# Chapter 1

# INTRODUCTION

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## 1.1 Statement of Problems and Opportunities

Since the early 1960s, there has been an ever-increasing demand for newer, stronger, stiffer, and yet lighter-weight materials in fields such as aerospace, transportation, and construction. High demands on materials for better overall performance has led to extensive research and development efforts in the composites fields. These materials have low specific gravity that make their properties particularly superior in strength and modulus [1, 2] to many traditional engineering materials such as metals (Table 1.1). As a result, these materials are now being rapidly utilized in industries that traditionally used metals, and these have become the forefront of research and development activity in many related areas.

Composite materials that exist today can be categorized into five major classes, which include ceramic matrix composites (CMCs), metal matrix composites (MMCs), intermetallic matrix composites (IMCs), carbon-carbon composites (CCCs) and polymer matrix composites (PMCs) [2]. In this discussion, considerable attention is paid to the latter class of materials (PMCs).

There are two important types of polymer matrix composites, short-fiber and continuous-fiber composites [1, 2]. The choice of polymer matrix for such composites can be either a thermoset or a thermoplastic. Some of the advantages and disadvantages of these matrices are summarized in Table 1.2.

Continuous-fiber composites that offer the best mechanical properties compared to other fiber-reinforced composites are primarily reinforced with high performance fibers

Table 1.1 Potential benefits of composites over metals [3]

- Potentially increased design flexibility
- Better damage tolerance
    - Increased impact resistance
    - Increased fracture toughness
    - Greater scuff resistance
- Better corrosion resistance
- High specific strength and stiffness
- Low thermal coefficient of expansion
- Better fatigue resistance
- Potentially lower component costs
    - Lower fabrication costs
    - Lower quality assurance costs
    - Lower scrappage rate
- Integral construction of composite structures
    - Minimal plies
    - Fewer joints
    - Ply dimensions can correspond to principal load path

Table 1.2 Summary of advantages and disadvantages of thermosets and thermoplastics as Composite matrix resins [3]

| Property | Thermosets | Thermoplastics |
|---|---|---|
| Formulations | Complex | Simple |
| Melt viscosity | Very low | High |
| Fiber impregnation | Easy | Difficult |
| Prepreg tac | Good | None |
| Prepreg drape | Good | None to fair |
| Prepreg stability | Poor | Excellent |
| Processing cycle | Long | Short to long |
| Processing temperature/ pressure | Low to moderate high | High |
| Fabrication cost | High | Low (potentially) |
| Mechanical properties | | |
| -54 to 93$^{o}$C, hot/wet | Fair to good | Fair to good |
| Environmental durability | Good | Unknown |
| Solvent resistance | Excellent | Poor to good |
| Damage tolerance | Poor to excellent | Fair to good |
| Database | Very large | Small |

such as carbon or Kevlar. These composites are often utilized in special applications like aircraft components in which the property benefits of the fibers are fully exploited. Such materials, however, cannot be adapted easily to mass production [4] and are limited in applications to shapes, which are formed by the ‘assembly’ of sheet-like or rod-like feedstock [5].

Short-fiber composites on the other hand are primarily reinforced with chopped fibers such as glass, graphite and cellulose fibers. These types of composites are very common and well established in many applications that require low strength and stiffness such as automotive and appliance applications [1]. Compared to continuous-fiber composites, short-fiber composites can be easily processed in a similar manner to the matrix [4]. In the case of thermoplastics, methods such as injection molding can be adopted to allow mass production of molded products with complex shape [4. 5].

The properties of a composite material are strongly influenced by the properties of its constituents and their distribution and also the quality of interactions among them. The most important of all the composite properties are usually the mechanical properties, since whatever may be the reason for the choice of a particular composite for some application, it must have certain characteristics of shape, rigidity and strength. The mechanical properties of continuous-fiber composites, such as stiffness, can be predicted using several prediction schemes such as the “Rule of Mixtures” and the Halpin-Tsai equations [1]. In contrast, in the case of short-fiber composites, these properties are difficult to predict. This is due to the various factors that influence the properties. Such factors include (i) the fiber dispersion, (ii) the orientation and geometry (aspect ratio) of the fibers within the composites, (iii) the fiber volume fraction, and (iv) the quality of the interface between the reinforcing fiber and polymeric matrix phase [4, 5, 6, 7, 8]. These parameters are often difficult to control particularly during processing.

The primary requirement for obtaining a high performance short-fiber composite is good dispersion of the fibers in the polymer matrix [6, 9]. Lack of fiber dispersion can result in clumping and agglomeration of fibers, which lead to composite properties falling short of their true reinforcing potential. Hence, it is important to examine the fiber dispersion throughout a composite sample. In 1994 Scott (1994) [10, 11] successfully patented a new nondestructive technique to quantify fiber dispersion. This technique, which is based on real-time radiographic imaging, uses image processing to determine the dispersion, and this can be used with a wide variety of two-phase systems [10, 11].

An interesting alternative for reinforcing polymeric matrices with short fibers is the use of cellulose fibers which has been reported in the literature to show remarkable reinforcing effects in plastics such as polypropylene, polyethylene and polystyrene (Table 1.3). The interest in using cellulose rather than synthetic fibers such as glass fibers is due to several attractive properties these fibers can offer such as a desirable aspect ratio (length divided by effective diameter, L/D) of around 100-200 for good performance after melt-processing (Table 1.4) [6, 12]. The increase in cost of petroleum based-plastics coupled with the environmental aspects of using renewable and biodegradable materials further make cellulose fibers favorable as reinforcements in composite materials.

Cellulose fibers, however, do have undesirable properties, which are based on their hydrophilic character, which limits their use in industrial practice. These limitations can

Table 1.3 Comparison of polypropylene (PP) composites [13]

| Property | Fiber type | | | |
|---|---|---|---|---|
| | None | Kenaf | Recycled newspaper fiber | Glass |
| Fiber content, % | 0 | 50 | 40 | 40 |
| Tensile Modulus, GPa | 1.7 | 8.3 | 4.4 | 9 |
| Tensile Strength, MPa | 33 | 65 | 53 | 110 |
| Elongation at Break, % | >10 | 2.2 | | 32.5 |
| Flexural Strength, MPa | 41 | 98 | 80 | 131 |
| Flexural Modulus, GPa | 1.4 | 7.3 | 3.9 | 6.2 |
| Notched Izod Impact, J/m | 24 | 32 | 21 | 107 |
| Specific Gravity ($g/cm^3$) | 0.9 | 1.07 | 0.98 | 1.23 |
| Water Absorption, % in 24h | 0.02 | 1.05 | 0.95 | 0.06 |
| Mold (linear) Shrinkage, cm/cm | 0.028 | 0.003 | | 0.004 |

Table 1.4 Length of fibers after processing [12]

| | | Before processing | | After processing | |
|---|---|---|---|---|---|
| Fiber | Fiber diameter (μm) | Length (mm) | L/D | Length (mm) | L/D |
| Glass | 13 | 6.35 | 488 | 0.22 | 17 |
| Carbon | 8 | 6.35 | 794 | 0.18 | 22 |
| Cellulose | 12 | 2.0 | 167 | 1.20 | 100 |
| Aramid | 12 | 6.35 | 529 | 1.33 | 111 |
| Nylon | 25 | 6.35 | 254 | 4.51 | 180 |

All fibers except cellulose fibers were chopped to 6.35 mm before being dispersed in an elastomer (NR or NBR) on a mill, then separated by solvent extraction and measured.

potentially be overcome with the introduction of improved compounding technology and new chemical fiber pretreatments such as steam explosion and surface acetylation. These processes, while significantly improving properties of cellulose fiber-thermoplastic composites, also increase the composite cost.

## 1.2 Research Objectives

The objective of this work was to examine the effect of fiber pretreatment as well as fiber volume fraction on composite properties. Impact on mixing torque during melt compounding and quality of fiber dispersion within the composites was also to be examined. Three types of cellulose fibers, different in degree of pretreatment at constant geometry were to be used to reinforce a commercially available thermoplastic cellulose ester. A commercial wood filler served as control.