PERFORMANCE OF FUNCTIONALLY GRADED S-2 GLASS/EPOXY COMPOSITES FOR ARMOR APPLICATIONS

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Introduction

- Current structural/armor GFRP components are made using a woven S-2 Glass infused with SC-15 toughened epoxy system and are not through thickness functionalized for optimum performance
- In this part of the program utilizes a materials by design (MbD) approach to improve the protective properties of a stand alone GFRP armor laminates

Fig. 1: Left: Army armored vehicle[1] and Right: GFRP laminate being impacted at high velocities

Penetration in GFRP

- Penetration event in GFRP is divided into 5 phases shown in Fig. 2, according to Gama[2]
- These phases have different damage modes and thus, require different properties
- Through thickness functionalization is desirable to meet the needs of phase I-V throughout the impact event

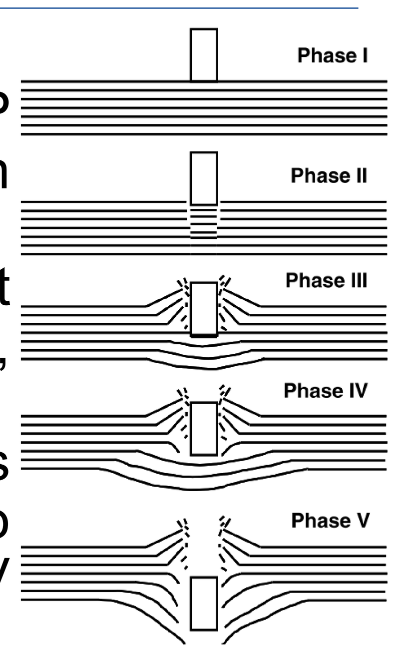

Fig. 2: Phases of a penetration in a thick section composite[2]

Functionally Graded Material

- The different phases of a penetration require different properties
- By functionally grading the through thickness properties to create a functionally graded material (FGM) the material can be tailored to meet the specific needs, schematic seen in Fig 3.
- The strike face needs high penetration resistance through high punch crush and punch shear strength
- The back face will require high in-plane tension but lower interlaminar fracture toughness to absorb energy though delamination

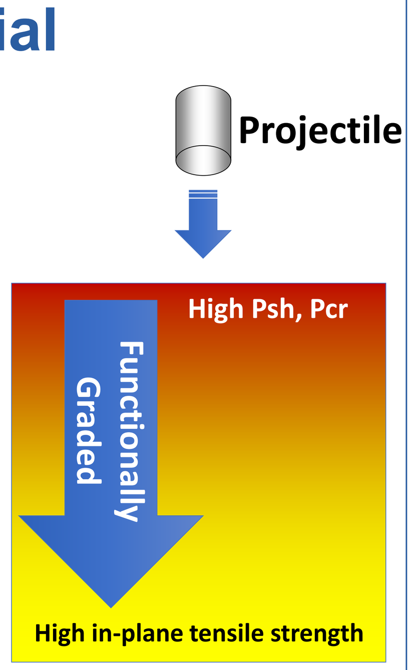

Fig. 3: Schematic of a FGM design for armor applications

Materials and Properties

- S-2 Glass with 463 and 933 sizing packages were used in this study
- Epoxy systems including SC-15, DER353/PACM, TGDDM, and a modified TGDDM, and a custom synthesized furan-based epoxy were tested
- The fiber, matrix, and fiber/matrix properties are presented below in Fig 4.

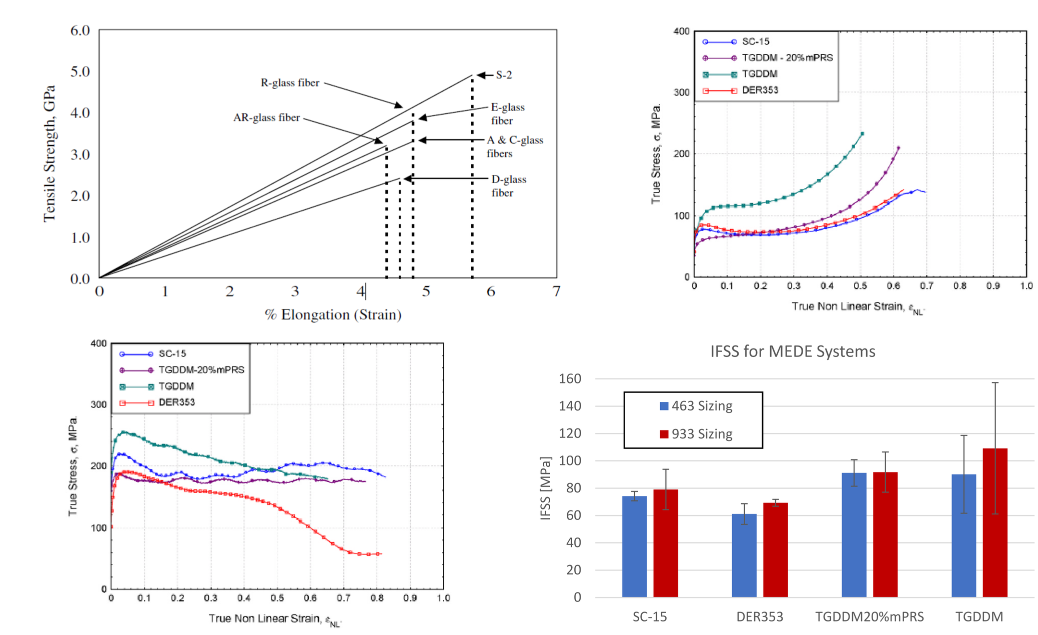

Fig. 4: Top Left: Fiber glass strength comparisons[3], Top Right: Quasi-static Bottom and Left: Dynamic compression data for the resins, and Bottom Right: Fiber/matrix interface properties for the sizing/resin combinations

Laminate Fabrication

- High fiber volume fraction (FVF) and potential hybridization requirements required a new laminate fabrication methodology to be developed
- A wet-layup/compression molding hybrid method was developed to achieve >65% FVF with <1% void content was developed show in the fig. 4

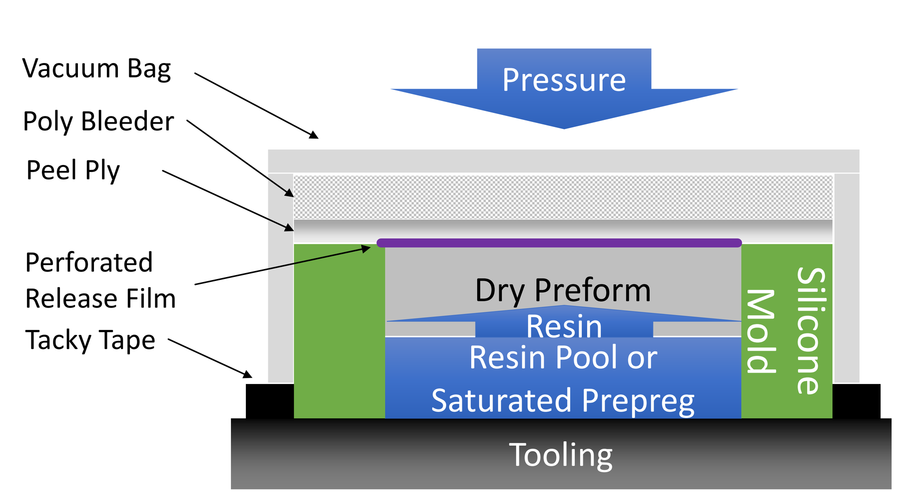

Fig. 5: Schematic of the hybrid wet layup/compression molding process developed for high-FVF, low-void content structural-protective GFRP laminates

- Using this methodology, 1" thick samples were fabricated for Depth of Penetration (DoP) tests, ¼" thick samples were made for thin-laminate Ballistic Limit (BL) tests, and ¾" thick FGM samples were made for the Capstone ballistic tests

Strike Face Down Selection

- Strike face and backing have different needs ie. High penetration resistance for strike and high in-plane tension for the back face
- The strike face material down select was conducted using the DoP test
- Top performer had a >25% reduction in DoP by controlling the damage mode, seen in Fig. 6

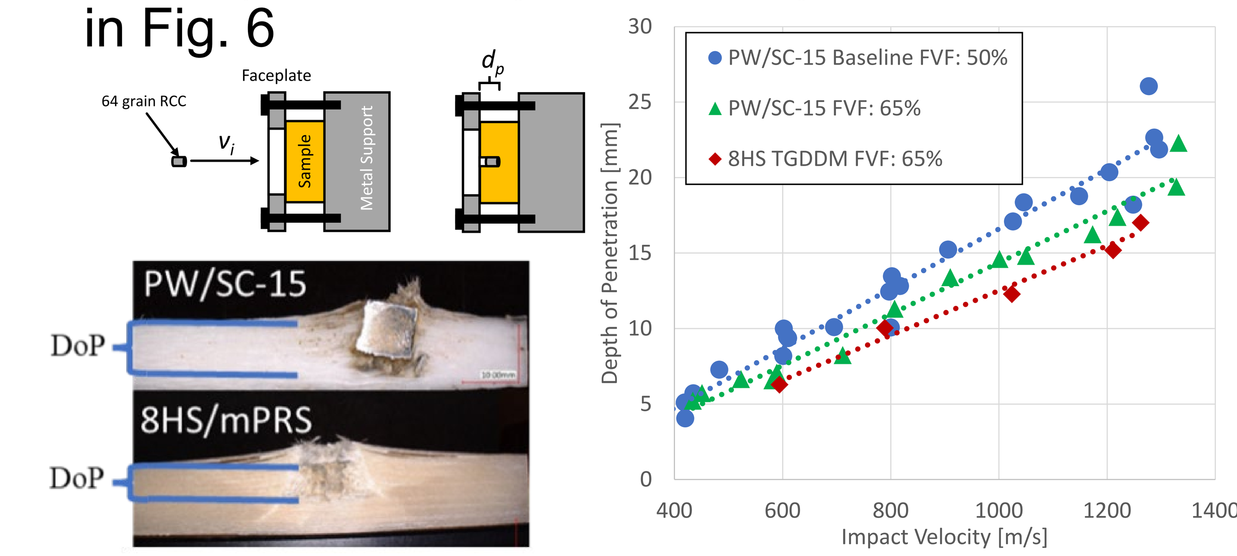

Fig. 6: Top Left: Schematic of the DoP test, Bottom Left: Sectioned laminates showing DoP, and Right: DoP vs impact velocity for key material systems

Back Face Down Selection

- The back face requires high in-plane tension and the ability to delaminate extensively to "catch" the projectile, tested using a thin laminate BL test, seen in Fig 7

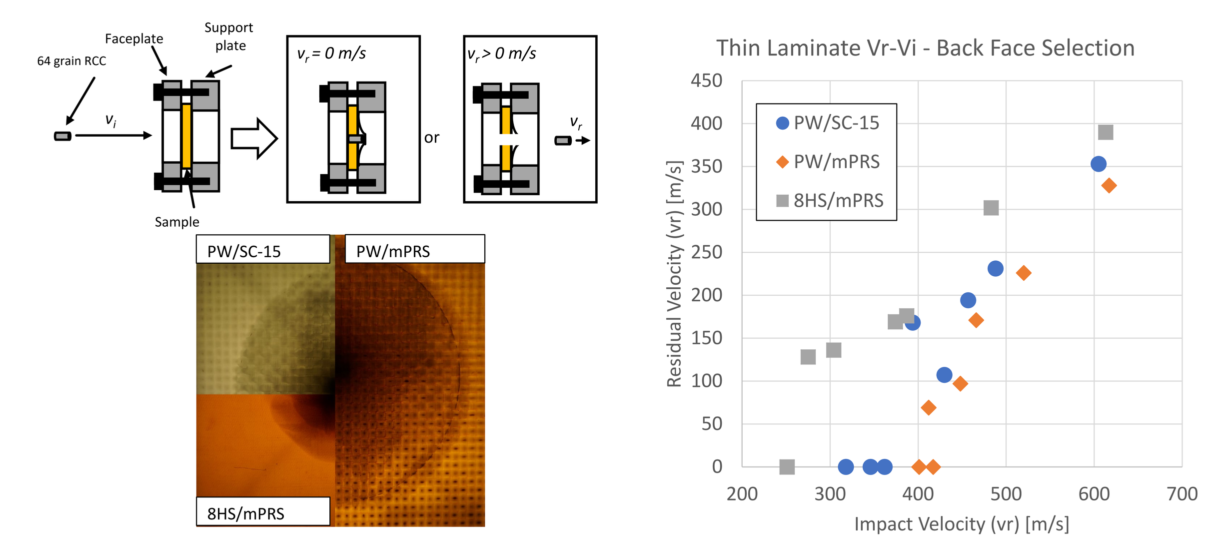

Fig. 7: Top Left: Schematic of the BL test, Bottom Left: shows the extent of delamination, and Right: Residual velocity vs impact velocity

FGM Design and Performance

- The top performer from the DoP and the thin laminate BL was used in a 2:1 thickness ratio to create the FGM design seen in Fig. 8 and tested using a BL test with ¾" thick laminates
- Damage mode was controlled and a the FGM design absorbed >30% more energy for comparable areal density

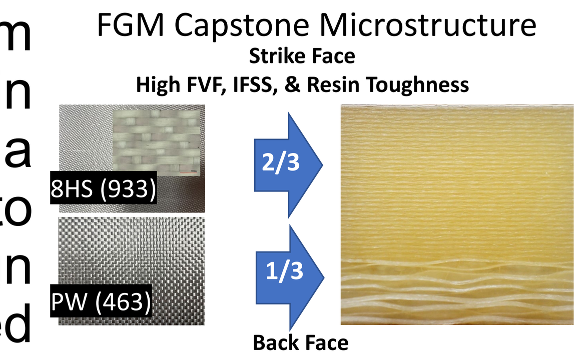

Fig. 8: Sectioned FGM panel to show design

Conclusions

- MbD approach was successfully implemented to improve the penetration resistance of GFRP through material design
- This work shows the significance of considering the fiber, matrix, and fiber/matrix interface as a system and the proper design/selection can influence the damage mode and extent, ultimately influencing the performance

V_{50} = +16%
Energy absorption = +34%
Weight = -14%
Thickness = -23%

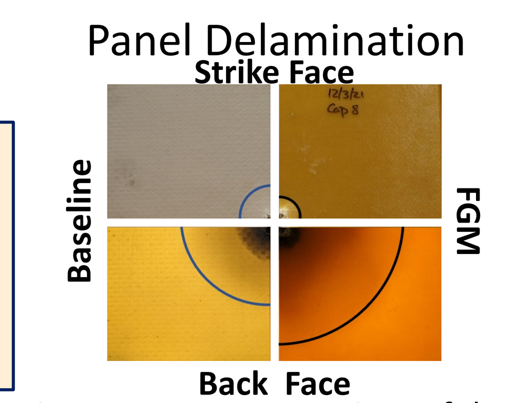

Fig. 9: Damage comparison of the strike and back face between the baseline and FGM

Path Forward

- Custom tailored interfaces can be synthesized onto the S-2 Glass®
- A Physics Informed Machine Learning platform and a complimentary vapor deposition approach is being developed to optimized the interface morphology to maximize energy absorption

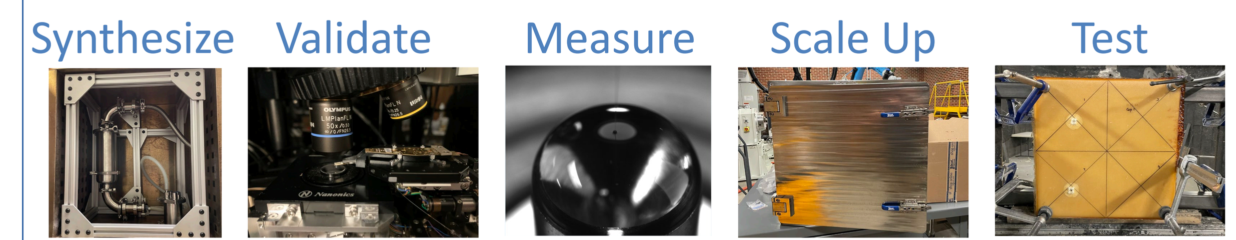

Fig. 10: Interface tailoring infrastructure development

References

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