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# Ballistic impact on composites

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## 1. Introduction

Ballistic impact is the interaction of a projectile and its target. With the new high-performance fibres, especially the para-aramid fibre, improved protection materials are possible. The two main areas of application are body- and vehicle-protection.
In general three forms of protection materials can be distinguished:

- a flexible pack of woven fabrics, mainly used in vests for soldiers and police forces.

- a laminate, in general a pack of woven fabrics impregnated with resin. Main application is the military helmet.

- a combination of a laminate and other materials like ceramics or steels. These composites are used when high protection levels are requested. Examples are the armouring of vehicles and the reinforcement of vests for police forces.

This paper will mainly deal with the last item.

## 2. Properties of the para-aramid fibre

As already mentioned mainly para-aramid fibres are used in modern ballistic protection materials. It is produced by the company Akzo under the tradename Twaron. The main properties are shown in fig. 1.

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| | | Twaron Standard | Twaron CT | Twaron HM |
|---|---|---|---|---|
| Specific density | $g/cm^3$ | 1.44 | 1.44 | 1.45 |
| Tenacity | mN/dtex | 195 | 230 | 195 |
| Modulus of elasticity | GPa | 70 | 90 | 121 |
| Elongation at break | % | 3.6 | 3.3 | 2.1 |

fig.1: properties of the para-aramid fibre Twaron

The fibre can be characterized by a high modulus and a relatively high elongation of break. This lead to a high energy absorption.

## 3. The ballistic properties of laminates

Fig. 2 shows the differences between structural and ballistic laminates. The fibre volume content is high, because a too good impregnation of the fibres leads to poor ballistic behaviour. This can be explained by the fact, that the fibres have to deform in order to absorb the energy of the projectile. This is impeded by the interaction with the matrix material. On the other hand the projectile has to be deformed by the bending stiffness of the laminate to facilitate its stopping. Therefore, roughly spoken, a ballistic laminate is always a compromise.

| Ballistic Laminates | | Structural Laminates |
|---|---|---|
| 80 - 85 % | fiber volume content | 50 - 60 % |
| poor (*) | fiber impregnation | good |
| moderate (*) | adhesion | good |
| existing (*) | bubbles | none |

(*) represents a functional advantage in ballistics

fig.2: differences between ballistic and structural laminates

Fig. 3 gives a more specific survey of the main factors influencing the ballistic properties of a laminate. The fibre has to have a high tensile strength, or more exactly, a proper combination of modulus and elongation at break. In general a smaller yarn count (smaller fibre diameter) is of advantage. A yarn is made of a high number of filaments (order of magnitude = 1000). Also a decrease in filament diameter improves the ballistic performance. The construction of the fabric, in general a woven fabric, is of high importance. This is connected with the areal weight and the force-elongation curve of the fabric. The mechanical properties of the matrix material and as already indicated its impregnating behavior are influencing factors because of their influence to the bending stiffness and the fiber/matrix adhesion.

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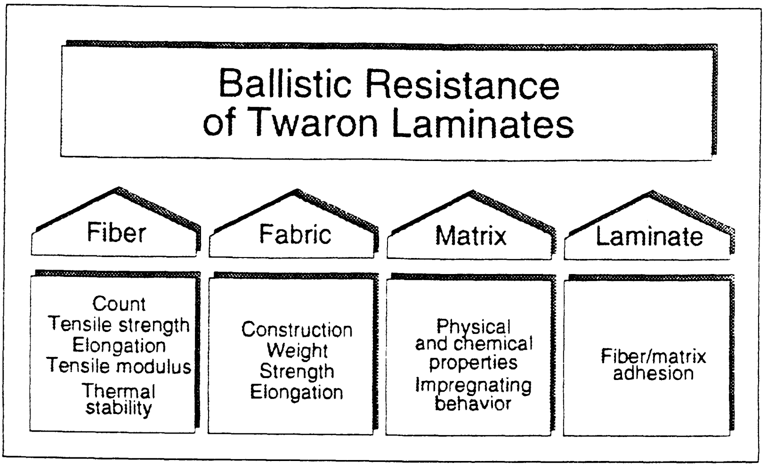


fig.3: parameters influencing the ballistic resistance of aramid laminates

## 4. Standards

| Class | Caliber | Ammunition type | Mass | $V_3$ |
|---|---|---|---|---|
| L | 9 mm Para | VMR/WK | 8.00 g | 365 m/s ± 5 m/s |
| I | 9 mm Para | VMR/WK | 8.00 g | 410 m/s ± 10 m/s |
| II | .357 Magnum | MsF | 7.50 g | 570 m/s ± 20 m/s |
| III | .223 Rem. | WK + P | 4.00 g | 920 m/s ± 10 m/s |
| | .308 Win. | VMS/WK | 9.55 g | 830 m/s ± 10 m/s |
| IV | .308 Win. | VMS/HK | 9.75 g | 820 m/s ± 10 m/s |

VMR/WK: Full Metal Jacketed
MsF: Brass-Flat-Nose Bullet
WK + P: Soft-Core Bullet + Penetrator
VMS/WK: Full Jacketed Pointed Soft-Core Bullet
VMS/HK: Full Jacketed Pointed Hard-Core Bullet

fig. 4: protection classes - German police

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The ballistic requirements for military and police armour are generally defined by national standards. Fig. 4 shows the German Police Standard and fig. 5 the widely used US standard of the National Institute of Justice (NIJ).

| Class | Round | Caliber | Ammunition type | Mass | Minimum bullet velocity |
|---|---|---|---|---|---|
| I | 1 | 38 Special | RN Lead | 10.20 g | 259 m/s |
| | 2 | 22 | LRHV Lead | 2.60 g | 320 m/s |
| II-A | 1 | .357 Magnum | JSP | 10.20 g | 381 m/s |
| | 2 | 9 mm | FMJ | 8.00 g | 332 m/s |
| II | 1 | .357 Magnum | JSP | 10.20 g | 425 m/s |
| | 2 | 9 mm | FMJ | 8.00 g | 358 m/s |
| III-A | 1 | .44 Magnum | Lead SWC | 15.55 g | 426 m/s |
| | 2 | 9 mm | FMJ | 8.00 g | 426 m/s |
| III | | 7.62 mm Win. | FMJ | 9.70 g | 838 m/s |
| IV | | 30-06 | AP | 10.80 g | 868 m/s |

AP Armor Piercing; FMJ Full Metal Jacketed; JSP Jacketed Soft Point; LRHV Long Rifle High Velocity; RN Round Nose; SWC Semi-Wadcutter

fig.5: Protection classes NIJ-Standard

The classes III and IV of the German police and the NIJ standard can only met with composite armour, e.g. with a combination of a laminate and ceramics.
The ceramics, as a rule in the form of small tiles (about 50 mm * 50 mm), is fixed on the front side of the laminates.
The purpose of the ceramics is to achieve a high degree of deformation or even destruction of the projectile. The use of small tiles leads to a better multi-hit behaviour.

## 5. Test results

Fig. 6 shows a comparison of weight between a Twaron laminate and a ballistic steel which both fulfil class I of the German police.

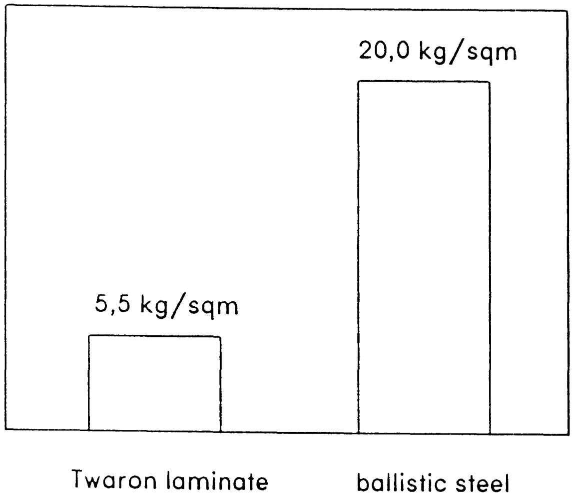


Fig. 6: solutions for class I of the German police

In fig. 7 some common matrix materials are compared. Total weight, fibre volume content, fabric construction and number of fabric layers were kept constant.
The values on top of the bars are the lowest velocities of the projectile which lead to penetration (9 mm Para, shooting test according to the erman police standard). Polycarbonate (PC) and phenolic resin (PH) are largely equal, polypropylene (PP) is worse.

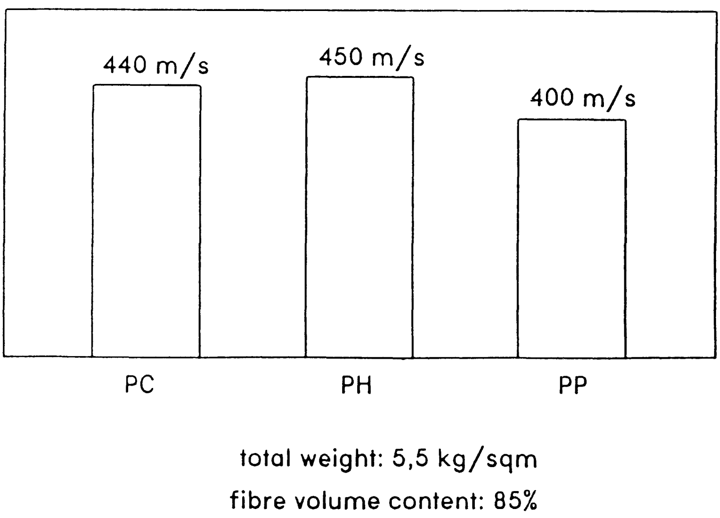


fig. 7: comparison of different matrix materials

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In fig. 8 the weights of two solutions for class IV of the German police are compared. The composite armour is composed of a Twaron laminate and $Al_2O_3$ tiles with a thickness of 8 mm in front it.

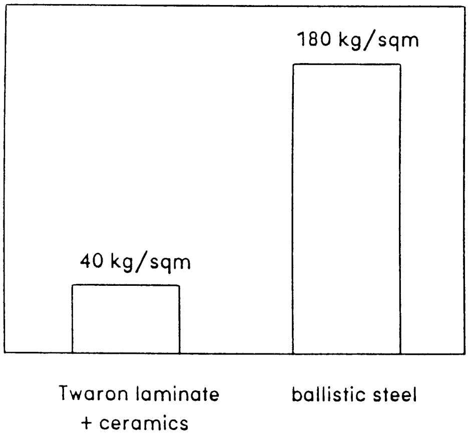


fig. 8: weight comparison of composite armour and steel

## 6. Numerical simulation of ballistic impact

Details are presented in the paper of Klaus Thoma, Condat GmbH.
The importance of such calculations is evident from the large number of parameters influencing the ballistic behaviour, which are difficult to optimize in an experimental way, in general shooting tests.
With a sufficient set of material parameters, i.e. elastic constants and strength values, we think it is possible to get a realistic simulation of the penetration process which considerably facilitates further developments.