Advanced Composite Materials & Technologies for Defence

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COMPOSITES FOR ARMOUR SOLUTIONS
What is Armour

❖ Role of Armour is to protect a person, structure or device

❖ Achieved by absorbing kinetic energy of the projectile

❖ Energy may dominantly be absorbed by plastic deformation and/or fracture processes

❖ Fragments as a result of fracture process should not cause damage to what is being protected and should be arrested by another layer at the back

❖ Armour plate may have to fulfill two roles: a protective role and structural role

❖ Both roles can be fulfilled by having sufficient strength at high strain rate and appropriate thickness to provide both protection and structural requirements of the Platform (Integral Armour / Structural Armour)
Technical Requirements

- Protection requirements are threat driven

- Very significant analysis is done to identify threat probability and threat development under different scenario.

- However, threats may be considered to be of some basic fundamental types

  - Impact
    - Kinetic Energy, Chemical Energy (“Shaped Charge”)

  - Blast
    * Mines (AP, AT, Influence), HESH

  - Combined blast and impact
    - Specific weapons, entrained debris (Claymore mines)
Some threats

Platform Threats

- Directed Energy Weapons
- Anti Tank Guided Munitions
- Tank kinetic energy
- Tank chemical energy
- Smart Artillery
- Smart Artillery
- Unguided Artillery
- Unguided Artillery
- Unguided / Guided Mortars
- Terminally Guided Sub Munition
- Bomblets
- Rocket Propelled Grenades
- Guns
- Improvised Explosive Devices
- Biohazard
- Mines
- Chemical hazard
- Radiological and nuclear hazard
Why Composites

- Desirability of composite solutions for armour - better mobility and transportability
- Ability of material to provide resistance to impact depends upon
  - Hardness to blunt projectile
  - High strain to failure to absorb energy via a global deformation process involving brittle fracture in ceramics and composites or plastic deformation in metals.
- Composites rely primarily on brittle micro fracture events to absorb energy. Ultimate energy absorption is largely controlled by strain to failure of fibers.
- Composites are soft and are not effective against hard projectiles (AP ammunition) However, when coupled with ceramics as laminates, they provide effective solution
- Composites also provide best protection against HESH ammunition
Penetration in Composites-Energy absorption

- Composites are relatively soft. No blunting of projectile occurs in most of the cases.
- Composites rely primarily on brittle micro fracture events to absorb energy.
- High speed of impact does not give target time to deflect with the impacting projectile.
- Fracture occurs in 2 separate phases:
  - (A) Initial entry phase of projectile results in a combination of compressive and shear failure in the material.
  - (B) As the projectile slows, the plate will bend giving rise to tensile elongation, delamination & fiber pull out during exit phase.

Failure of E-glass-phenolic composites against 7.62 x51 Lead projectile tested in DMRL.
Energy absorption of E & S2-glass composites against 7.62 soft projectiles

- S2 glass composite shows better energy absorption than E-glass composite at all the thicknesses.
- S2 glass laminate is 20-25% better than E-glass against lead projectile at higher thicknesses.
- >15mm thick shows more energy absorption.

- S2 glass fiber has higher Strength and failure strain & hence shows more energy absorption.
- S2 glass shows less shear of fibre and more stretching as compared to E glass.
- S2 laminates shows more delamination as compared to E glass laminates.
<table>
<thead>
<tr>
<th>Armour grade composite Vs <strong>Structural composite</strong></th>
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<tbody>
<tr>
<td><strong>Resin content:</strong> 18 – 22 % by wt</td>
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<tr>
<td>Weak interaction between fiber and resin</td>
</tr>
<tr>
<td>Composite undergoes delaminations upon impact</td>
</tr>
<tr>
<td>Energy absorption takes places by self destruction</td>
</tr>
<tr>
<td>High strength and high elongation is preferable</td>
</tr>
<tr>
<td><strong>Resin content:</strong> 30 – 35 % by wt</td>
</tr>
<tr>
<td>Strong interaction between fiber and resin</td>
</tr>
<tr>
<td>Delamination is not acceptable</td>
</tr>
<tr>
<td>Absorbs load without any damage</td>
</tr>
<tr>
<td>High strength and high elongation preferable</td>
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Composites- Fibers for Ballistic Armour

- Since energy absorption in composite primarily occurs due to elongation and failure of fiber, fiber with high tensile strength and high strain to failure are best candidates.
- In addition, high sonic velocity in the fibre (depends upon Elastic Modulus & Density) can lead to enhanced ballistic performance due to its ability to spread out energy to larger areas.
- A Ballistic figure of merit $U$ for ballistic applications has been proposed where

$$
U^* \left[ \frac{m^3}{s^3} \right]^{1/3} = \frac{\sigma_F \varepsilon_F}{2\rho} \sqrt{\frac{E}{\rho}}
$$

- Kevlar (Aramid fiber), S 2 Glass & Dyneema (UHMPE) are already in use for ballistic applications.
- Future armour may use M5 fiber (PIPD) & SWCNT (single wall carbon nano tube) fibers.
Composites-Resins for ballistic Armour

- Compatible with fibers- Good Wetability
- Moderate interface strength-should allow de-lamination and fiber deformation
- High elongation to allow fibers to stretch to their limits
- Fire and Water Resistance
- Both thermo set and thermoplastic resins are being used
  - Thermosets
    - Phenolics, Epoxies
  - Thermoplastics
    - Polypropylene (PP), Styrene-isoprene-styrene (SIS), Polyethylene (PE)

However, as compared to fiber, effect of resin matrix is only marginal
Design of Composite Armour

- Design of Armour depends on:
  - Type of ammunition
  - Type of application
  - Permissible weight penalty
  - Cost

Classical approach - Applique Armour
- Armour is strapped to structure
- Fastening arrangements to be provided
- Weak at seams, parasitic masses
- Difficult to make complex shapes

Integral armour
- Full structure made with composites
- Armour and structure integrated as a single multifunctional composite

Typical Armour Locations

Cross-section of strap-on armour

Cross-section of integral armour
Design of Composite Armour for Soft Projectiles (SMC, AK-47 & SLR)

Core material in soft projectile: Lead antimony or mild steel

- Striking velocity: 390 – 830 m/s at 10 m distance
- Impact energy: 1000 J - 3500 J
- Typical applications: BPJ, Helmet and VIP Vehicles

Material choice:
- Glass composites
- Aramid composites
- UHMWPE composites

Increase in Cost

Decrease in weight

7.62 Lead & MS, 9mm Lead Projectiles
Armour Design against Hard Projectile: Ceramics-Composite

**Energy Absorption Mechanism**
- Composites coupled with ceramics can provide protection against hard projectiles.
- Ceramics facing blunts the projectile and composite backing helps in arresting.

**Fragments of projectile and ceramics**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
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<tbody>
<tr>
<td>Stage -I</td>
<td>The projectile tip is destroyed and backup plate starts to yield at the conoid interface.</td>
</tr>
<tr>
<td>Stage -II</td>
<td>The ceramic fragments erode the projectile. About 40% of impact energy is carried off by eroded projectile material.</td>
</tr>
<tr>
<td>Stage -III</td>
<td>The backup plate acts to absorb the resulting 60% energy contained in the fractured projectile and ceramic.</td>
</tr>
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Schematic representation of projectile – ceramic composite armour interaction
An Example: Ceramic-Composite Armour

Design for Armour Piercing Projectiles (5.56, 7.62 AP(I), 12.7AP(I) & 14.5AP(I))

Core material in AP projectile: Hard steel (900 – 1000 VHN)

- Striking velocity: 830-1000 m/s at 10 m distance
- Impact energy: 4000 J - 34000 J
- Typical applications: BPJ, Helicopters, Navy boats & ICVs

Material choice:

Ceramic (B₄C)+ Polymer composite (UHMWPE)

Tested Panels at DMRL

14.5, 12.7, 7.62 AP(I), 5.56 Projectiles

Front  Rear

LCA Boat

15 LCH
Composite Armours at DMRL

- Ceramic composite armour technology developed
- Indigenously developed armour grade composites can be produced in bulk
- Ex: Alumina, ZTA, Boron carbide and Polymer composites
Integral Armour (Structural Armour)

Large Composite structures for vehicles such as ICV

Vacuum assisted resin transfer moulding (VARTM)

- Suitable for large structures
- Not suitable for high temperature curing resins
- Resin viscosity is a critical issue

Resin film infusion (RFI)

- Suitable for all resins
- Large thick structures possible with minimum voids

VARTM & RFI at R&D (E)

Specimen subjected to ballistic impact
Process Design

Modified VARTM and RFI at R&DE(E) to make multi-layered integral armour in one-go

Lay-up of ceramic tiles

Lay-up of dry fabric with interconnected beams and aluminum cuffs

Infusion of the structure using VARTM in one-go

Simulation based process design: Simulation of resin flow during VARTM process
Futuristic armour materials

Options
1. Fibers + composite of polymer & nanoparticles
2. Fibers + mixture of polymer & nanoparticles in fibers
3. Fibers filled with nanopowder

Fibers
Dyneema, Kevlar, M5 (magelaen), nanofibers

Particles
Nanotubes, al si zeolytes, cubicles, nanoclay platelets, hexagons, chitosan, nanocoated metal/ ceramic particles
STF Armour

• Flexible armour made of using **shear-thickening** binder technology.

• A shear thickening binder is made of a flexible matrix with a high load of silica nanoparticles.

• At low shear rate the binder is flexible, allowing fabric to bend and adjust to deformation.

• At high shear rate the binder and the whole fabric becomes stiff and rigid.

Ref: Wetzel, 14th Intl Conference on Composite materials, July 2003
Half the threads in this textile are black carbon nanotube threads.

- CNTs can be spun into fibers to make high strength fabrics.
- Spun CNT can be 3x stronger than spider silk.
- Armours using nano composites, nanocrystalline metals, porous & biomimic structures and materials.

- Body armour of 600 μm thickness made from six layers of 100 μm carbon nanotube yarns could bounce off a bullet with a muzzle energy of 320 J.
- Other important progress is made with inorganic fullerene-like nanotubes and nanospheres made from inorganic compounds such as WS₂, MoS₂, TiS₂ and NbS₂ (ApNano, Israel).
- Showing extremely high degree of shock absorbing ability such as for body armour.
Future research directions in COMPOSITE ARMOUR DESIGN

RFI technique for enhanced strength

- Nano-fillers can be incorporated in RFI technique
- Nano-fillers for
  - Stealth
  - Enhanced compressive strength
  - Better ballistic performance
- Multifunctional structures

Biologically inspired armour

Seashells are thousand times tougher than aragonite (CaCO₃)
Architecture of seashells replicated at R&DE(E) using ceramic tapes-polymer composites
Process patented by R&DE(E)
Experiments revealed more than two-fold increase in toughness

Cross-section of ceramics-polymer composite
Self-healing armour

- Embed hollow pipes or micro-capsules with healing polymer in armour
- Apply to VARTM, RFI process to enable large structure fabrication with self-healing characteristics
- Initial studies in progress
  - Polymer effectiveness evaluation
  - Filling hollow pipes with resin by vacuum infusion

Hollow capillary tubes forming the self-healing network to be embedded in composites

Studies for evaluation of healing characteristics of polymer

Studies to fill hollow pipes with healing material using vacuum infusion
This tiny block of transparent **Aerogel** is supporting a brick weighing 2.5 kg. The aerogel's density is 0.1 g/cm³.

**Carbon nanotubes** have numerous remarkable physical properties including the strongest \( sp_2 \) bond, even stronger than the \( sp_3 \) bonds that hold together diamond.

**Fullerenes** can be made substantially stronger than diamond, but for greater energy cost.
COMPOSITE TECHNOLOGIES
COMPOSITE TECHNOLOGIES

- Composite rocket motor case
- Grid stiffened structures for primary & secondary structures
- Re-entry vehicle structure
- Composite canister & launch tubes
- Development of CRMC with tow prepreg technology
- Flex / fixed nozzle system
- Extendable nozzle exit cone
- Jet deflector / flame deflector
- Jet vanes

- CRMC
- Re-entry vehicle
- CC Thin walled cone
- Flex Nozzle System
- Jet deflector
- Jet vanes
- Iso-grid/plate
- Canister
- CE/CP shells
- Air bottle
- Tow prepreg vessel
DEVELOPMENT OF COMPOSITE CANISTER ASSEMBLIES BY 0/90 TAPE LAYING PROCESS FOR BRAHMOS

(D) Detailed Composite Cross Section of Canister

SPECIFICATIONS

LENGTH : 8923 mm
DIAMETER : 710 mm
WEIGHT : 850 Kg
TECHNOLOGIES ESTABLISHED

- E/M DESIGN AND PERFORMANCE PREDICTION
- CONTOUR WOVEN SOCKS (GLASS / KEVLAR / QUARTZ)
- LOW LOSS POLYESTER / POLYITAKONIMIDE RESINS
- TOOLING TO CLOSE TOLERANCES
- RAIN EROSION / ANTI STATIC PAINT
- LIGHTNING PROTECTION

DESIGN & DEVELOPMENT CAPABILITY ESTABLISHED FOR A RANGE OF RADOMES FOR MISSILES & AIRCRAFTS
ABLATIVE TECHNOLOGY

JET DEFLECTOR

- Materials used: E-glass phenolic & E-glass epoxy
- Weight saving with composite jet deflector is 70%
- Composite jet deflector is designed as integral part of missile carrier

Composite jet deflector (AGNI4)  
Metallic jet deflector with ablative liners
LCA - Composites

- Design driven by buckling
  - Carbon Fibre Composite (CFC) materials provide much higher specific stiffness than metallic materials (Al Alloys)
- Thickness and lay-up optimized
  - Thickness tapering from root to tip
- Monolithic CFC skins supported by
  - CFC substructure with C – section spars and ribs
  - Metallic end members
- Bolted construction
- Integral fuel tank: sealing/leakage – proof
- Lightning – proof: Integral piping and conduits
- Skins cured in a single cure – excellent productivity

Graphite/Epoxy
Boron/Epoxy
Glass/Epoxy
Titanium
Steel
Aluminium

Tensile Strength/Density (in x 10^6)

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<td></td>
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<tr>
<td>Aluminium</td>
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Elastic Modulus/Density (in x 10^8)

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<tr>
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<th>Elastic Modulus/Density (in x 10^8)</th>
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<tbody>
<tr>
<td>Aluminium</td>
<td></td>
</tr>
<tr>
<td>Carbon composite</td>
<td></td>
</tr>
<tr>
<td>Glass composite</td>
<td></td>
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<tr>
<td>Kevlar composite</td>
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45% By weight of airframe

90% Wetted Area

LCA - PV

- LCA-CFC wing spar assembly
- Cocured LCA - Fin
- Rudder
- LCA-CFC fuselage assembly
- KEVLAR polyester LCA - Radome

Composites, 45%
Al Alloys, 43%
Others, 2.5%
Steels, 4.5%
Ti Alloys, 5%
Others, 5%
THANK YOU