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LIGHTWEIGHT PASSIVE ARMOUR FOR INFANTRY CARRIER VEHICLE

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With the proliferation of the modern day weapons (both chemical and kinetic energy threats) in tension areas, it is no longer sufficient or possible for the Bionix Infantry Carrier Vehicle or other similar weight class armoured vehicles to rely on steel armour alone to protect the crew. In order to give the crew the best possible chance to accomplish their mission, the vehicle must be equipped with the most efficient lightweight armour utilising state-of-the-art technology in protecting the crew against the threats they will face in modern battlefield.

INTRODUCTION

In this paper, the design philosophy for the selection of the technology to be employed on the modern day infantry fighting vehicles (IFVs) will be presented. The details of the considerations (including weight, cost, performance, etc.) made in the assessment of possible passive and reactive armour state-of-the-art passive armour for the Bionix Infantry Carrier Vehicle (ICV) (Fig. 1) as well as modern infantry fighting vehicle of the same class will also be highlighted.

Figure 1: Bionix ICV.

ARMOUR PROTECTION TREND

During the era of WWI and WWII with the advent of armoured vehicles, generally basic hull materials were made with metallic armour material. This gave adequate protection to crew members from injuries and death due the onslaught of enemy fire arms munitions. Armoured vehicles were able to move into the depths of the defence of the enemy lines in the form of a moving fortress. Threats increased from jacketed projectiles to armour penetrating projectile to the modern day kinetic energy projectiles and shaped charges. This in turn created the need to improve the protection of armoured vehicles.

The prevailing trend to improve the survivability of the personnel and equipment in vehicles, the thickness of monolithic armour is increased so that they were better able to stop ever improving munitions! The common armour material was the rolled homogeneous armoured steel which reduces the penetration of kinetic energy rounds and shaped charges through its high strength and hardness. The capability of the steel to reduce the penetration of shaped charges has also been confirmed theoretically by Held [1] [2] through using the hydrodynamic formula for first a continuously stretching and then particulised jet for the formation of the crater.

$$P = \frac{B - v_j * t_p}{\gamma - Z_0} \quad \text{with} \quad B = (\gamma+1) * Z_0 * (t_p/t_0)^{1/(1+\gamma)} \tag{1}$$

The extensive use of RHA led subsequently to it becoming the yard stick where other materials and configurations that substituted steel were compared with. The most frequently used comparison factors are namely the mass efficiency and space efficiency defined as below:

$$E_m = \frac{M_{REF}}{M_{TEST}} \qquad E_s = \frac{LOS_{REF}}{LOS_{TEST}} \tag{2}$$

where M_{REF} and LOS_{REF} is the mass and line-of-sight envelope of the reference target and M_{TEST} and LOS_{TEST} is the mass and line-of-sight envelope of the test configurations.

The other trend in the defeat of armoured vehicle was the application of obliquity to better ricochet the incoming projectile as well as increasing the projectile path length. This generally works as most projectiles were designed with an ogive shape to give it better aerodynamic performance that improves it range and stability.

With the increasing need for thicker monolithic armour for greater protection, it significantly increased the weight of vehicles, and this approach is no longer acceptable in view of the penetration capabilities of the modern threats. Nowadays, the armour on vehicle are typically a combination of various materials in specific configurations or make-up such that their defeat mechanism is optimised. In summary, the basic approach of armour designers in the protection of the vehicle is to integrate the base armour of a given vehicle in the most synergic way with the add on armour to provide the maximum protection to the vehicle.

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MODULAR PROTECTION SYSTEMS

With various differing weight budget and user-defined mission profile, a feasible approach in the armouring of the fighting vehicle is the use of modular armour system with the possibility to expand with increase in threat or change of armour systems. This concept enable the enable to provide a total protection systems from modern threats.

Protection systems may be classified as direct protection and indirect protection. The possibility to combine the various protection systems will help to complement their attractive properties to provide a total protection systems. Direct protection comes in the form of modular armour system that directly interacts with the munitions. Indirect protection, namely signature reduction and soft kill active protection, are used by armour and vehicle designers to enhance the survivability of the vehicle in the modern battlefield.

DEFINITION OF PASSIVE AND REACTIVE ARMOUR

With the increasing demands on the direct protection of armoured vehicles against the better modern day munitions, the available combat weight for troops, equipment and munitions, and degradation in the mobility of the vehicles will be significant if only monolithic armour is used. This is especially critical in the case of light to medium weight class vehicles such as the Bionix ICV that needs to be protected against multiple threats (Fig. 2). The race to find more weight efficient solution is a MUST.

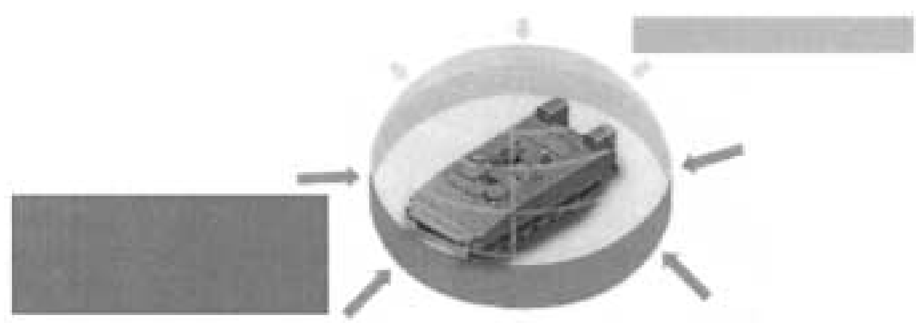

Figure 2: All round protection necessary for modern armoured vehicles in view of modern day requirement to protect against multiple threats.

One of the possible solutions came with the use of explosive reactive armour (ERA). It was first proposed and successfully achieved by Held [3] in the defeat of shaped charged jets from handheld anti-tank launchers. These reactive sandwiches, consisting essentially of steel plates with an inner high explosive layer, has been shown to be highly effective against the high velocity jets from shaped charges.

Another possible solution is the use of advanced passive armour with very high mass efficiency to reduce the weight of the system. This can be in the form of new advanced material such as the Ballistal® from IBD or multi-layered composite armour such as the

MEXAS™ light and medium armour [4]. Passive armour system do not use any explosives. Instead, it utilises other effects such cratering (Fig. 3), geometry, material properties and kinematics to defeat the threat. Such systems have been shown to be effective against both Kinetic Energy (KE) and Chemical Energy (CE) threats.

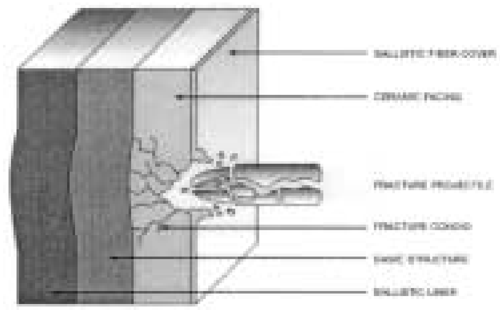

Figure 3: Cratering in ceramic armour absorb the energy and reduce the threat penetration.

COMPARISON BETWEEN PASSIVE AND REACTIVE ARMOUR

The selection and evaluation of a particular is complex and requires considerations to be made on many factors. The Table 1 [5] below gives a list of assessment points for armors with the highlighted points frequently cited as positive acpects of reactive armour. However, it is also clear there are many more factors that needs to be considered in determining the best system to be used on a particular platform. Reactive and passive armour could be compared in the paramenters listed in Table 1.

In terms of performance, ERA has been shown to be highly effective against jets from shape charges. However, the actual performance of the reactive armour is also highly dependent on the impact angle as shown in Fig. 4 [5]. Reactive armour is superior in the simple one-plate target as compared to the passive armour primarily when the impact angles are steep (≤ 40°N) but the difference reduces as the angles of impact becomes flatter (e.g. >50°N), usually the case for integration on vehicles. Substantial differences exist when it comes to performance against tandem shaped charges, which are becoming more common in the modern day battlefield. Reactive armours are virtually ineffective against modern tandem shaped charges whereas the performance of passive armour against the tandem shaped charge is only slightly worse than for the monolithic shaped charges. At the same time, the requirement for add-on armour on modern IFVs typically include protection enhancement against both shaped charges and small/medium calibre KE ammunition, which ERA usually cannot provide.

Table 1: Assessment table for armour selection

Ballistic Performance	Integration	Handling Safety	Costs
EM and ES against ● SC ● KE ● EFP Multi-Hit Capability Growth Potential Influence of Impact Angle	Weight Technical Risks ● *Conducted Tests* ● *Experience with Other Vehicles* Parasitic Weight ● *Confinement* ● *Mounts* ● *Fixtures* Secondary Effects of the Armour ● *Shock Effects on the Structure* ● *Blast* ● *Fragments* Resistance against Mechanical Forces ● *Driving Forces* ● *Torsion Forces* ● *Blast* Impact Energy Management ● *Collateral Damage* ● *Structural Stability* ● *Shock Absorption* ● *Shock Propagation* Influence on the Vehicle Signature ● *Radar* ● *IR* ● *VIS* Mountability of Tools and Equipment	Safety against in Theatre Threats ● *Fragments* ● *Blast* ● *Fire* ● *Small and Medium Calibre Ammunition* Storage ● *Fire* ● *Mass Detonation* Influence on the Environment ● *Fragments* ● *Blast* ● *Shock* Environmental Resistance ● *Test acc. MIL-STD-810F*	Raw Materials Producibility Storage Disposal Handling Exchangeability Repairability Recycling Transportability

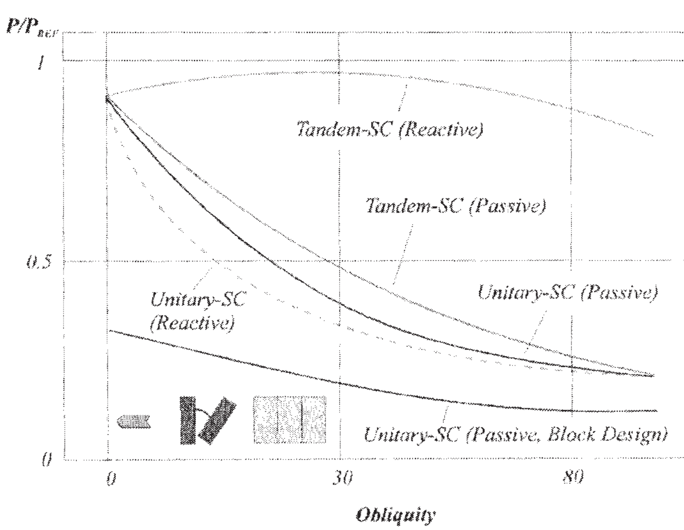

Figure 4: Penetration relative to obliquity curve.

Other than performance, the next factor for considering in the selection of the type of armour to use for IFVs is the integration and survivability of vehicles protected by the armours. For reactive armour, appropriate air gaps or shock absorption systems are required when such systems are integrated onto the vehicle. This is necessary to avoid sympathetic detonation of the ERA modules and any collateral destruction. All this translate to a large unprotected area between the modules which may amount to 30–60% of the covered area (Fig. 5a). *For ERA, its main application is as add-on armour and space is needed for the movement of the flyer plates.* Inherent to these systems are the problem caused by the undesired interaction of the flying plates with the main armour and the environment. For IFVs, the main hull armour is typically relatively thin and therefore more likely to be deformed by the blast and impact of the reactive armour. With considerations of the interaction to the environment, the life-cycle costs of these explosive sandwich systems are also generally higher than inert systems. Passive armour systems, such as those inert sandwiches which are based on the mechanisms described in the open literature by N. Gov, Y. Kivity and D. Yaziv [6], do not require explosive materials for plate acceleration. The kinetic energy of the jet is used to create the necessary movement of the metallic plates in the form of bulging which gives similar jet/plate interaction to ERA. The inert interlayer enhances the bulging by spreading the jet momentum radially. Due to the reduced plate movement in such sandwiches, it becomes possible for them to be fully integrated in armour packages. Such packages do not require the same gaps as ERA since no explosive is present and therefore is capable of protecting up to 85–95% of the vehicle area (Fig. 5b) as compared to 60% for ERA. With passive armour packages, unwanted interactions with the environment are very limited. The damage to the main hull armour is also reduced.

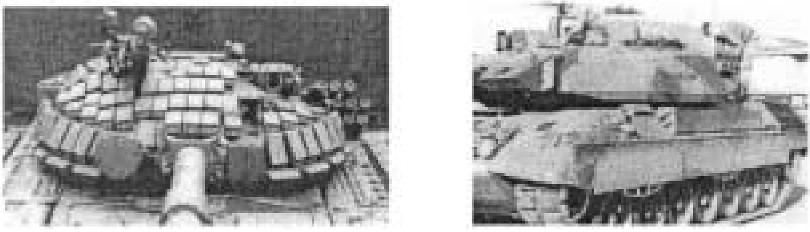

Figure 5: Typical turret integrated with (a) ERA; (b) passive armour.

PASSIVE DIRECT PROTECTION SYSTEMS

The main factors contributing to the advances and development of passive direct protection systems are in the areas of new protection materials and new protection concepts. With the development and improvements in the protection technologies, it is now possible to increase the protection for light and medium vehicles without increase in the weight per unit area of add-on protection armour and significant mobility trade-offs.

New protection materials involves the development of smart materials that improves its strength even under adverse change in material behaviour when under high dynamic deformation when materials are impringed with high impact stresses. These material includes Ultra High Strength material with strength in the region of 2500 MPa, new high strength alloy with low mass density, intermetallic materials with significantly high ballistics performance, composites with new fibre concepts, ceramics with reduced mass density and functionally graded materials that interact effectively with the changing destruction properties of the moving threats in the armour.

New protection concepts comes from the combination of compatible ballistic materials that synergised their protection performances, and layout of the different usage of materials. For example, the performance of many of the base armour structure of vehicles built from armour steel of older specifications against small calibre AP ammunitions can be greatly enhanced through the incorporation of an interior direct contact liner as in Fig. 6 [7]. The precondition is that the liner has to be bonded to the metallic base armour by glue without any air gap, and that the liners impedance is carefully tuned.

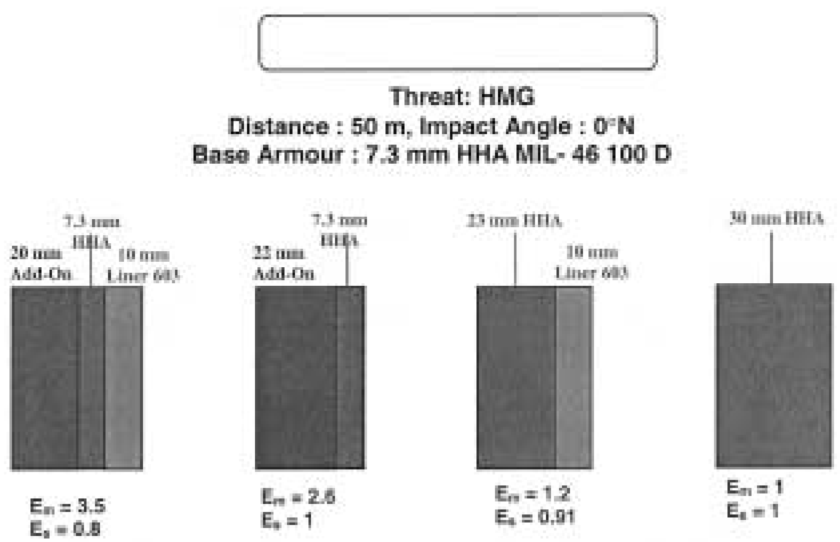

Figure 6: Synergistic and modularity concept.

CONCLUSION

For the relatively light weight class vehicle, such as the Bionix ICV, the passive modular armour is best in achieving the desire total protection solution with the lowest possible weight. This solution also allows future upgrades and incorporation of new technologies into the armour to protect against new threats.

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