Department of Materials Science & Engineering

MSE Team MMIC
Microlaminated Metal Intermetallic Composite Armor

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Problem Definition

We hypothesize a microlaminated metal intermetallic composite (MMIC) material will provide superior ballistics protection performance relative to traditional metallic or ceramic armor

Traditional Armor

- Steel
  - Heavy
  - Secondary fragment danger
- Ceramic
  - Poor durability
  - Shatters
- Composite UHMWPE
  - Complex & expensive
- Steel & Ceramic
  - Lack of intrinsic crack propagation barriers

MMIC Armor

- Brittle intermetallic & ductile metallic layer
  - Resists deformation and disperses energy
- Allows incorporation of crack propagation barriers
- Lower density
- Low cost
- Has been done with Ti-Al systems

Materials Selection

Al + Fe ⇒ FeAl Intermetallic

- Aluminum
  - Melting point: 660°C
  - Cheap, foil available
  - Forms many intermetallics
- Iron
  - Melting point: 1530°C
  - Low cost steel foil available
    - 1010 Steel: 99% Fe
- Mechanical Properties
  - Higher elastic modulus than Ti_3Al
- Processing
  - Commonly available foils and materials
  - Far lower cost

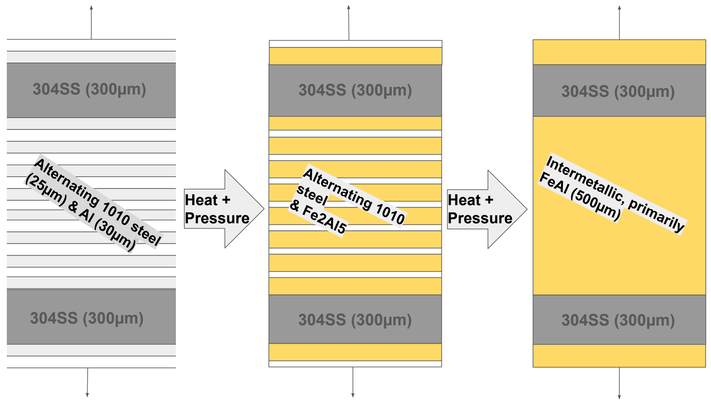
Objective: **Using mathematical models and diffusion simulations, design a MMIC material for use in ballistics protection, devise a process to fabricate material, and test material properties.**

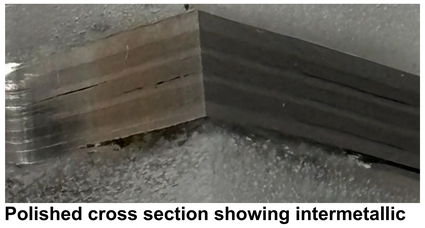
Final Design

A metal matrix intermetallic composite material was designed and manufactured for use in ballistics protection

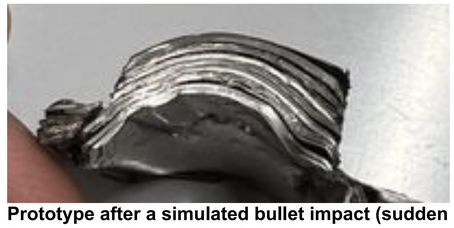
Base pattern: alternating layers of **30μm** aluminum and **25μm** 1010 steel foil were sandwiched between **300μm** of 304 stainless steel

The final prototype employed **six layers**





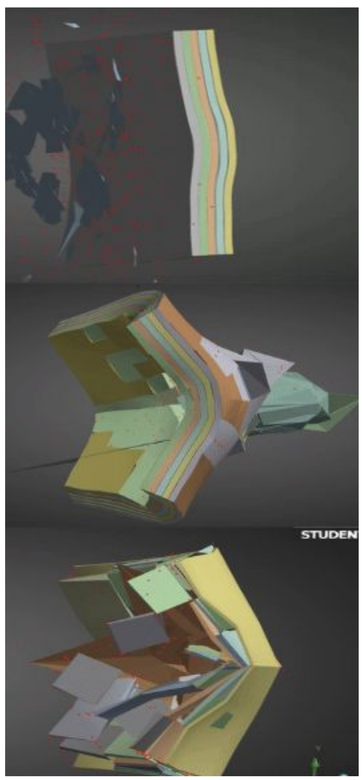
Polished cross section showing intermetallic (dark grey) and metallic (grey) layers



Prototype after a simulated bullet impact (sudden impact imparting ~600 J of kinetic energy)

Design and Simulation

- ANSYS Finite Element Analysis (FEA) simulation of a bullet impact to find ideal theoretical intermetallic/metallic layer ratio
- Three step simulation of intermetallic diffusion to find ideal theoretical processing parameters



Alternating 100 μm FeAl and 700 μm 304SS layers

Alternating 700 μm FeAl and 100 μm 304SS layers

Alternating 500 μm FeAl and 300 μm 304SS layers

The diffusion simulation offers insight on the following parameters:

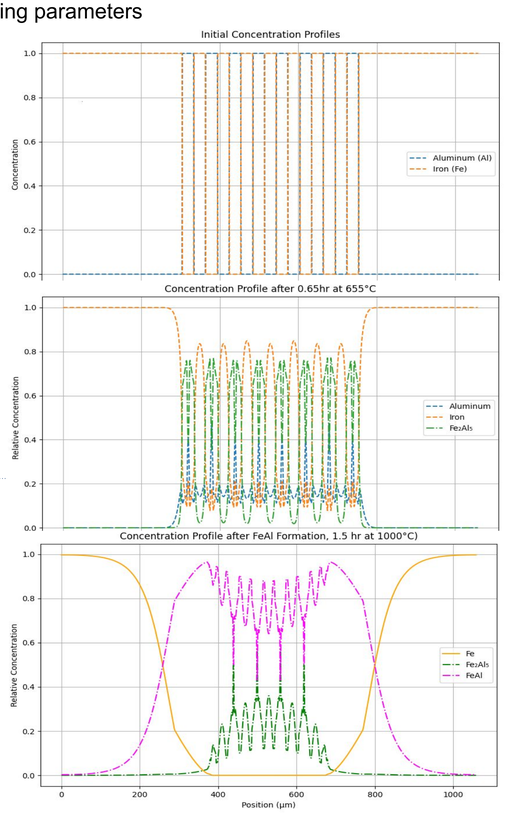
- Initial thickness of:
  - 1010 steel layer (pure Fe)
  - Al layer
  - 304SS (stainless steel) layer
- Processing temperatures
- Processing times

Simulation Assumptions:

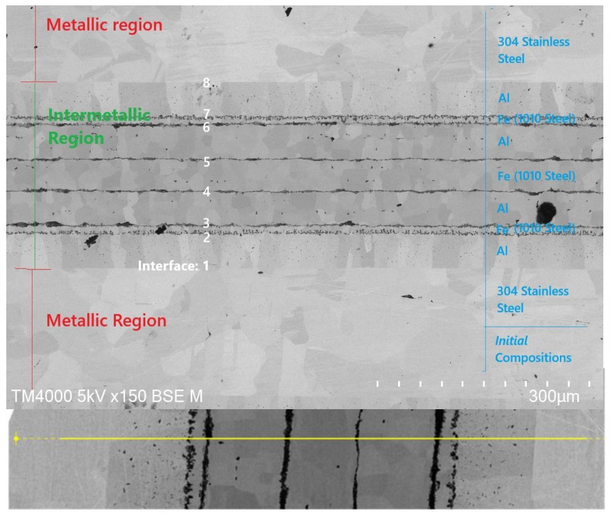
- Does not account for alloying elements in 304SS
- Both 1010 steel and 304 stainless steel
- Approximates oxide barriers as static

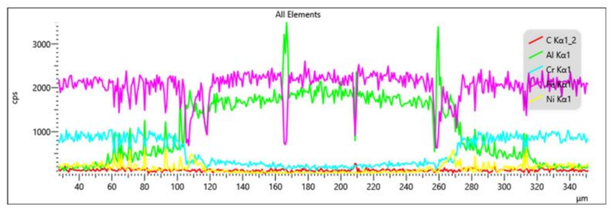
For desirable final concentration profile, simulation suggests:

- **25μm Fe and 30μm Al layers**
- **Processing at 655C for 0.65 hours followed by processing at 1000C for 1.5 hours**

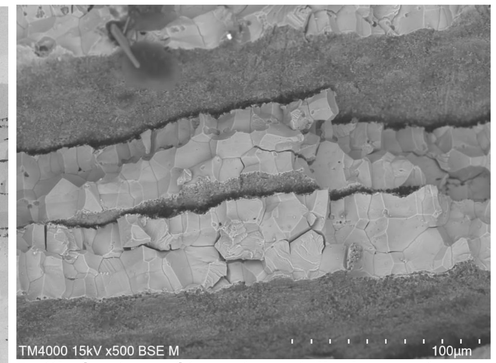


Prototype and Testing Analysis

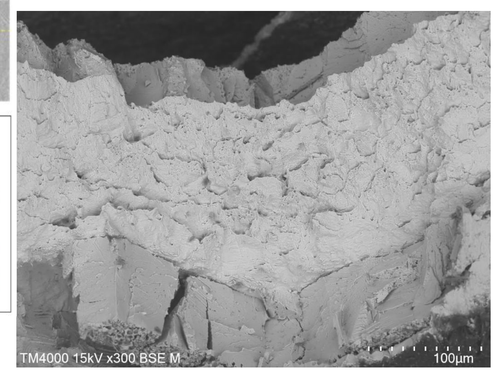




SEM and EDS microscopy suggest prototype samples (lower thickness) successfully form FeAl intermetallic stoichiometry, with a distribution of iron and aluminum throughout the entire intermetallic region. Significant void interfaces are also visible, serving as crack propagation barriers



Brittle fracture of the intermetallic layer with crack propagation barriers visible



Ductile fracture of metallic layer with coherent interface shared with the first intermetallic layer visible