Defence Science Journal, Vol. 61, No. 4, July 2011, pp. 394-402

Armour Protection and Affordable Protection for Futuristic Combat Vehicles

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ABSTRACT

Protection creates a shift in the internal paradigm of the soldier and leads to multiplied psychological stamina for moving fearlessly in the battlefield which generates a major force-multiplier effect. Hence, the mechanized forces are still likely to be one of the dominant forces on the futuristic battlefield and would be the primary target of enemy forces capable of engaging from tank guns up to 4-5 km in a direct fire mode and up to 8-10 km in an indirect fire modes. Increased protection is possible only using advanced armour technology. Throughout the history of warfare, materials technologies have had a significant impact on land-combat force capabilities. Armour materials have progressed through improvements in metallic systems and development of advanced, lightweight (low areal density) composite materials. The advancements in ceramic systems have further improved the performance. Similarly, the advances in development of explosive reactive armour has generated efficient armour system against all contemporary high explosive antitank (HEAT) ammunition and missile threats for armoured vehicles. Yet, to achieve armour performance exceeding that of the current light combat vehicles and main battle tanks for new vehicular systems, weighing significantly less than the present combat vehicles, advances in new armour materials, systems, and survivability technologies are required. This paper describes various approaches and advancements in the metallic, ceramic, and composite armour materials and new dynamic armour systems that are essential to improve the survivability of armoured vehicles in the futurisitic multi-spectral battlefied scenarios.

Keywords: Ceramic armour, composite materials, metals, combat vehicles, bulging armour, electromagnetic armour, dynamic armour, intelligent armour, active protection system

1. INTRODUCTION

In a true sense, one of the most important elements of survivability is armour protection. Gone are the days when soldiers could be treated as cannon fodder. In the words of Gen Shergill[1], today casualties are a cause for alarm and human life is taken as a very precious commodity. It is therefore critical to develop materials and modules which can withstand all futuristic threats, including those from terrorism. This calls for novel concepts in design and testing methods for optimisation of armour even ahead of the ammunition to create systems that are protected well.

The weight of armour in combat vehicles has always been constrained by the overall weight of the vehicle and the power-to-weight ratio. Changes in the type of threats in recent years have led to shift in focus on the need for protection against multi-spectral threats[2]. Enormous efforts are being put worldover on the development of armour materials and systems to provide greater ballistic protection with some increase in weight of the vehicle[3].

For providing such a protection, it is essential to create high performance passive, reactive, dynamic, intelligent and active armour technologies with creative armour design concepts. Today, no single material is capable of effectively defeating wide range of threats, and hence, a wide variety of armours have to be developed. The combat effectiveness of a tank basically depends on three main factors: firepower, protection, and mobility. The tilt in emphasis has always remained towards firepower but may not remain so in the future when human life will be considered the most precious of all, even in the battlefield. This means that a tank should withstand the firepower from enemy tanks very well. It should withstand artillery, missiles, and mines along with antitank kinetic energy rounds.

1.1. Main Battle Tanks

Figure 1 shows the trend in improvements of firepower of tanks in terms of their rolled homogenous armour (RHA) penetration capabilities. The armour naturally kept pace with the ammunition, partly by increased weight and thickness and partly by increased effectiveness. From the trends in the development of HEAT penetrators shown in the figure, it is seen that, in general, there has been an increase in the penetration efficacy of HEAT by about 20 per cent every decade. This trend is expected to continue looking at the improvements in materials and ammunition research. However, in the case of kinetic energy (KE) penetrators, though the general improvements have been about 10-15 per cent, this improvement in efficiency of KE penetrators would reach saturation due to limitations in propulsion and gun technology, though improvements in penetrator material and design might improve the penetration performance by little over 10 per cent during the next decade.

Received 20 April 2010, Revised 23 April 2011, published online 25 July 2011

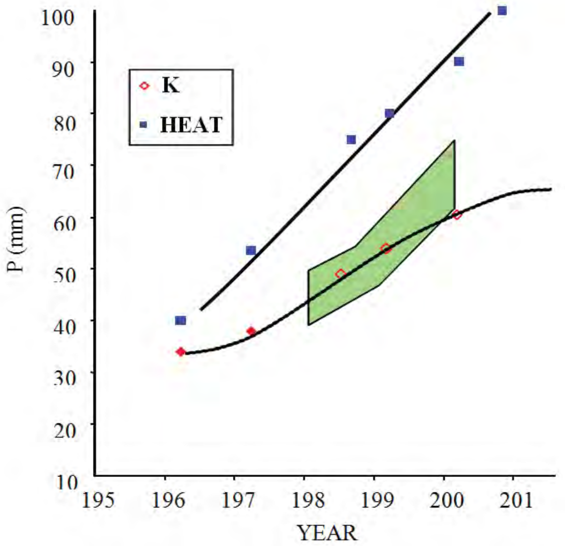


Figure 1. Trends in improvement of firepower of tanks.

The improvements in efficiency of armour over the past years is shown in Fig. 2. It can be seen that there is a need to increase the efficiency to more than double the weight efficiency compared to RHA steel to meet the challenges of the futuristic threats while the weight of the tank is being brought down by about 30 per cent. This is shown as the dotted path in the lower curve of Fig. 2.

This would indeed call for huge concerted efforts in research on newer protective materials and systems[4-6]. Usually, advanced latest armour technologies are not available for purchase. They tend to become available only after a few decades, just before these becoming obsolescence. Therefore, it becomes imperative to have one's own indigenous integrated armour research activity to keep pace with the developments of anti-armour threats. One of the approaches for creating the future combat systems (FCS) is to make systems that are more agile, quickly deployable, which is possible by developing a system of systems integrating the unmanned vehicles, sensors, manned combat and other mission vehicles, into a highly

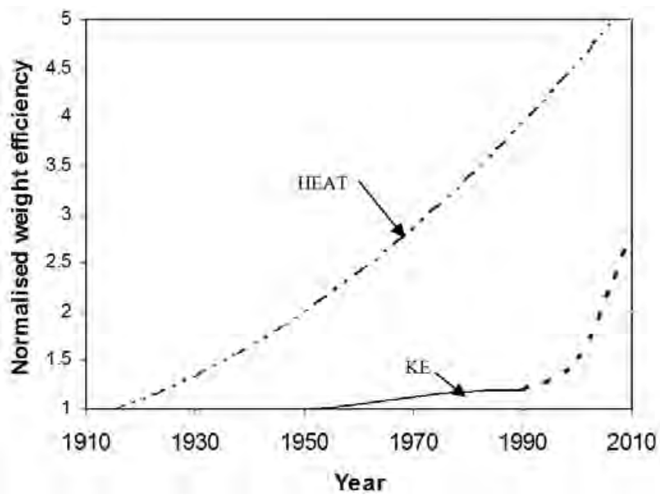


Figure 2. Improvements in armour efficiencyin tanks.

communicating[7] single network. With the war scenarios shifting to urban warfare, the FCS should be able to operate under asymmetric threats, operate under urban and complex terrains, and also be well protected against all the threats.

For the future main battle tanks (FMBTs) to defeat the futuristic antitank threats, it has to rely on both, the active protection system (APS) as well as an optimal passive protection system (PPS), along with explosive reactive armour (ERA)/dynamic passive armours.

1.2 Infantry Combat Vehicles

The principal threats to these vehicles all around have been from the small arms fire of up to 14.5 mm armour piercing(AP) which has become the norm for light-to-medium weight armoured vehicles which is defined as Level 4 of NATO's AEP-55 STANAG 4569 specifications. The frontal threat has typically been increasing with the increase in firepower of the infantry combat vehicles (ICVs). Figure 3 shows improvements in protection of ICVs during the past two decades.

These levels of protection are much higher than that possessed by light armoured vehicles whose basic armour is designed to withstand only 7.62 mm Ball and AP shots. The need to increase the protection level has led the use of add-on armour made from high hardness steel (HHS), very high hardness steel (VHS), ceramic and other more effective types of armour materials that are more weight efficient than RHA.

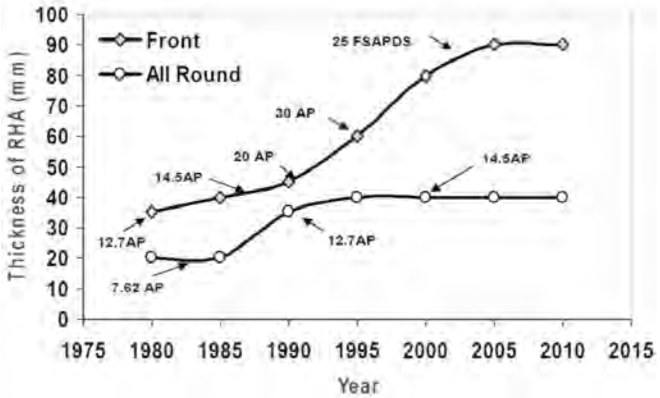


Figure 3. Trends in armour protection to infantry combat vehicles.

2. ADVANCED ARMOUR MATERIALS

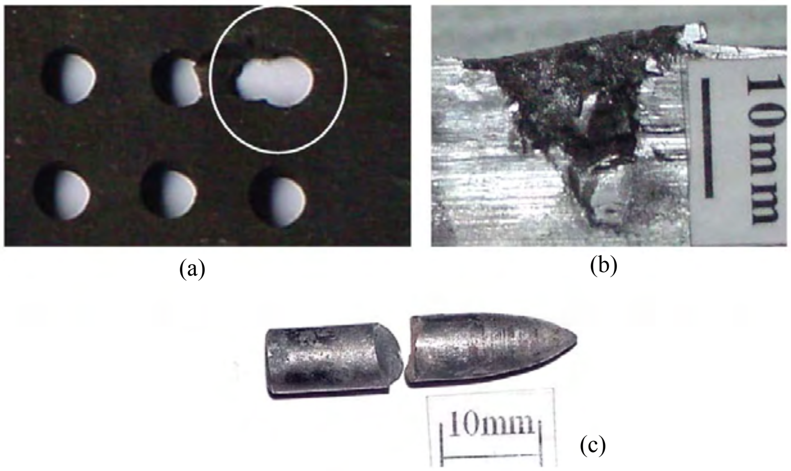
2.1 High Hardness Armour Steels

The armour on combat vehicles has always been constrained by its weight and with rising threat levels this has become an increasingly serious problem. Much effort is consequently being devoted to the development of armour that would provide greater ballistic protection with small increase in vehicle weight. The most direct approach to the problem has been to improve the ballistic properties of steel armour[8-9]. This can be achieved by designing new alloys and by adapting suitable heat treatments. The outcome of this approach has been the achievement of VHS, which has hardness of 600 BHN or more and HHS which has a hardness of around 550

VHN as against RHA having hardness of 350 VHN. DMRL has developed these technologies which are in use on MBTs as well as on ICVs. HHS does not impose constraints of weldability and also reduces the weight by about 20 per cent for a given level of ballistic protection when compared with RHA[5,6]. In an experimental ICV developed by VRDE, Ahmednagar, VHS armour has been used as one of the two components of a dual-hardness compound armour as shown in Fig. 4.

Figure 4. Experimental infantry combat vehicle with appliqué VHS armour visible on the glacis.

Another form of add-on armour is perforated high hardness steel plates. One such perforated configuration on a high hardness steel designated as MARS 300 of about 600 BHN, had been combined with 5083 aluminium armour and fitted on a M113[10,11]. Ballistic studies were carried out at DMRL using perforated high hardness steel plates of 550 BHN backed by 7017 aluminum alloy. The perforated steel plate showed a mass efficiency of 2.4 when compared to the reference backing material[12]. Figure 5 shows a ballistically evaluated perforated high hardness steel plate when impacted with 7.62 mm AP. Also shown are the depth of penetration in backing aluminium alloy as also the bullet that got fractured during the process of penetration.



(a) (b) (c)

Figure 5. Photograph of: (a) perforated high hardness steel plate, (b) depth of penetration in backing *Al*-7017 alloy, and (c) fractured projectile after the impact.

2. Titanium Armour

Advantages of titanium arise from its high strength-to-weight ratio, excellent corrosion resistance, and excellent ballistic performance compared with steel and aluminium alloys. *Ti* alloys are readily fabricated at the existing production facilities and are easily recycled. One disadvantage with titanium is adiabatic shear band formation, which may result in spalling. High strength and homogeneous deformation are essential conditions for maximising energy absorption under high strain rate deformation conditions such as those encountered in ballistic impact events[13]. Although titanium alloys have been used successfully in aircrafts for many years, the high cost of titanium coupled with the sparse information on its ballistic properties have prevented widespread use of titanium for ground vehicles. MIL-A-46077 and MIL-T-9046 are the two military specifications followed for this alloy. The ballistic efficiency of the titanium armour against 7.62 mm AP and 120 mm FSAPDS has been assessed at DMRL and is given in Table 1.

Table 1. Mass efficiency of *Ti*-alloy armour against 7.62 AP and 120 FSAPDS

Material	Mass efficiency (Em)	
	7.62 AP	120 FSAPDS
RHA (300 BHN)	1.0	1.0
Ti-6*Al*-4V	1.5	1.5

2.3 Ceramic and Polymer Armours

The need to reduce the weight of the armour system as well as the requirement of meeting a combination of threats have led to the concept of developing compound armour systems containing metallic, ceramic, and polymeric materials and their composites. Ceramics have the attractive properties of higher hardness, lower density, higher modulus coupled with some flexural strength and fracture toughness. Metals, on the other hand, provide the higher strength and toughness combinations with lower hardness levels. Table 2 shows the typical properties of ceramic armour materials with these important parameters for the commonly used ceramics. Also included in the table is the ballistic efficiency parameter (EH/ρ).

The application of ceramics for armour continues to be primarily in lightweight armour systems for protection against small arms and medium-caliber machine gun threats[14]. The design of these systems is typically based on those mechanical properties of the ceramic which cause fracture in the penetrator and also on the ability of the rear layer to catch the projectile debris and the damaged ceramic material. During the process, majority of dynamic interaction time is spent in energy conversion of the kinetic energy of the debris into deformation and delamination of the backing material. Ballistic efficiency of ceramic varies with the grade and thickness of the ceramic as also with the velocity of the projectile[15]. Performance of ceramics has been improved significantly using

Table 2. Properties of ceramic armour materials

Property	B_4C	TiB_2	SiC	AlN	Al_2O_3
Density (gm/cc)	2.5	4.5	3.15	3.25	3.8
Flexural strength (MPa)	410	400	400	310	379
Elastic modulus (GPa)	400	565	370	330	340
Hardness (Kg/mm^2)	3000	3300	2700	1300	1600
Fracture toughness (MPa√m)	2.5	6.2	4.3	3.7	3.5
Ballistic efficiency parameter (EH/ρ)	480	418	311	130	143

novel encapsulation techniques adopted for the ceramic composite armours[16].

Optimisation of ceramic armour configuration depends on the ballistic efficiency of the ceramic against a specific threat[17] and the overall armour configuration for which the system is designed. DMRL has developed ceramic armour system for an experimental infantry combat vehicle, designed and integrated it on the vehicle. Figure 6 shows photographs of few ceramic armour panels fitted on the experimental ICV.

Figure 6. Ceramic armour components fitted on the experimental infantry combat vehicle.

With ever increasing protective requirements during the counterinsurgency and anti-terrorism operations, there is need for development of lightweight armours. Current polymer materials are basically made from high performance polymers like S2-glass, aramids, and high density polyethylenes. Besides many novel materials are currently being developed[18-25]. Extensive research is also being pursued in developing nano fabrics using carbon nanotubes.

2.4 Nano-structured Metallic Intermetallic Laminate Armour

Metallic intermetallic laminate composite is one of the emerging candidates materials for armour applications. These composites can be designed for structural use to optimise the unique properties and benefits of the constituent components, resulting in materials that have the high strength and stiffness of the inter-metallic phase and the high toughness of the metal[26].

Metallic intermetallic laminate composites offer a unique combination of excellent specific mechanical properties such as high strength, high hardness, and high fracture toughness, with the ability to be formed into complex shaped penetration-resistant structural materials. Attempts are being made world over in developing this new material for armour applications. Preliminary studies carried out at DMRL have indicated that these composites could provide a mass efficiency of about 2.0 mm against 7.62 mm Ball ammunition.

3. ADVANCED ARMOUR SYSTEMS

Passive armour forms the main armour envelope of all combat vehicles and it will continue to be the main method of protection of such vehicles. For kinetic energy shots, passive armour is the best conceivable way of offering assured protection. Active armour is likely to emerge as the main mechanism of protection against slow-flying missiles. This may also be extended for protection against fast moving KE shots which is currently under various stages of R&D the world over. Attempts are being made to integrate these armours on light armoured vehicles. Other new armour concepts like the non-explosive reactive armour, hybrid ERA, intelligent dynamic armour, and electromagnetic armours are some of the promising candidate armour systems for the future armoured platforms.

The effectiveness of HEAT weapons stems from their high usage in the battlefield and the ease of concealed attacks, in addition to their capability of attacking at short distances and from virtually any direction. This is particularly significant aspect in low-intensity conflicts in urban civilian areas, and more specifically, in peacekeeping operations. A few advanced armour concepts currently being developed are dynamic passive armour, intelligent dynamic armour, explosive reactive armour, electric armour, and active armour.

3.1 Dynamic Passive Armour

Dynamic passive armour (DPA) is a new system being pursued. Unlike in the ERA where the jet initiates an explosive and which disrupts the jet, in DPA, the jet impinges on a passive plate system which forms a bulge. The bulging plates cause jet disruption by moving transverse to the jet. A recent test result on dynamic passive armour at DMRL has shown that a single thin module of the armour can knock-off more than half of penetration from HEAT missile. Figure 7 shows photographs of the test set up and the DPA bulge and damages after firing, carried out at DMRL against a HEAT missile.

3.2 Intelligent Dynamic Armour

Another approach is to develop an intelligent dynamic armour (IDA). A schematic of the functioning of IDA[27] is shown in Fig. 8. Here, a set of dynamic armour modules suitably designed are kept in tandem. A suitably designed propellant or low explosive with a detonator is kept at the rear. Sensors are fixed on the front plates. Upon impact by the incoming projectile, the sensors would activate and generate data on the velocity and other features of the threat. Based on these inputs, the threat will be identified. If the incoming projectile is identified to be the designated one, the propellant will be activated, through the activation of initiating detonator, thereby mov-

Figure 7. Ballistic evaluation of dynamic passive armour against HEAT missile: (a) test set-up, and (b) damage of the cassette material.

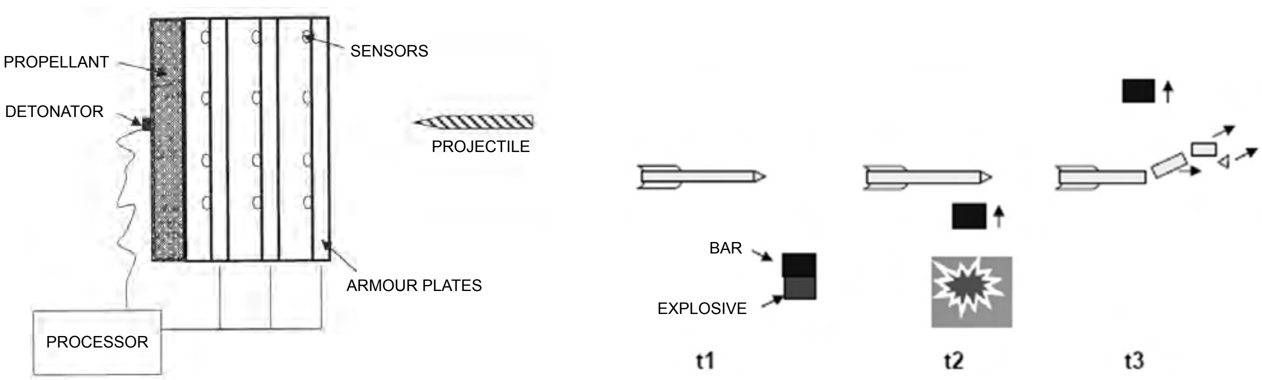


Figure 8. Schematic concept of an intelligent dynamic armour.

ing the armour plates to the front and breaking the projectile. The critical technologies involved are the generation of suitable sensor mechanisms and intelligent processor, as also the design of the dynamic plates. These efforts, when successful, would develop into an intelligent dynamic armour system.

3.3 Integrated Explosive Reactive Armour

An effective form of protection against rocket propelled RPG-7s as well as HEAT missiles is by the use ERA, which has been in use on battle tanks since 1980s. In its original form, ERA is not suitable on light armoured vehicles (LAVs) due to the thin skin on such light vehicles. However a new configuration of panels is being developed. These panels consist of a combination of explosive sandwich with a backing sandwich and an inert interlayer, which is compatible to LAVs. Such concept is claimed to create low collateral damage[28].

Another promising area is the dual-purpose ERA or Hybrid ERA that works against KE penetrators as well as HEAT ammunition and also adaptable to light armoured vehicles. The task would need optimisation of explosive composition, sensitivity, detonation velocity, etc so that the armour will respond only when required. Explosive reactive armour consists of a layer of explosive sandwiched between two plates of a metal. A fine balance has to be struck between making the front sandwich plates heavy enough to be effective against the penetrators and not too heavy to be contained by the outer layer of the armour. Integrated ERA offers future vehicles possibility of protection, both against the KE projectiles and the jets of shaped charge weapons (even those with tandem warheads)[28].

3.4 Electromagnetic Armour

A potential alternative to ERA is the electromagnetic armour. Its effectiveness was demonstrated by Defence Science & Technology Laboratory (DSTL), UK in 2002 for possible use on IFVs[11,29]. The armour typically has two spaced plates, as shown in Fig. 9, one of which is connected to a high-voltage capacitor bank. This armour is essentially made up of two or more conductive plates separated by space or by an insulating material, creating a high-power capacitor. In operation, a high-voltage power source charges the armour. When an incoming body penetrates the plates, it closes the circuit to discharge the capacitor, transferring energy into the penetrator, vapourising it or turning it into a plasma, significantly diffusing the attack. Magneto-mechanical instabilities in the jet lead to its break-up and evaporation. In the case of the penetrators too, electrical currents can cause instabilities and disruption of the penetrator. It is not known whether this will function against both kinetic energy penetrators and shaped charge jets, or only the latter[30]. This armour can be made intelligent by coupling it to a detector system[28].

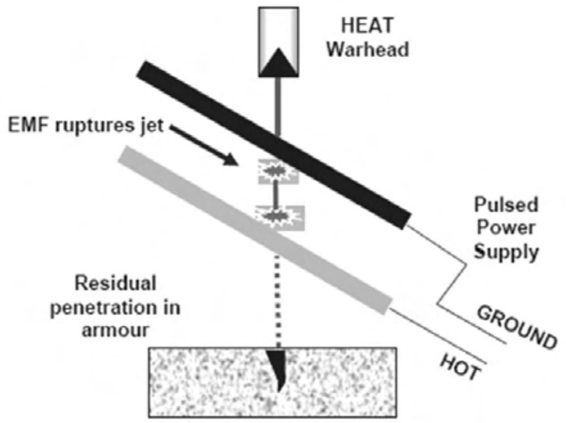


Figure 9. Principle of electromagnetic armour.

3.5 Active Protection System

Today's multi-spectral and fragmented battlefield creates new demands for the protection of combat vehicles.

To augment the available armour of modern AFVs, newer active protection systems (APS) are being developed for heavy AFVs (main battle tanks), light tanks, wheeled armoured vehicles, and armoured infantry fighting vehicles[31]. The use of such countermeasures has become a primary requirement to complement the traditional passive armour protection.

In the near future, vehicles will need, an IR detector, a target identification system, a laser warning system, a radar warning receiver, and a device to coordinate their signals and instantaneously control a countermeasures suite. These countermeasures fall into two categories: the soft-kill systems and the hard-kill systems.

The soft-kill systems make the attacking munitions miss their targets without damaging these. These confuse the incoming missile, by using decoys, smoke and electro-optical signals, infrared or laser jamming. The sensors must be capable of discriminating between true and false targets, missiles or other rounds that impact the vehicle and also determining the direction of the incoming threat. Laser warning receivers combined with smoke-grenade launchers are used against laser-beam-riding missiles. Infrared decoys or jammers are used to counter optically-guided ATGMs.

The hard-kill system is designed to intercept and destroy the incoming projectile or missile before it hits the vehicle. Countermeasures include fragmentation charges, steel bars, high pressure shock waves that destroy the incoming threat, destabilise or disrupt it flight path, or divert it from its course. These systems use millimeter-wave radar to detect and track approaching missiles. Shtora and Arena of Russia; Galix, KBCM and Spatem of France; FSAP, FCLAS and IAAPS of USA; MIDAS of UK; AwiSS and Muss of Germany; and Pomals and Trophy of Israel are some of the known APS systems around the world.

Limitation of the current generation APS world over is their incapability to engage kinetic energy projectiles. Next generation APS may be able to destroy these threats.

3.6 Protection against Mines and IEDs

A landmine detonation under a vehicle causes structural deformations, and sometimes, vehicle hull rupture, which affects (psychologically and physically) the occupants. Following the detonation, mechanical effects like shock, structural deformation, and global movement (mostly vertical), have the potential to cause injuries to the human body. Vehicle hull rupture also results into direct harming effects like fragments, fire, gases and blast overpressure. Injury criteria, tolerance levels, and measurement methods were employed to assess the most vulnerable body regions to a blast mine strike under a vehicle have been documented by NATO research and technology[32].

During the conflict in Kosovo, and more recently in Afghanistan and Iraq, it became clear that soft, unprotected vehicles and even heavy armoured vehicles became primary targets for guerilla attacks. There is a strong need for the light vehicles as well as the battle tanks to provide protection against mine blasts and many vehicles are now being designed to provide protection against mines[2,4,33]. It is necessary to have similar standards extended to heavy vehicles and MBTs at least as an add-on armour.

The main mechanisms that can be incorporated into the design of vehicles and equipment to render protection against the blast effect of mines are

(i) Absorption of energy,
(ii) Deflection of blast effect away from the hull, and
(iii) Keeping adequate distance from detonation point.

The effect of blast against the hull of a vehicle can be re-

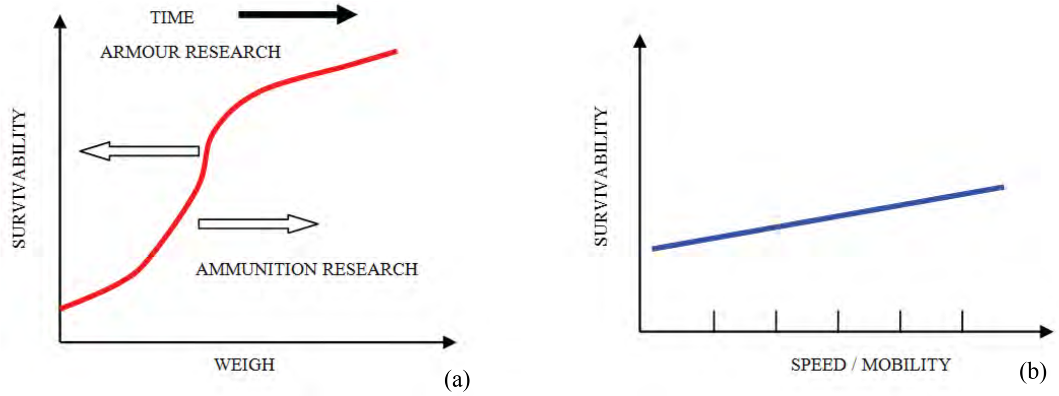


Figure 10. Survivability as a function of: (a) weight, and (b) mobility.

duced considerably by incorporating steel plates at an angle to the direction of blast, because highest pressures are generated only when the blast direction is at a 90° angle to the plate. This approach has led to the introduction of V-hulls, which have been successfully used in the protection of light- and medium-sized vehicles against mines.

With the increasing possibilities of use of infantry combat vehicles for urban warfare and other low-intensity conflict operations, ICVs too are becoming more vulnerable to the threat of mines. Therefore it is desirable to provide mine and blast protection to these vehicles too. This calls for change of the floor design to cater for protection against these threats.

4. AFFORDABLE PROTECTION

In general, armour has not been a major cost element in ICVs and battle tanks because steel, which is cheap, has continued to be the main armour element. But, as we shift to ceramics and composites, the cost rises three-fold. ERA and dynamic passive armour are relatively cheap approaches for providing protection against HEAT. Cost of active armour protection would depend on the sophistication of the system as well as the sophistication of the buyer.

There is also the question of affordability in terms of weight. In this connection, it is worthwhile for a moment to consider the competition between protection and mobility. Increased mobility often demands reduced weight, and hence, sacrifice in protection. But the competition is not that straight forward because increased protection also increases mobility. One can move freely without pause, without expecting supporting firepower and without fear. Also, protection is a highly nonlinear function – almost a step function with weight as seen in Fig. 10.

At a given level of materials technology, there is a certain threshold areal density below which protection falls down exponentially. The threshold weight moves to higher weight with advances in ammunition research and to lower weight with advances in armour. In contrast, there is no such catastrophic debilitating effect of decreased mobility at any weight or power/weight ratio. Therefore, all futuristic tanks may contain firepower and protection as the main determinants of vehicle design and be relieved from the grip of power/weight ratio.

5. DISCUSSION

In a true sense, one of the most important elements of defence is armour protection because it is a great morale booster for the soldier. Intense research needs to be done on various types of materials, concepts, and structures which could be used for armour applications. New advanced materials and concepts can be developed and incorporated in the futuristic light armoured vehicles to make these lightweight and yet adequately protected. For this, there is a need to generate novel concepts of protection and also continue R&D on refining the available materials and systems to be prepared to take up futuristic challenges of protection in the shortest possible time. To meet the challenge it is necessary to have a paradigm shift in our thinking and allocation of priorities for research from increasing damage capabilities to increasing protection capabilities.

In view of the trends of increasing battle range and severe weight constraints, for the FMBT, the tank should be protected against HEAT with full immunity against all contemporary threats at the front from the battle range with an extra buffer of about 15 per cent for enhanced protection from the threats of the future. On the sides and top, the armour should provide a high chance of survival (greater than 85 per cent) against contemporary HEAT threats with at least 80 per cent chance of survival against futuristic higher threats possessing 15 per cent higher penetration capability. In addition, one should have readymade selective protection enhancement kits for each location (top, sides, front and bottom) which can be integrated as add-ons, on a need basis. With this philosophy, it is also possible to make older generation of tanks also battle-worthy and fit using latest add-on armour modules and enhanced firepower using advanced KE and other ammunitions.

6. CONCLUSIONS

Armour for the futuristic main battle tanks can be created as a multi-layered armour protection system comprising basic passive armour modules (PAM) over which a layer of intelligent dynamic armour (IDA) modules to substantially degrade selective KE projectiles, and bulging armour modules to degrade the HEAT missiles. An added envelop of active protection system (APS) on the turret top and sides of hull can reduce the chance of hit by HEAT and other threats.

Similarly for a futuristic ICV, while protection against fragments and National institute of Justice Standard 0101.06 level IV protection be provided all around, selective KE protection may be opted at the direct front and HEAT protection from the sides and top along with enhanced blast protection suites at least for the crew. As with the MBT, it would be prudent to place less emphasis on mobility to enable creation of an excellent combination of firepower and protection to defeat the enemy and yet remain protected.

Thus, one can make a near failsafe lightweight advanced affordable armour protection system for the futuristic combat vehicles.

ACKNOWLEDMENTS

The authors wish to express their sincere thanks to Director, Defence Metallurgical Research Laboratory(DMRL) for giving permission to publish this work. The authors are also grateful to the officers and staff of Armour Division, DMRL for their support.

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