the fiber due to the fiber surface coating and/or the preferential adsorption of one or more reactive monomers. The interphase is expected to display different moisture uptake compared to the neat resin.

Diffusion in a polymer composite is affected by the presence of fibers and in the case of unidirectional composites diffusivities along and perpendicular to the fiber directions are distinctly different with values being dependent on aspects such as fiber loading, fiber arrangement, and interphase characteristics.<sup>148–150</sup> It is, however, noted that for most conventional composites the diffusion along the fiber direction can be assumed to be analogous to the thermal conduction, enabling the longitudinal diffusivity,  $D_z$ , to be determined as

$$D_z = D_r(1 - V_f) \quad [14]$$

where  $D_r$  is the diffusivity of the bulk resin and  $V_f$  is the fiber volume fraction. Further using the analogy with thermal conductivity, Shen and Springer<sup>151</sup> determined that for a square fiber array, the transverse diffusivity (perpendicular to the fiber direction),  $D_x$ , could be expressed as

$$D_x = D_r \left( 1 - 2\sqrt{\frac{V_f}{\pi}} \right) \quad [15]$$

While the thermal conductivity analogy has been shown to provide fairly accurate predictions of transverse diffusivity for unidirectional composites with fiber loadings of about 50 vol%, strictly speaking the models are inappropriate since diffusivity is related to both the rate of moisture diffusion and the level of equilibrium uptake.<sup>150</sup> In other words, the product of diffusivity and equilibrium uptake level, rather than diffusivity alone, corresponds to the thermal conductivity. In view of this, Kondo and Taki<sup>150</sup> proposed a modified model, incorporating a special parameter  $b$  (the degree of randomness), which was shown to be more accurate in predicting transverse diffusivities for composites with fiber volume fractions greater than 50%. It is noted that the transverse diffusivities predicted by Kondo and Taki's method using the recommended value of  $b=0.5$  are significantly lower than those determined with other models. Using eqns [14] and [15], a ratio of diffusivities,  $D_z/D_x$ , can be obtained as a function of fiber volume fraction. While some deviations from the theoretical estimates can be attributed to the explanation provided by Kondo and Taki,<sup>150</sup> other substantial deviations are likely when water uptake is accelerated by capillary action and wicking along micro-cracks in the bulk resin and along debonded fiber–matrix interfaces, especially under conditions of hygrothermal exposure at higher temperatures or long ageing times.<sup>148,149</sup> It is noted that the deviation is further complicated by complex bulk resin phenomena, induced by moisture uptake, such as plasticization and swelling, as well as the acceleration of stress relaxation<sup>152</sup> and progression of post-cure,<sup>153</sup> most of which can occur simultaneously.

It is interesting to measure  $D_x$  and  $D_z$  for a unidirectional CFRP plate, because a remarkable deviation between the calculated and tested ratios of  $D_z/D_x$  is commonly realized. The difference comes from the assumption for calculation (e.g., using eqns [14] and [15]) that no fiber debonding or matrix crack occurs during exposure.<sup>139,145</sup> Therefore, the difference between the calculated and tested ratios of  $D_z/D_x$  can be considered as an indicator describing the damages of CFRPs due to water ingress.<sup>147</sup>

To obtain  $D_z$  and  $D_x$  of a CFRP through experiments, apparent diffusivities ( $D_a$ ) of CFRP samples of various lengths needs to be determined firstly. Following Shen and Springer,<sup>151</sup>  $D_a$  for unidirectional continuous fiber reinforced composites can be defined as:

$$D_a = D_x \left( 1 + \frac{h}{l} \sqrt{\frac{D_z}{D_x}} + \frac{h}{w} \sqrt{\frac{D_y}{D_x}} \right)^2 \quad [16]$$

where  $D_x$ ,  $D_y$ , and  $D_z$  are the diffusion coefficients in the  $x$ ,  $y$ , and  $z$  directions, respectively, with the  $z$  direction being defined as the fiber direction,  $h$  is the thickness of the specimen,  $w$  is the width of the specimen, and  $l$  is the length of the specimen. For unidirectional composites, the transverse diffusivities can be assumed to be equal,  $D_x=D_y$  leading to the simplified form of

$$\sqrt{D_a} = \left( 1 + \frac{h}{w} \right) \sqrt{D_x} + \frac{h}{l} \sqrt{D_z} \quad [17]$$

which can be used to determine the longitudinal and transverse diffusivities<sup>149</sup> by plotting  $\sqrt{D_a}$  versus  $h/l$ , the graph of which yields a straight line with a slope  $D_z$  and an intercept of  $(1+h/w)\sqrt{D_x}$ . Compared to the calculated ratio of longitudinal to transverse diffusivity ( $D_z/D_x$ ) based on the assumption of perfect bonding between fiber and resin matrix, the higher ratios of  $D_z/D_x$  indicate the degradation of the fiber-matrix adhesion and/or cracks formed in the resin matrix<sup>145,147</sup> of a FRP.

In contrast to the resin matrix (e.g., epoxy resin), CFRPs tend to exhibit a two-stage water uptake process, rather than following the classic Fick's law.<sup>139</sup> Therefore,  $D_a$

has to be determined based on a modified model, as suggested in literatures.<sup>148,154</sup> According to the two-stage water uptake, the water uptake ( $M_t$ ) at time  $t$  can be approximately written as

$$M_t = M_\infty (1 + k\sqrt{t}) (1 - \exp[-7.3(\frac{D_a t}{h^2})^{0.75}]) \quad [18]$$

where  $k$  is the time dependent coefficient, characterizing the rate of polymer relaxation due to water ingress;  $D_a$  is the diffusivity at Fickian stage;  $h$  the specimen thickness;  $t$  the immersion time. The model can be satisfied to simulate the water uptake of CFRP,<sup>139</sup> and other kinds of fiber reinforced FRPs.<sup>145,147</sup>

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## The response of aerospace composites to temperature and humidity

F.R. Jones, J.P. Foreman, in Polymer Composites in the Aerospace Industry, 2015

### 12.8.3 Effect of moisture absorption

The resin matrix in a composite absorbs water in service. As discussed in this chapter, this process is kinetically slow, so the concentration of water in the resin will vary with time and location. Thermal cycling will tend to move the water into the structure. Furthermore, the absorption of the water causes the polymer to expand; however, in a composite, the swelling is constrained in an analogous way to that described for thermal contraction. Thus, the process of conditioning in moist environments leads to a reduction in magnitude of the thermal strain present in the laminate.

The degree of swelling can be described quantitatively in analogous equations. For example, the swelling strain in the transverse ply in the longitudinal direction ( $\epsilon_{tl}^s$ ) is given by

$$\epsilon_{tl}^s = \frac{E_1 b (\beta_t - \beta_l) (M_1 - M_2)}{E_1 b + E_t d} \quad (12.14)$$

where  $M_1$  and  $M_2$  are the initial and final moisture concentrations, respectively.

As a result, the thermal strain in a laminate composite will relax (i.e. reduced) on moisture diffusion. The extent of moisture swelling by resins used for composites can vary significantly, so the effect on the residual stress state differs widely.

However, the major problem is not the benefits associated with thermal stress relaxation, but the fact that the plasticisation of the matrix may enhance its expansion coefficient. Therefore, on cooling, a wet resin matrix either from its cure temperature or after a thermal cycle can, according to Eqn (12.9), lead to higher values of  $\epsilon_{tl}^{th}$  and  $\epsilon_{tl}^{th}$ . Figure 12.14 shows how the transverse thermal strain in the 90° ply is reduced on isothermal moisture absorption and restrained matrix swelling, but in the presence of a thermal excursion the combination of cooling from the elevated temperature and higher matrix expansion coefficient results in a much lower effect of moisture absorption. For some matrices, thermal spiking can enhance the residual thermal strain and cause thermal cracking [22].

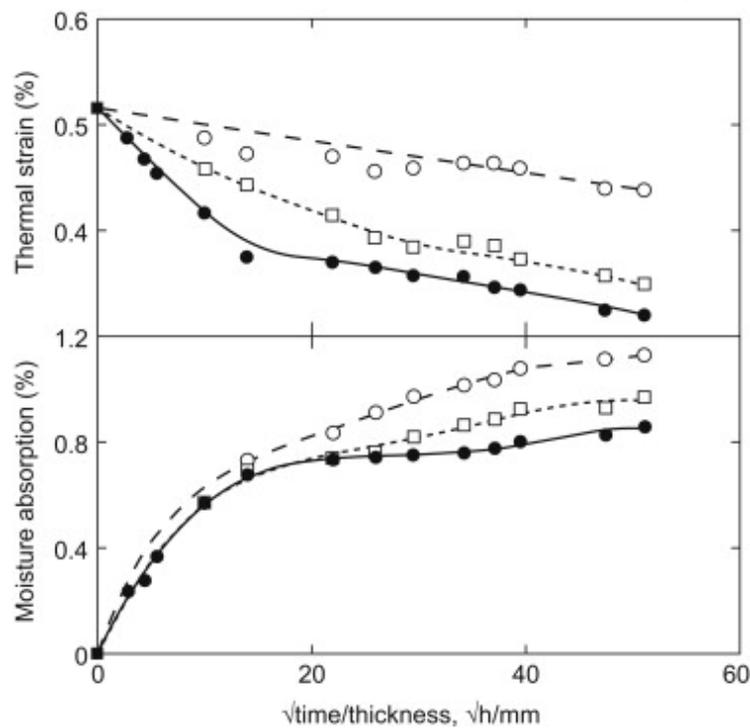


Figure 12.14. Effect of moisture absorption at 50 °C and 96% RH on the thermal strain in a balanced 0°/90°/0° 927C laminate estimated from the curvature of an unbalanced 0°/90° beam [3].

Control (●); 120 °C spike (□); 140 °C spike (○) [7,22].

The higher degree of contraction of a wet cross-linked polymer (which will be constrained) tends to arise from the appearance of a secondary relaxation peak or peaks in the expansion coefficient temperature profile. The thermal response will mirror any changes which occur in the DMTA spectrum. This may have its origin in the number of different types of polar groups present in the cured polymer matrix and their mechanism of interaction with water. Moisture absorption will decrease  $T_g$  and hence  $T_1$ , but since this is not usually exceeded in a thermal excursion its influence on the thermal strain is limited. That means that during a thermal excursion, even to temperatures below the glass transition temperature or postcure temperature of the material, the higher constrained contraction on subsequent cooling may induce a higher residual thermal strain.

In Figure 12.15 [23,24], the additional contraction, which manifests itself as an increase in residual thermal strain on cooling, is represented by the difference between the areas under the two curves. In the next cycle, moisture absorption may lead to a further swelling of the material and a reduction in the thermal strain. However, after a subsequent thermal cycle, the thermal strain will be again enhanced. If the thermal stresses which are induced into the material exceed the transverse cracking strain of the individual ply, then thermal cracks will form. Because of the 3D nature of the thermal stresses, thermal cracking occurs in every ply. As shown in Figure 12.16, thermal cracking of the plies will occur differentially because the moisture absorption will not be uniformly distributed throughout the material. In Figure 12.16, the thermal cracking occurred more rapidly in the outer ply [25]. Matrix cracking during thermal cycling of PMR 15 composites is complicated by the release of volatiles during cure, which become occluded in the matrix. This causes the thermal expansion coefficients of the plies and the stress free temperature to vary during thermal cycling because these volatiles slowly

desorb over a number of thermal cycles. As a result the composites exhibit thermal cracking (or thermal fatigue) on cooling from each thermal excursion [26].

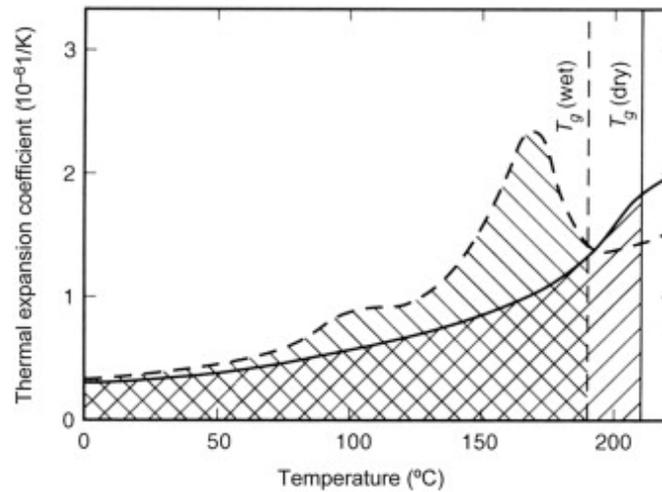


Figure 12.15. Temperature dependence of the transverse thermal expansion coefficients of a bismaleimide modified epoxy resin-based carbon fibre composite (Narmco Rigidite 5245C): dry (continuous curve) and wet (dashed curve).

The hatching illustrates the differing constrained shrinkages (and hence thermal strain) for wet and dry laminates [23,24].

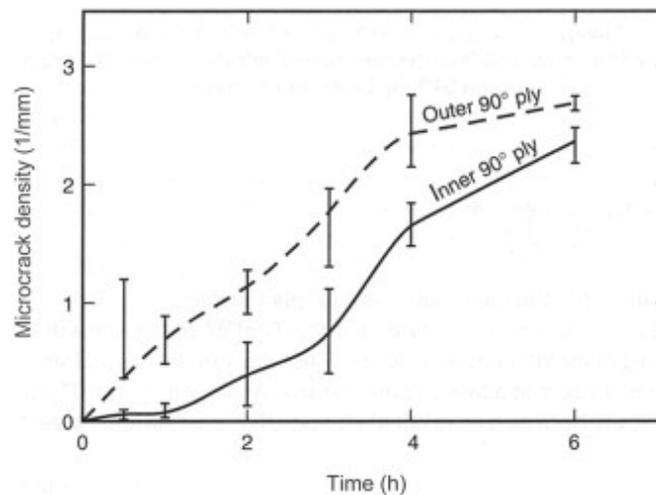


Figure 12.16. Thermal transverse cracking of a 0°/90°/0° laminate from PMR15 during ageing at 390 °C [25].

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## Bamboo reinforced polymer composites

In [Tribology of Natural Fiber Polymer Composites](#), 2008

### Surface modification of fibers

The poor adhesion between resin matrix and bamboo leads to debonding of the composites on ageing. Interfacial adhesion is improved by chemical treatment. For instance, polyesteramide polyol used as an interfacial agent improves [interfacial adhesion](#) and hence the mechanical properties of the composites.<sup>6</sup> Both [tensile](#)

strength and flexural strength of treated bamboo–epoxy and bamboo–polyester composites show significant improvement. The attachment of polyesteramide polyol organofunctionality onto the fiber surface is stable because of the hydrogen bonding between the functional group of polyesteramide polyol and the surface reactive protons of bamboo fiber.

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## Bamboo-reinforced polymer composites

Navin Chand, Mohammed Fahim, in Tribology of Natural Fiber Polymer Composites (Second Edition), 2021

### 6.2.1.1 Surface modification of fibers

The poor adhesion between resin matrix and bamboo leads to debonding of the composites on ageing. Interfacial adhesion is improved by chemical treatment. For instance, polyesteramide polyol used as an interfacial agent that improves interfacial adhesion and hence the mechanical properties of the composites [6]. Both tensile strength and flexural strength of treated bamboo–epoxy and bamboo–polyester composites show significant improvement. The attachment of polyesteramide polyol organofunctionality onto the fiber surface is stable because of the hydrogen bonding between the functional group of polyesteramide polyol and the surface reactive protons of bamboo fiber.

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## Recycling of reinforced plastics

R.D. Adams, ... R. Watkins, in Structural Integrity and Durability of Advanced Composites, 2015

### 28.1.3 Hydrolysis

Hydrolysis involves depolymerisation of the resin matrix using water and an acid or base catalyst (Allred, Gosau, & Shoemaker, 2001). The products can be used as ingredients in other processes. This process can only be used to decompose polyethylene, polyester, and polyamides. Polyester is the only commonly used matrix with FRPs. The main problems with this process are that the scrap material has to be separated into matrix polymer types before recycling and postprocessing is needed to recover the fibres. The fibres themselves are likely to be degraded by the action of the water and acid.

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## Antibacterial adhesives for bone and tooth repair

E.A. Abou Neel, A.M. Young, in Joining and Assembly of Medical Materials and Devices, 2013

Composites

Dental composites consist of a resin matrix (mostly high molecular weight, hydrophobic, dimethacrylate monomers), silane-treated inorganic fillers (often silica based) and an initiator/activator (typically camphorquinone and dimethylparatoluidine) system. Upon exposure to a blue light (e.g. from an LED source), the highly filled composite pastes placed within a tooth structure set via free radical initiated polymerisation. This produces a cross-linked three-dimensional network and a material with suitable strength and wear characteristics to replace lost tissues. Gaining a strong, resilient bond between the composite and dentine can, however, be difficult. It generally requires a number of complex dentine pre-treatment steps and use of additional more hydrophilic methacrylate resin adhesives (see below).

A major problem with dental composites is polymerisation shrinkage during set. This causes stress on the bond between the material and tooth structure leading to gap generation at their interface. Additionally, differences in thermal expansion coefficients of the material and tooth can mean changes in temperature widen these gaps. This problem is then further exacerbated by cyclic loading. Water and enzyme penetration ('nanoleakage') at the material/dentine interface may weaken the adhesive and break down collagen, respectively. Ultimately 'bacterial microleakage' through widened gaps of micron dimension can occur. This can lead to staining around the restoration margins, breakdown of adhesion, recurrence of caries, inflammation of the tooth pulp and also postoperative pain (Hersek *et al.*, 2002; Murrey *et al.*, 2002).

Recurrent caries is considered the major contributing factor responsible for tooth restoration failure. Attempts made to reduce the polymerisation shrinkage by modifying the composite composition (e.g. increasing the filler loading, using a high molecular weight methacrylate monomer or pre-cured resin as filler) and stress on the tooth by placement of the material in thin consecutive layers have been only partially successful. Additionally, in modern dentistry, there is a drive to remove less of the disease damaged tissue (Splieth *et al.*, 2001). In this situation, there is greater possibility of residual bacteria within the tooth cavity and so development of materials with some antibacterial action is becoming ever more crucial.

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## Nanostructure Formation in Thermoset/Block Copolymer and Thermoset/Hyperbranched Polymer Blends

Yuan Meng, Xinghong Zhang, in Nanostructured Polymer Blends, 2014

### 6.3.3.1 Shell Chemistry

Interactions between the modifier and the resin matrix predict the miscibility of the system (as suggested by Eq. 6.3) and thus determine the resultant morphology. Perhaps it just seems intuitive to modify the system compatibility by varying the molar mass, or generation of the HBP, however, changing the size of a HBP modifier has little effect on compatibility [65,67]. As pointed out by different research groups [65,67,71], the chemistry of the shell functional groups is a major factor for the control of phase interaction. It is even believed that the

hyperbranched aliphatic polyester can play the role of hardener in a curing system once appropriate terminal groups are introduced [69].

G3 to G5 aliphatic polyester HBP functionalized with hydroxyl groups (Figure 6.13(a)) are the most popular series of modifiers applied in related researches, because of the presence of the large number of strong hydrogen bondings with epoxy matrix necessary for a decent miscibility. Alternatively, due to the ability of covalent incorporation into the matrix via curing, epoxidized HBP (Figure 6.13(b)) is also a good choice for epoxy toughening. This HBP allows for a gradual change in functionality and hence solubility, through controlling the number of epoxy groups attached onto the particle. Epoxy equivalent weights (EEW) describe the amount of mass required to give one equivalent of reactivity; the higher this value, the lower the density of epoxy groups, and the poorer the compatibility. Other HBP with novel terminal functionality includes vinyl, benzoate, and so on [69,79].

Mezzenga et al. investigated the effect of shell chemistry on received morphology by varying the number of epoxy groups on G3 HBP at fixed  $T_{cure}$ . [66] Decreasing the EEW of a blended modifier (from 1050 to 408 g/equivalent) was accompanied by a decrease in phase-separated HBP particle size (average diameter drop from 0.50 to 0.15  $\mu\text{m}$ ) as the miscibility between the resin and the modifier increased; the total number of particles  $N_{tot}$  showed an opposite trend. As was stated in Section 6.3.1, it is generally accepted that the conversion window available for primary growth and coalescence of dispersed domain is limited between the onset of phase separation (cloud point) and the matrix gelation point. Since the cloud point tends to shift to a higher conversion with increasing system miscibility (decreasing EEW) while the gelation point remains invariant (theoretical conversion=0.60), (1) the overall conversion window available for the phase separation and particle coalescence to proceed is restricted to lower EEW (see Figure 6.14); and (2) the matrix viscosity at the onset of phase separation increases (diffusion constant  $D$  goes down according to Equation (6.6)) as the cloud point conversion, and hence the degree of cross-linking, increases. Both explanations may invoke a second phase that is smaller in size due to its confined formation mechanism.

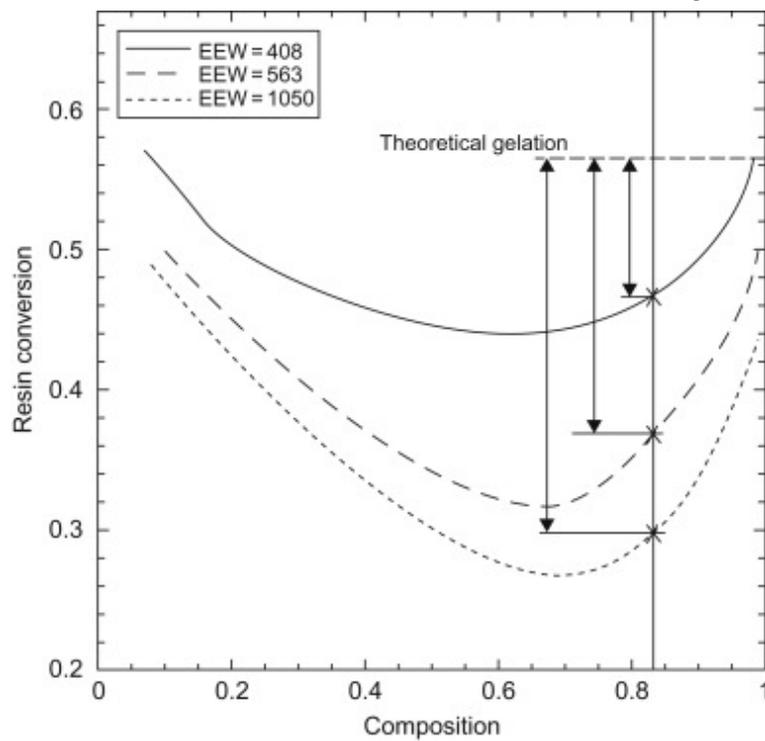


Figure 6.14. Conversion window of phase-separating systems with different EEW [66].

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## Antibacterial composite restorative materials for dental applications

I.M. Mehdawi, A. Young, in *Biomaterials and Medical Device - Associated Infections*, 2015

### 10.2.3 Current direct aesthetic restorative material limitations

*Composites* are essentially composed of an organic resin matrix, inorganic filler and silane agent that bonds the two parts together. They are bonded to the tooth using various procedures usually involving acid containing resin based adhesives. Dental composite polymerization shrinkage, however, affects bonding integrity and can lead to gaps at the adhesive/tooth interface. These gaps increase the possibility of bacterial microleakage<sup>24</sup> leading to discoloration of the restoration, hypersensitivity of restored teeth, secondary caries and pulpal inflammation.

*Conventional glass-ionomer cements* (GICs) consist of fluoroaluminosilicate glass fillers and an aqueous solution of polyalkenoic acid. They set through an acid-base reaction mechanism.<sup>25</sup> These materials exhibit early moisture sensitivity,<sup>26</sup> delays in final strength development and low mechanical properties.<sup>27,28</sup> Therefore, their use is limited to non-stress bearing areas.<sup>29</sup>

*Resin modified glass ionomer cements* (RMGICs) are chemically similar to conventional GICs, but with additional photo-polymerizable monomers, frequently 2-hydroxyethylmethacrylate (HEMA).<sup>30</sup> The RMGICs are vulnerable to some of the limitations of resin-based materials, including polymerization shrinkage and heat generation. Mechanical properties of RMGICs are, however, still generally below those of the composite.<sup>31</sup>

The compomers or polyacid-modified composite resins were introduced to overcome the low mechanical properties and moisture sensitivity of glass ionomer cements. The compomers however, exhibit lower mechanical properties compared to dental composites.<sup>32</sup> They are therefore mostly indicated for restoration of primary teeth or non-stress bearing areas.

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## Advanced manufacturing techniques for composite structures used in aerospace industries

Raghu Raja Pandiyan Kuppusamy, ... Kaushik Kumar, in Modern Manufacturing Processes, 2020

### 1.2 Processing methods

The manufacturing methods bring a way to combine resin matrices and reinforcement fiber mats to the required shape of the target component ensuring minimum voids and maximum resin-fiber wetting. Hence, the objective of any composite processing method is to accomplish a maximum wet-out, satisfying the part performance requirements with the desired rate of production. The measure of resin impregnation is governed by the processing parameters such as applied pressure and cure temperature of the manufacturing method employed. Irrespective of the selected manufacturing technique, factors such as raw material characteristics including reinforcement permeability, fiber volume fraction, resin curing kinetics, viscosity, and product dimension and complexity affects the outcome of the finished part. These factors may get affected with changes made in the processing parameters and hence, the dependency of these factors with the process parameters should be revealed for the successful production of high quality products [2].

There are raw material parameters and processing method variables that influence the manufacturing method and properties of finished product. Resin cure kinetics, resin viscosity, resin gelation time, and exothermy are the resin parameters that influence the manufacturing processes and final product characteristics. Reinforcement fiber mat architecture, mat porosity, and mat direction permeabilities are the reinforcement fiber parameters that influence manufacturing processes and final product characteristics. Maximum fiber volume fraction, maximum fiber-resin wetting, no voids formation, ease in shaping, reduced cycle times, ease in temperature application for curing, and less tools requirements are the favorable parameters to make a processing method as a choice to manufacture a composite component. During curing, resin undergoes chemical and physical changes. Physically resin changes from liquid to gel state, then to rigid solid state. Chemically, resin undergoes cross linking with the help of curing aids such as accelerators and catalysts and with the application of temperature. The resin cures with the release of heat. With increase in curing, the viscosity of resin increases exponentially. Hence, parameters like resin gelation time, peak exothermic temperature, resin cure kinetics, and resin cure viscosity are major parameters for manufacturing processes. Several resins have been developed specifically for each manufacturing process in accomplishing processing traits with desirable physical properties. Heat is often used to speed up the curing process [5].

Mold filling phase and curing are the two major phases for any manufacturing method. With complexity in geometry, both phases find difficulty in pressuring

resin for fiber impregnation. Then, in curing, applied temperature may not be uniform, thus we have different cure distribution along the product thickness. The major manufacturing techniques are molding, winding, and other continuous automated production methods such as pultrusion methods. However, the choice of the composite production process for a particular application is governed by a trade-off between lower manufacturing cost, high performance part, production rate, size, shape, and ease in making complex geometries.

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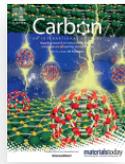
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