ADHESIVE BONDING OF CARBON FIBER REINFORCED PLASTIC TO ADVANCED HIGH STRENGTH STEEL

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Co-PI: Kevin Simmons, Pacific Northwest National Laboratory

2018 DOE VTO Annual Merit Review

June 19, 2018

Project ID # MAT-137

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OVERVIEW

Timeline

- Start: Oct, 2017
- Finish: Sept, 2020
- 20% Complete

Budget

- Project Funding – $2,025K
  - FY18 - $675K
  - FY19 - $675K
  - FY20 - $675K

All proposed future work is subject to change based on funding levels

Barriers

- Limited scientific understanding of joining mechanisms for metal to composite joints
- Few technologies exist for joining metals to composites
  - Low joint strength
  - Crack arrest resistance in crash
  - Thermal expansion mismatch
  - Durability and environmental effects

Partners

- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory

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RELEVANCE

- **EERE-VTO Goal:**
  - By 2025, demonstrate a cost-effective 25% glider weight reduction at no more than $5/lb saved by 2025 as compared to a 2012 baseline

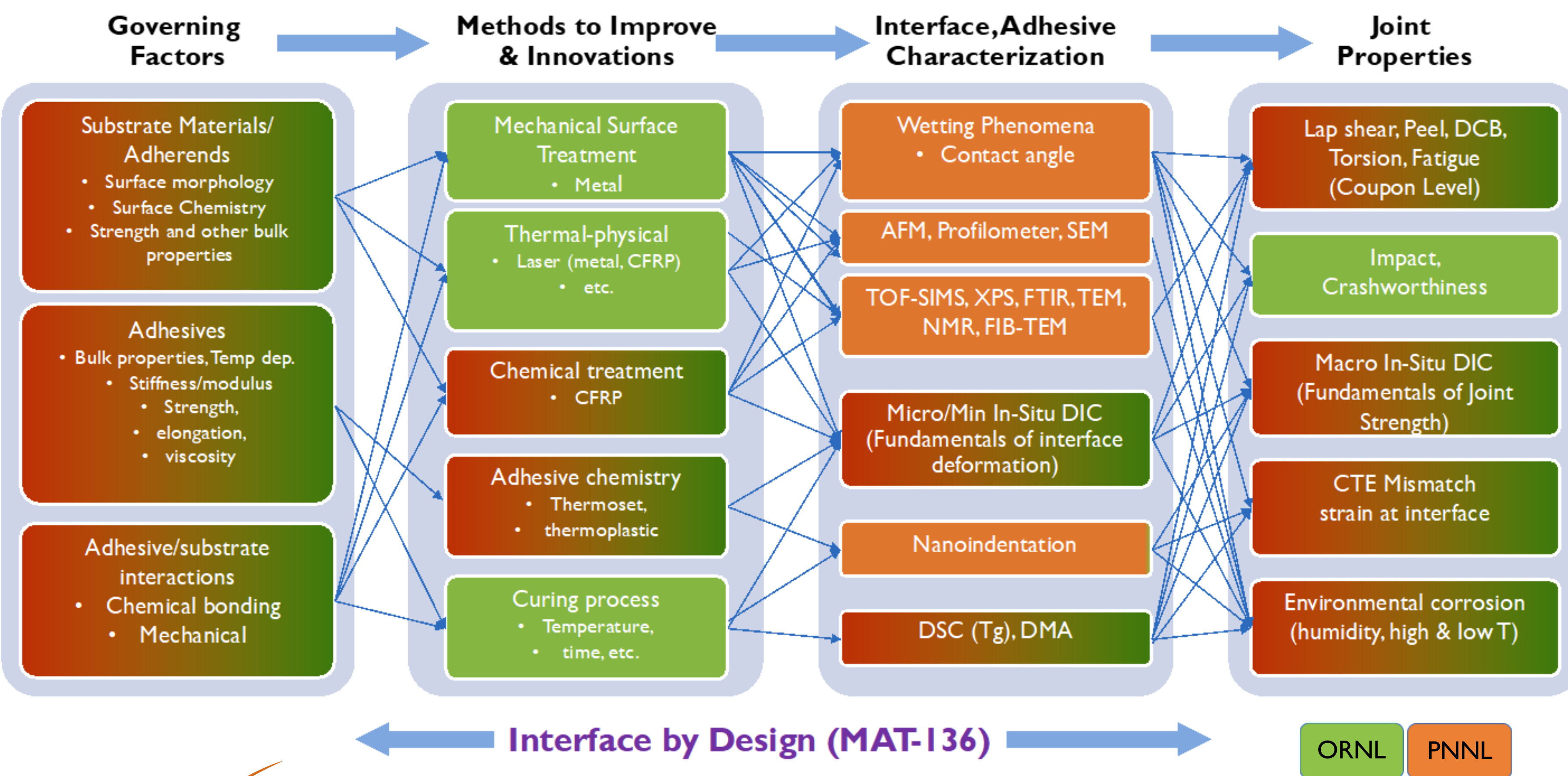
- **Project Objectives**
  - Early-stage R&D focusing on
    - Fundamental understanding of CFRP to AHSS adhesive bonding characteristics at nano/micro scales;
    - Identify and explore innovative adhesive bonding concepts and approaches for performance and productivity through scientific understanding
    - Develop better tools for adhesive bonding performance, joint design, and lifetime prediction
    - Closely interact with the **Interface by Design** Task
  - Enable increased use of CFRP in multi-material body structure for weight reduction

FY18 MILESTONES

Milestone Name/Description	End Date	Type
Identify potential surface/interface engineering process/methodology for Interface-By-Design. Down-select one or two potential processes for feasibility investigation of interface engineering	12/30/2017	Quarterly Progress Measure (Regular)
Demonstrate completion of surface characterization of PP and Nylon CFRP and DP980 steel to determine the surface chemistry and surface morphology	6/30/2018	Quarterly Progress Measure (Regular)
Demonstration capability of electrical resistivity-based health monitoring of Steel/CFRP joints	9/30/2018	Quarterly Progress Measure (Regular)

APPROACH

OVERALL PLAN FOR ADHESIVE BONDING OF CFRP-AHSS



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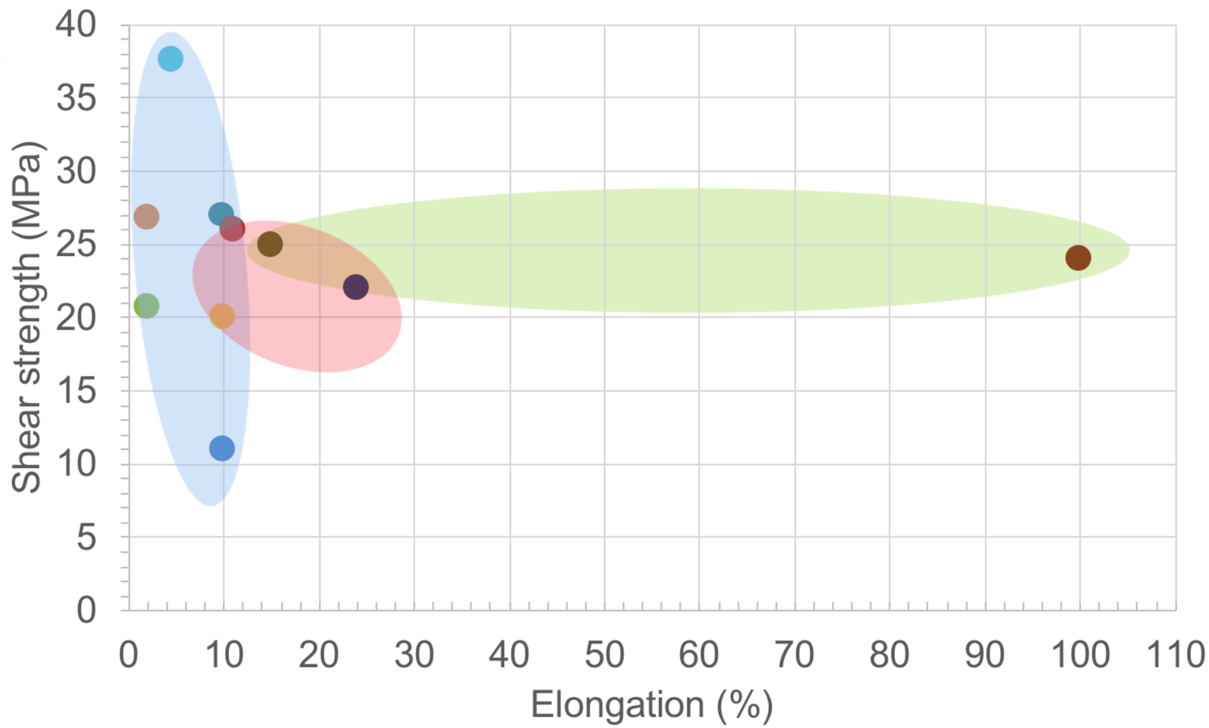
ACCOMPLISHMENT
SURVEY OF DIFFERENT ADHESIVES

- Wide range of shear strength and elongation of adhesives in literature
- How will these factors contribute to metal to adhesive bonding?



* Data provided by three major automotive adhesive suppliers

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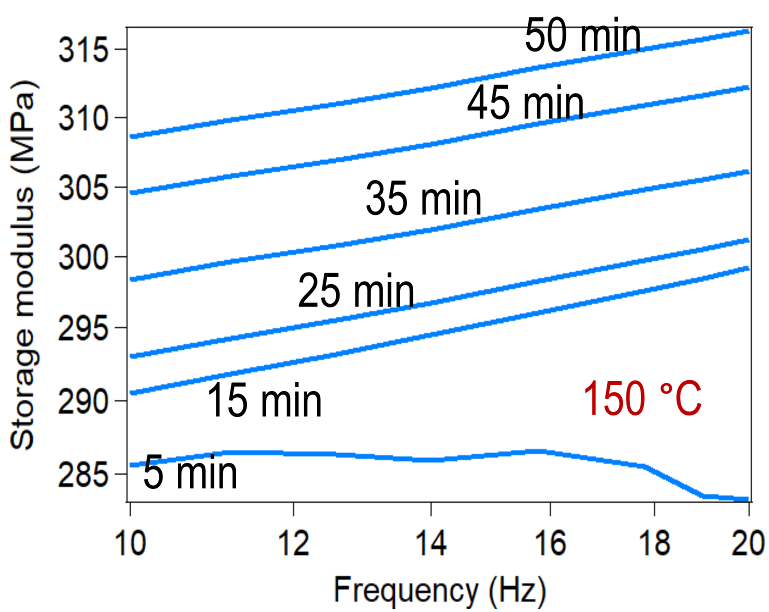
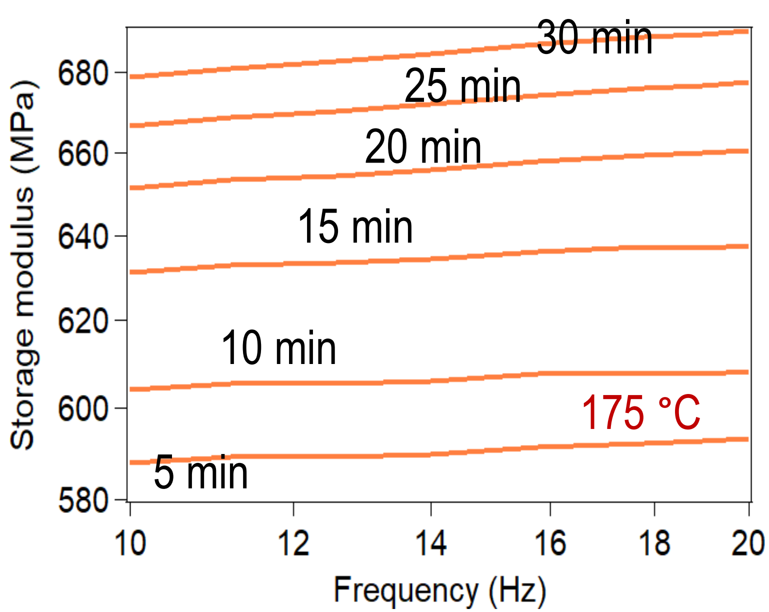
EFFECTS OF CURING TEMPERATURE AND TIME

Steel/Adhesive #3/Steel



Steel/ Adhesive #3/Steel



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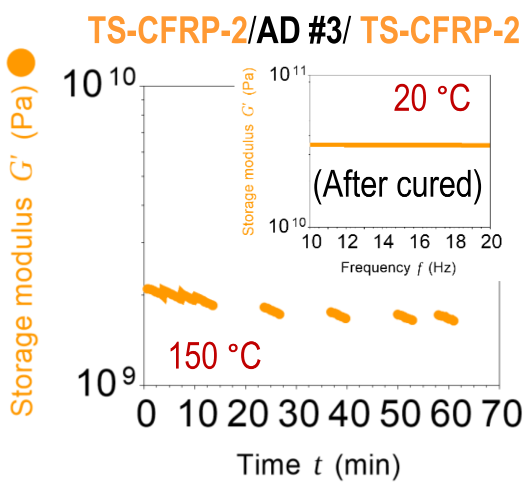
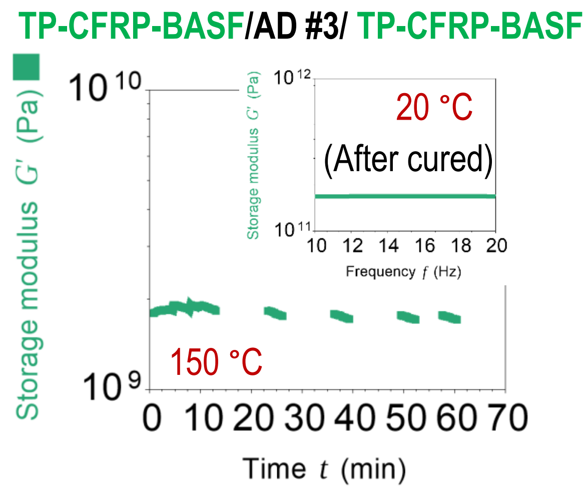
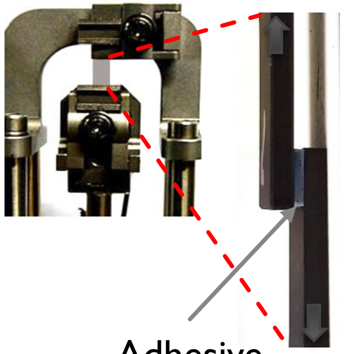
CHAIN MOBILITY: CFRP SURFACE DEFORMABILITY AND ADHESIVE BONDING

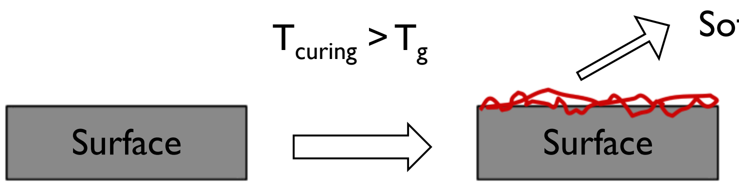




In-situ curing and oscillatory shear

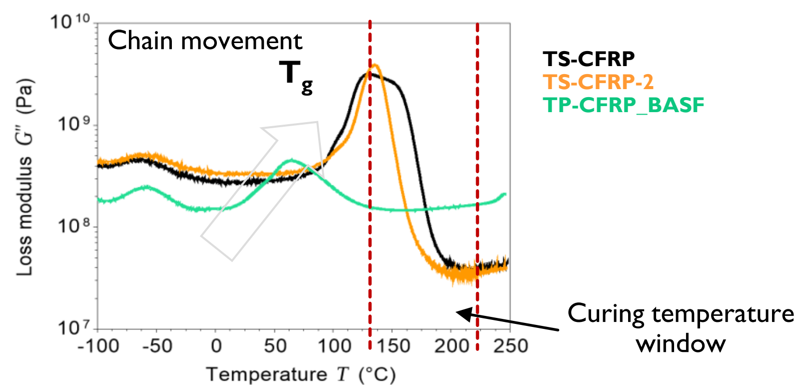


Adhesive (L8513)



Softening: changing surface energy/ adhesive bonding

Polymer based composites



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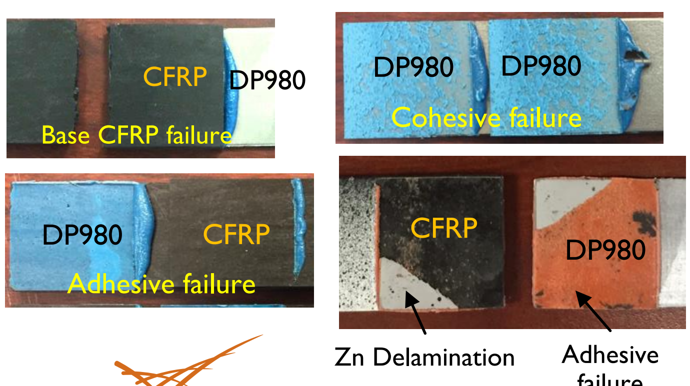
INITIAL ADHESIVE BONDING TESTS OF CFRP-AHSS WITH DIFFERENT ADHESIVES

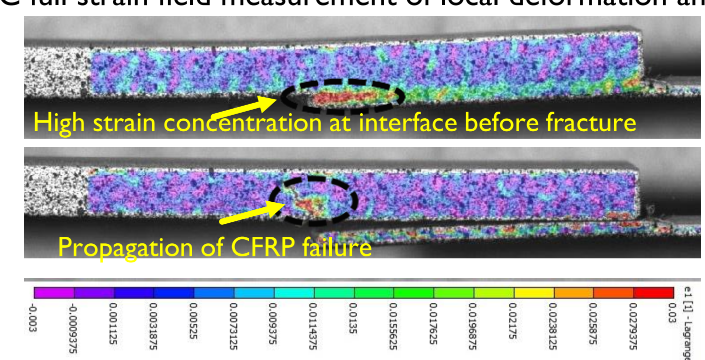
- Lap shear test revealed considerable differences in joint strength and failure modes

Material Combination	Adhesive #1		Adhesive #2		Adhesive #3	
	TSS (kN/ MPa)	Failure Mode/location	TSS (kN/ MPa)	Failure Mode/location	TSS (kN/ MPa)	Failure Mode/location
DP980/DP980	20.8/ 33.3	• Cohesive	16.1 / 25.7	• Zn Delamination	20.3/32.5	• Cohesive
DP980/CFRP	8.7/14	• Base CFRP	13.1 / 21	• Base CFRP • CFRP side adhesive • Zn delamination	3.6/5.7	• Adhesive
CFRP -CFRP	4.7/ 7.6	• Adhesive • Adhesive & CFRP	11.3 / 18.8	• Base CFRP • Partial Adhesive	3.4/5.4	• Adhesive

- Bare DP980/1180: t=1.2mm; CFRP (PPA): t=3.1mm; Curing: supplier recommendations



DIC full strain field measurement of local deformation and failure



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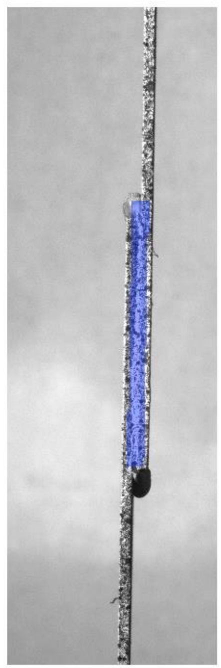
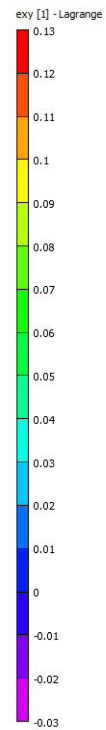
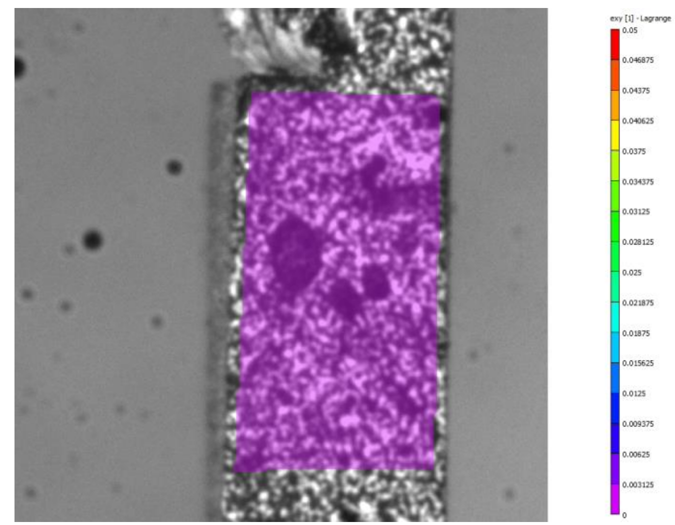
DEFORMATION AND FAILURE PROPOGATION AT ADHESIVE BOND LINE AS REVEALED BY DIC LOCAL STRAIN FIELD MEASUREMENT







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RESPONSES TO PREVIOUS YEARS REVIEWERS' COMMENTS

- Project is a new start in FY18.
- No prior year comments to address.

COLLABORATION AND COORDINATION

- An integrated R&D team from ORNL and PNNL
  - Closely coordinated research activities and responsibilities as highlighted in Approach on Page 4
  - Bi-weekly web meetings between research team members
- Industry partners Dow Automotive, L&L, 3M, PPG provided adhesives

Core Research Team Members

- ORNL: Zhili Feng, Amit Naskar, Yong Chae Lim, Jian Chen, Ngoc Nguyen, David Warren, Xin Sun
- PNNL: Kevin Simmons, Leo Fifield

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REMAINING CHALLENGES AND BARRIERS

- Limited fundamental understanding of metal to CFRP adhesive bonding characteristics at nano/micro scales;
  - Effects of surface conditions (morphology, chemistry) of substrates
  - Adhesive chemistry and additives, compatible to both AHSS and CRFP
  - Long-term performance and environmental degradations
  - Inhibition of galvanic corrosion,
  - Compatibility with CTE mismatch

- Lack of scientifically sound, effective approaches to design and engineering high performance adhesives and assembly technologies

PROPOSED FUTURE WORK

- Continue on in-depth understanding on interface bonding, deformation and roles of adhesive properties at nano/micro scales (FY18/19)
  - Connect to macroscopic level joint deformation and failure
- Innovative surface modification technology (FY19)
  - Identify and develop surface modification concept based on above in-depth understanding and interface by design for improved bonding strength.
  - Develop processes that will effectively modify both the interface morphology and interface chemistry
- Adhesives tailored for metal to CFRP bonding (FY19/20)
- Heath monitoring of curing/manufacturing process and structural soundness in service (FY19/20)

Any proposed future work is subject to change based on funding levels

SUMMARY

- This early stage research focuses on the fundamental aspects of adhesive bonding between CFRP to AHSS. In concert with the Interface by Design Effort, innovative adhesive bonding concepts would be identified and explored.
- This project was initiated in FY18
  - Established overall R&D plan, schedule and material combinations
  - Quantified surface roughness and no-uniformity of CFRP
  - Determined cure kinetics, structure formation and thermomechanical properties of CFRP and adhesives
  - Completed baseline study on the influence of adhesives on bonding strength and failure modes
  - Initiated in-depth study on interface bonding, deformation and roles of adhesive properties at nano/micro scales

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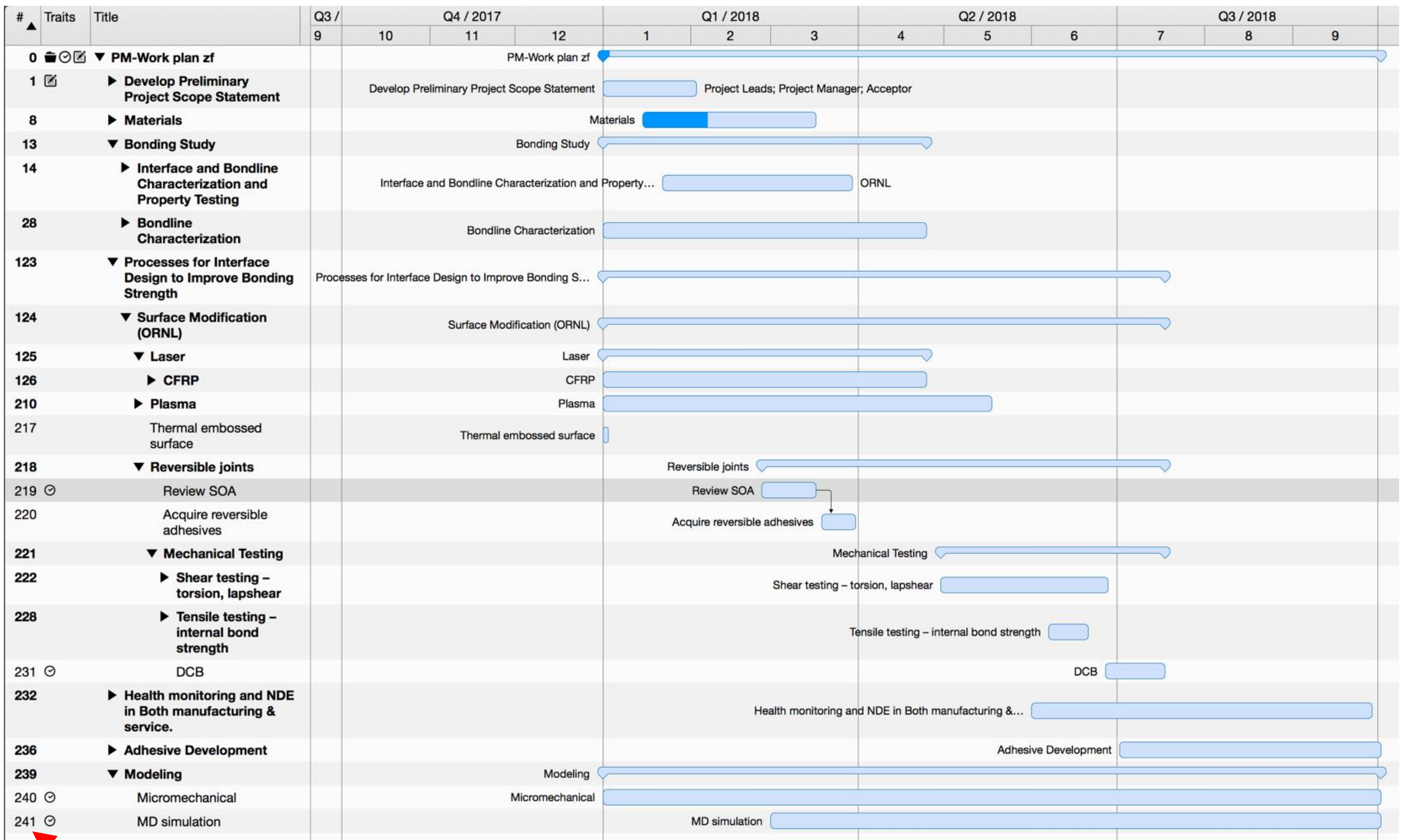
TECHNICAL BACKUP SLIDES

DETAILED TASK PLANNING (GANTT CHART)



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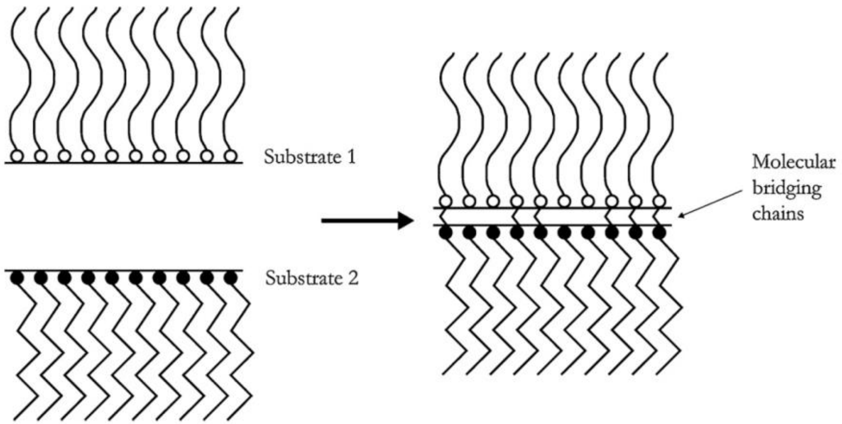
COMPLEXITY OF ADHESIVE BONDING

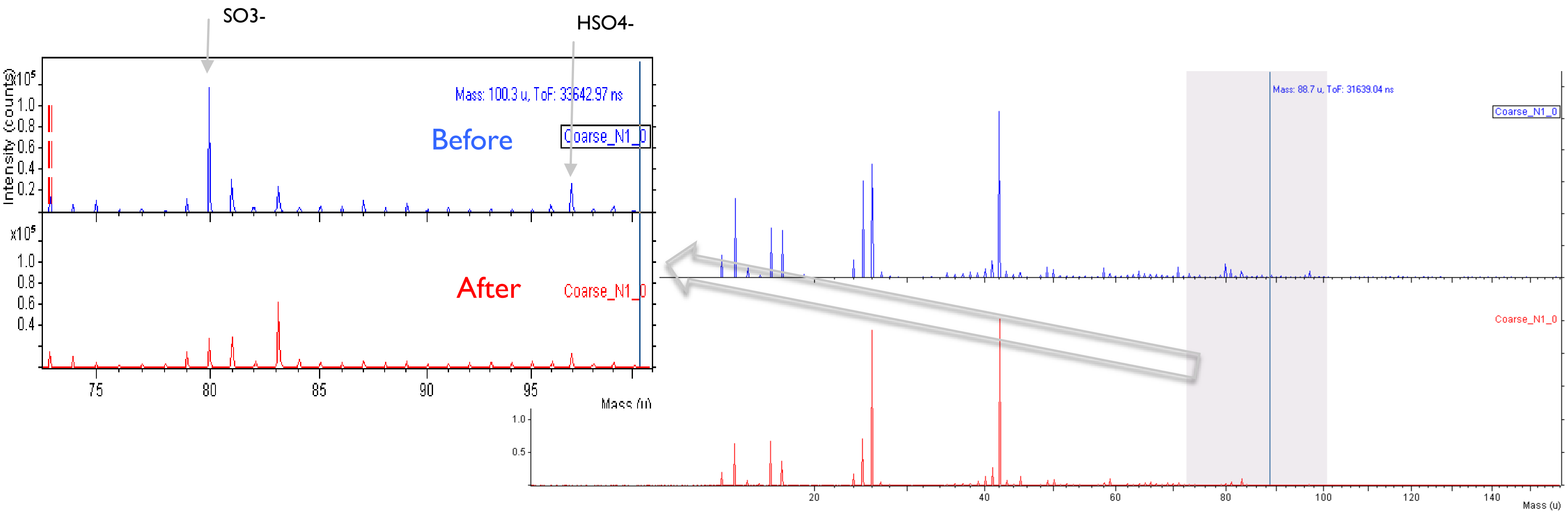
- Multi-disciplinary topic
  - surface chemistry
  - Physics
  - Rheology
  - polymer chemistry
  - stress analysis
  - polymer physics
  - fracture analysis
- Adhesion mechanisms
  - Diffusion
  - Mechanical
  - molecular and chemical and thermodynamic adhesion phenomena



F. Awaja et al. / Progress in Polymer Science 34 (2009) 948–968

ACCOMPLISHMENT

SURFACE ANALYSIS VIA TOF-SIMS, SURFACE CONTAMINATION



- The SIMS spectra of 40%CF/ PA66 before and after Acetone/Alcohol/Water cleaning look similar;
- However, surface contamination, e.g., SO_3^- and HSO_4^- greatly decreases.

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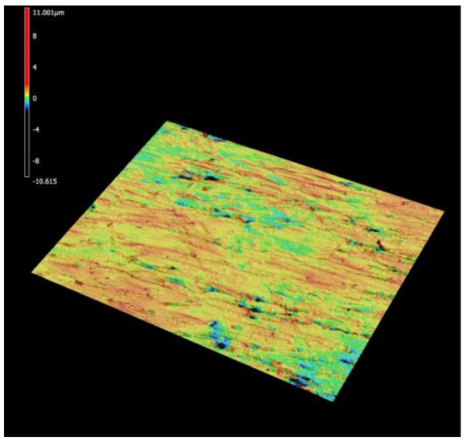
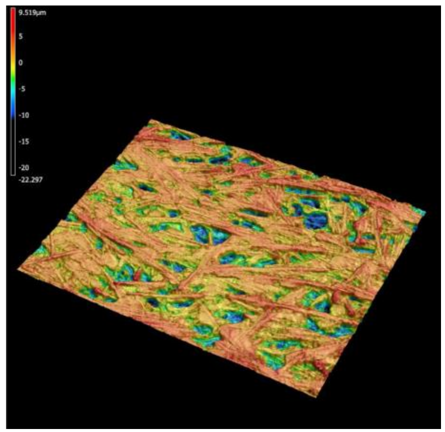
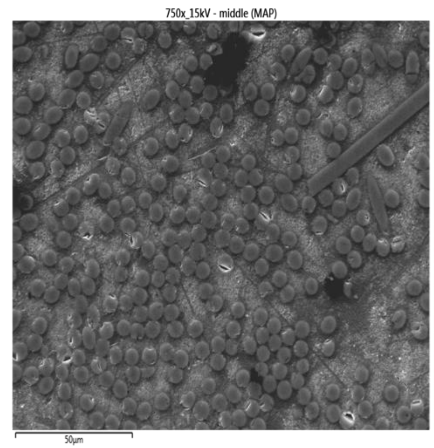
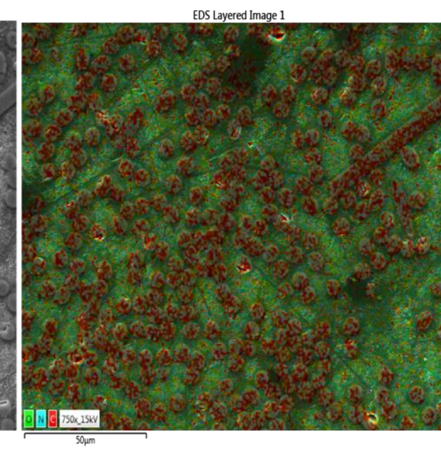
SURFACE ANALYSIS ON 40%CF-PA66 IM PLAQUE









Keyence Laser Profilometer Surface Roughness

- Smooth region
  - Average Ra=0.314 µm
  - Max profile height Rz=18.116µm
- Rough region
  - Average Ra=2.213 µm
  - Max profile height Rz=28.258 µm

Carbon fibers are easily differentiated in the energy dispersive spectroscopy (EDS) elemental mapping. Carbon, oxygen, and nitrogen were the elements observed

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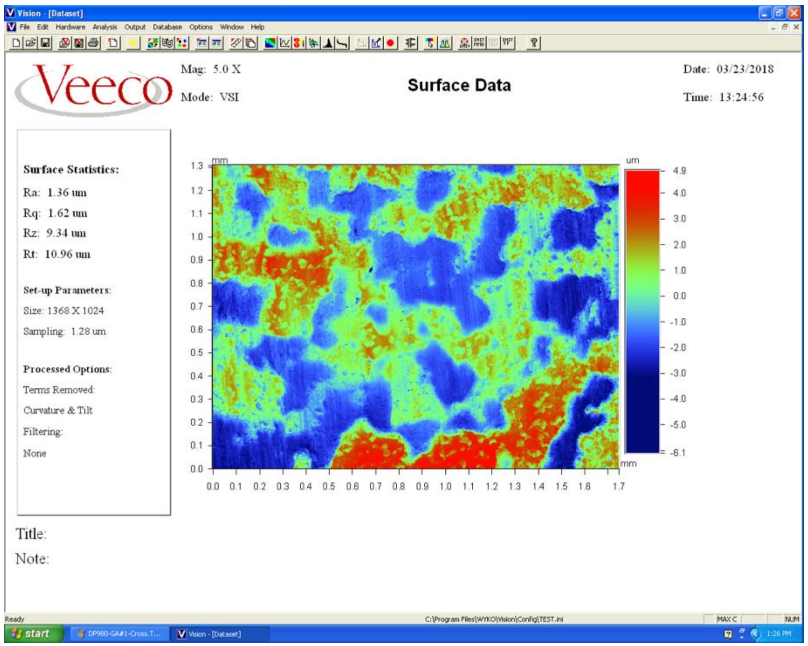
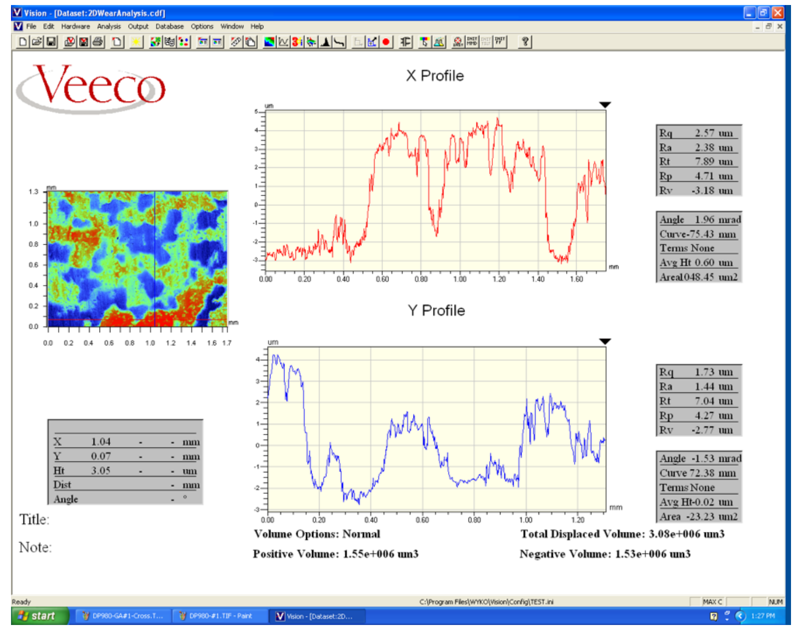
SURFACE ROUGHNESS OF DP980 (BARE)





Sample	Ra (um)	Rz (um)
1	1.36	9.34

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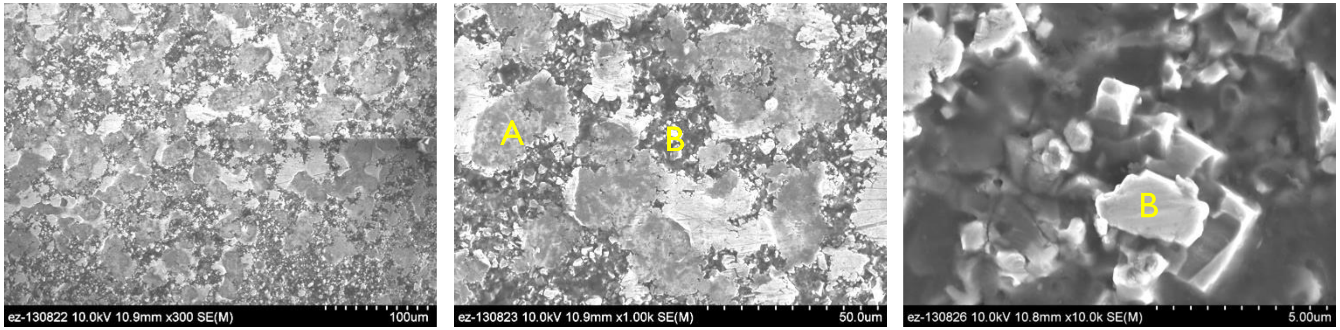
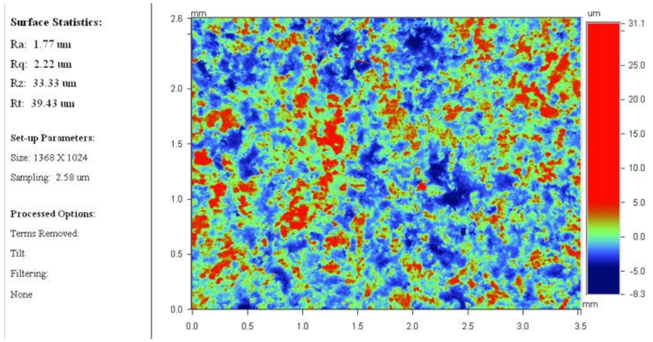
SURFACE CHARACTERIZATION OF GALVANNEALED DP980 (45/45)

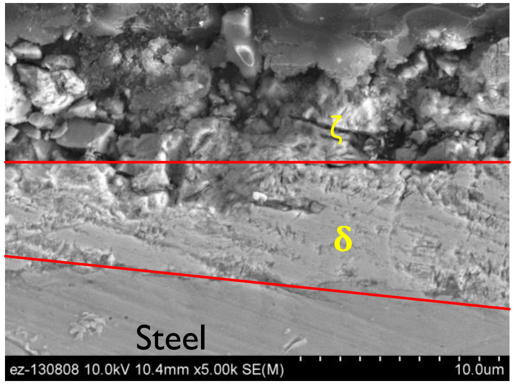
Top view



compressed zeta phase (A) and crystallized zeta phase (B)



Cross section view



ζ	$FeZn_{13}$
δ	$FeZn_7$
Γ	Fe_3Zn_{10}

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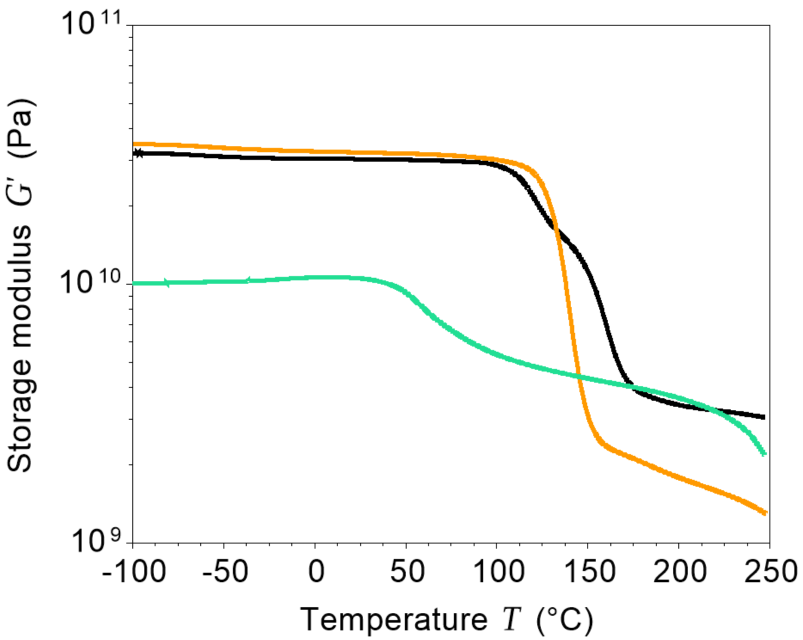
THERMOMECHANICAL PROPERTIES OF CFRP

(3-point bending with a ramp rate of 3 °C/min)

TS-CFRP
TS-CFRP-2
TP-CFRP_BASF



Storage modulus at two selected reference temperatures (Unit: GPa)

Sample	150 °C	180 °C
TS-CFRP	10.1	3.8
TS-CFRP-2	3.1	2.1
TP-CFRP_BASF	4.3	3.9

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GLASS TRANSITION TEMPERATURE OF CFRP

Glass transition temperatures determined by max G"

Sample	T_{g1} (°C)	T_{g2} (°C)
TS-CFRP	-66.2	126.8/ 152.4
TS-CFRP-2	-61.9	135
TP-CFRP_BASF	-58.1	64.2

Glass transition temperatures determined by max tan (δ)

Sample	T_{g1} (°C)	T_{g2} (°C)
TS-CFRP	-63.2	131.1/158.7
TS-CFRP-2	-61.9	142
TP-CFRP_BASF	-58.1	70.2

Note: The TS-CFRP has two thermal relaxation overlapped at T_{g2} showing a very broad transition peak in both G" and tan (δ) graphs.

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TECHNOLOGY TRANSFER ACTIVITIES

- Project is just starting.
- No technology transfer activities to date.

- Maintained close interactions with auto OEM and adhesive suppliers
- Results and findings will be disseminated through publications