Development of Composite Armors Using Natural Rubber Reinforced with Steel Wire Mesh for Ballistic Resistance

Seksak Asavavisithchai*, Teeranan Marlaiwong, Nuthaporn Nuttayasakul

Innovative Metals Research Unit, Department of Metallurgical Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand
Department of Civil Engineering, Chulachomklao Royal Military Academy, Nakornnayok, 26001, Thailand
E-mails: seksak.a@chula.ac.th; teeranan.mar@gmail.com; nuthaporn.crma@gmail.com

Abstract. A protective ballistic armor used for military buildings, that will meet the anti-terrorism and force protection demands, are increasingly needed, particularly in Thailand's southernmost provinces. A new type of ballistic armor system has been developed, composing of composite layers, using natural rubber reinforced with steel wire mesh, and Al plate. The composite layers were used as front material while the Al plate was used as backing plate. The armors were tested against NIJ-Type III threats using NIJ 0108.01 ballistic test standard. The armor, with 12 mm Al backing plate, can successfully resist the NIJ-Type III threat with only combination of two composite layers. Different than hard and brittle plate, such as ceramic, the use of composite layer at the front did not blunt and erode the projectile, due to its ductile property. However, the composite layer effectively reduces the velocity of projectile, due to high fracture toughness, as a result of reinforcing steel wire mesh layers in the composites. The projectile was finally stopped by the Al backing plate.

1. Introduction
In past decades, there have been continuously shooting and bombing attacks in Thailand's southernmost provinces from a long-dormant separatist insurgency [1]. The terrorist attacks resulted in loss of lives and properties in both government officers and civilians. To minimise the effect of attack, high efficiency protection systems have been developed and installed on building walls and vehicles. Currently, most of ballistic protection walls are the reinforce concrete system, due to relatively high compressive strength and low cost. However, drawbacks of this system is low tensile strength, ductility and toughness.

High-performance hard armor systems for ballistic protection typically consists of multiple layers [2]. It usually uses a hard material, such as ceramic or hardened steel plate, at the strike face, coupled with a ductile material, such as steel, aluminium or fiber reinforced composite [3, 4]. Upon the projectile impact, the hard material can blunt and erode the projectile, due to its high hardness, resulting in fracture of bullet. The ductile material, as backing plate, at the rear face then absorb the residual kinetic energy of the fractured or deformed projectile through plastic deformation [5]. High-performance composites, such as Kevlar™ and Twaron™, or Spectra™ or Dyneema™, are frequently used as backing plate to absorb the kinetic energy of the projectile [6-8]. Nevertheless, the major drawbacks of hard armor protection system are weight and cost. The use of ceramic or hard steel plate result in increasing weight to the armor. Development of light-weight protection system is then necessary, especially for transportation vehicles, in order to maintain high mobility. In addition, the
use of high-performance composites also results in high armor costs, contributing to limit in widespread use of the armor.

Alternatively, rubber composite materials can be used as backing plate in ballistic protection system applied in tanks, infantry fighting vehicles, and shipbuilding [9, 10]. The rubber composite provides high mechanical properties, such as low density, high specific strength and high specific modulus. It is reported that the rubber composite materials have high anti-eroding performance on bullets, grenade fragments, and kinetic energy projectiles. Compared with other high-performance composites, the rubber one is superior in terms of safety and environmental effects [11].

The present research aims to develop a protective ballistic armor used for military buildings that will meet the anti-terrorism and force protection demands. The armor is made of composite materials, composing of A5083 Al plate and natural rubber reinforced with steel wire mesh. Ballistic testing was performed using U.S. National Institute of Justice (NIJ) standard 0108.01 for 5.56 mm NATO (Type III High Power Rifle) [12].

2. Experimental Procedure

The ballistic composite armor (BCA) panel, with a size of 30.5 × 30.5 cm, is manufactured, using either A5083 aluminium (Al) plate, with a thickness of 6, 8, 10, 12 mm, or 400 stainless steel (SS) plate, with a thickness of 8, 10, 12 mm, and natural rubber reinforced with steel wire mesh (SWM). The Al plate is obtained from META Metal Enterprise (Thailand). The steel wire sheets, with a mesh size of 12 × 12 mm, is supplied by Global House. The mesh was sectioned to 30.5 × 30.5 cm and embedded to pre-vulcanised natural rubber (NR) latex. The NR latex, provided by Rubber Authority of Thailand, has chemical composition as shown in TABLE I. The mesh was orderly layered up to 5 layers. The NR, reinforced with steel wire meshes, and either A5083 Al plate or 400 SS was used as backing and strike plates, respectively. The mechanical bonding, using bolt and nut fasteners, were performed around the corner of BCA panels. The total thickness of BCA panels was varied between 30 and 48 mm.

Tensile testing of NR embedded with different steel wire meshes was conducted, following ASTM D3039 standard, using a universal testing machine (UTM), in order to examine mechanical behavior of samples. The testing was performed, using speed of 2 mm/s. Ballistic testing of BCA panels was conducted, using the guidelines included in the National Institute of Justice (NIJ) standard 0108.01 for Type III [12]. The test was performed at Military Explosive Factory. The projectile speeds were measured, using velocity chronographs BETA Model Cl35-0005, placed before and after the BCA panels. The shooting distance was maintained at 15 m between the gun and the panels with a zero angle of obliquity the gun. The tests were performed with combined two or three composite layers at the front and with Al plate at the back for different thicknesses, as presented in Fig. 1.

Table 1. Natural Rubber (Nr) Latex Composition

| Chemical agents                             | Content | Phr: (Part per hundred of rubber) |
|---------------------------------------------|---------|-----------------------------------|
| STR 5L                                      | 1,000   | 100                               |
| Zno                                         | 50      | 5                                 |
| C_{18}H_{36}O_2 (Stearic acid)              | 20      | 2                                 |
| CaCO_3                                      | 3,000   | 300                               |
| Color agent                                 | 50      | 5                                 |
| WSL (Wing Stay L)                           | 10      | 1                                 |
| N-Cyclohexylbenzothiazole-2-sulphenamide    | 15      | 1.5                               |
| Tetra methyl thiuramdisulphide              | 2       | 0.2                               |
| S (Sulfur)                                  | 25      | 2.5                               |
3. Results And Discussion

Fig. 2 presents densities and mechanical stress-strain curves of NR reinforced with different SWM layers. It is clear that the composite density increases when the layers of SWM in the composites increase. The highest density of 1,976 kg/m$^3$ is then obtained from the composite with five SWM layers. The addition of SWM layers in the composites results in increasing stresses. Similar to the effect of SWM addition to composite density, the more the addition of SWM, the higher the resistant stress. The maximum stress of 0.11 MPa is therefore found in the composite with the addition of five SWM layers.

![Figure 2](image-url)

**Figure 2.** (a) Densities and (b) mechanical stress-strain plots of composites reinforced with different steel wire mesh layers

![Figure 3](image-url)

**Figure 3.** Mechanical stress-strain plots of composites at different thicknesses.
Fig. 3 shows the stress-strain plots of composites with different thicknesses. The thickness of 24 mm is estimated from placing two bolted composite samples under penetration testing. Due to the limit of compression machine capability, the maximum thickness of NR reinforced with SWM can be produced up to five layers, which is equivalent to approximately 12 mm thickness. It can be seen that the stress increases when thickness of composite sample increases. The larger the thickness, the higher the stress, as well as energy absorption. The energy absorption is calculated from the area under the stress-strain curves. The composites with thickness of 12 and 24 mm show the energy absorption of 9.7 and 11.4 J, respectively. An increase in composite thickness results in increasing stress.

| Armor panel | 1st composite layer | 2nd composite layer | 3rd composite layer | A5083 Al backing plate thickness |
|-------------|---------------------|---------------------|---------------------|---------------------------------|
|             | Front face          | Front face          | Front face          |                                 |
| 1           | ![Image](1)         | ![Image](2)         | ![Image](3)         | 6 mm                            |
| 2           | ![Image](4)         | ![Image](5)         | ![Image](6)         | 8 mm                            |
| 3           | ![Image](7)         | ![Image](8)         | ![Image](9)         | 10 mm                           |
| 4           | ![Image](10)        | ![Image](11)        | ![Image](12)        | 12 mm                           |

**Figure 4.** Damages in front face strike and rear face of impact area of NIJ-Type III tests

The images of the front faces of individual composite layer assembled to BCA panel after NIJ-Type III ballistic tests are shown in Fig. 4. In all cases, the BCA panels can stop the projectiles upon impact, meeting NIJ-Type III standard requirements. In all cases, the projectiles were found to reside in Al backing plates, suggesting that the bullets were slowed and stopped by the plates. The BCA
panels, which composed of three composite layers, with at least 6 mm Al backing plate, are required to resist the NIJ-Type III treat. However, the BCA panels, with 12 mm Al backing plate, can successfully resist the NIJ-Type III treat with only combination of two composite layers. In all cases, no fragment of projectiles was found outside of the BCA panels.

Different than hard and brittle plate, such as ceramic, the use of composite layer at the front show no radial crack at the impact area, due to its ductile property. Only holes in small craters were formed at the impact areas, indicating full penetration of projectiles through the composites. In all cases, no fragment of bullets is observed in all composites layers, suggesting that the composites did not cause any physical damage to the bullets. It is expected that the composite layers can effectively reduce the velocity of bullet and absorb its most kinetic energy through plastic deformation. The inspection of Al backing plates, after the NIJ-Type III ballistic tests, showed that they had deformed bullets, with small fragments, embedded at the front surface. This indicates that the Al backing plate had successfully absorbed the residual kinetic energy of the bullet through compression.

Generally, in ballistic impacts, the kinetic energy of the projectile is transformed into plastic deformation and fracture of the projectile and armor plate, and heat. In this system, upon the impact, the ductile composite layers effectively slow the projectile, due to high fracture toughness, as a result of reinforcing SWM layers in the composites. Fig. 5 presents the fracture surface of composite, reinforced with two SWM layers, after tensile test. It can be seen that the NR latex is still attached to the surface of steel wire, even after the severe damage. The steel wire has much higher strength than the NR latex, resulting in increasing resistance to deformation developed in the composite during the penetration of projectile.

![Figure 5](image)

**Figure 5.** Fracture surface of composite sample reinforced with two steel wire mesh layers.

### 4. Conclusion

Composite using natural rubber reinforced with steel wire mesh have been successfully produced. Two or three composite layers, used as front material, were attached to A5083 aluminium plate, used as backing plate. A combination of the composite layers and Al plate results in a new ballistic composite armor system. The armors were tested against NIJ-Type III threats using NIJ 0108.01 ballistic test standard. The armor, with 12 mm Al backing plate, can successfully resist the NIJ-Type III treat with only combination of two composite layers. Upon the impact, the ductile composite layers effectively slow the projectile, due to high fracture toughness, as a result of reinforcing steel wire mesh layers in the composites. The projectile was finally stopped by the Al backing plate. The study of these composite armors can lead to improvement in more effective and sustainable ballistic armors with lower material cost.

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