CHAPTER VIII
BALLISTIC RESISTANCE

8.1 Introduction

The violence in the southernmost provinces of Thailand has created a high demand for bulletproof vests. Generally, a bulletproof vest (ballistic vest or bullet-resistant vest) is an item of personal armor designed to protect the wearer's vital organs from injury caused by firearm projectiles, and is worn on the torso. The manufacturing of bulletproof vests is mainly concerned with performance, efficiency, and safety. In recent years, the highest performing fibers such as Kevlar® and Zylon® have been used to make the bulletproof vests. This is due to their rigid-rod chain molecules providing high modulus, high tensile strength, and high thermal stability. This research work takes an interest in Nylon12 (Polyamide 12 or PA 12) due to its lower cost for the manufacturing of bulletproof vests.

Nylon12 is a semicrystalline polymer; hence, the crystallization of Nylon12 can take place under mechanical stretching for making fibers, leading to the increasing of hydrogen bonding. This in turn increases the stiffness (elastic modulus) and the strength of Nylon fiber. With a long hydrocarbon chain and a low concentration of amides (nitrogen-containing organic compounds), Nylon12 absorbs very little moisture. The association of water with amide groups is essentially a replacement of the amid-amide hydrogen bond with the amide-water hydrogen bond. Consequently, low water absorption allows components made from Nylon12 to retain a high degree of dimensional stability even in environments with fluctuating humidity levels.

While the vest can prevent bullet penetration, the vest and wearer still absorb the bullet's energy. Even without penetration, modern pistol bullets contain enough energy to cause blunt force trauma under the impact point. Vest specifications will typically include both penetration resistance requirements and limits on the amount of impact energy that is delivered to the body. This research work has studied the incorporation of natural rubber (NR) and polystyrene/maleated natural rubber copolymer (PS/MNR) into Nylon12 in order to prevent the blunt trauma. This is due to a high elasticity of rubber that can promote more energy absorption and energy dissipation of the materials. In other words, it is capable of absorbing the bullet thus stopping it from reaching the skin and scatters the impact of the bullet over a larger portion of the materials. Besides, the presence of succinimide linkages via the reaction between maleic anhydride and amine-end groups of Nylon12 as well as hydrogen bonds makes the molecular chains at Nylon12/NR interfaces become more stiff and difficult to entangle. This leads to an increase of modulus of [Nylon12/NR]/[PS/MNR] blends. Consequently, the bullet can be deformed and stopped when it hit the material. This ballistic resistance makes it effective in protecting the wearer from ballistic threats.

Based on the discussion above, the materials made from Neat Nylon12, [Nylon12/NR]/[PS/NR] blends, and [Nylon12/NR]/[PS/MNR] blends were prepared into a sheet with a thickness of 3 mm by using a compression molding machine. The ballistic resistance of these materials was then investigated by using a shotgun insert.

8.2 Bullet Specification

The revolver (shotgun insert) .38 special (Smith & Wesson brand) with lead bullets (Winchester) shown in Figure 8.1 was used to study the ballistic resistance of the materials. The bullet specification is shown in Table 8.1.

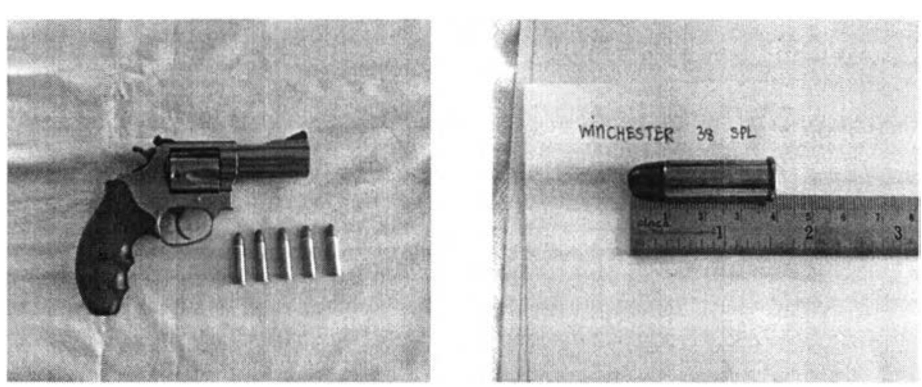

Figure 8.1 The .38 special revolver with lead bullets.

Table 8.1 Specification of .38 special revolver with lead bullets

	Specification	
1	Revolver	.38 special with 5 shot bullets
	· Dimension	195 x 120 x 32 mm
	· Barrel length	76 mm (3 inch)
	· Weight	·695 g
	· Trigger -pull force	Double 5,450 g (12 lb) and single 2,050 g (4.5 lb)
2	Lead bullet	
	· Weight	158 grain
	· Speed	800 ft/s at 50 yards (45.72 m)
	· Bullet energy	225 ft·lb (305 J)

8.3 Bullet Energy Calculation

Bullet energy or muzzle energy is the kinetic energy of a bullet as it is expelled from the muzzle of a firearm. It is often used as a rough indication of the destructive potential of a given firearm or load. The heavier the bullet and the faster it moves, the higher its bullet energy and the more damage it will do. The general formula for the kinetic energy is shown in Equation (8.1).

$$E_k = \frac{1}{2}mv^2 \qquad (8.1)$$

when E = energy (J)

m = mass (kg)

v = velocity (m/s)

However, in United States engineering units and the National Institute of Justice (NIJ) standard, weight and speed of the bullets are reported in grain (gr) and feet per second (ft/s). Hence, E_k is typically given in foot-pound force (ft·lbf) as shown in Equations (8.2) and (8.3).

$$E_k = \frac{1}{2}mv^2 \times \left[\frac{1\,\text{ft}\cdot\text{lbf}}{7000\,\text{gr} \times 32.163\,\text{ft}^2/\text{s}^2}\right] \tag{8.2}$$

Hence, $$E_k = \frac{mv^2}{450282} \tag{8.3}$$

when	E	=	energy (ft·lb)
	m	=	mass (grain)
	v	=	velocity (ft/s)

and the value of 32.163 is an acceleration due to gravity (ft/s^2)

Average bullet energies for common piston cartridges are shown in Table 8.2. These velocities and energies of bullets also depend on the length of the barrel that a projectile is fired from.

Table 8.2 Average bullet energies for common piston cartridges

Cartridge	**Bullet Energy**		**Cartridge**	**Bullet Energy**	
	ft·lbf	**joules**		**ft·lbf**	**joules**
.380 ACP	199	270	.357 Mag	550	750
.38 Special	310	420	10 mm Auto	650	880
9 mm Luger	350	470	.44 Mag	1,000	1,400
.45 Colt	370	500	.50 AE	1,500	2,000
.45 GAP	400	540	.454 Casull	1,900	2,600
.45 ACP	400	540	.460 SW	2,400	3,300
.40 S&W	425	576	.500 SW	2,600	3,500
.357 Sig	475	644			

8.4 Ballistic Resistant Testing Method

The ballistic resistance of materials was done by shooting the bullet to the material sheet with thickness of 3 mm. The shooting distance was 5 m, and the wood board with thickness of 25.4 mm was used as a backup part as shown in Figure 8.2.

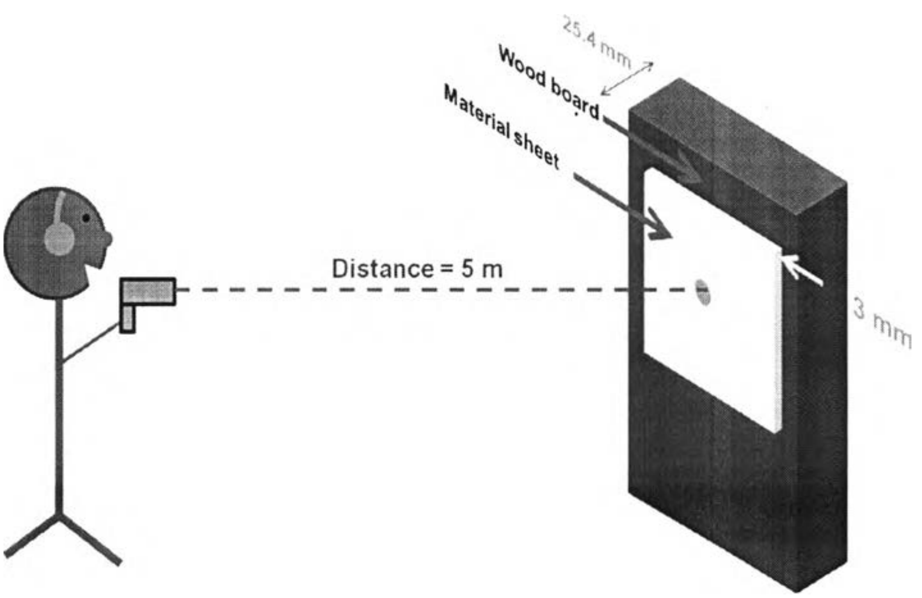

Figure 8.2 Ballistic resistant testing.

8.5 Results and Discussion

Generally, the bullet slows down when it leaves the barrel due to the gravitational force and air friction. So, it means that the further the target is, the less damage will be delivered. The materials after bullet testing are shown in Figure 8.3. The results demonstrate the penetration of bullet through the materials; Neat Nylon12 (left), [Nylon12/NR]/[PS/NR] (middle), and [Nylon12/NR]/[PS/MNR] (right). However, more energy absorption and energy dissipation (white region around a defect point) are found in the blends using reactive compatibilization ([Nylon12/NR]/[PS/MNR] blends) as compared to the blends using non-reactive compatibilization ([Nylon12/NR]/[PS/NR] blends) and Neat Nylon12, respectively.

The Nylon12 matrix with high modulus deforms the bullet head while the dispersed rubber phase with high elasticity helps in the energy absorption and energy dissipation leading to the reduction of bullet velocity. In other words, the more energy absorption of the material, the lower energy and velocity of the bullet will be obtained. Consequently, the penetrating distance of the bullet through the wood board is found to decrease from 12 mm for neat Nylon12, to 8 mm for [Nylon12/NR]/[PS/NR] blends, and to 2 mm for [Nylon12/NR]/[PS/MNR] blends. Figure 8.4 also shows the bullet head before and after the ballistic testing. The materials catch and deform the bullet, spreading its force over a larger portion of the materials. The rubber phases in the materials absorb the energy from the deforming bullet, bringing it to a stop before it can completely penetrate through the wood broad as mentioned above.

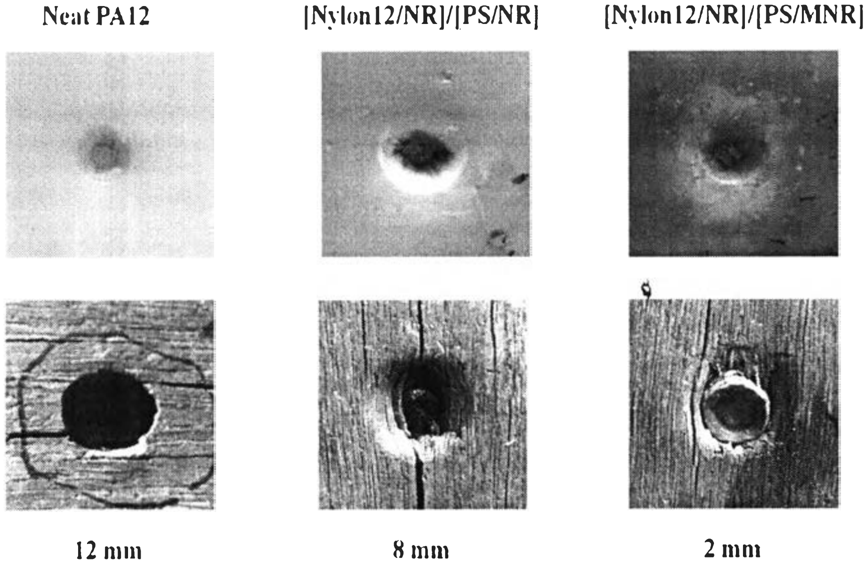

Figure 8.3 The ballistic resistance of neat Nylon12 (left), [Nylon12/NR]/[PS/NR] blends for non-reactive compatibilization (middle), and [Nylon12/NR]/[PS/MNR] blends for reactive compatibilization (right).

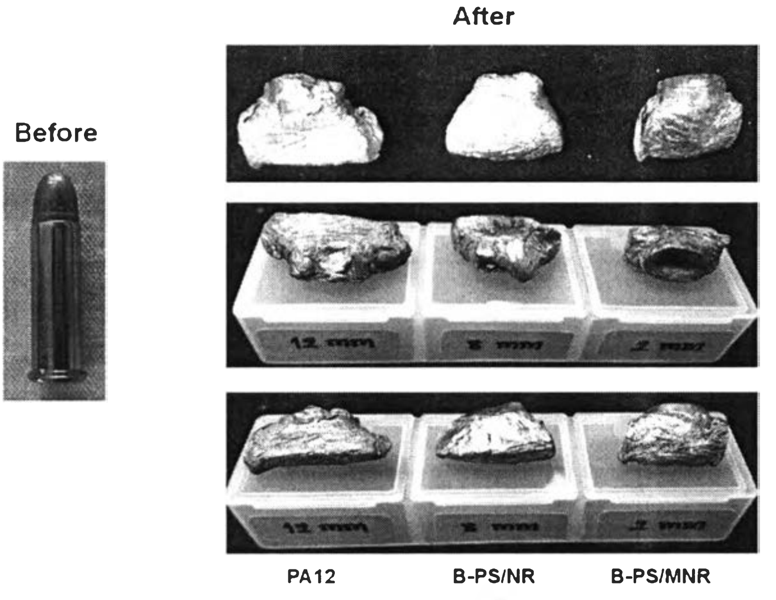

Figure 8.4 The bullet head before and after testing of Neat Nylon12, B-PS/NR for non-reactive compatibilization, and B-PS/MNR for reactive compatibilization.

8.6 Conclusions

The bullet was deformed when it penetrated through the material sheets made from neat Nylon12 and the compatibilized Nylon12/NR blends using graft copolymers of PS/NR and PS/MNR as non-reactive and reactive compatibilizers, respectively. This is due to high modulus (stiffness) of Nylon12. For bullet energy absorption, compared with neat Nylon12, the presence of natural rubber in both [Nylon12/NR]/[PS/NR] blends and [Nylon12/NR]/[PS/MNR] blends provides more energy absorption and energy dissipation in these materials. It leads to the reduction of bullet energy and bullet velocity. As a consequence, the bullet stops before it can completely penetrate through the wood broad.