



Research Paper

## Mechanical Properties of High-Performance Epoxy Resins Used in Composite Material

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**ABSTRACT:** Composites that use fibers as reinforcement typically include a matrix and high-modulus fibers that are either introduced into or connected to the matrix at various points. The physical and chemical properties of the fibers and matrix are maintained in this structure, but they combine to provide a composite of traits that neither component could achieve on its own. The matrix encases the fibers, which hold the bulk of the material's weight, keeps them in place, transfers stress among them, and shields them from harmful elements like dampness and heat. In a fiber-reinforced composite material, the matrix serves many purposes as the fibers bolster it. Low molecular weight organic liquid resins with a number of epoxide groups—three-member rings made up of one oxygen atom and two carbon atoms—are the starting materials for the epoxy matrix. There are two types of structural components that are used as matrix materials, oxides and nonoxides. Additionally, it has exceptional resilience to high temperatures. AlN is of interest because to its high thermal conductivity. Because of its thermal stability and compatibility with a wide variety of oxide and non-oxide ceramic materials.

**Keywords:** Mechanical Properties, High-Performance, Epoxy Resin, Composite Material.

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### I. INTRODUCTION

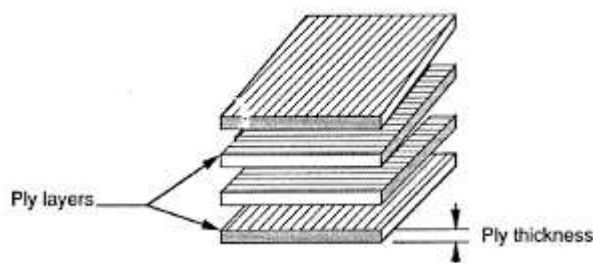
Fiber-reinforced composite materials include high-strength and high-modulus fibers inserted in or attached to a matrix, with different interfaces between the two components. In this configuration, both fibers and matrix preserve their physical and chemical identities, but they provide a composite of qualities unattainable by each ingredient alone. Fibers serve as the primary weight-bearing components, whilst the surrounding matrix maintains their position and orientation, facilitates load transmission among them, and protects them from environmental damage, such as high temperatures and humidity. Consequently, as the fibers strengthen the matrix, the matrix simultaneously fulfills many beneficial roles in a fiber-reinforced composite material.

The primary fibers used commercially are different forms of glass, carbon, and Kevlar 49. Other fibers, including boron, silicon carbide, and aluminum oxide, are used in restricted amounts. All these fibers may be integrated into a matrix in either continuous or discontinuous (short) lengths. The matrix material might consist of a polymer, metal, or ceramic. Diverse chemical compositions and microstructural configurations are feasible within each matrix group.

The predominant configuration of fiber-reinforced composites used in structural applications is known as a laminate, formed by layering many thin sheets of fibers and matrix, which are then consolidated to achieve the specified thickness. The fiber orientation in each layer and the stacking sequence of different layers in a composite laminate may be manipulated to provide a diverse array of physical and mechanical characteristics for the composite laminate. This work examines the physics, performance, production, and design of fiber-reinforced polymers. The majority of the data in this work pertains to continuous fiber-reinforced epoxy laminates, however alternative polymeric matrices, including thermoplastic matrices, are also addressed. Metal and ceramic matrix composites are relatively recent, although notable advancements in these composites have transpired. Injection-molded or reaction injection-molded (RIM) discontinuous fiber-reinforced polymers are not addressed; yet, some mechanics and design ideas presented in this work are relevant to these composites as well. A material of significant commercial interest is categorized as particulate composites. The primary constituents of these composites include particles of mica, silica, glass spheres, calcium carbonate, and others. Generally, these particles do not enhance the load-bearing capacity of the material and function more as fillers

than as reinforcements for the matrix. Particulate composites, in their own right, need special attention and are not discussed in this work.

Another category of composites with the potential to emerge as a significant material in the future is nanocomposites. Despite being in the nascent stages of development, nanocomposites are now garnering significant attention from academia and several industries, including aerospace, automotive, and biomedical sectors. The reinforcement in nanocomposites consists of either nanoparticles, nanofibers, or carbon nanotubes.



**Figure 1: Laminated Composite Plate**

## II. GENERAL CHARACTERISTICS

The combination of strength and modulus offered by many fiber-reinforced polymers is on par with, or even better than, that of many conventional metallic materials.

The strength-weight and modulus-weight ratios of these composite materials are much better than those of metallic materials due to their low density. Also, many composite laminates have great fatigue strength and fatigue damage tolerance. As a result, fiber-reinforced polymers are now a prominent structural material class, with several weight-critical components in the aerospace, automotive, and other sectors using them or considering them as a metal substitute.

Because their characteristics are the same or about the same in any direction of measurement, classic structural metals like steel and aluminum alloys are said to be isotropic. Typically, fiber-reinforced composites are not isotropic materials since their characteristics are very directionally dependent. When measured in the direction of the fibers' longitudinal orientation, the tensile strength and modulus of a fiber-reinforced polymer that is unidirectionally oriented, for instance, are at their highest. These characteristics are diminished when seen from any other perspective. When measured in the fibers' transverse direction, which is at 90° to the longitudinal direction, the least value is recorded. Other mechanical and thermal parameters, including impact strength, thermal conductivity, and coefficient of thermal expansion (CTE), have a similar angular dependency. A better balanced set of characteristics is achieved by bi- or multidirectional reinforcing. These features are inferior to a unidirectional composite's longitudinal qualities, but they're still light years ahead of the competition when it comes to conventional structural metals per weight.

Compared to metal structures, fiber-reinforced composites are much more challenging to design since their properties vary in different directions. However, a fiber-reinforced composite material's unique ability to adjust its properties to design requirements is a result of its nonisotropic nature. You can use this design flexibility to reinforce a structure in specific directions, make it stiffer in a desired direction, create curved panels without secondary shaping operations, or make structures with zero thermal expansion coefficients. An additional degree of design flexibility not readily achieved with metals may be achieved by constructing sandwich beams, plates, or shells from fiber-reinforced polymers with lightweight cores made of materials like aluminum honeycomb, plastic foam, meta I foam, or balsa wood. This kind of sandwich construction may provide a high level of rigidity with very little weight gain. There is another sandwich construction that has found widespread usage in airplanes and other applications. This one has a fiber-reinforced polymer core with an aluminum alloy exterior, and it has better fatigue performance and damage tolerance than aluminum alloys.

In addition to the fact that properties rely on direction, structural matrix and fiber-reinforced composite sites differ in a number of other ways as well.

As an example, metals often display plastic deformation and yielding. When it comes to tensile stress, the majority of fiber-reinforced composites are elastic.

Nevertheless, these materials' heterogeneous properties allow for mechanisms of microscopically scale energy absorption, similar to the yielding process. Composite laminates typically do not break catastrophically, but they may exhibit progressive degradation in properties depending on the kind and degree of external stresses. It is important to take into account the distinct mechanisms of damage formation and growth in metal and composite structures when designing structures that include fiber-reinforced polymers instead of metal.

### III. APPLICATIONS

There is no way to possibly catalog all of the many commercial and industrial uses for fiber-reinforced polymer composites. Only the most important structural application areas—aircraft, space, automobiles, search engines, marine, and infrastructure—will be covered in this section. Fiber-reinforced polymer composites are also used in electronics (e.g., printed circuit boards), building construction (e.g., floor beams), furniture (e.g., chair springs), power industry (e.g., transformer housing), oil industry (e.g., offshore oil platforms and oil sucker rods used in lifting underground oil), medical industry (e.g., bone plates for fracture fixation, implants, and prosthetics), and in many industrial products, such as step ladders, oxygen tanks, and power transmission shafts. Many areas of engineering have the potential to benefit from fiber-reinforced composites. Refined design technique and appropriate process development based on understanding of their particular mechanical, physical, and thermal characteristics are required to put them to real use.

### IV. STRUCTURE OF EPOXY

The building blocks of an epoxy matrix are organic liquid resins with a low molecular weight that comprise a number of epoxide groups. Each epoxide group consists of three carbon atoms and one oxygen atom. Diglycidyl ether of bisphenol A (DGEBA) is a typical starting material because it has two epoxide groups—one on each end of the molecular bond. Additional ingredients that may be added to the starting liquid include diluents to make it less viscous and flexibilizers to make the cured epoxy matrix stronger.

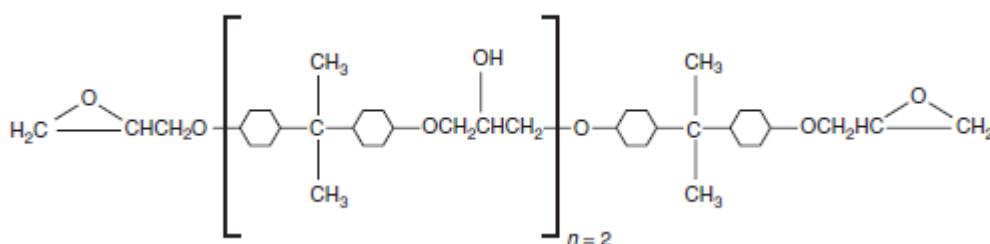


Figure 2: Principal ingredients in the preparation of an epoxy matrix

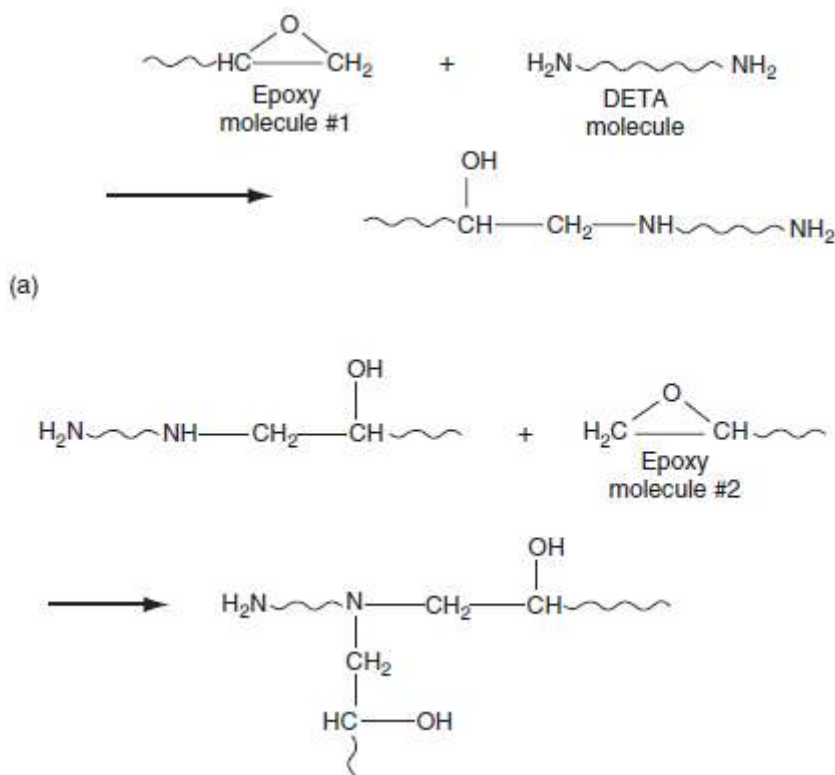


Figure 3: Schematic representation of a cross-linked epoxy resin

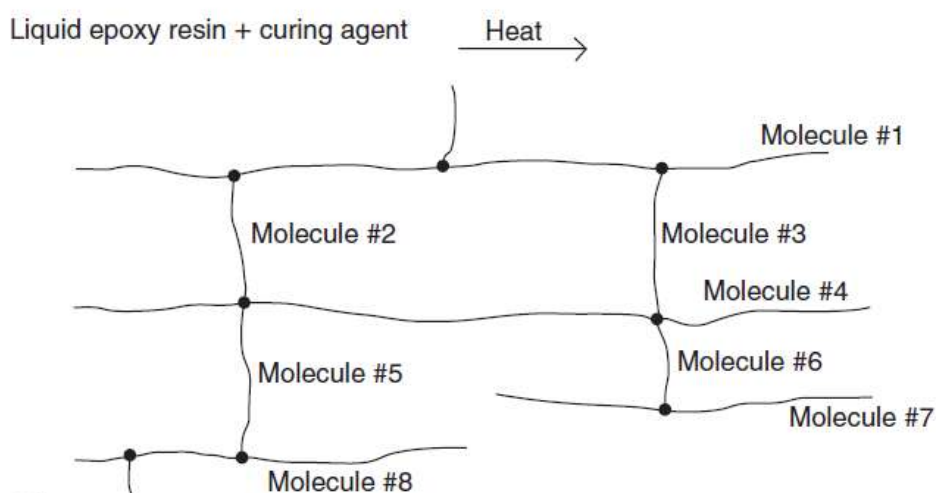


Figure 3: Three-dimensional network structure of solid epoxy

### V. RESULTS AND DISCUSSION

Cast epoxy resins typically have the properties shown in Table 1. Tetrahydrodiphenylmethane (TGDDM) is the basis of one epoxy resin utilized in the aerospace industry. Diaminodiphenyl sulfone (DDS) with or without an accelerator is used to treat it. Because of its high glass transition temperature (240–260 degrees Celsius, compared to 180–19 degrees Celsius for DGEBA systems) and excellent strength retention even after extended exposure to elevated temperatures, the TGDDM-DDS system is employed. The relatively low curing reactivity of DDS in the "B-stage d" resin allows prepregs created with this system to be stored for a longer length of time. Low strain-to-failure ratio, excessive atmospheric moisture absorption (because of its highly polar molecules), and poor hot-wet performance are the limitations of the TGDDM-DDS system. Its glass transition temperature, modulus, and other mechanical properties are all negatively impacted by high moisture absorption.

Table 1 : Properties of Epoxy Resin (at 23°C)

Density (g/cm <sup>3</sup> )	1.2–1.3
Tensile strength, MPa (psi)	55–130 (8,000–19,000)
Tensile modulus, GPa (10 <sup>6</sup> psi)	2.75–4.10 (0.4–0.595)
Poisson's ratio	0.2–0.33
Coefficient of thermal expansion, 10 <sup>-6</sup> m/m per °C (10 <sup>-6</sup> in./in. per °F)	50–80 (28–44)
Cure shrinkage, %	1–5

Although changing the chemistry may reduce the problems of moisture absorption and hot-wet performance (Table 2), brittleness or low strain-to-failure is an inherent drawback of highly cross-linked resins.

For damage-tolerant composite laminates, it is vital to improve fracture toughness and the matrix strain-to-failure. One way to do this with epoxy resins is to add a little quantity of a highly reactive liquid elastomer called carboxylterminated butadiene-acrylonitrile (CTBN). This elastomer will create a second phase in the cured matrix, which will prevent microcracking.

Table 2 : Mechanical Properties of High-Performance Epoxy Resins

Property	Epoxy 1	Epoxy 2	Epoxy 3 (Tactix 742,
		(Epon HPT 1072, Shell Chemical)	Dow Chemical)
$T_g$ , °C	262	261	334
Flexural properties (at room temperature)			
Strength, MPa (ksi)	140.7 (20.4)	111.7 (16.2)	124.1 (18)
Modulus, GPa (Msi)	3.854 (0.559)	3.378 (0.490)	2.965 (0.430)
Flexural properties (hot-wet) <sup>c</sup>			
Strength (% retained)	55	65	—
Modulus (% retained)	64.5	87.3	—
Fracture energy, $G_{Ic}$ , kJ/m <sup>2</sup> (in. lb/in. <sup>2</sup> )	0.09 (0.51)	0.68 (3.87)	0.09 (0.51)
Moisture gain, %	5.7	2.6	—

## VI. CONCLUSIONS

The goal of this work is to investigate the Mechanical Properties of High-Performance Epoxy Resins used in laminated composite plates under various applications circumstances. A wide range of benefits are possible because to the abundance of starting materials, curing agents, and modifiers. While curing, volatile materials are not present. Curing causes little shrinkage. Very resistant to chemicals and solvents. Exceptional adherence to a broad range of fillers, fibers, and other substrates. Changing the resistance chemistry may reduce the problems of moisture absorption and hot-wet performance. resin with a high cross-link density is brittle or has a low strain-to-failure ratio. For damage-tolerant composite laminates, it is vital to improve fracture toughness and the matrix strain-to-failure.

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