Protection Against Secondary Fragmentation From AP Mines Based on Natural Fibre Composites

Paul Wambua  
*Katholieke Universiteit, Royal Military Academy*

Marc Pirlont  
*Katholieke Universiteit, Royal Military Academy*

Ignaas Verpoest  
*Katholieke Universiteit, Royal Military Academy*

Follow this and additional works at: [https://commons.lib.jmu.edu/cisr-journal](https://commons.lib.jmu.edu/cisr-journal)

Part of the Defense and Security Studies Commons, Emergency and Disaster Management Commons, Other Public Affairs, Public Policy and Public Administration Commons, and the Peace and Conflict Studies Commons

**Recommended Citation**

Wambua, Paul; Pirlont, Marc; and Verpoest, Ignaas (2005) "Protection Against Secondary Fragmentation From AP Mines Based on Natural Fibre Composites," *Journal of Mine Action*: Vol. 9 : Iss. 1 , Article 49. Available at: [https://commons.lib.jmu.edu/cisr-journal/vol9/iss1/49](https://commons.lib.jmu.edu/cisr-journal/vol9/iss1/49)

This Article is brought to you for free and open access by the Center for International Stabilization and Recovery at JMU Scholarly Commons. It has been accepted for inclusion in Journal of Conventional Weapons Destruction by an authorized editor of JMU Scholarly Commons. For more information, please contact dc_admin@jmu.edu.
Wambua et al.: Protection Against Secondary Fragmentation From AP Mines Based on Natural Fibre Composites

Published by JMU Scholarly Commons, 2005

Protection Against Secondary Fragmentation From AP Mines Based on Natural Fibre Composites

by Paul Wambua, Marc Pfister, Stefan Lemon and Ignasi Vergez (Kingsley University's Royal Military Academy)

The 1997 Orsag Convention defines a mine as a munition designed to be placed on the ground or in water and to be exploded by the presence, proximity or contact of person or vehicle. An AP mine is defined as a mine designed to be exploded by the presence, proximity or contact of a person or vehicle that will incapacitate, injure or kill one or more persons.

AP mines are either fragmentation or blast types and are equipped with high explosives (chemicals that do not detonate). Fragmentation mines (such as POMZ [75 g TNT]) are normally triggered by a tripwire and project metal shards at very high speeds toward the victim. Bullets thrown to persons are caused by fragmentation as opposed to blast effects. Blast mines (e.g., PMN40 g TNT) cause injuries through direct or indirect blast effects. Direct blast effects are those involving changes in environmental pressure due to the movement of an air blast. Blast waves may therefore cause injuries to a deminer through overpressure. On the other hand, blast effects can be subdivided into secondary effects, namely effects (whole body displacement) and miscellaneous effects (e.g., dust).

Secondary effects include secondary fragmentation from mine blast casing, inner mine components, shrapnel, surrounding dirt, gravel, fragmented demining tools (such as those depicted in Figure 3), etc., all of which are blasted at the victim at different speeds depending on the mass of the projectiles. The extent of injury depends on the mass, velocity, shape, density and angle of impact of the fragments.

The level of protection provided by an armour composite material depends on its energy absorption capability, which is in turn influenced by the type of reinforcing fibres and fibres, number of fibre layers, areal density, and compressive strength.

The current protective clothing (flak jackets) and rigid armour for deminers are manufactured from high-performance fibres such as aramid (Kevlar, Twaron®) fibres and their composites.
Materials and Sample Preparation

Thin wove 80 g/m² (wet) density 280 g/m², 10 ends and pick(s) was purchased from Libeco, Lurate, Meulbeek, and Belgium, while polypropylene in sheet form was supplied by Japan GMT Co. Ltd. Details of other natural fiber composites tested in the ballistic study can be found in a paper titled "The Response of Natural Fiber Composites to Ballistic Impact by Fragment-Simulating Projectiles," submitted for publication in Composite Structures.

The fabric and polypropylene sheet were cut into rectangular specimens at a pressure of 60 kg/cm² at a rate of 15 minutes. The resulting fiber volume fraction varied from 40 to 50 percent by reducing the thickness of the multifilament. The effect of steel was investigated by bonding thin 0.8 and 1.5 mm mild steel plates onto the composites with epoxy glue.

Ballistic Testing in the Laboratory

The experiment was conducted by measuring the deviation of a material against ballistic fragmenting. The aim of the STANAG 2920 is the determination of the so-called terminal velocity, and the velocity of the projectile with the probability of perforation of the Planner Projectile is 0.5. For ammunition, a VFP of 450 m/s is related to a fragmenting projectile (FRP) of 1.1 g as standard.

The weapon used was a Block Metal Annular Cartridge Rechargeable Cartridge (BMAC) (see Figure 2, previous page) and the FRP (Figure 3 and 4) was used. The diameter of the BMAC was 5.385 mm and was made of alloy steel with a Rockwell hardness of 50.2. The mass of the BMAC was 1.1 g. The propellant used was ball powder 650-inch shot and the inert was seven inches per round.

The room temperature during the tests was maintained at 22°C.

The natural fiber composite panels and composites were subjected to a high-momentum blast from a mild steel sheet placed 10 m from the weapon. The mean velocity of the projectiles was calculated with the help of a chronometer that measured the projectile flight time between two measuring bases 2 m apart. The projectile impact and residual velocities were required to calculate the amount of kinetic energy absorbed by the target. A Doppler radar antenna linked to a computer was used to determine the velocity of the projectile after perforation.

Results of Laboratory Tests and Discussion

Initial ballistic tests

The results of the ballistic test are shown in Table 1. When the mean fiber composite panels did not meet the criteria set by NATO STANAG 2920 (VFP 850 m/s), the composite mild steel-hybrid was adopted at VFP of at least 466 m/s. Despite the low VFP, the fiber composite panels were compared for their resistance to dynamic loads, including the external shock and the secondary fragmentation from blast. The fiber composite panels were cut into 100 mm by 100 mm specimens for the composite material. Most of the secondary fragmentation is usually of much lower density and lower diameter than metallic projectile fragments. The irregular shape and large surface area presented to the armor material further decreases the possibility of complete encapsulation of the projectile.

Optimized solution The ballistic performance of composite materials can be improved by processing high fiber volume fractions. Depending on the application, the most suitable material for ballistic protection provides a good balance among weight, cost, and the level of protection. While it is possible to use very low post-impact, such as synthetic fiber (e.g., Kevlar, glass) composites, natural fiber composites processed with various high fiber volume fractions. A normal threepoint bending test was conducted to monitor the bonding at the interface so as to ensure the mechanical integrity of the composite panel. The flexural modulus of the flex composite increased with increasing fiber volume fraction up to VFP 50 percent, then showed a decrease as VFP 50 percent as demonstrated in Table 3. A fiber volume fraction of 50 percent was utilized in the processing of samples for the field tests. The increase in the fiber volume fraction resulted in a decrease in the composite thickness and total density (which in turn causes a reduction in the VFP). With the high fiber volume fraction (50 percent), the composite presented a good balance among weight, toughness, and VFP. Table 3 presents the properties of the composite and composite material hybridization for this research work. These two materials were used for the field tests.

Ballistic Field Testing

Simulated AP mine mines containing C4 explosives were utilized in the field tests carried out at the NATO test site at the Vizcaya-Holtenberg shooting field in Belgium.

Experimental details

The panel was placed in front of a wooden support fixed to the ground as illustrated in Figure 5. The test was conducted using 35 g, 70 g, and 150 g of C4 explosives to simulate the small, medium, and large AP mines. The explosives were placed in the ground at a distance of 30 m and 50 m (50 cm only for plain composite) from the target and covered with different kinds of projectiles, such as stones, in order to increase the amount of secondary fragmentation and to simulate detonating accidents. The results of the field tests are summarized in Table 4.

Table 3

<table>
<thead>
<tr>
<th>Field Test Number</th>
<th>Composite Type (flex)</th>
<th>Distance from mine (cm)</th>
<th>Mass of C4 explosives (g)</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>hybrid</td>
<td>fixed/side back support</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>2</td>
<td>hybrid</td>
<td>fixed/back support</td>
<td>50</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>hybrid</td>
<td>fixed/no support</td>
<td>35</td>
<td>150</td>
</tr>
<tr>
<td>4</td>
<td>composite</td>
<td>fixed/back support</td>
<td>50</td>
<td>70</td>
</tr>
</tbody>
</table>

The following are three types of composites:

- Flex composite
- Steel composite
- Hybrid composite

Table 5: Summary of field test results
Wambua et al.: Protection Against Secondary Fragmentation From AP Mine Based on Natural Fibre Composites

Published by JMU Scholarly Commons, 2005

Materials and Sample Preparation

Tensile tests and specific (areal density) 280 g/m², 10 ends and picks (cm) was purchased from Liebes, Lagaer, Meubelbel and Belgium, while polypropylene in sheet form was supplied by Japan GFO Co. Ltd. Details of other natural fibre composites tested in the ballistic study can be found in a paper titled "The Response of Natural Fibre Composites to Ballistic Impact by Fragment-Simulating Projectiles." submitted for publication in Composite Structures.

The fabric and polypropylene sheet were cut into 30-cm square pieces that were stacked and wrapped in aluminium foil. The composite samples were processed by compressing the stacking in a compression moulding press at a pressure of 64 bar (0.64 MPa) on the material at 190 C for 15 minutes. The resulting fibre volume fraction varied from 46 to 56 percent by reducing the number of polypropylene plys. The effect of steel was investigated by bonding, bonding, 0.8 and 1.5 mm mild steel plates onto the composites with epoxy glue.

Ballistic Testing in the Laboratory

The composite was used for measuring the efficiency of a material against ballistic fragmentation is the North Atlantic Treaty Organisation Standardization Agreement (NATO STANAG 2194.1). The aim of the STANAG 2928 is the determination of the so-called V50 performance. V50 is the velocity for which the probability of perforation of the chosen projectile is 0.5. For demanning equipment, a V50 of 450 m/s related to a fragment-simulating projectile (FSP) of 1.1 g is standard.

The weapon used was a Block Marko Caliber 3.8 mm carbine gun (BMG) (see Figure 2, previous page) and the FSP (Figure 3A and 3B) was a brass-nosed, had a diameter of 3.8 mm and was made of alloy steel with a Rockwell hardness of 90.2. The mass of the FSP was 1.1 g. The propellant used was ball powder 5.0-inch thick and the round was seven inches per revolution. The room temperature during the tests was maintained at 22 °C.

The natural fibre composite panels and composite steel hybrid structures were clamped on a mild steel stand placed 10 m from the weapon. The mean velocity of the projectile was calculated with the help of a chronometer that measured the projectile flight time between two measuring bases 2 m apart. The projectile impact and residual velocities were required to calculate the amount of kinetic energy absorbed by the target. A Doppler radar antenna linked to a computer was used to determine the velocity of the projectile after perforation.

Results of Laboratory Tests and Discussion

Initial ballistic tests

The results of the ballistic tests are shown in Table 1. Whereas the plain fabric composites tested did not meet the criteria set by NATO STANAG 2928 V50 = 450 m/s, the composite mild steel hybrids met the V50 of at least 466 m/s. Despite the low V50, the fibre composite panels were earmarked for field uses since the envisaged threat and the secondary fragmentation from blunt AP mines is considered less than that posed by primary fragmentation from fragment mines. Most of the secondary fragmentation is usually of much lower density and larger diameter than metallic primary fragments. The irregular shape and large surface area present to the amour material further decreases the probability of the composite material not penetrating the target.

Optimized solution: The ballistic performance of composites can be improved by processing to high fibre volume fractions. Depending on the application, the most suitable material for ballistic protection provides a good balance among weight, cost, and the level of protection. While it is possible to use very low zinnia contents in synthetic fibre (e.g., Kevlar, glass) composites, natural fibre composites present interesting problems in high fibre volume fractions. A laminar (three-point bending) test was conducted to monitor the bonding at the interface so as to ensure the mechanical integrity of the composite panel. The flexural modulus of the flax composites increased with increasing fibre volume fraction up to Vf = 55 percent, then showed a decrease at Vf = 58 percent as demonstrated in Table 2. A fibre volume fraction of 52 percent was utilized in the processing of samples for the field tests. The increase in the fibre volume fraction resulted in a decrease in the composite thickness and overall density (which in turn cause a reduction in the V50). With the mild steel fibre volume fraction (52 percent), the composites presented a good balance among weight, thickness, and V50. Table 3 presents the parameters of the composite and composite/steel hybrid solutions for this research work. These two materials were used for the field tests.

Ballistic Field Testing

Simulated AP mines containing C4 explosives were utilized in the field tests carried out at the NATO test zone at the Hathorn-Middleron shooting field in Belgium.

Experimental setup: The panel was placed in front of a wooden support ground to the ground as illustrated in Figure 2. The test was conducted using 35 g, 70 g, and 150 g of C4 explosives to simulate the small, medium, and large AP mines. The explosives were placed in the ground at a distance of 30 and 50 cm (5 cm only for plain composite) from the target and covered with different kinds of planks, stones, as stones, to increase the amount of secondary fragmentation and to simulate detonating accelerants. The results of the field tests are summarized in Table 4.

Table 2 shows the effect of fibre volume fraction on the flexural modulus of fibre composites.

<table>
<thead>
<tr>
<th>Code</th>
<th>Material</th>
<th>Flexural Modulus (GPa)</th>
<th>Vf (%)</th>
<th>Thickness (mm)</th>
<th>Density (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>52FLG</td>
<td>Flax composite</td>
<td>5.83 ± 0.31</td>
<td>52</td>
<td>0.73</td>
<td>3.1</td>
</tr>
<tr>
<td>55</td>
<td>Flax composite</td>
<td>0.67 ± 0.18</td>
<td>55</td>
<td>0.73</td>
<td>3.1</td>
</tr>
<tr>
<td>58</td>
<td>Flax composite</td>
<td>0.73 ± 0.18</td>
<td>58</td>
<td>0.73</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Table 3: Summary of field tests

Field Test Number | Composite Type | Distance from Mine (cm) | Mass of C4 Explosives (g) | Result |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>hybrid</td>
<td>10</td>
<td>50</td>
<td>no deflection</td>
</tr>
<tr>
<td>1b</td>
<td>hybrid</td>
<td>30</td>
<td>50</td>
<td>no deflection</td>
</tr>
<tr>
<td>1c</td>
<td>hybrid</td>
<td>30</td>
<td>150</td>
<td>no deflection</td>
</tr>
<tr>
<td>1d</td>
<td>hybrid</td>
<td>30</td>
<td>200</td>
<td>no deflection</td>
</tr>
<tr>
<td>2a</td>
<td>composite</td>
<td>10</td>
<td>50</td>
<td>no deflection</td>
</tr>
<tr>
<td>2b</td>
<td>composite</td>
<td>30</td>
<td>50</td>
<td>no deflection</td>
</tr>
</tbody>
</table>

Published by JMU Scholarly Commons, 2005

Field Test Number | Composite Type | Distance from Mine (cm) | Mass of C4 Explosives (g) | Result |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>hybrid</td>
<td>10</td>
<td>50</td>
<td>no deflection</td>
</tr>
<tr>
<td>1b</td>
<td>hybrid</td>
<td>30</td>
<td>50</td>
<td>no deflection</td>
</tr>
<tr>
<td>1c</td>
<td>hybrid</td>
<td>30</td>
<td>150</td>
<td>no deflection</td>
</tr>
<tr>
<td>1d</td>
<td>hybrid</td>
<td>30</td>
<td>200</td>
<td>no deflection</td>
</tr>
<tr>
<td>2a</td>
<td>composite</td>
<td>10</td>
<td>50</td>
<td>no deflection</td>
</tr>
<tr>
<td>2b</td>
<td>composite</td>
<td>30</td>
<td>50</td>
<td>no deflection</td>
</tr>
</tbody>
</table>
Some Steps to a Reduced ESOTERIC SCENT TECHNOLOGY

Clear Path International CD to Benefit Landmine Survivors

In May 2005, in coordination with the 30th anniversary of the Vietnam War, Clear Path International was released featuring such artists as Natalie Merchant, Philip Glass, Julianne Hough and The String Cheese Incident. These artists have all responded to the landmine situation in Vietnam by contributing songs for the CD. Approximately 100,000 Vietnamese have been injured and 40,000 killed by landmines since the end of the Vietnam War. Profits from the CD will assist landmine victims. Clear Path International aids landmine survivors in Vietnam and Cambodia and on the Thai-Burma border by providing medical, social and technical support to the families and hospitals. The CD is available for purchase at www.cpi.org.

New Explosive Detector Developed

A team from the Massachusetts Institute of Technology in Cambridge, MA, has developed a new explosive detector that is up to 50 times more sensitive to landmines and explosives than the most sensitive detectors today. The technology is based on the fact that the signal for an explosive is a function of the time and the amount of energy it takes to detect it. The team's new device, which works at a distance of 30 feet, incorporates a laser to increase sensitivity and is able to detect a femtogram of explosive at 1-millisecond intervals. A laser, as well as some other factors (e.g., temperature, humidity, volume of sampled air) are discussed.

Holographic Landmine Detection System

Holographic technology has been shown to be effective in detecting landmines. The system works by creating a hologram of the mine, which can then be used to identify and locate the mine. However, the technology is not yet widely used and further development is needed to make it more practical.

Some challenges in the holographic detection system include the need for high-quality images and the difficulty of detecting small landmines. Additionally, the technology can be expensive and requires specialized equipment. Despite these challenges, holographic technology offers great potential for landmine detection and could provide a valuable tool for clearing minefields.