CHAPTER I

INTRODUCTION

1.1 General Introduction

There have been numerous attempts to analyze the dynamics of ballistic impact on a yarn to provide a design guidance. There are two major publications that deal with the ballistic resistance of soft body armor. One is a book by Lyons in 1963 and one by Laible in 1980. The first book presented early work and theories in the 1950s and 1960s. The early work was entirely related to fibers, which implied that the ballistic behaviors of fabrics were controlled by fibers. The second book reviewed work in the 1970s on fibrous armor and penetration mechanics. It largely ignored the previous fiber theories. The fiber-matrix interaction was consequently considered to play an essential role in the ballistic protection as well (Yang, 1993).

1.1.1 Ballistic fibers

The high strength of fibers has been developed rapidly for armor structure. Fibers conventionally used include aramids (Kevlar^{TM} or Twaron^{TM}) . polyethylene fiber (Spectra^{TM} or Dyneema^{TM}) , nylon fiber , glass fiber and the like (Jacobs and Dingenen, 2001). The selection of fibers for application depends heavily on its mechanical property. Several factors must be considered i.e. sonic velocity and energy absorption of the specimens. Fibers provide excellent impact resistance in that the fibers have high sonic velocity and high specific energy absorption because of its distribution of kinetic energy upon ballistic impact

Specific energy absorption, E_{sp}, depends on some physical parameters with the relationship shown below:

$$E_{sp} = \frac{0.5\sigma_{rupt} * \varepsilon_{rupt}}{\rho} \tag{1.1}$$

Where σ_{rupt}, ε_{rupt} and ρ are fiber stress at rupture, elongation at rupture and its density respectively. Whereas sonic velocity in fiber, V_s, is defined as $V_s = \sqrt{E/\rho}$ where E is fiber modulus.

Table1.1 Mechanical properties of important high strength fiber (Jacobs and Dingenen, 2001)

Fiber	Strength (GPa)	Modulus (GPa)	Elongation at break (%)
Aramid	2.8-3.2	60-115	1.5-4.5
HPPE	2.8-4.0	90-140	2.9-3.8
LCP	2.8	65	3.3
PBO	5.5	280	2.5
S glass	4.65	87	5.4

Note: HPPE is high performance, LCD is Vectra® liquid, and PBO is poly (p-phenylene benzobisoxazole),

One class of fibers useful for ballistic armor application is polyamide fiber e.g. Kevlar™ because of its excellent thermal properties, highly crystalline, and highly oriented fine structure as well as high tensile properties. Its highly crystalline, highly oriented structure gives rise to high modulus which is required for enhancing sonic velocity. The high tenacity and moderate elongation of Kevlar™ fiber provide high toughness and thus high work to break for the transverse deformation. These characteristics attribute to the fairly effective absorption and distribution of the impact force along the longitudinal axis: therefore, useful for ballistic applications. The fiber is consequently considered as a major reinforcing constituent for ballistic armor in this work.

1.1.2 Polymer matrix for ballistic composites

The types of binders such as thermoplastic resins, thermosetting resins, and alloys between thermoplastics and thermosets have been used as matrices for ballistic resistance. The resin function is to hold the fibers firmly in a three-dimensional array of crossing layers. The selection of a resin for the ballistic composite depends on its required characteristics. Some important factors should be considered including rigidity, environmental resistance, thermal stability, wear resistance, combustibility, processing ability, and shelf-life. The resin content is generally carefully controlled to achieve a balance of structure and ballistic properties. The amount of resin necessary to consolidate the fibers comprises 75-80 percent by weight having been reported (Park, 1996, 1999). If the amount of resin substantially increases above the desired amount the matrix, it will become a major part of the armor volume weakening the materials. However, if the resin is substantially less than that required to wet all fibers, this will result in the composite material wherein the fibers are not properly consolidated and held in the proper position so that upon impact, the fiber tends to separate relatively easily allowing the projectile to pass through before the fiber absorbs impact forces (Epel, 1987).

In general, the resins used as a binder in ballistic armor have an adhesive characteristic with respect to the fiber but with the tensile strength less than that of the fiber. That is, upon impact, the fiber will function predominantly to transmit impact force along its longitudinal axis. In principle, it is required that the resin should not hold the fiber too rigidly along the surface but allow some small amount of movement of the fiber surface longitudinally within the resin. Obviously, the composite structure resists and provides a limited fiber spreading transversely to the fiber axis upon projectile impact.

Phenolic resins provide one future class of resins suitable for a matrix of a composite armor. Phenolic resins are inexpensive, can be handled using conventional processing technology, and do not bond too firmly to ballistic fibers especially Kevlar^{TM}. However, phenolics do require that moisture be driven from the resins during a curing stage which is one additional step in the composite fabrication process. Other binders which have been reported to be used for Kevlar^{TM}-reinforced composites consisted of epoxy resin, styrene-isoprene-styrene, and phenolic polymer alloys with poly(vinyl butyl ether) etc. (Denommee, 1976; John, 1992; Li et al., 1996).

Polybenzoxazine, a novel class of phenolic resins, has a wide range of mechanical and physical properties that can be tailored to various needs. The polymer can be synthesized by ring-opening polymerization of the aromatic oxazines with no by-products released upon curing, no catalysts needed, no solvent elimination, and no need of monomer purification (Ishida, 1996). The property balance of the material renders the polymer with good thermal, chemical, electrical, mechanical, and physical properties including very low A-stage viscosity, near-zero shrinkage, low water absorption, high thermal stability, good fire-resistant characteristics, and fast development of mechanical properties as a function of curing conversion. (Ishida and Allen, 1996).

One major outstanding property of benzoxazine resin is its ability to form hybrid network with several other resins for tailor-made behaviors (Ishida and Allen, 1996; Takeichi et al., 2000; Rimdusit and Ishida, 2000). In our recent work, urethane elastomer was used to alloy with benzoxazine resin to improve thermal and mechanical properties of the resulting polymer hybrids (Rimdusit et al., 2005). This observation also makes it possible to fine tune and enhance the property of the obtained ballistic armor composites. As a consequence, the systems of polybenzoxazine alloying with urethane elastomer as ballistic composite matrices will be evaluated in this study.

1.1.3 Ballistic polymer composites

The development of composite technology has improved properties of the resulting armor structure. Fibers are usually selected as a major reinforcement for the composites. Eventhough each parent materials cannot provide sufficient ballistic properties, after combining the parent materials, the level of protection is sometimes improved significantly. This is because the resulting composite is able to generate more energy absorption mechanisms. Hence, there are many literature data about the usage of the normal fiber i.e. E-glass fiber (Naik et al., 2005), carbon fiber (Ulven et al., 2003), graphite fiber (Hosur et al., 2005) etc. to produce ballistic composites. These fibers are capable of forming effective armor composites with their suitable polymer matrices. Absorption of kinetic energy of composite material composes of several mechanisms, including tensile failure of fibers, elastic deformation of a composite, interlayer delamination, and inertia effect due to impact. In general, kinetic energy can be absorbed and distributed according to basic factors such as mechanical property and direction of fiber arrangement, matrix properties, and interfacial strength (Thornton, 2001; Morye et al., 2000).

1.2 Objectives

1. To develop a light weight ballistic armor based on Kevlar$^{\text{TM}}$-reinforced composites using benzoxazine alloys as matrices.
2. To study suitable composition ratios of the polymeric alloys between benzoxazine and urethane resins and a number of layers of the Kevlar cloth to produce ballistic composites of level IIA or higher.

1.3 Scope of the Study

1. Synthesis of the polymeric alloys between the benzoxazine resin (BA) and the flexible urethane elastomer based on IPDI-polypropylene oxide polyols (PU) at the mixing ratios of BA:PU equal 100:0, 90:10, 80:20, 70:30, and 60:40.
2. Investigation of the effect of resin composition ratios on the curing reaction or crosslinking process of the alloys in (1).
3. Fabrication of the composite samples between the matrices in item (2) and Kevlar$^{\text{TM}}$ fiber at varied layers of the Kevlar$^{\text{TM}}$ cloth i.e. 10, 20, 30 layers. The

resin content is kept at about 20wt%. Some relevant mechanical properties and physical properties are evaluated.

4. Fire test with 9 mm hand gun of full metal jacket, 124 grain (8.0 g) projectiles (NIJ level IIA).
5. Evaluation of the interfacial bonding between the alloys in item (3) and the Kevlar^{TM} fiber by analysis of fracture surface using a microscope.