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Integrated Survivability Concept - A Hybrid Protection System for AFVs – A Literature Survey Report

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Abstract*— Most of the current combat vehicles were solely made of Rolled Homogenous Armour (RHA) steel to counter the anti tank projectile threats. But the threat to combat vehicle has increased manifold due to advancement in weapon technologies and there is a necessity of protecting the vehicle from these weapons threats. The protections by means of RHA Steel will lead to increase in weight, which affects the tactical mobility of the vehicle. Hence, the concept of protection has to give way for the concept of survivability with more exotic form of protection methods and counter measures. This paper highlights integrated survivability concept, direct protection systems and indirect protection system constituting hybrid protection concept.

***Index Terms*— Integrated Survivability, Direct protection, Secondary protection, indirect protection system.**

I. INTRODUCTION

Combat vehicle is a complex weapon platform. The main role of the combat vehicle is to counter another contemporary vehicle firing Kinetic and chemical energy Projectiles. Most of the current combat vehicles were solely made of Rolled Homogenous Armour (RHA) steel to counter these threats. But the threat to combat vehicle has increased manifold due to advancement in weapon technologies and there is a necessity of protecting the vehicle from these weapons threats. The protections by means of RHA Steel alone or in combination with Reactive armor will lead to increase in weight, which affects the tactical mobility of the vehicle. Hence, the concept of protection has to give way for the concept of survivability with a lighter and agile combat system [1]. As the future vehicles are to be highly agile and light weight, there is a need for more exotic form of protection methods and counter measures for the survival of the vehicles against enemy threat.

II. MEANS OF ACHIEVING SURVIVABILITY

The Integrated Survivability can be achieved by the following means [2]:

- Direct Protection System
- Indirect Protection System

III. DIRECT PROTECION SYSTEM

It is the ability of the tank to survive from a projectile hit. This system is categorized into the following:

- Passive Armour
- Reactive Armour
- Means of Surviving Hits

IV. PASSIVE ARMOUR

Passive armour [3] is classified into three categories:

- Metallic
- Non-metallic
- Special materials

A. Metallic Armour

Metallic armour: can be classified into the following categories:

- Steel armour
- Aluminum armour
- Titanium armour
- Du armour

Rolled Homogenous Armour (RHA) steel is primary metallic armour used for combat vehicles because of its strength, toughness, hardness and relatively reasonable cost. It is used as plates, although it is bent to a limited extent to form curved pieces. It can be welded into a vehicle structure with least difficulties.

Aluminum (AL) alloy armour is lightweight, generally used in light armoured vehicles, but the medium and large calibre projectiles impacting on heavy aluminum alloy plates produces cracks as well as spall. It also has a tendency to produce pyrophoric impact debris. These disadvantages coupled with its higher cost make it less attractive for armoured Vehicles.

Titanium Armour (TA) is now affordable for armoured vehicle application and used in the light armored vehicles but it requires special welding technique.

Depleted Uranium (DU) is considered as one of the best material for armour application. The density and hardness of DU is more than the steel. DU armour is very effective against the KE projectile. But this armour produces toxic gases on impact of the projectiles, which will harm the crew and hence its application as armour is limited. The properties of the metallic armour are given the Table 1.

Table 1: Properties of Metallic Armour

Properties	RHA	AL	TA	DU
Tensile strength MPa	1170	350	970	825-1000
Density g/cc	7.86	2.70	4.50	19.00

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B. Non Metallic Armour

Non metallic armour: can be classified into the following categories:

- Ceramic Armour
- Polymer Matrix Composites

Function of ceramic materials at the front facing of the armour [4] is for

- Blunting the projectile
- Erosion of the projectile
- Deformation, cracking and fracture
- Breaking of the projectile
- Absorbing the Kinetic Energy of the Impact

Variety of ceramic materials is being used for armour application due their higher protection efficiency and low density. The ceramic material generally preferred for armour application are listed below:

- Aluminum Oxide Al_2O_3
- Silicon Oxide - SiC
- Zirconium Toughened Aluminia - ZTA
- Boron carbide- B_4C
- Titanium Diboride - TiB_2
- Aluminium Nitrate - AIN

Aluminium Oxide / Alumina (Al2O3) is a most widely used ceramics for armour application. The higher percentage of Alumina is generally preferred. The percentage of alumina ranges from 85% to 99.5% aluminium oxide. It has moderate strength, hardness and Toughness.

Zirconia Toughed Alumina (ZTA): Alumina ceramic materials have limited its usage because of its poor fracture toughness. This can be improved by incorporating zirconia in to an alumina matrix to give dramatically higher toughness values and substantially higher fracture strengths. It has high hardness and toughness with moderate density.

Silicon Carbide (SiC) is hard and corrosion resistant. It is excellent in high wear and chemically aggressive environments. It also has strength and moderate density and toughness.

Boron Carbide (B_4C) is an Ultra high hard, light weight material. It has low volume mass, low toughness and High effective cross section of neutron. It has very high erosion resistance property. This material provides the lightest weight available for Aircraft and Helicopter use. They are used in air craft and helicopter systems for armour, integrated seating, floor and side panels and many fixed wing panel assemblies.

Titanium boride ($TiB_{2)}$ has high strength and high hardness but it has high density. Aluminum Nitrate (AIN) has very high thermal conductivity and corrosion resistance. Mechanical Properties of the different type of ceramic materials are given in the Table 2.

Table 2: Mechanical Properties of ceramic materials

Material	Density g/cc	Hardness GPa	Young's modulus GPa	Fracture toughness Mpa (m)1/2
Al_2O_3	3.68	20	380	3.234
B_4C	2.5	49	400	3.66
SiC	3.2	33	370	4.38
TiB_2	4.5	33	570	8.0
ZTA	4.1	16	360	8.0
AIN	3.26	11.2	310	2.49

The Polymer Matrix Composite [5] has the following reinforcing fibres:

- Glass fibres
- Aramid /Kevlar
- Dyneema
- Spectra

Glass Fibers are the most common of all the reinforcing fibres of Polymers Matrix Composite. The Advantage of the glass fibre is high tensile strength, high hardness, high Chemical resistance and low cost. But they are relatively low tensile modulus, high specific gravity and low fatigue resistance. Types of glass fibers are generally preferred for armour applications are E Glass and S Glass. A lower cost version of S Glass is S_2 Glass. S_2 Glass fibres offer significantly more strength than the conventional fibers. It offers 85% more strength in impregnated strands. Better fibre toughness, modulus of resilience and impact deformation than conventional glass fibres. Laminates made from S_2 glass fibre provides an inherent balance of tensile, compressive, stiffness and fatigue properties as well as the ability to perform as a ballistic material.

Aramid fibers [6] are the generic name for aromatic polyamide fibres. DUPONT introduced Aramid fibres under the trade name of Kevlar. Kevlar is used for high performance composite applications where lightweight, high strength, high stiffness, damage resistance, fatigue resistance and stress rupture are important. Two commercial used Kevlar types are

- Kevlar 29
- Kevlar 49

Dyneema [8] is patented product of DCM. It is made of Ultra High Molecular weight (UHMW) polyethylene fibres. This fibre is produced under the trade name of Dyneema. It is a high strength, high modulus, high energy absorbing capability and low weight fibres suitable for all the ballistic applications. DCM developed following type of Dyneema based products:

- Dyneema SK60
- Dyneema SK 65
- Dyneema SK 75
- Dyneema SK 76

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Spectra fibre [9] and shield technology is a patented product of Honeywell, USA. It is a synthetic yarn made of extended chain, high modulus polyethylene fibre. Because the spectra fibre is a polyethylene with a carbon-carbon molecular structure likes that of a diamond, it creates a continuous filament yarn with incredible performance and endurance. It is designed to provide super fine, super strong and ultra light weight fibres for armour. Spectra fibre withstands high loads stain rate velocities and exhibits outstanding toughness and exordinary Visco-elastic properties. It also resists degradation from many chemicals, water and ultra violet rays. It has an excellent vibration damping, flex fatigue and internal fibre- friction characteristics and its low dielectric constant makes spectra fibre virtually transparent to Radar. The firm launched many grades product mentioned below under this trade name for ballistic application:

- Spectra fibre 900, 1000, 2000
- Spectra flex, Gold flex,
- Spectra shield -LCR, PCR
- Spectra Shield Plus – LCR, PCR

The mechanism of energy absorbing by the composite material [9] [10] will be depending upon the following failure criteria:

- De bonding
- De lamination
- Fiber pullout
- Fiber breakage
- Matrix cracking

The Strength of the fiber material given by the manufacture is given below.

Table 3- Mechanical properties of fibres

Fibers	Specific gravity	Tensile strength (Gpa)	Tensile modulus (Gpa)
E-Glass	2.54	3.40	72.0
S-Glass	2.50	4.00	86.0
Kevlar 29	1.44	3.30	70
Kevlar 49	1.45	3.60	130.0
Dyneema	0.97	2.7-3.6	100-120
Spectra	0.97	3.3-3.5	124

C. Special Armour

It is a well-known fact that no single material can provide protection against all types of ammunitions, which work on different principles. However, different materials suitably combined in the form of a special material, which can optimally provide the required protection. The development these materials are in the advanced stage of research. This armour material classified into the following:

- Nono technology based Armour: The mechanical properties of armoured steel and composite armour can be increased by improving micro structure embodying superfine particles using nono technology [11]. This armour material will have greater ductility with hardness and giving an unparalleled multi- hit capability. Carbon nano tube / Nono fiber reinforced composite will impart improved properties to armoured materials that enables higher protection level with reduced weight.
- Functionally Graded Material: It is a multi-layered material of different properties. The materials of different properties can be claded by explosive welding to become single material. The outer layer/ surface of the material may be hard surface to resist impact indentation; and the inner material may be made of tough ductile/titanium/composite material to absorb kinetic energy of the projectile impact. The density of the functionally Graded Material will be lesser than the steel as non-metallic content will be more and hence the Material will become lightweight.

V. REACTIVE ARMOUR

The reactive armour [12] classified in to the following:

- Explosive Reactive Armour (ERA)
- Heavy ERA
- Advanced ERA
- Integral ERA

A. Explosive Reactive Armour (ERA)

The use of shaped charge weapons inspired the development of reactive armour by sandwiching an explosive between two layers of metal plates. ERA reduces the penetration of shaped charge jets by virtue of its explosive layer detonating when penetrated by the jet, thereby, creating a high pressure zone causing lateral disturbances which reduce its ability to penetrate armour located behind the ERA. The ERA panel generally has the following limitations:

- ERA would be considered a one shot protective system in the normal battlefield condition.
- It is possible that sympathetic detonation between ERA panels occur; which causes severe damage to the nearby tank optics, radio antennas hampering communication with other tanks.
- ERA panel does not provide protection against tandem shaped charge warheads.

B. Heavy ERA

The ERA, which was devised against shaped charge anti-tank weapons, consisted of sandwiches made with steel plates of thickness 2-3 mm. This thin steel plate ERA was not effective against high velocity Kinetic energy projectiles of the tank guns. To degrade the performance of these weapons, the steel plates of the ERA sandwiches had to be considerably thicker than those of the original ERA, which led to the development of HEAVY ERA.

C. Advanced ERA

Non-explosive ERA is a novel technique of providing protection against the battle tank with least penalty. The

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explosive content ERA replaced with an inert liner of energetic metallic powder (NERA). When this panel exposed to the intense stimuli of shaped charge, some of the impact energy is dissipated into the inert liner layer, and the resulting high pressure causes a localized bending or bulging of the plates in the area of the impact. As the plates bulge, the point of jet impact shifts with the plate bulging, increasing the effective thickness of the armour. The sympathetic detonation between ERA panel is completely avoided.

D. Integral ERA

Explosive Reactive Armour (ERA), Heavy ERA, and Advanced ERA have been designed after vehicles were developed. This means that it could only be used as add-on or appliqué armour, instead of being fully integrated with the vehicle. Therefore, there is a scope for further development of ERA and in particular for incorporating it from the start in future tank design. In principle, the integration of ERA into the design of tanks amounts to splitting their armour into outer and inner layers and spacing them well apart, so that ERA sandwiches can be installed in between. Such an arrangement protects the sandwiches from damage by small arms, shell fragments and other means and reduces the danger around tanks due to flying plates and blast.

VI. MEANS OF SURVIVING HITS

This is the system, which gives secondary protection against armour threat. The secondary Protection System are given below:

- Nuclear, Biological and Chemical (NBC) protection System
- Advanced Fire suppression system
- Frontal Engine Configuration
- Anti spall liners
- Self sealing Fuel tank
- Mine protection systems

A. NBC Protection System

NBC Protection System fitted in all the current MBTs. The system consists of nuclear radiation detection / warning sensors and chemical sensor, blower for over pressurization of the crew compartment and boron pads. In the future vehicle will be equipped with more than 60% of electronic components / systems. These systems should be EMP hardened.

B. Advanced Fire Detection and Suppression System

The automatic fire detection and suppression system can suppress explosion / fire on the battle tank. The system is capable of detecting an explosion of fire and suppress within 100-150 ms. This system consists of control panels connected to different type of sensors and fire extinguisher bottles filled with Helon/ Non Helon under high pressure.

C. Frontal Engine Configuration

Most of the current MBTs, the power pack is fitted in the rear. The driver and crewmember were positioned in the frontal area. The frontal engine configuration can give additional protection to the crew. In case of multi fold threat level, the crew can be safely located centrally in the hull.

D. Anti Spall Liner

Spall is the dispersion of finely divided or melted metal of ammunition produced upon impact of the projectile with armour plate or other hard objects. These fragments travel at extremely high speeds and capable of injuring personnel or damaging equipment.. The effect of spall can be eliminated by lining material such as a rubber, plastic and Kevlar with the armour. This liner material deflect the spall and absorbs its kinetic energy.

E. Self Sealing Fuel Tank

Fuel tanks of current MBTs are made of Aluminum, or thin sheet of steel plates. But this fuel tank is not self-sealing type. The Fuel tank should be of self-sealing type with fire and explosion proof against 7.62 mm / 12.7mm bullet. The fuel tank is to be provided by special treatment of its outer surface and inside [13]. The fuel tank shall be coated with two-layer protection system as given below:

- Fire proof coating – Provides protection against open fire
- Self sealing Polymer Coating – Prevents fuel leakage if g
- The fuel tank is filled by open cell filler, which prevents fuel vapor

F. Mine Protection System

Current MBTs are provided with mine protection against conventionally activated blast mine with few kg of explosive content. Mine protection provided in the current MBT consists of belly plates just thick enough to withstand the blast of mines. But the level of protection required for future vehicle is more than doubled. Following technique is to be used to increase the survivability of the tank with less weight penalty.

- Roof mounted crew seat
- Energy absorbing materials as add-on at the bottom plate
- Honey comb structured composite material
- Active mine protection system.

VII. INDIRECT PROTECTION SYSTEM

This system enables the tank to avoid being it by the enemy. This system employs following technique:

- Detection Avoidance Techniques
- Hit Avoidance Technique

VIII. DETECTION AVOIDANCE TECHNIQUES

Due to advancement of firepower and accuracy, once the MBT is detected it will be killed. Hence for the maximum survivability, the MBT is to be designed in such a way that it

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cannot be detected. The following Detection Avoidance Technique will be adopted for survival of the MBTs.

- Camouflage techniques
- Increasing the agility of the tank
- Low vehicle silhouette

A. *Camouflage Technique*

Current Tanks are made to merge with the surrounding by applying paints with some pattern / shapes, nets and false vegetation. This technique gives counter measures only in the visual range of electromagnetic spectrum. But due to the development of Electro optical sensors operating in thermal IR and use of Radar /Laser Range Finder/ Designator, most modern tanks are to be equipped with multi spectral camouflage system aimed at providing camouflage in the visible, IR and radar wavelengths. Current passive camouflage system uses the combination of Signature management and Coating material to achieve the multispectral requirement [14] [15]. Visual signature can be reduced by having low Silhouette vehicle. The thermal signature can be reduced by following methods

- By positioning the engine at the rear of the vehicle
- By mixing in cool air with the exhaust gas.
- Thermo barrier coating at engine exhaust pipes
- Composite materials based bogie wheels and tracks
- Use of composite material in the chassis

Radar signature can be reduced by properly shaping the vehicle and incorporation Radar transparent composite material. Acoustic signature can be reduced by using composite / rubber band tracks / wheels and incorporation of electric transmission. The coating material will consists of many layers as given below.

- Visual and Near-Infrared: The outer layer is printed with color, pattern and its infrared properties to match with the surrounding background. This outer layer should have a non-glossy 3-dimensional surface structure to blend in with the surroundings.
- Thermal Infrared properties: The coating should have a layer of insulating material, having low emissivity material (Iron ball/ Metallic fibres) and construction should aid to have convective cooling
- Radar. Few layers of Radar Absorbing .Material.

B. *Agility of vehicle*

It is the ability of a tank to take evasive action in the event of detection. This will be achieved by having High power to weight ratio of the tank. The acceleration of vehicle also aids for the agility of the vehicle. The power to weight ratio ranges from 22 - 25 kW/t and the acceleration level of 0 to 32 km in 7-8 seconds is preferable. .

C. *Low Silhouette*

Lower the tank silhouette, harder will it be to detect the vehicle. This can be achieved by having external turret with auto loader at the bustle. This results in the reduction in crew (Ammunition Loader). The reduction of crewmember has a favorable effect on reducing overall silhouette of the tank.

IX. HIT AVOIDANCE TECHNIQUE

This is the technique, which avoids the tank being hit by the projectile. This technique is categorized into the following:

- Active Protection System
- Electro Magnetic Armour

A. *Active Protection System*

Active Protection System [16] for tank is a close range anti-missile/anti-warhead defence system that creates an active protection area at a safe distance around the vehicle. There are two types of active protection system –

- Soft kill
- Hard kill

Soft Kill Mechanism - It is an Electro – optical jammers that jam enemy's semi automatic command to the line of sight (SACLOS) anti tank guided missiles and laser guided missiles that results in diverting the missile away from the target. Two types of the soft kill system have been developed [17] [18]

- IR decoys
- Laser jammers.

Hard Kill Mechanism - Hard kill system has radar which detects & tracks the threat and activates suitable mechanism of deploying a fragmentation warhead or explosively formed projectile that would kill the attack threat.

B. *Electromagnetic Armour*

In Electromagnetic Armour, has three types- Passive, reactive and active [12]. Passive Electromagnetic armour has two fairly widely spaced plates, one of which is connected to high voltage capacitor bank, while other is grounded. When under attack, a shaped charge jet penetrates the plates and acts as a switch between them and triggers a discharge of electrical energy, which causes a large current to surge through it. This creates magneto mechanical instabilities in the jet, which lead to its break up, and drastically reduces its penetration capacity. The Reactive type electric armour is electro thermal. It is made up of pairs of metal plates one of which is concerned to the capacitor bank, which the other is grounded. But the plates are smaller and separated by a relatively thin layer of insulating material instead of a sizable air gap. When a pair of plates is pierced by a shaped charge jets or a kinetic energy penetrators there is a surge of electrical current from one plate to the other. This causes the insulating layer to expand explosively, throwing the plates apart. Electro thermal armour is therefore self actuating and acts against jets or penetrators in much the same way as explosive reactive armour. Active type electromagnetic armour requires the detection of attacking long-rod penetrators or missiles at short distance from their target Once this has been done by some

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multi sensor detection system; a computer based control unit closes a switch, which sends a surge of large current from a capacitor bank to the pancake coil of an induction type plate launcher. This projects a plate in the path of the incoming penetrator or missile to collide with it and there by break or at least deflecting the former and to disrupt and detonate the latter. The operation of the three types of electric armour would clearly depend on tanks carrying high voltage capacitor banks to provide the necessary amounts of electrical energy, which could be considerable.

X. CONCLUSION

In this paper an attempt has been made to outline the concept of Integrated Survivability, materials and systems constituting direct and indirect protection system. These details will help in arriving at a consensus on the choice of materials / systems required for increasing the survivability of the vehicle. All the information given in this article is taken from the open literatures / Internet Survey.

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