Passive Protection Concepts

Michael Rust

Passive protection is the basis for every comprehensive vehicle protection concept due to the multitude of the threat scenarios. It is characterised by a wide range of achievable protection levels, multi-hit capability and a low price-performance ratio. The possibility to combine various technologies allows adapting and upgrading the protection concepts to almost every platform.

The importance of light weight armour can be seen from reports about the MRAP (Mine Resistant Ambush Protected) vehicles deployed to Iraq and Afghanistan. According to users the highly blast protected vehicles are too large for the tactical missions. Only few roads are paved. Unpaved roads can collapse underneath a MRAP and cause it to tumble. Rough terrain cannot even be thought of. Therefore a high percentage of the terrain is not accessible for large and heavy vehicles.

This illustrates the need for high performance armour at low weight.

Advanced passive armour

The latest technologies in advanced passive armour are based on the experiences gained with the so-called „3rd-Generation"-Protection installed on platforms like the Leopard 2, STRV 122, Fuchs (Rheinmetall), LMV (Iveco), ASV (Textron), CV90 (BAE Systems) and LAV Stryker (GDLS).

With the results of intensive research and development in material sciences the 4th generation of passive armour was introduced and has now been applied to platforms. This new generation of armour takes advantage of the latest developments in material sciences of

- Nano-ceramics
- Steel technology
- Light metal alloys
- Advanced composites

Author:
Dipl. Phys. Michael Rust,
IBD Deisenroth Engineering

Advanced nano-ceramics

The high hardness of ceramics, combined with a density significantly less than half that of steel, makes it indispensible in the design of light weight protection concepts. The following figures show the comparison of the ballistic performance of Rolled Homogenous Armour (RHA) steel.

Since weight plays an important role the mass effectiveness factor E_M has been inaugurated to compare the effectiveness of different armour solutions. E_M is defined as follows:

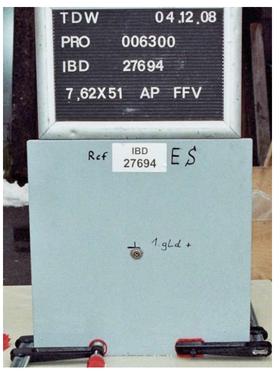
$$E_M = \frac{\textit{Areal Density of RHA steel}}{\textit{Areal Density of alternative armour}}$$

For the calculation of E_M the weight of the specified armour solution for a specific protection level is referenced to the weight of an equivalent RHA steel solution. This means the larger the E_M-value the better is the armour solution.

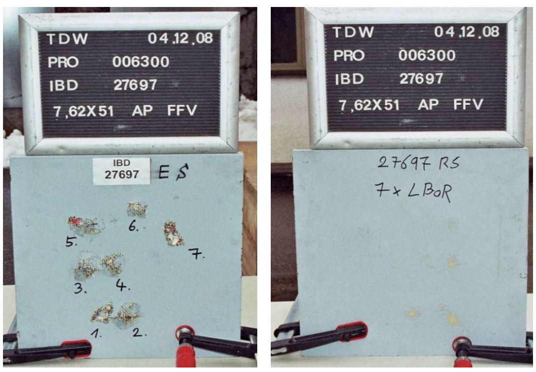
A threat according to STANAG Level 3 will penetrate 25 mm of RHA steel which has an areal density of about 200 kg/m².

Armour consisting of cermic combined with a liner backing has an areal density of about 60 kg/m². Compared to RHA steel this gives a mass efficiency E_M of more than 3 because the equivalent RHA steel solution would have to have an areal density of more than 200 kg/m². Applied to the same conditions as the steel plate this solution is able to defeat the threat with only light bulges on the backside. Furthermore the multi-hit capability is demonstrated. According to STANAG 4569 requirements shots 1 and 2 as well as 3 and 4 are spaced 25 mm while the shot pairs 1/2 and 3/4 have a distance of about 100 mm.

The technology described above represents the 3rd generation of ceramic technologies. With the IBD development of nano-cristalline ceramic material of the 4th generation the ballistic performance could be improved significantly. For example the hardness of the new ceramic material could be increased by more than 70 percent compared to state-of-the-art ceramics. This is essential since hardness is the relevant factor for the destruction of the projectile. The

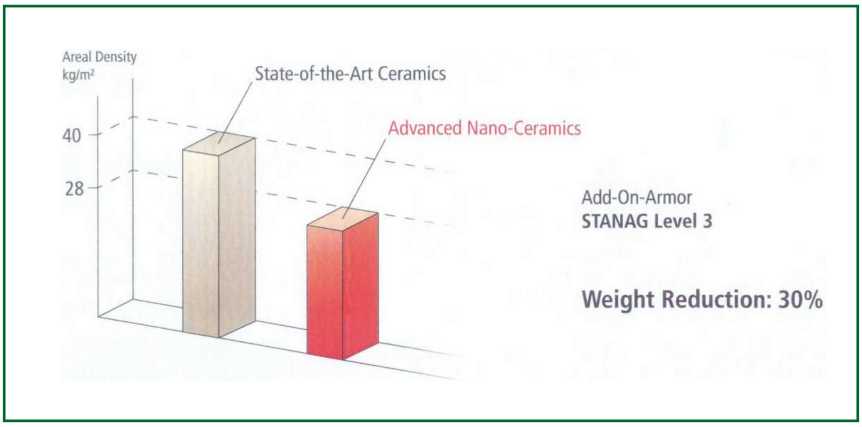


Target 25 mm RHA



Ceramic on liner backing, seven hits but just light bulges on the backside (right); note the distances between shot pairs

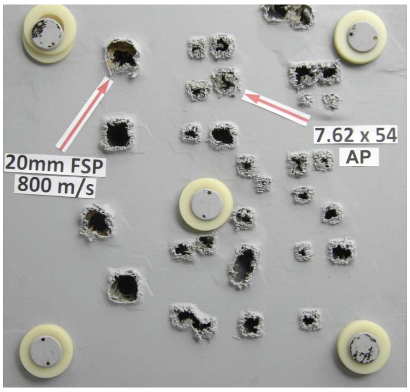
(Illustrations: Author)



Weight reduction with nano-ceramics

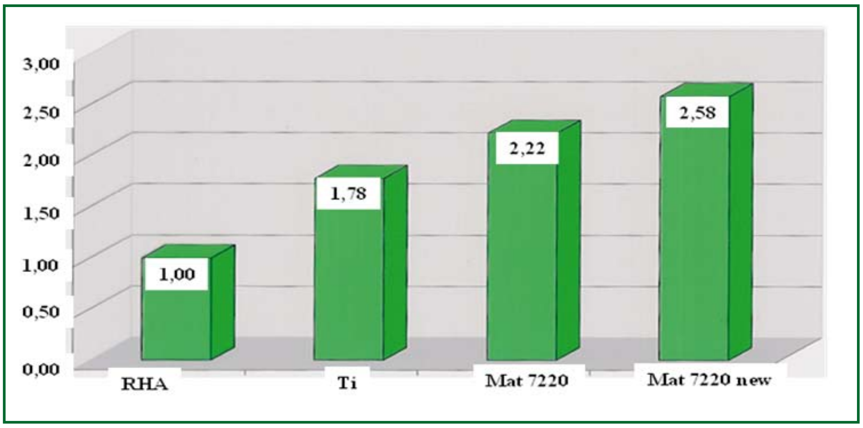
reduction of the armour weight is about 30 percent while maintaining the same protection level (STANAG Level 3). The mass efficiency factor E_M is larger than 4. On a medium platform like an 8x8 wheeled vehicle with ceramic faced armour the weight saving can easily amount up to 500 kg. Alternatively the protection level can be increased with the same armour weight.

The higher costs for nano-ceramics will be compensated by other savings either due to reduced target weight or increased service life.



Multi-hit Capability on a STANAG Level 2 target, note "unfair" hits at the upper edge

The multi-hit capability is also significantly improved due to increased fracture toughness. On a STANAG Level 2 target the distance of hits on the target are much smaller than the requirements of STANAG 4569. This applies to both the 7.62x54 AP and the FSP 20 mm threats. Also hits close to the upper edge, which would have been considered unfair hits according to STANAG 4569, did not penetrate. This additional advantage will help to minimize ballistic holes when applied and integrated on a platform.



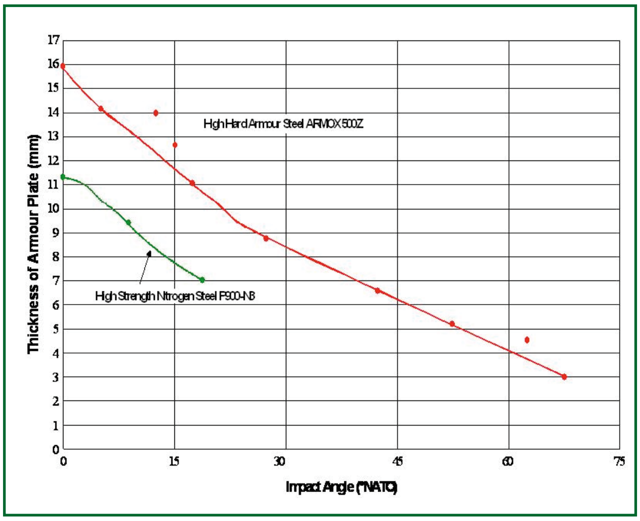
E_M values for advanced light materials

Steel technologies

In the past few years, together with steel suppliers, IBD succeeded in the development of highly improved steel materials that have comparable ballistic performance as standard ceramic materials. The new High Strength Nitrogen steel has been compared with High Hard Armour steel ARMOX500Z. Both types were tested with AP ammunition 7.62x54R B32 at 890 m/s. The results show that with the new material the plate thickness can be reduced by about 30 percent. For a vehicle with an surface area of about 30 m² the total weight reduction for STANAG Level 3 armour can be up to 1000 kg. The big advantage of these materials is the application as cost efficient (add-on) armour and the possibility to integrate them as structural elements into the design of vehicles. This enables to better integrate protection from the beginning of the design process of new platforms.

Aluminium-titanium technologies

In the last few years significant improvements in the development of Titanium- and Aluminium-Titanium alloys have been achieved. The mechanical properties of these alloys have come close to the ballistic properties of ceramics while their weight, compared to RHA, has come down from 58 percent (Titanium) to now 38 percent for the new alloy type 7220. Since these materials are easy to process, this results in very cost efficient solutions.



Armox compared to Austenic nitrogen steel

Transparent armour/glass

Vehicles deployed in peacekeeping missions need to have a "friendly" appearance. This means that the visual contact between the soldiers and the population shall be supported by large windows. However due to the high weight of transparent armour large screens have a negative effect on the total weight balance of the vehicle. They raise the centre of gravity significantly which deteriorates the dynamic behaviour of the vehicle.

Therefore the development of light transparent armour allows the installation of large front windows even with high protection levels with good optical properties. Due to the current developments in transparent ceramics there is still potential for further weight reductions.

IBD has developed glass with excellent performance, i.e. high transparency and low weight, which is now integrated into various platforms.

Composite materials

The most common composite materials used in the design of protection concepts are liners. IBD has developed a large variety of liners with a large span of properties. Even liners with a density of less than 1 g/cm³ are at its disposition for weight critical applications (e.g. to support floatability of platforms).

Liners are primarily used as spall protection. In case of a so-called overmatch situation, i.e. penetration, fragments of the hull tend to spall off the inner side of the hull. These fragments form a spall cone of about 90° expanding into the crew compartment. This spall has highly lethal effect and causes severe damage to the interior. With a liner mounted to the inside of the hull this spall cone is drastically reduced to about 10°. Correspondingly the survivability of the crew is increased.

When glued to the inside of the hull the liner also reinforces the whole vehicle structure. This is because both steel and liner form a composite material. The steel being the hard but more brittle material while the liner is the more ductile component. In the same way the liner can also be combined with ceramics to form such a composite material.

Finally liners have positive effects on the acoustic and infrared signature of the platform. Both signatures are lowered so that the detectability of the vehicle is reduced.

New composite materials are used to design so-called slat armour systems as protection against RPG-7 shaped charges. The original slat armour is built with steel forming large, heavy cages around the vehicle. In case of a hit these cages are difficult to repair. With the new material IBD was able to reduce the weight of the slat armour to about 10 kg/m². By separating the slat in smaller modules they can be designed as retractable elements. If the protection is not needed (for example during transport) the modules can be retracted such reducing the lateral dimensions of the vehicle by about 50 cm. Also the modules can easily be exchanged in case of damage.

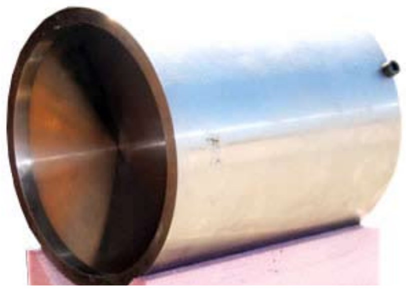
Shaped charge protection

The most frequently used threats in theatre are the variants of the RPG-7. The grenades in use cover a penetration range from about 360 mm RHA (RPG-7-V) up to about 800 mm RHA (RPG-7-VR). These threats cannot be defeated with the same measures as for ballistic small calibre threats. When the shaped charge is ignited the concave formed cover of the charge made from copper, the so-called liner, creates a multi-slug consisting of a stream of metal chunks that penetrates the armour.

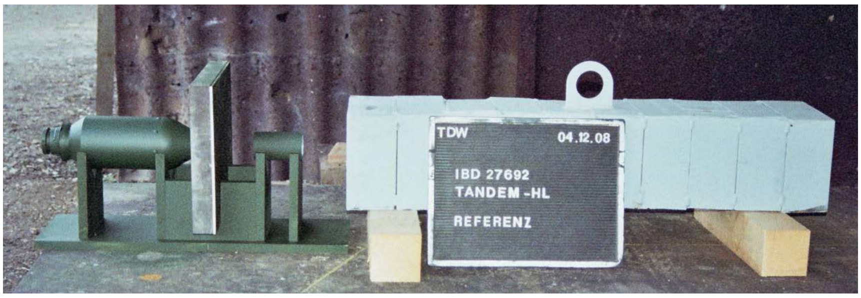
IBD developed a spezial track skirt applied for example at the Leopard 2 A4 Evolution. The module is designed to erode the slug. Combined with a base armour of e.g. a ceramic protection it is able to defeat even the most dangerous shaped charges used in theatre.

IED/EFP-protection

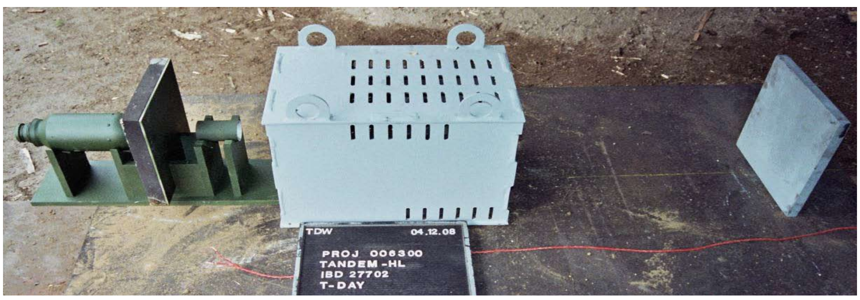
Improvised Explosive Devices (IEDs) using Explosively Formed Projectiles (EFPs) are more and more manufactured like industrially designed weapons and made available to the insurgents. The housing of a typical EFP-IED is mostly made from plastic tubes. The front is closed by a copper or steel liner with a concave shape. When the explosive inside is ignited, the liner forms a multi-slug in case of a copper liner and a mono-slug, when steel is used.



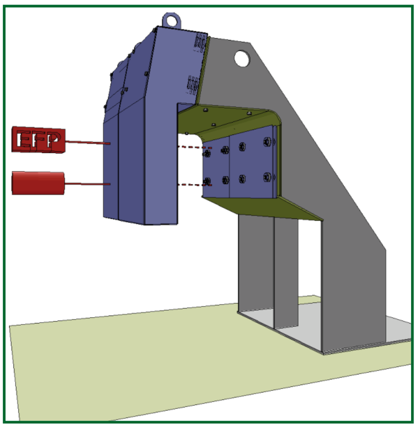
EFP-IED



Penetration capability of a RPG-7-VR



Shaped charge protection



Sketch of EFP-IED protection

The design of an IED/EFP-protection is similar to that of shaped charges. A typical setup for a configuration to be mounted on a wheeled vehicle includes an outer part that would cover thew heels (or the tracks). This element is designed to erode the slug generated by the EFP-IED. On the hull an add-on armour (e.g. ceramic armour) is mounted to defeat the remaining energy of the slug.

Mine/IED protection

As long as only blast mines had to be considered the mine protection could be designed in steel only. However this solution is not able to withstand a combination of blast and fragments. The plate brakes because the fragments hit the steel plate when it reaches maximum tension due to the blast. This problem can be solved by adding a ceramic layer to the steel plate. The ceramic is able to erode the energy of the fragments while the blast is withheld by the steel plate.

Special seats for crew and driver are an important part of the mine and IED protection. To prevent direct exposure of the occupants to the shock of a mine/IED blast the seats must be decoupled from the floor. Additionally foot-rests need to be added because the floor movement of the hull would break the legs of the passengers. Alternatively a second floor with a sufficient spacing from the hull floor can be used. The crew members themselves must be fixed with retention belts with quick release.

All equipment stored in the vehicle is subjected to the high acceleration and can become a severe threat to the crew. Therefore suitable fixtures need to be installed for small arms and other equipment.

Holistic approach of the evolution survivability concept

The change from a frontal to a spherical attack scenario requires an all-around survivability concept with the following characteristics:

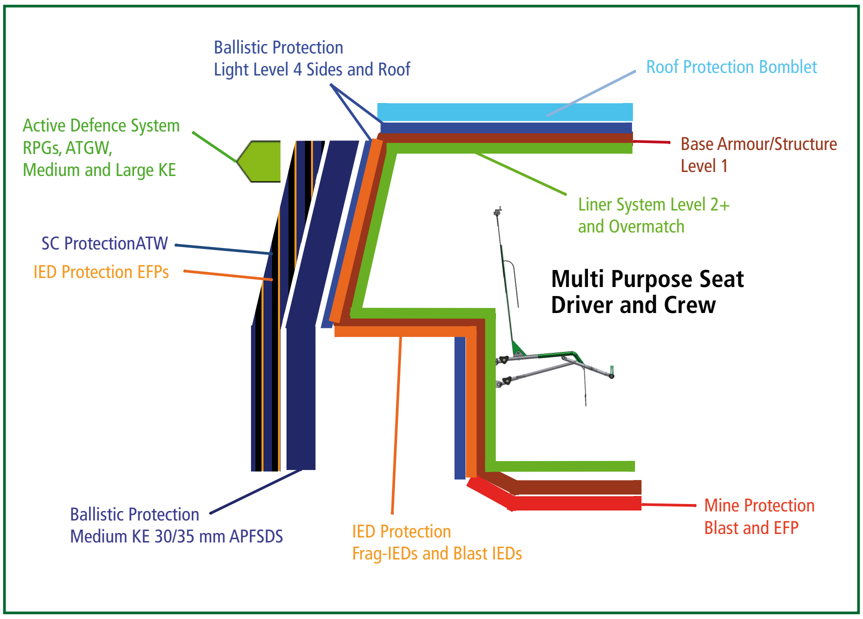
Mine protection seats and storage

- Protection against all relevant threats
- Light weight to maintain the tactical mobility
- Easy and quick installation even under field conditions
- Modularity for maintenance and repair
- Upgradeable with new technologies and for new requirements

A protection concept that meets these requirements has been introduced by IBD Deisenroth Engineering, called the Evolution Survivability Concept. It is based on the technologies and products of the 4th generation as described above, which are part of the Advanced Modular Armour Protection (AMAP) family. The products of this family are modular and can be combined to form a balanced spherical protection against the full spectrum of threats encountered in theatre.

Depending on the specified protection level a selection of the protection elements is combined using synergistic effects to meet the requirements at minimum weight. The protection moduls are arranged inside and outside the platform and form nested shells (see figure on top of the next page). The hull of the vehicle with its base armour (brown) serves as the supporting structure. On the inside the liner (light green) is mounted to reinforce the base armour and to reduce the spall cone in overmatch situations. Liners also have a positive effect in terms of signature management. They reduce IR emissions as well as acoustic noise. Since liners only contribute a minor amount to the overall weight budget and due to their combined effects they should always be considered in the formation of a protection concept.

The next layer of the vehicle forms the ballistic protection of the sides and the roof (blue). This protection module is preferably designed with ceramic because of the low weight and can be built to provide protection up to STANAG level 4. However with the new steel technologies low cost solutions can also be designed. This protection module can either be integrated in the vehicle structure during the design of the vehicle. The light 4x4 Light Multirole Vehicle (LMV) of IVECO is an example. Or as in most cases this module is designed as add-on-armour on the



Principles of the moduar spherical protection concept

outside. Examples for this type of application are the 8x8 Light Armoured Vehicles (LAV) of different customers and the ASTRA truck of IVECO.

To complete this layer mine protection (red) under the vehicle and IED protection (orange) in the sponson area are added. Special seats are an important part of the mine protection. They are decoupled from the floor to reduce the shock applied to the hull by the mine blast.

Since today's threats go far beyond the existing STANAG 4569, special protection modules against higher threat levels can be applied, such as modules against large calibre KE and CE projectiles as well as IED/EFP threats or an improved roof protection against bomblets and anti-tank hand grenades like the RKG-3.

The active defence system is an important amendment to the Evolution Survivability Concept. Application of this system will save a lot of weight because it can replace the heavy protection modules against large calibre KE and SC projectiles. Also light vehicles, as already demonstrated with the LMV, can be protected against threats like shaped charges that could not be considered without active defence systems.

The composition of the protection modules is done according to the requirements of the customer and does not necessarily include all options shown in the Fig. on this page. However the combination of the products of the AMAP-family, developed by IBD, creates synergistic effects. This results in higher protection levels at low weight. ■