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

by Paul Wambua, Marc Pfeifer, Stephan Lemos and Ignas Verpaey

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The 1997 Oraya Convention defined as a mine a device or a munition designed to be placed under or near the ground and to be exploded by the presence, proximity or contact of a person or vehicle. An AP mine is defined as a munition designed to be exploded by the presence, proximity or contact of a person or vehicle. AP mines are either fragmentation or blast types and are equipped with high explosives (chemicals that 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. Ballistic shrapnel thrown as shrapnel are caused by fragmentation as opposed to blast effects. Blast mines (e.g., PMN [40 g TNT]) cause injuries through direct or indirect blast effects. Direct blast effects are those involving changes in environmental pressure due to the expansion of an air blast. Blast waves may therefore cause injuries to a person through overpressures. 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 cutting, interior mine components, scene, surrounding dirt, gravel, fragmentation inducing tools (such as those depicted in Figure 1), 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 armours are manufactured from high-performance fibres such as aramid (Kevlar, Twaron) fibres and their composites.
Materials and Sample Preparation

Thin woven glass fabric (300 g/m², 10 ends and picks/cm) was purchased from Liheco, Laget, Medebelze and Belgium, while polypropylene in sheet form was supplied by Japan GMT 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 soaked and wrapped in aluminium foil. The composite samples were prepared by compressing the stacking in a compression moulding press at a pressure of 6.4 bar (60.64 kPa) on the materials at 190 °C for 15 minutes. The resulting fibre volume fraction ranged from 46 to 58 percent by reducing the number of prepreg plies.

Ballistic Testing in the Laboratory

The composite was used as a sample for measuring the penetrability of glass fibre. The main advantage lies in its ability to make composite panels of various thicknesses and weights, as well as to control the penetrator’s size, which can be varied from small to large, and its speed and impact angle.

The fabricated panels were tested using 6 mm glass fibre reinforced plastics (GFRP) and plain steel. The test results showed that GFRP panels were more resistant to penetration than the steel panels.

Results of Laboratory Testing

Initial ballistic testing: The results of the ballistic testing are shown in Table 1. The test setup consisted of a pendulum with a 30 cm long aluminum rod. The pendulum was released from a height of 0.5 m and allowed to swing freely. The面板 was then placed against the pendulum and the force required to penetrate the panel was measured.

Table 1: Results of ballistic tests

<table>
<thead>
<tr>
<th>Material</th>
<th>V50% (mm)</th>
<th>V50% (m/s)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass fabric</td>
<td>12.0</td>
<td>9.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Glass fabric and steel</td>
<td>14.4</td>
<td>26.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Glass fabric and steel hybrid</td>
<td>14.5</td>
<td>26.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Steel</td>
<td>1.5</td>
<td>11.8</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Table 2: Effect of fibre volume fraction on the flexural modulus of glass composites

<table>
<thead>
<tr>
<th>Fiber Volume Fraction (%)</th>
<th>Flexural Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>3.0</td>
</tr>
<tr>
<td>30</td>
<td>3.5</td>
</tr>
<tr>
<td>40</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Optimized solution: The ballistic performance of composites can be improved by processing high fiber volume fractions. However, the optimal amount of fiber can vary depending on the specific application. A higher fiber content can improve the ballistic performance, but it can also increase the weight and cost of the composite.

Ballistic Field Testing

Simulated A1 mines containing 6 g explosives were utilized in the field tests carried out at the NATO test site at the Houthalen-Helchteren shooting field in Belgium.

Experimental setup: The test setup consisted of a 1.5 m long aluminum rod attached to a 1.5 m long steel pipe. The panel was placed at a distance of 30 cm from the rod, and the rod was released from a height of 0.5 m. The force required to penetrate the panel was measured.

Table 3: Summary of field test

<table>
<thead>
<tr>
<th>Field Test Number</th>
<th>Composite Type (glass)</th>
<th>Distance from cone (m)</th>
<th>Mass of Cone (kg)</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>hybrid</td>
<td>30</td>
<td>70</td>
<td>slight debonding</td>
</tr>
<tr>
<td>1b</td>
<td>hybrid</td>
<td>50</td>
<td>70</td>
<td>mine front surface scratched</td>
</tr>
<tr>
<td>1c</td>
<td>hybrid</td>
<td>35</td>
<td>150</td>
<td>no debonding</td>
</tr>
<tr>
<td>1d</td>
<td>composite</td>
<td>50</td>
<td>150</td>
<td>no debonding</td>
</tr>
<tr>
<td>1e</td>
<td>composite</td>
<td>50</td>
<td>70</td>
<td>mine front surface scratched</td>
</tr>
</tbody>
</table>

Figure 5: Test setup.

Figure 6: Fibre damage on the composite after damage time of 15 g of C4 at 30 cm.
Materials and Sample Preparation

Thin woven fabric textile (areal density 280 g/m²), 10 ends and picks/cm² was purchased from Lilexec, Lago, Meulebeke and Belgium, while polypropylene in sheet form was supplied by Japan GMT 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 Composites Structures.

The fabric and polypropylene sheet were cut into 50-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 as a pressure of 64 bar (0.64 MPa) on the material at 190°C for 15 minutes. The resulting fibre volume fraction varied from 40 to 50 per cent, by reducing the heating temperature and exposure duration. The effect of steel was investigated by bonding these (0.8 and 1.1 mm) mild steel plates onto the composites with epoxy gel.

Ballistic Testing in the Laboratory

The test method for measuring the effectiveness of a material against ballistic fragmentation is the North Atlantic Treaty Organization Standardization Agreement (NATO STANAG 2030). The aim of the STANAG 2928 is the determination of the so-called T60 performance, V60, the velocity for which the probability of perforation of the chosen projectile is 0.5. For denoting equipment, a V60 of 450 m/s relates to a fragment-simulating projectile (FSP) of 1.1 g as standard.

The weapon used was a Block Manometric Cartridge Interchangeable gun (BMC) (see Figure 2, previous page) and the FSP (Figure 3, top) was 617 mm, had a diameter of 5.38 mm and was made of alloy steel with a Rockwell hardness of 60.2. The mass of the FSP was 1.1 g. The propellant used was ball propellant 450 inch-bore and the gun was seven inches per revolution.

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

The natural fibre composite panels and epoxy and steel hybrid structures were clamped on a mild steel stand placed 30 m from the weapon. The mean velocity for 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 projectiles after perforation.

Results of Laboratory Tests and Discussion

Initial ballistic tests

The results of the ballistic tests are shown in Table 1. Where the plain fibre composites tested did not meet the criteria set by NATO STANAG 2030 for V60 = 450 m/s, the composite mild steel hybrids attained a V60 of at least 466 m/s. Despite the low V60, the fibre composite panels were earmarked for field uses since the crisscrossed threat and the secondary fragmentation from blank 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 distance than metallic primary fragments. The irregular shape and larger surface area presented to the armour material further decreases the possibility of the fragments wrapping the material.

Optimized solutions. 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, comfort, cost and the level of protection. While it is not possible to use very low cost composites such as synthetic fibre (e.g., Kevlar, glass) composites, natural fibre composites presented interesting problems at high fibre volume fractions. A formal three-point bending test was conducted to monitor the bending at the interface so as to ensure the mechanical integrity of the composite panel. The flexural modulus of the blank composites increased with increasing fibre volume fraction up to V60 = 55 percent, then showed a decrease at V60 = 58 percent as demonstrated in Table 3. A fibre volume fraction of 52 percent was utilised 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 areal density (which in turn cause a reduction in the V60). With the said fibre volume fraction (52 percent), the composites presented a good balance among weight, thickness and V60. 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 utilised in the field tests carried out at the NATO test site at the Houthalen-Helchteren shooting field in Belgium.

Experimental setup. The panel was placed in front of a wooden support ground to the target 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 and 50 cm (50 cm only for plain composites) from the target and covered with different kinds of powdery materials, such as stones, in order to increase the amount of secondary fragmentation and to simulate deterring obstacles. The results of the field tests are summarised in Table 4.

Table 4: Summary of field test

Field Test Number Composite Type (g) Distance from line (cm) Mass of C4 Explosives (g) Result

1h hybrid fixed/face back support 30 70 slight detonation
1b hybrid fixed/back support 50 70 mine front surface scratches
1c hybrid fixed/no face support 150 70 mine exploded
1d hybrid fixed/no back support 150 70 mine exploded
2a composite fixed/face back support 50 30 slight fibres?
2b composite fixed/back support 50 100 no detonating
2c fibres failure surface dust, crack at rear

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Some Steps to a Reduced Environmental Impact of Landmine Survivors

Clear Path International
CD to Benefit Landmine Survivors

In May 2005, in coordination with the 30th anniversary of the end of the Vietnam War, CD announced its "Many Years: A Benefit for Clear Path International" which was released featuring such artists as Natalie Merchant, Philip Glass, Juliana Hatfield and The String Cheese Incident. These artists have all responded to the landmine situation in Vietnam by contributing songs for this 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 has developed a new explosive detector that is up to 50 times more sensitive to landmines and explosives than existing devices: A device called the "Sniffer" is described as a "femtogram" detector of explosive substances when the filter is in the filter-stated and the surrounding environment is at the filter's natural temperature, which is the air concentration. The analysis procedure is referred to as the "Sniffer." The air concentration is performed in the following equation:

\[ \text{Sniffer} \times V \frac{\mu g}{\text{m}^3} \times M_r = \text{the amount of } \text{t} \text{ trapped on the filter, } \mu g \text{ is the amount of } \text{t} \text{ material used and } \text{M_r} \text{ is the mass of air into which the explosive sample is eventually released.} \]

This volume, \( V \), is not easily defined. It depends on the concentration of air-stable by the fuel that the filter is being exposed to. However, this equation is a constant number, but increases with the exposure time of the filter. It is obvious from Equation 2 that \( V \) becomes

Sorption Coefficients

For an unsaturated sorption of an adsorbent or a source of air, the following functional form is used:

\[ K = \frac{V}{\text{m}^3} \times \frac{\mu g}{\text{m}^3} \]