

## **CHAPTER I**

### **INTRODUCTION**

Composites provide a unique combination of properties and therefore can substitute for other conventional materials. One of the most widely used composites is made from unsaturated polyester (UPE) resin with glass fiber reinforcement. Glass fiber is widely used because of its high tensile strength, excellent resistance to attack by water, and low dielectric constant. However, many studies have shown that natural fibers can also be used as suitable reinforcements in polymer matrices. Natural fibers have several advantages over glass fibers including being of lower density, easy availability, a renewable resource, and using less energy in production. In this study, kenaf fibers are used as the composite reinforcement which grow abundantly in Thailand. They are lower in cost and lighter in weight than glass fibers and can be used as a natural renewable resource. For the matrix material, UPE resin is widely used because of its low cost, ease of use, and good mechanical and chemical resistance properties. However, nowadays polybenzoxazine (PBZX) offers an alternative to traditional phenolic resins and other thermosetting resins such as UPE resins and epoxies. The major advantages of PBZX resin compare with phenolic resin are near-zero volumetric shrinkage, strong catalysts are not required, and it produces no polymerization by-products which eliminates the formation of voids. This makes the newly developed PBZX ideally suited for matrices for high performance composite applications.

## 1.1 Polybenzoxazine Resin

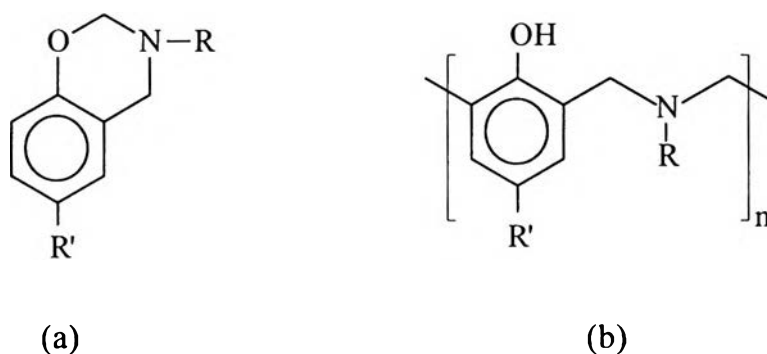
PBZX is a newly developed class of thermosetting resins that are based on the ring-opening polymerization of benzoxazine precursors. These new materials overcome the shortcomings associated with traditional phenolic resins which are derived from a condensation of phenol and formaldehyde in the presence of acid or alkaline catalysts. Resole and novolac resins suffer from the evolution of volatiles upon curing, use strong acids or alkalines as catalysts, release water and ammonia during the curing process, give high volumetric shrinkage during the processing step, have high viscosity precursors, give brittle products, and have limited shelf life. However, they offer many advantages such as high temperature resistance, dimensional stability, good electrical insulation, good heat resistance, flame retardancy, low flammability, and low smoke generation. Another important advantage is the low cost of raw materials. Phenolic resins are widely used in electrical facilities, construction, furniture, coating, adhesives, molding compounds, foundry resins, laminates, wood bonding, structural composites, and in high-technology applications in the electronics and aerospace industries.

The properties of benzoxazines are typical for phenolic resins. They exhibit good heat resistance, flame retardancy, and good dielectric properties. A number of polybenzoxazine properties are superior to those of conventional phenolics. These new materials possess high glass transition temperatures, high moduli, low water absorption values, near-zero shrinkage or a slight expansion upon cure, excellent processability through flexible molecular design, no strong acid or alkaline as crosslinking catalysts, and no reaction by-products are released.

Benzoxazine is a single benzene ring fused to another six-membered heterocycle group containing one oxygen atom and a single nitrogen atom,

called an oxazine ring. The oxazine ring is the reactive site for curing of the benzoxazine. There are a number of possible isomers of benzoxazine depending on the relative positions of the two heteroatoms and the degrees of oxidation of this oxazine ring system. Benzoxazines may be monofunctional or difunctional. The latter can produce crosslinked structures.

PBZX is synthesized by the ring-opening polymerization of benzoxazines. The chemistry of benzoxazine synthesis offers a wide range of molecular design flexibility by using derivatives of phenol, primary amine, and aldehyde. Various combinations of amines and phenols have been used to synthesize benzoxazines. PBZX has a repeating unit of the form [-Ph(OH)-CH<sub>2</sub>-NR-CH<sub>2</sub>-]. Molecular structures of the monomer and resulting polymer are shown in Figure 1.1.



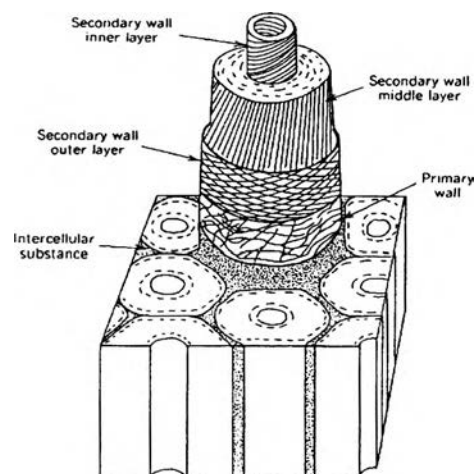
**Figure 1.1** Molecular structures of (a) benzoxazine monomer, (b) repeating unit of polybenzoxazine (R = amine group, R' = phenol group).

## 1.2 Kenaf Fiber

### 1.2.1 Structure

The morphology of kenaf fibers is very similar to that of wood fibers, which is illustrated in Figure 1.2. Kenaf is a kind of bast fiber obtained

from the stem of the plant *Hibiscus sabdariffa* Linn. *Var. altissima* which form the fibrous bundles in the inner bark of the plant stems. The fiber bundles consist of strands of individual fibers held together by intercellular material. These ultimate fibers of bast origins are multicelled and used as strands. The ultimate kenaf fibers are 2-11 mm long and 13-33  $\mu\text{m}$  in diameter. They are nearly cylindrical in shape with thick cell walls. Kenaf strands are usually 2-4 m long. The cell cross section of each individual fiber is a five or six-sided polygon with a central oval lumen. The cross-sectional view of kenaf fiber is shown in Figure 1.3.



**Figure 1.2** Schematic representation of the fine structure of a wood fiber, (Mark *et al.*, 1986).

The secondary walls are fibrillar in nature and the fibrils are helically disposed although with a smaller helical angle and no structural reversals. Also, fibers are not convoluted so that the spiral angle is not distorted with respect to the fiber axis as in cotton. As a result, bast fibers are generally stronger, stiffer and less extensible than cotton.



**Figure 1.3** Cross section ( $\times 500$ ) of kenaf fiber, (Kroschwitz and Mary, 1993).

### 1.2.2 Chemical Composition

The chemical composition of kenaf fiber (Table 1.1) consists mainly of cellulose. The intercellular material contains high contents of lignin, which contributes to the stiffness of kenaf fibers, and an equally high percentage of hemicellulose, with a small amount of extractives.

**Table 1.1** Chemical composition of kenaf fibers, wt% (Kroschwitz and Mary, 1993).

Cellulose	Hemicellulose	Lignin	Extractives
63.0	18.0	17.0	2.0

## 1.3 Composite Material

A composite material can be defined as a solid material composed of polymeric matrix and fibrous reinforcement in which strong and high modulus fibers with diameters of the order of 10-100  $\mu\text{m}$  are used.

The matrix generally performs the function of a binder to transfer stress to the reinforcing fibers and ensure their cooperative interaction. Both

thermosetting and thermoplastic polymers can be used as the matrix for polymer-based composites.

The fiber performs the function of reinforcing the strength of weak polymers. Reinforcing fibers can be either man-made or of natural origin. In general, the strength of a composite,  $\sigma_c$ , is given by

$$\sigma_c = \sigma_f v_f + \sigma_m v_m \quad (1)$$

where  $\sigma_f$  is tensile strength of fiber,  $\sigma_m$  is tensile strength of matrix,  $v_f$  is volume fraction of fiber, and  $v_m$  is volume fraction of matrix.

The strength of a composite depends on the strength of the fiber, the strength of the matrix, volume fraction of fibers, and volume fraction of matrix according to the above equation (Kroschwitz and Mary, 1993).

#### **1.4 Resin Transfer Molding (RTM) Process**

This method is now generally accepted as being the most suitable for the fully automatic production of complex composite parts. It is used today to manufacture a wide variety of articles ranging from small armrests for buses to large water treatment plant components (Johnson, 1990).

RTM is a low pressure molding process where mixed resin and catalyst is injected into a closed mold containing a fiber pack or preform. When the resin has cured, the mould is opened and the finished component removed. The RTM technique has many advantages and benefits such as reducing material wastage, uses only low pressure injection, parts have uniformity of thickness and fiber distribution, good surface finish on both sides, and tooling costs are comparatively low.