PUNCH CRUSH AND PUNCH SHEAR EXPERIMENTS AT SUB-MILLIMETER LENGTH SCALES

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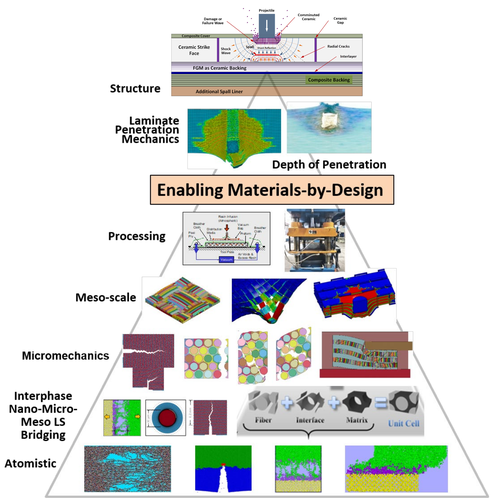
Introduction

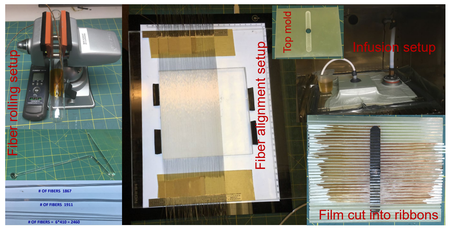
- Punch crush and punch shear occurs during projectile impact on a target
- The study of punch shear and punch crush is needed to understand the damage mechanism and failure mechanics of the composite targets subjected to high velocity ballistic impacts
- It is necessary to perform these experiments to investigate the damage evolution and fracture mechanism at sub-millimeter length scale
- These experimental results are used to validate micro mechanical FEA model
- MEDE research covers atomistic level to the structure level. Micro punch shear and crush tests of Unidirectional composite ribbons fits in it at the micromechanical length scale

MEDE Composites Research Objectives

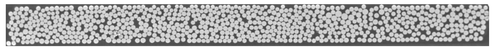


- ❑ Fabricate Unidirectional [UD] ribbons
  - ❑ Thickness: 60 – 100 um
  - ❑ Through the thickness fiber # 6 – 10
  - ❑ FVF: 55% - 65%
- ❑ Conduct punch shear and punch crush experiments on UD ribbon composites at sub-mm length scale
- ❑ Understand the damage mechanism and fracture mechanisms to validate FEA micro mechanical Model

Fabrication Of Sub-Millimeter Thick Composite Film & Testing



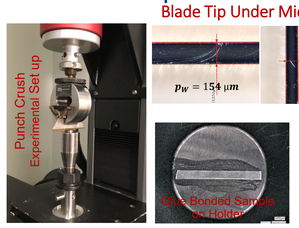
- Dimension of the film: 5"X4" X 80 to 100 micron
- S-2 Glass sub tow rolled on the test tube and aligned 32/inch and flattened with glass spatula at 100F, vacuum debulking has been applied 5 times before resin infusion, cure and post cure
- Composite film has been cut into 1 mm wide ribbons with slot grinder



SEM Cross Section of unidirectional Composite Ribbons

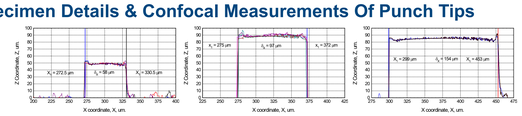
Micro Punch Crush Experiments : A Unique Test Method

Blade Tip Under Microscope



- ❖ Razor blade has been used as a punch
- ❖ Tip of the blades have been polished very carefully by sandpapers.
- ❖ Expected blade tip width $P_W = 50\ \mu m$ $100\ \mu m$ & $150\ \mu m$
- ❖ VHX Measurement gives Punch width $P_W = 54\ \mu m$, $97\ \mu m$ & $154\ \mu m$ respectively
- ❖ Specimen dimension : $s_L \approx 12mm$ $s_W \approx 1mm$, $s_T \approx 100\ \mu m$

Specimen Details & Confocal Measurements Of Punch Tips



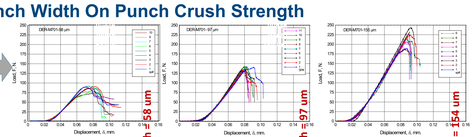
Punch Width = 58 um | Punch Width = 97 um | Punch Width = 154 um

Material ID [with debulking]	Punch Width, um	FVF [#sample]	Avg, t, um [#sample]
933-DER-M701	58	60 ± 4 [50]	102 ± 1 [10]
933-DER-M701	97	60 ± 4 [50]	99 ± 2 [10]
933-DER-M701	154	60 ± 4 [50]	101 ± 2 [10]
AVERAGE		60 ± 4	101 ± 2

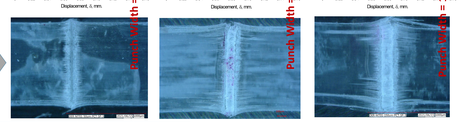
- ❖ Punch widths have been measured from confocal microscopy data plots
- ❖ Punch crush test has been performed of DER-933 ribbons at Punch width $p_W = 58\ \mu m$, $97\ \mu m$ & 154
- ❖ Specimens are similar in term of FVF and thickness
- ❖ To see the effects of punch width on crush strength

Effects Of Punch Width On Punch Crush Strength

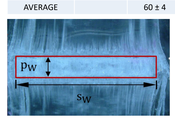
Load vs Displacement



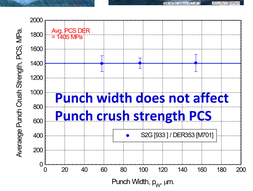
Crush damage surface



Material ID	P_W, um	FVF [#sample]	Avg, t, um [#sample]	AVG PCS, MPa.
933-DER-M701	58	60 ± 4 [50]	102 ± 1 [10]	1400 ± 110
933-DER-M701	97	60 ± 4 [50]	99 ± 2 [10]	1406 ± 71
933-DER-M701	154	60 ± 4 [50]	101 ± 2 [10]	1409 ± 119
AVERAGE		60 ± 4	101 ± 2	1405



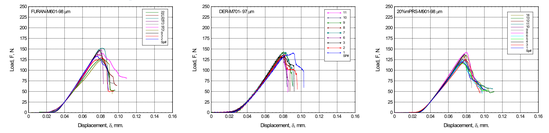
P_W = Punch Width
S_W = Specimen width
F_{Max} = Maximum Force
Punch crush strength
$PCS = \frac{F_{Max}}{P_W \times S_W}$



Avg. Punch Crush strength as a Function of Punch Width

Results and Analysis

Punch Crush Experiment on Three Different Materials

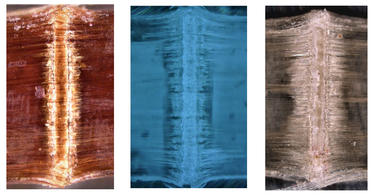


S2G [933] FURAN Sample # 11
PCS = 1405 ± 121 MPa
T = 99 ± 2 um, FVF = 58 ± 7

S2G [933] DER Sample # 10
PCS = 1406 ± 71 MPa
T = 99± 2 um, FVF = 60 ± 4

S2G [906] 20% mPRS Sample # 12
PCS = 1395 ± 80 MPa
T = 99± 1 um, FVF = 61 ± 4

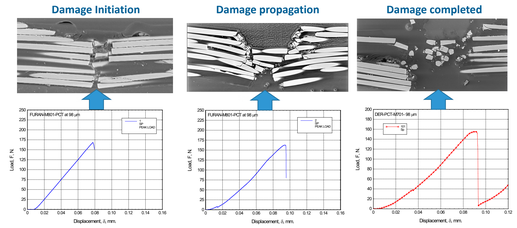
Punch crush strength performance of all three material is very similar.

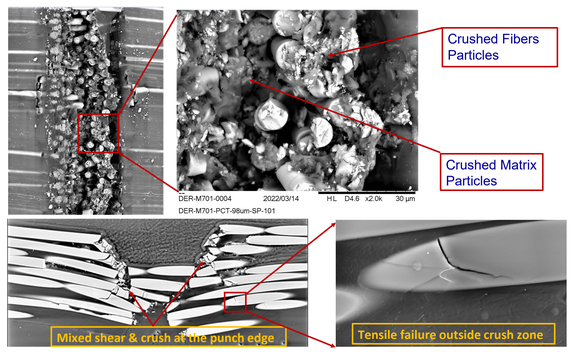


- FURAN-M601
- DER353-M701
- 20%Mprs-m901

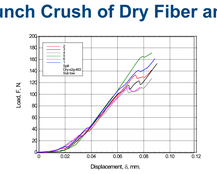
- ❖ Material flows towards the free boundary & free surface
- ❖ Damage propagation area are different for different material implying difference in energy dissipation

Punch Crush Damage Evolution through the Thickness of Specimens

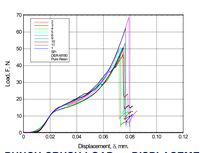




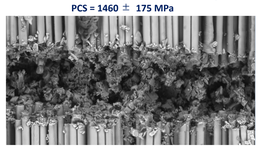
Punch Crush of Dry Fiber and Pure Resin Ribbon



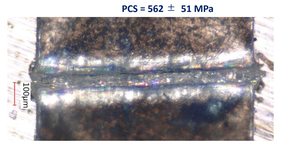
PUNCH CRUSH LOAD vs DISPLACEMENT
S2G463-DRY SUBTOW [bundle of 410 fibers]
PCS = 1460 ± 175 MPa



PUNCH CRUSH LOAD vs DISPLACEMENT
DER353 RESIN , t = 103 ± 3 um,
PCS = 562 ± 51 MPa



SEM: Dry Fiber Punch Crush, Punch Width: 98 um

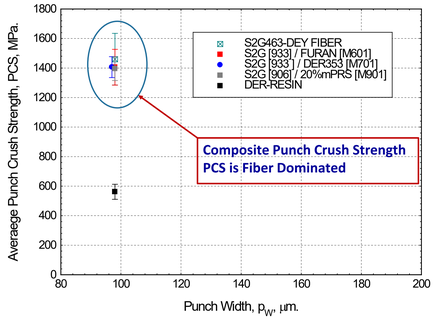


VHX: Pure DER Resin Punch Crush, Punch Width: 98 um

Results and Analysis

Punch Crush Strength Summary of Fiber, Resin and Composites Studied

Material [Type]	Punch Width, um	AVG PCS, MPa
S2G[463]-[DRY FIBER]	98	1460 ± 175
S2G[933]-FURAN-[Composite]	98	1405 ± 121
S2G [933] DER353-[Composite]	97	1406 ± 71
S2G [906] 20%mPRS-[Composite]	98	1395 ± 80
DER353- [Pure Resin]	98	562 ± 51



Summary and Conclusion

- ❖ Unidirectional Ribbon Composite film of 100 - 80 um thickness with 8-10 fibers through the thickness and [60±4]% fiber volume fraction has ben fabricated successfully which has even distribution of fibers in the cross section
- ❖ Micro punch crush experiment of three different unidirectional composite and pure resin and dry fiber have been performed
- ❖ SEM punch crush surface analysis and punch crush damage evolution through the thickness of the composite has been studied
- ❖ All of the three composites studied shows very similar punch crush strength
- ❖ It is observed that punch crush strength is fiber dominated
- ❖ These punch shear and punch crush results can be used to validate finite element micromechanical models
- ❖ Micro punch shear and punch crush experiments can be used to test which material is superior in impact resistance performances.

Acknowledgements

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