Laser-Assisted Joining Process of Aluminum and Carbon Fiber Components

Project ID: LM097

PI's:

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ORNL Team

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2015 DOE Vehicle Technologies Annual Merit Review and Peer Evaluation Meeting

June 12, 2015

MAGNA COSMA BODY & CHASSIS SYSTEMS

3M

PLASAN CARBON COMPOSITES

Managed by UT-Battelle
for the Department of Energy

OAK RIDGE National Laboratory

Overview

Timeline

- Project start date: 10/1/2013
- Project end date: 9/30/2015
- Percent complete: 70%

Budget

- Total project funding $600,000
  - DOE share: $600,000
  - Cost share: $30,000
- FY14 Funding: $300,000
- FY15 Funding: $300,000

Partners

- Magna
- 3M Company
- Plasan Carbon Composites

Barriers Addressed

- Dissimilar Material Joining
- Rapid/Consistent Joining of Multi-Material Structures
- Corrosion between Dissimilar Materials

Subcontractors

- Clearwater Composites, Inc. ($5K composites)
- University of Tennessee Knoxville ($50K, Optical micrographs and laser processing: J. Jones, A. Hackett, C. Frederick, C. Greer - undergraduate students, 3 mo. assignments)

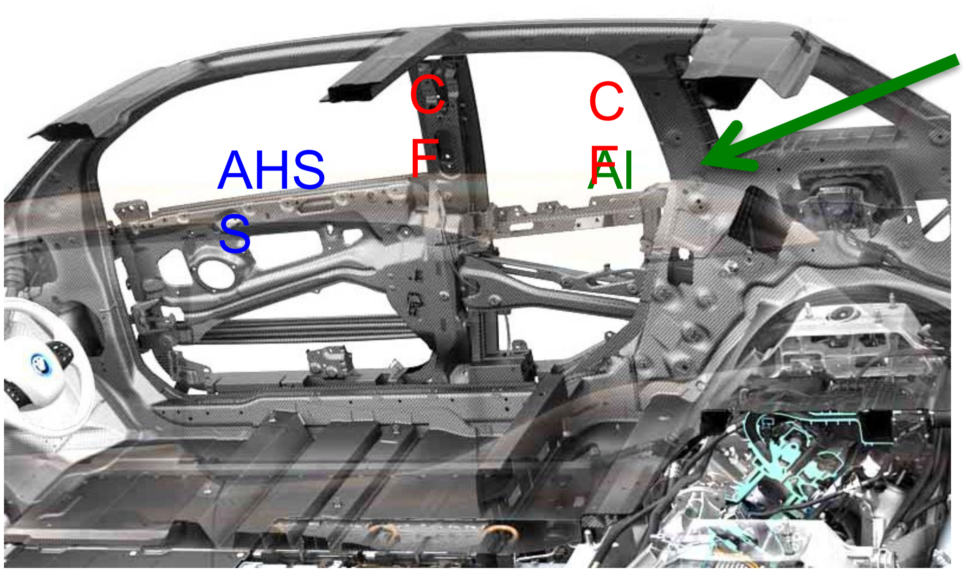
Opportunity
Sustainable Lightweight Manufacturing

Surface preparation of Carbon-Fiber Polymer Composite (CFPC) and other materials (Al) via laser structuring will enable:

- high-volume, automated, in-line production for auto industry
- enable the expansion to more structural joints, which are now limited to panel/sheets for automotive applications.

OBJECTIVE

Demonstrate a breakthrough surface preparation for joining carbon fiber polymer composites (CFPC) and aluminum (Al) components



http://www.extremetech.com/extreme/162582-bmw-i3-will-bmws-new-ev-finally-be-the-breakthrough-for-carbon-fiber-cars

Surface preparation of Al and CFPC via laser structuring will:

- increase joint strength
- reduce variability in surface preparation (laser surface texturing is a much more controlled process),
- elimination of empirical, labor-intensive surface preparation methods that are incompatible with automation required by automotive manufacturing.

Advantages of laser-structured CFPC and Al

- Eliminates sanding and solvent cleaning
- Removes resin rich surface layer
- Provides a greater contact area
- Yields a fiber reinforced adhesive/composite interface

Relevance to Goals of the Vehicle Technologies Program

Light-Duty Vehicles

- Develop technologies and a set of options to enable up to 50% reduction in light-duty petroleum-based consumption*

Multi-Material Systems

- Future vehicles will increase the use of mixed material systems to deliver lightweighting solutions needed to maximize vehicle performance and efficiency (p. 6, Materials Technical Team Roadmap)

Lightweighting, *Joining and Assembly.*

- High-volume, high-yield joining technologies for lightweight and dissimilar materials needs further improvement. 2.5-3*
- Joining methods must be rapid, affordable, repeatable, and reliable and must provide at least the level of safety that currently exists in production automobiles. 2.5-4*
- Successful Al-CF joining in this project will enable an increase in CF use in automotive and consequently lead to significant weight reduction.

* *VT Program, Multi-Year Program Plan 2011-2015, Dec 2010, pp. 1.0-2, 2.5-3, 2.5-4.*

Project Status
Milestones/Deliverables

Date	FY14 Milestones/Deliverables	Status
31-Dec-2013	Identified and/or obtained, the Al alloy, composite material system, and the laser ablation wavelengths	Complete
31-Mar-2014	Identified appropriate adhesives and obtained baseline adhesive joint properties (i.e., without laser structuring)	Complete
30-Jun-2014	Demonstrated laser-structuring for CFPC and the aluminum	Complete
30-Sep-2014	Go-no-go - Demonstrated 20% improvement in the lap shear strength of a single-lap joint produced by using Al and CFPC	Complete
31-Dec-2014	Identified optimum operating parameters for the laser-structuring of Al and laser ablation for CFPC.	Complete
31-Mar-2015	Identified optimum adhesive.	Complete
30-Jun-2015	Demonstrate 20% improvement in lap shear strength of a double lap shear joint produced by using Al and CFPC	On schedule

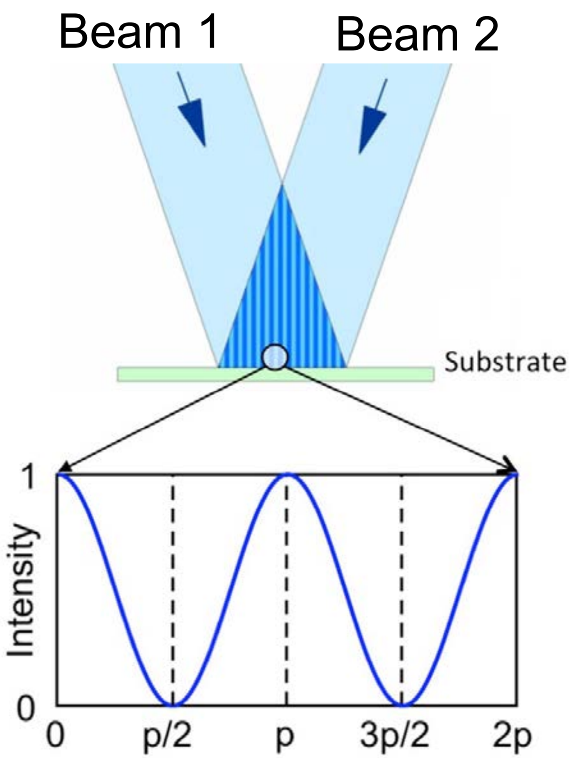
To date, all milestones have been achieved

Background

ORNL's laser facility with wave interference used for laser structuring

Laser-interference technique systematically "roughens" the surface:

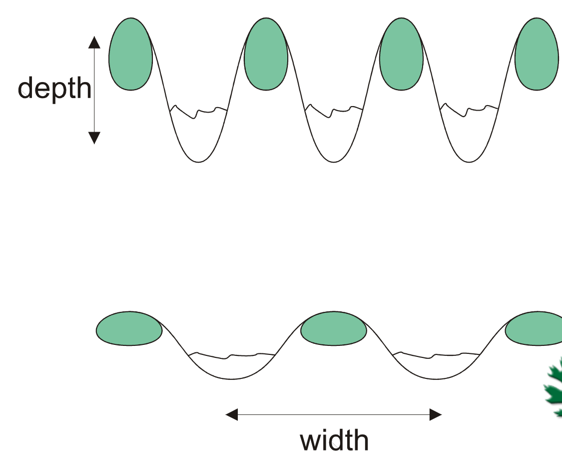
- Constructive interference of two (or more) laser beams intensifies power creating pits on the surface,
- Destructive interference leaves the surface unchanged



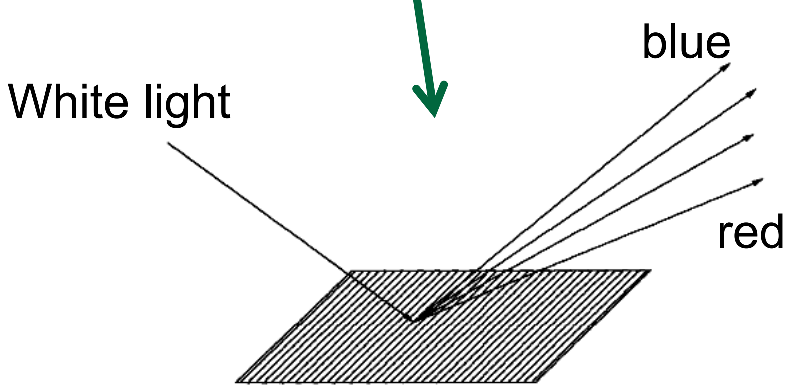
Features of the structured surface morphology:

- Undulation spacing: 0.5 - 50 μm,
- Density: 200-20,000/cm,
- Feature size: 1- 500nm,
- Structured area: 0.27cm^2/shot,
- Velocity: 10,000 lines at a time, 79 million dots at a time, up to 162 cm^2/min.

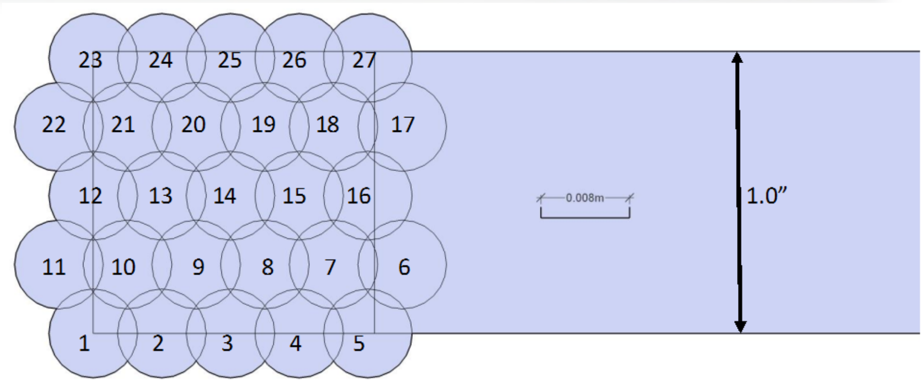
Alternating, high-power and low-power profile created by wave interference yields localized melting, solidification, and surface structuring.



Technical Accomplishment
Laser processed Al 5182 structuring spot-by-spot



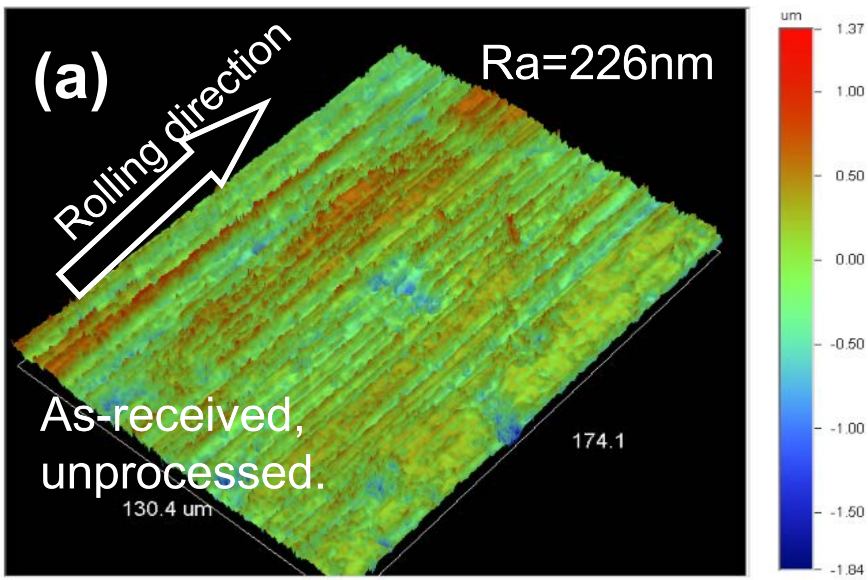
Processed area acts like diffraction grating.



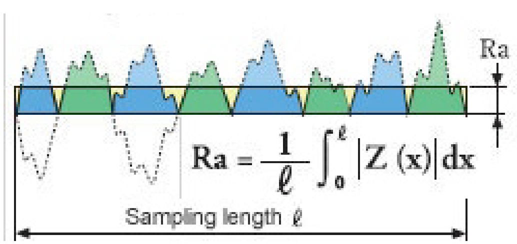
Spot-by-spot processing
- Position beam on spot,
- Fire a given number of laser pulses,
- Move to next spot

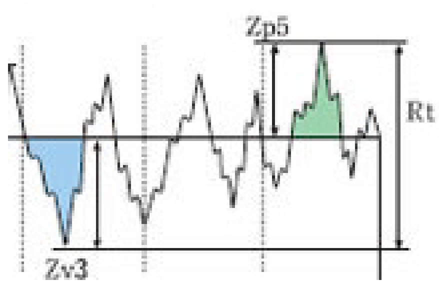
Technical Accomplishment

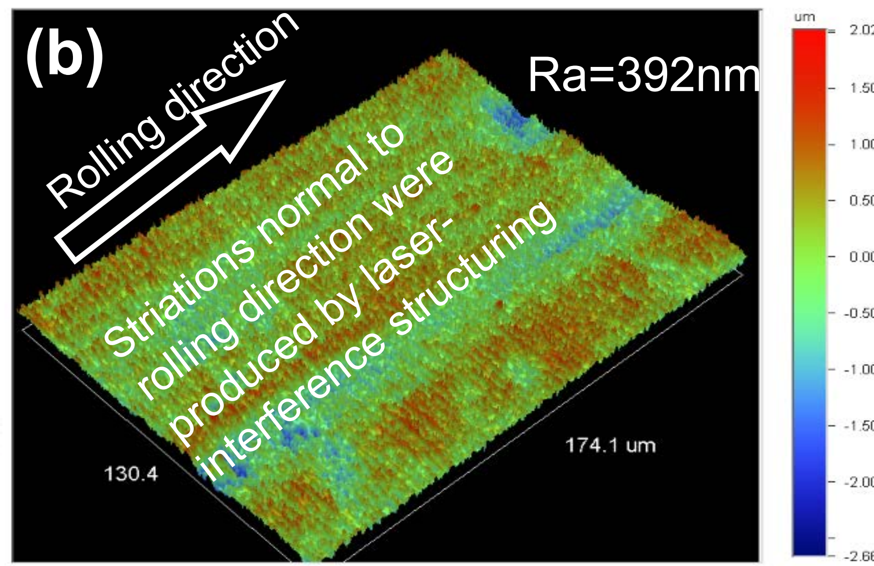
Increased surface roughness from 226 nm to 392 nm for the laser interference structured surface



Condition	Ra [µm]	Rq [µm]	Rt [µm]
a. As-received	0.226	0.286	3.21
b. Laser treated	0.391	0.493	4.68



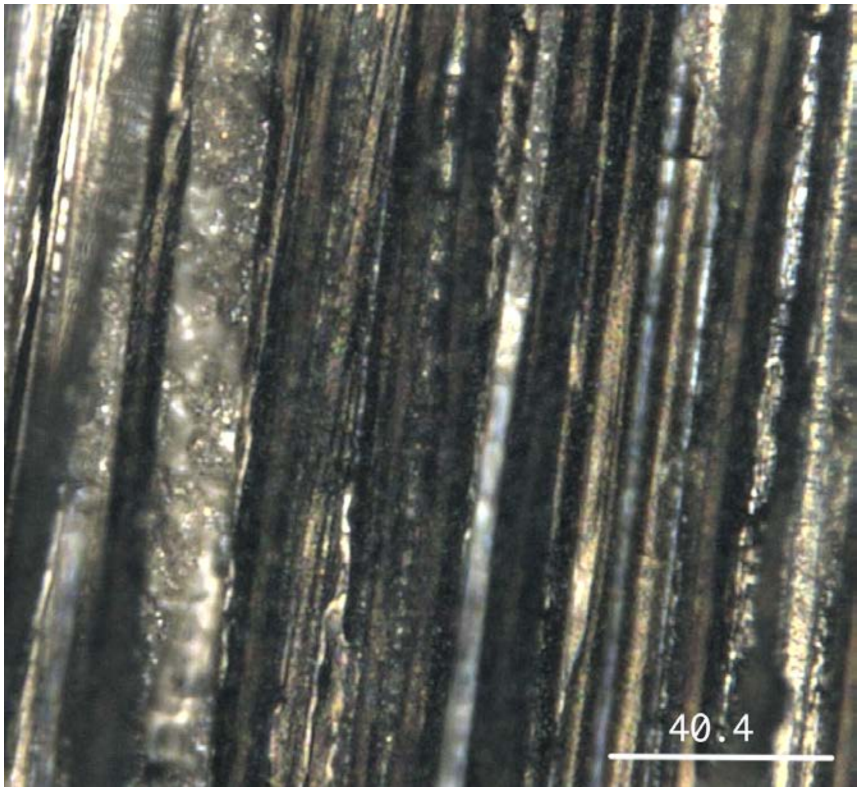




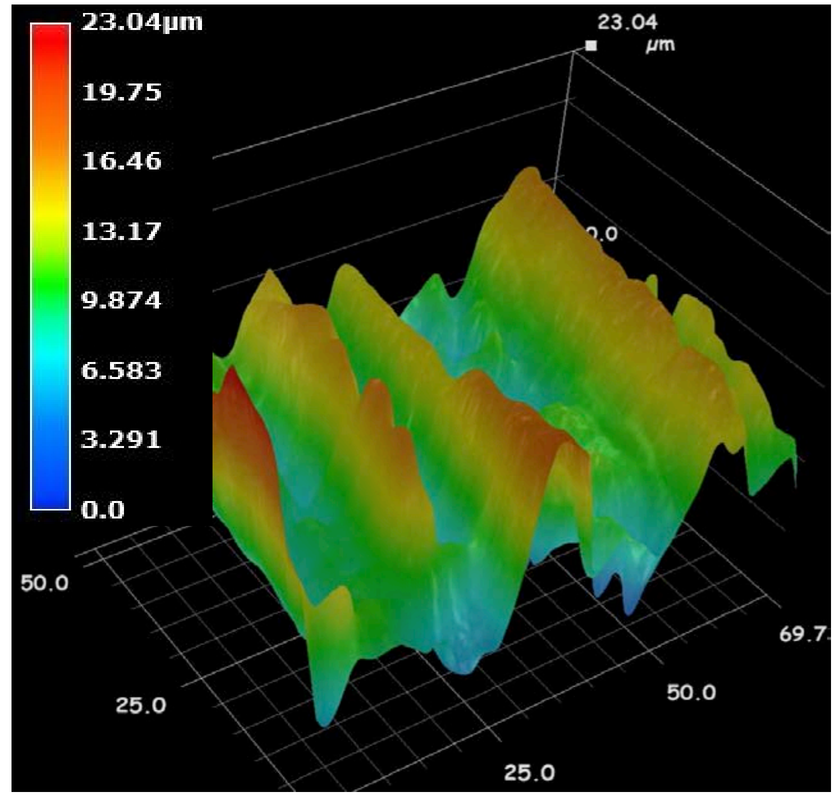
Optical surface profile 10 pulses/spot (λ=355 nm, pulse fluence of 1.2 J/cm^2)

Technical Accomplishment

3D Keyence depth profile indicates that the resin is ablated between carbon fibers



One-beam laser (no interference structuring): scanning speed 0.5mm/s,1.43 W average power, 4mm diameter spot.



3D Keyence depth profile showing that the resin between carbon fibers is ablated.

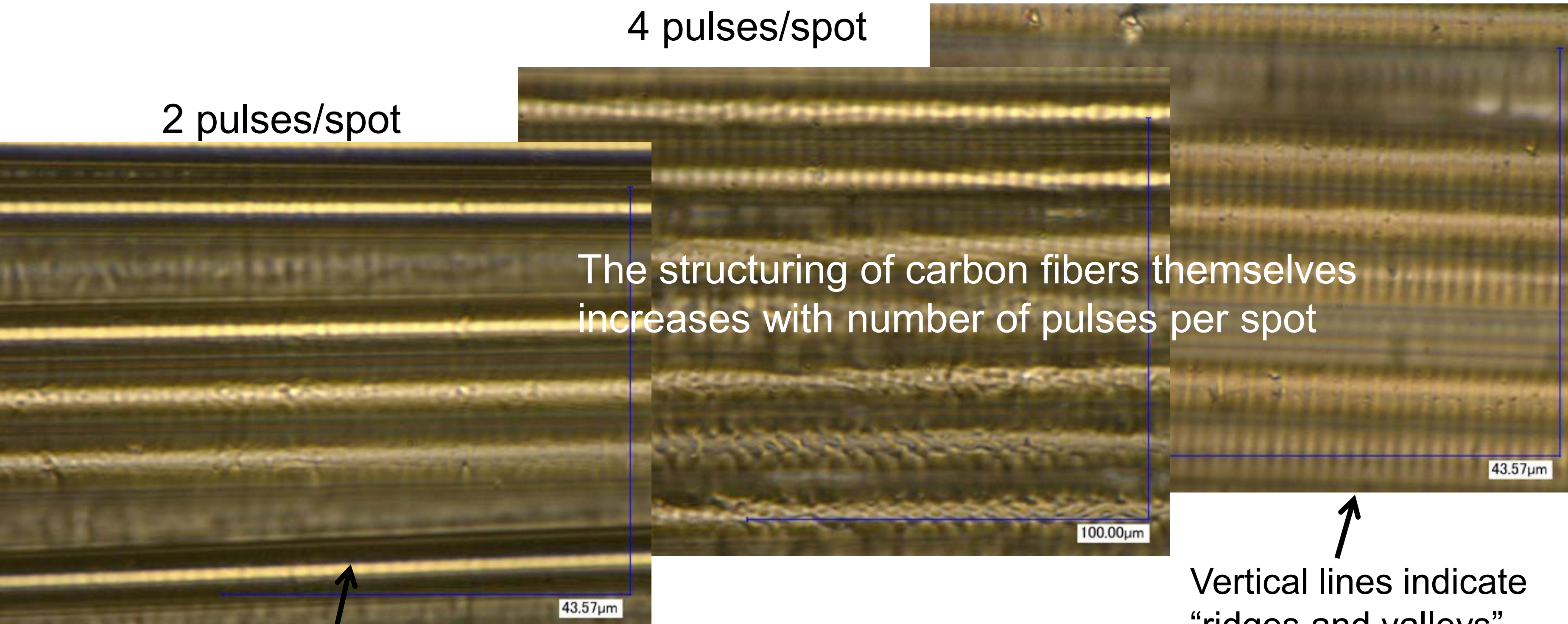
Technical Accomplishment

The structuring of carbon fibers themselves increases with number of pulses per spot

8 pulses/spot

4 pulses/spot

2 pulses/spot



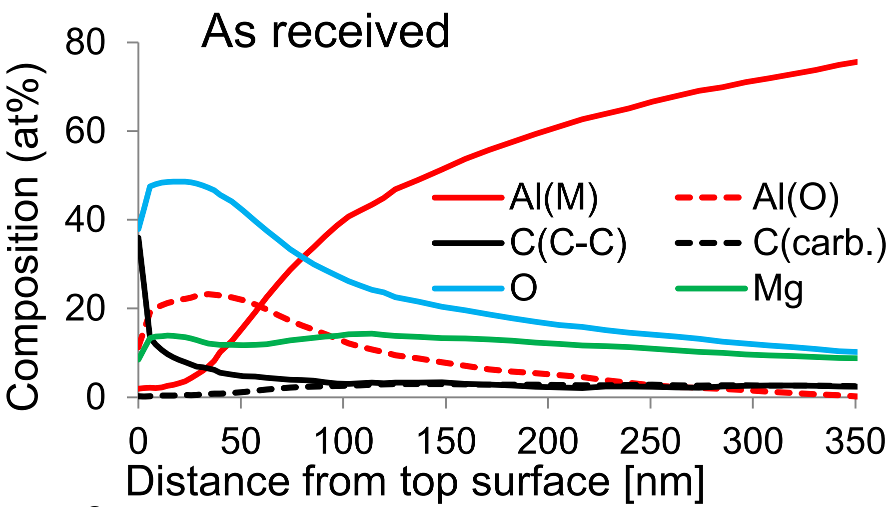
Vertical lines indicate "ridges and valleys" produced by the laser wave interference

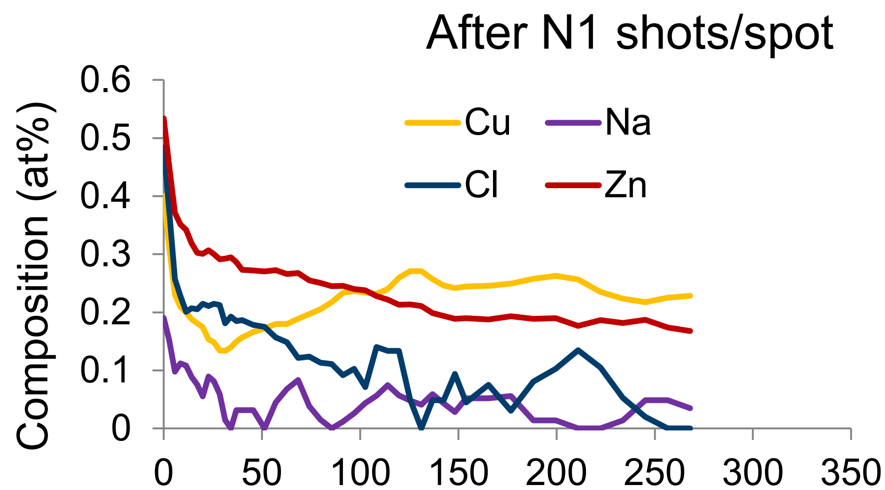
Carbon Fiber

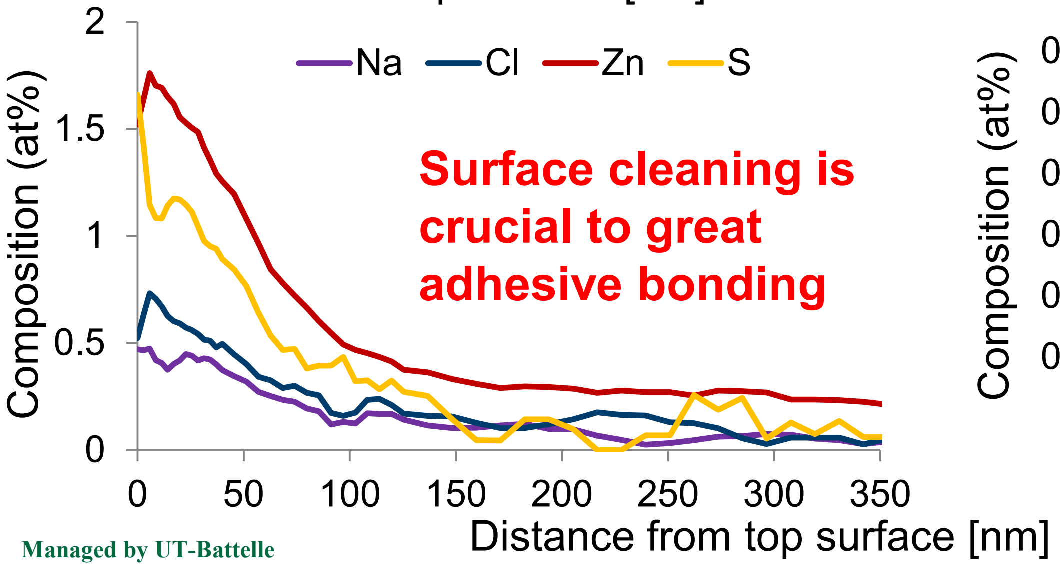
Surface micrographs for 6mm laser spot show structuring of CF themselves by the two-beam laser-interference (355 µm wavelength)

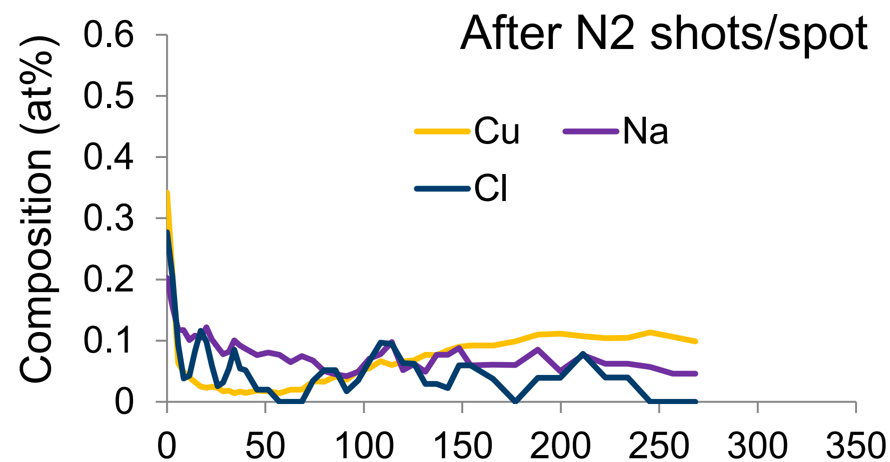
Technical Accomplishment

Depth profile for Al specimens demonstrates that laser treatment is effective at removing surface contamination





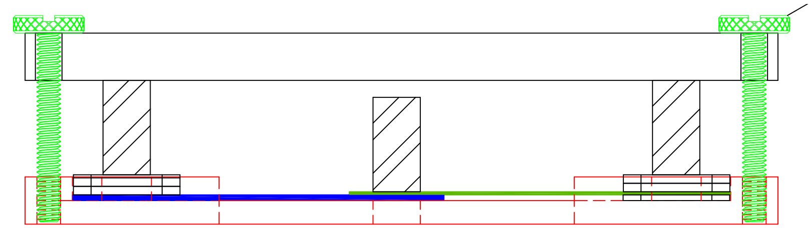


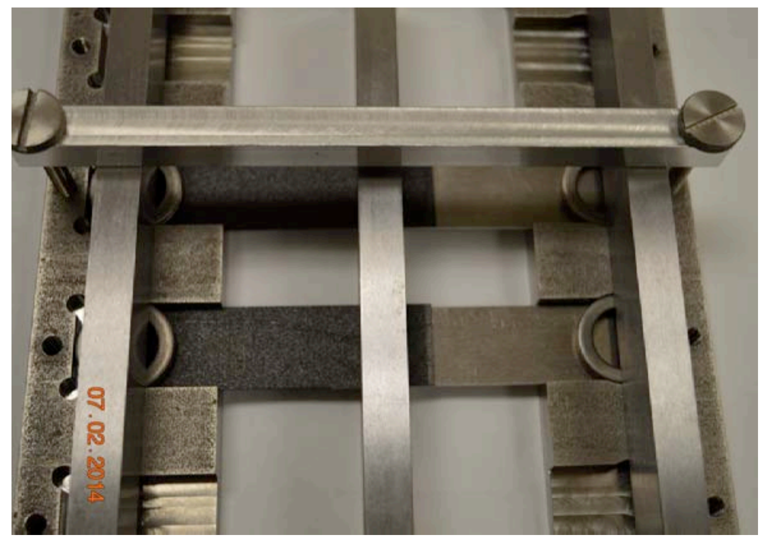


Technical Accomplishment

Sample preparation for laser-structured samples included only air blow-off, prior to adhesive application

Laser-structured specimens were stored in cases to avoid surface contamination following structuring.

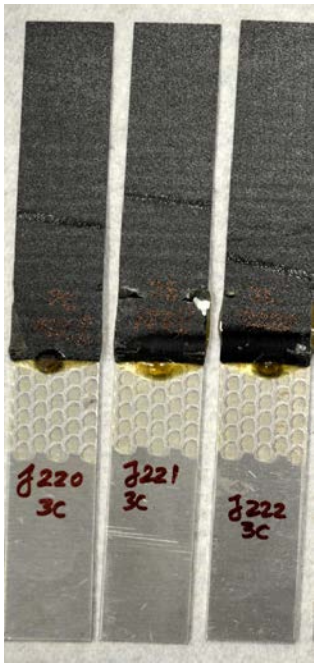




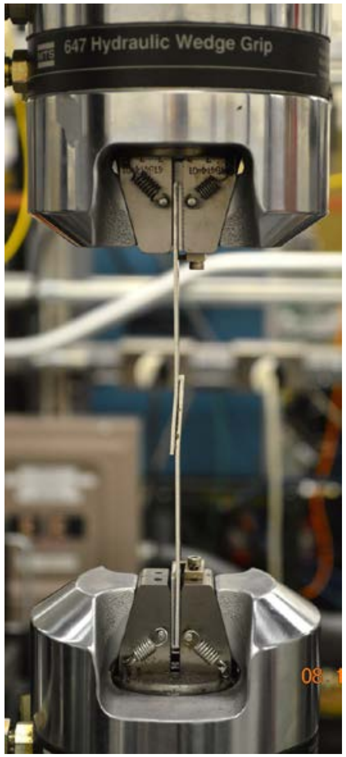
The use of the joining fixture insured consistency of the joining process.

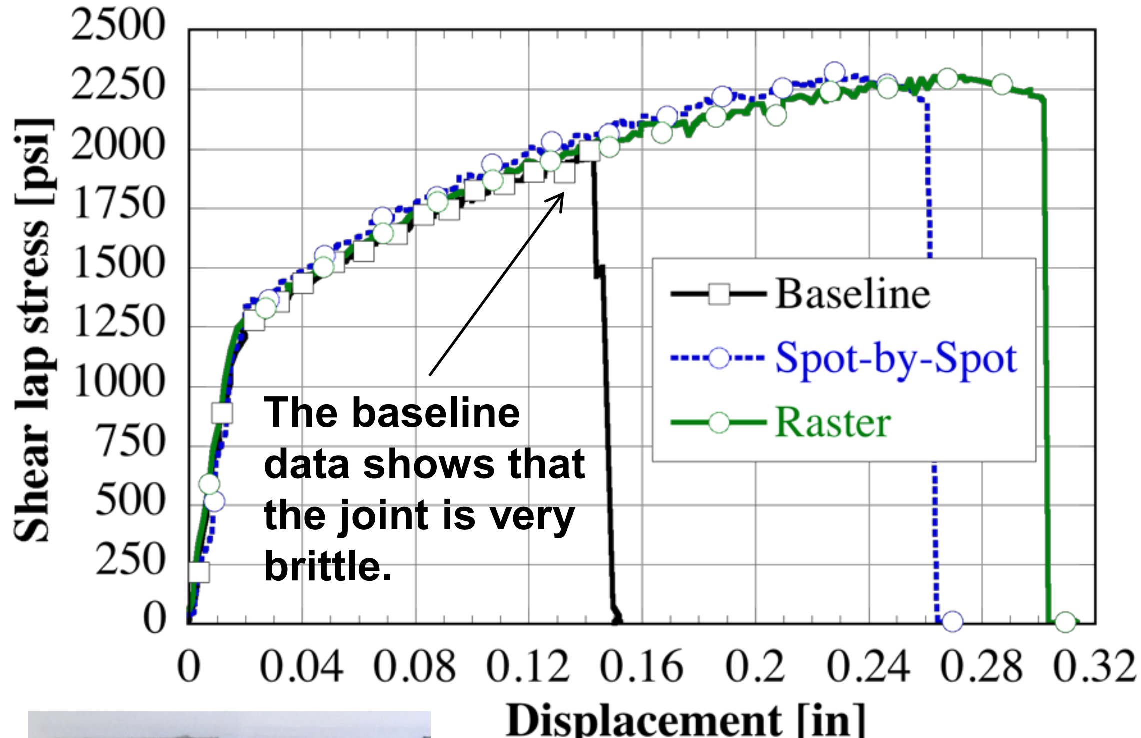
Technical Accomplishment

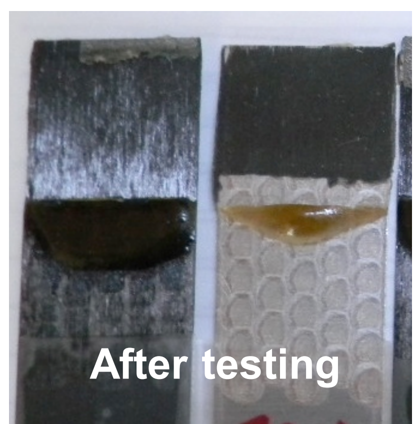
Laser-structured joints are more ductile, indicating an enhanced bonding of adhesive to both Al and CFPC



Before testing





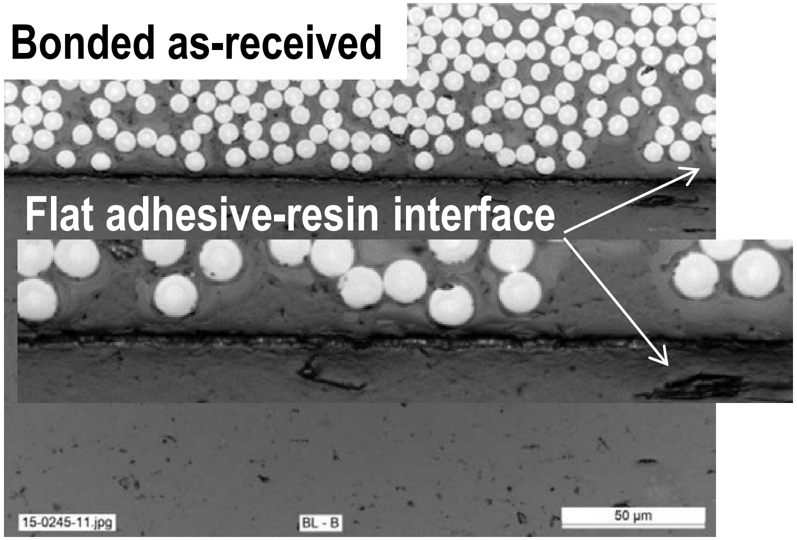


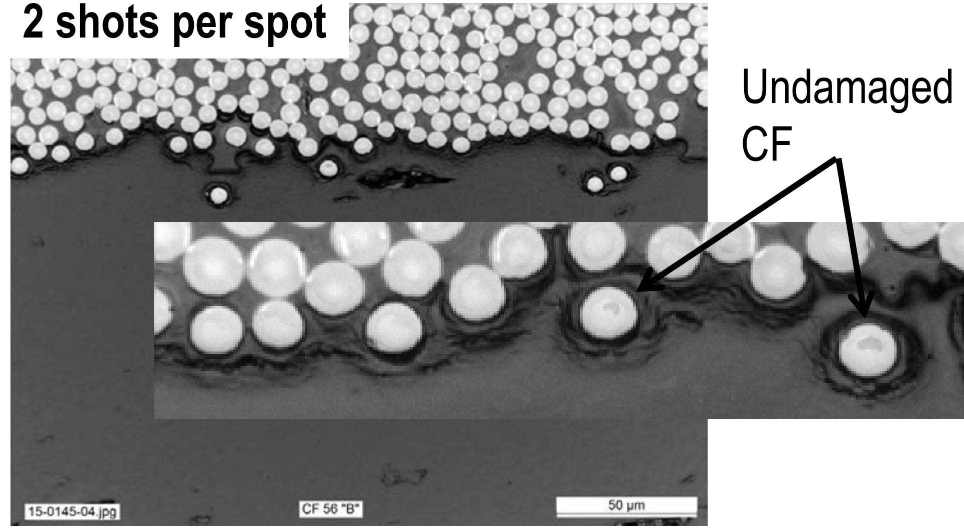
Data obtained for adhesive DP810 provided by 3M.

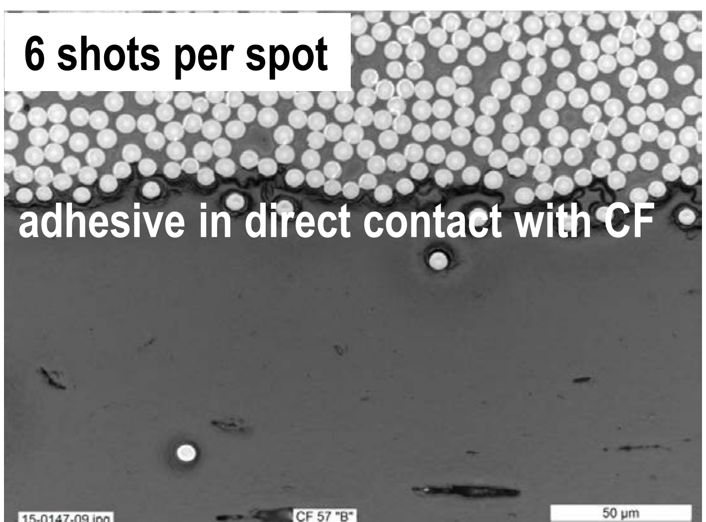
Laser structured joints can absorb approx. 50% more more energy than baseline joints.

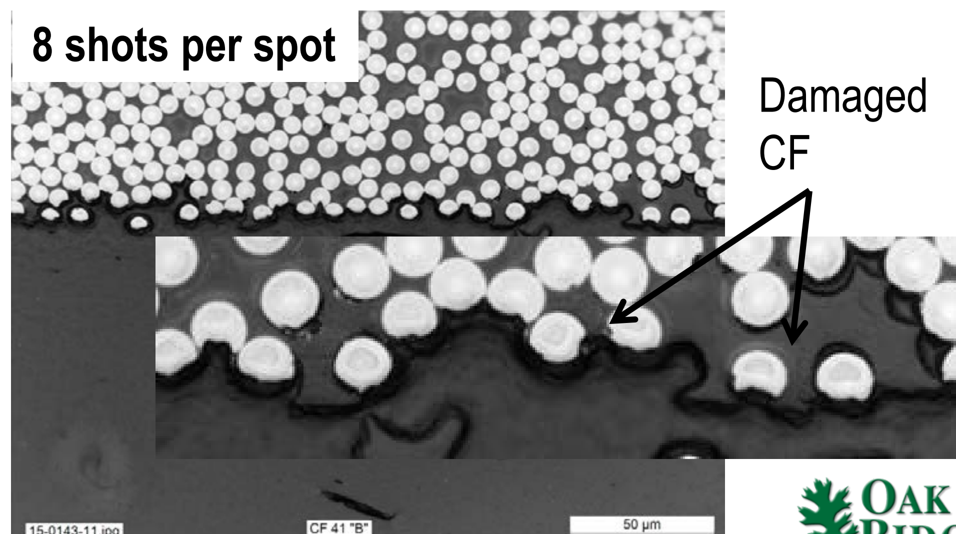
Technical Accomplishment

Adhesive contacts the CF for laser-structured specimens





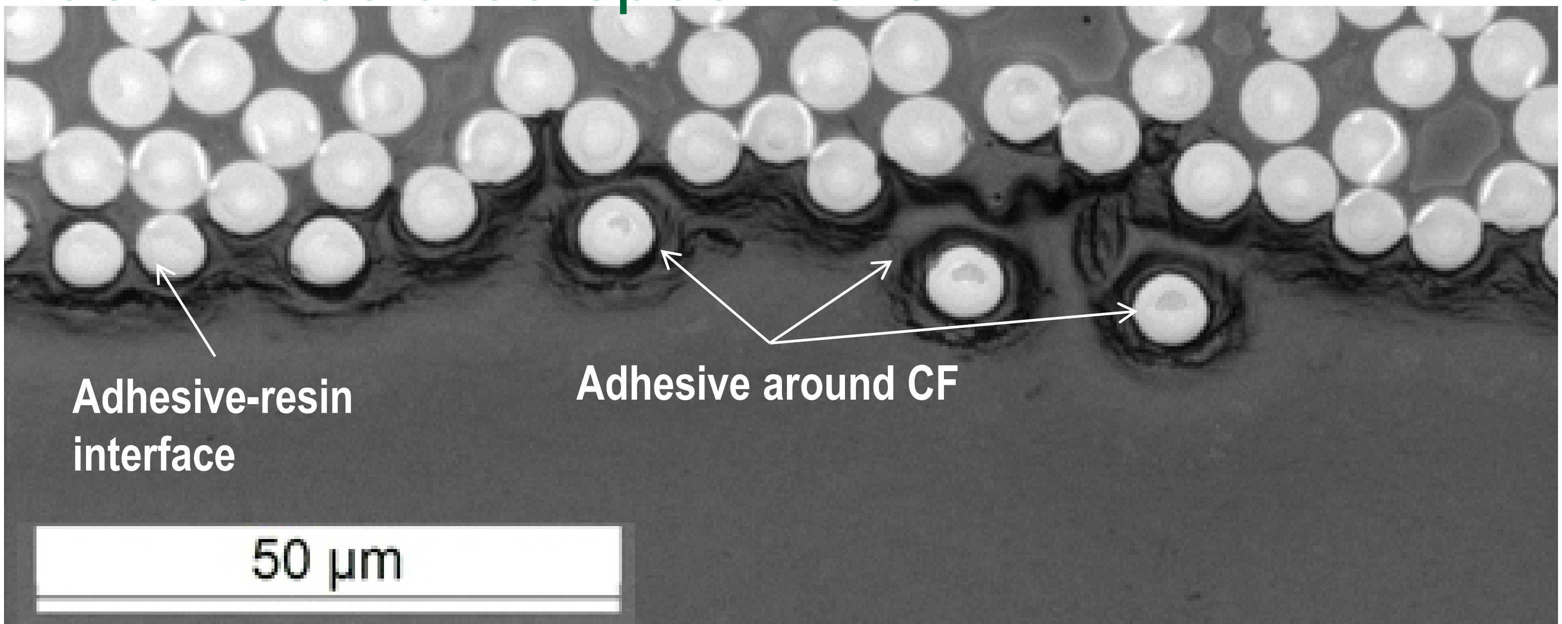


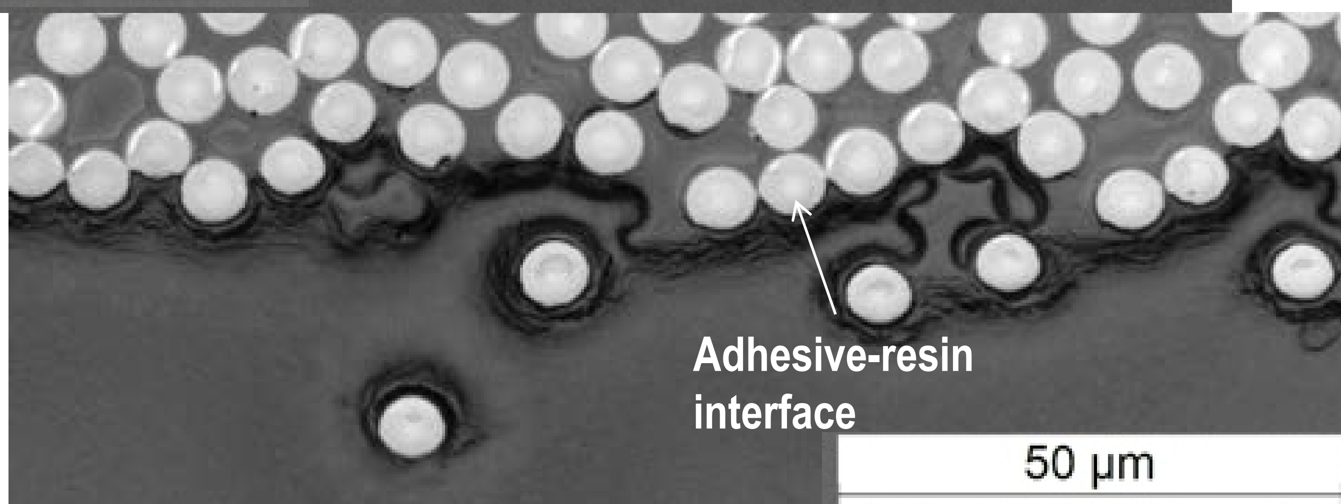


Technical Accomplishment

Adhesive contact with carbon fibers is enhanced for laser-structured specimens

2 shots per spot





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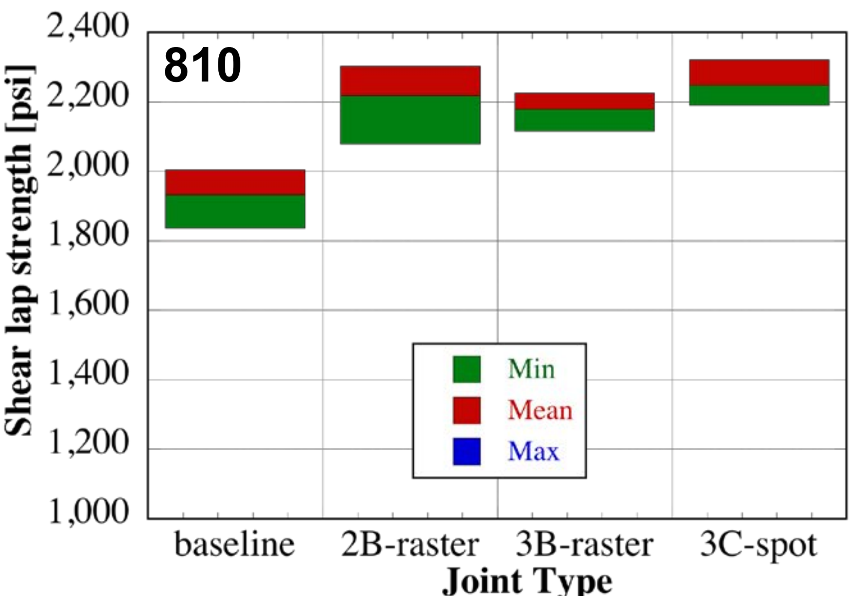
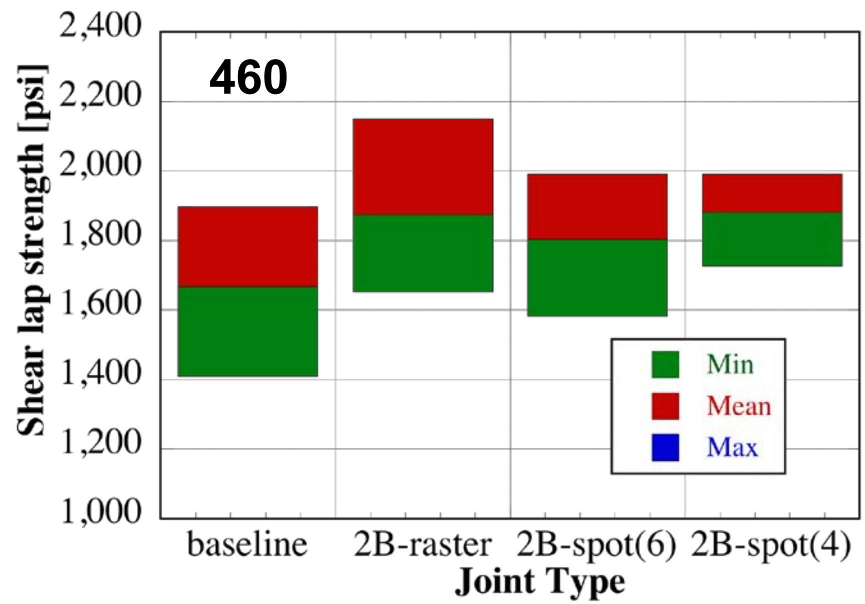
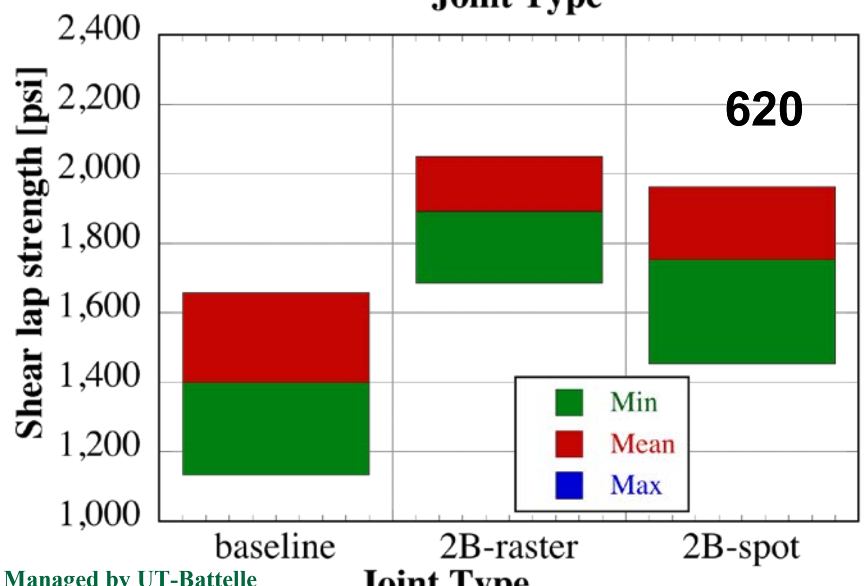
Technical Accomplishment

Shear-lap strength laser structured Al and CFPC - all adhesives







Adhesive	% increase Spot-by-spot	% increase by raster
810	16.3	12.7-14.8
460	8.2-12.8	12.8
620	25.4	35.3

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Technical Accomplishment

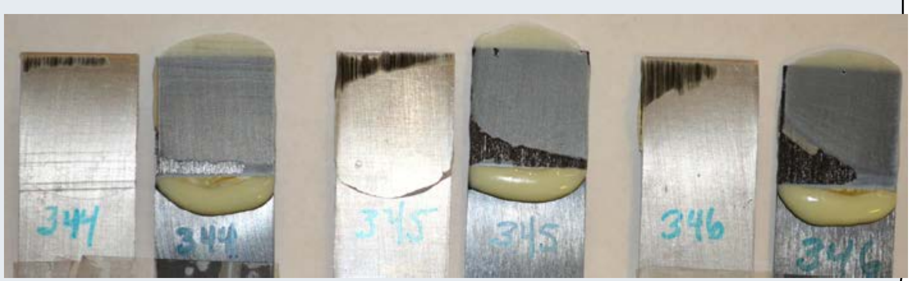
Failure mode changed due to laser-structuring

- Increased adherence for 620 adhesive
- Failure in the composite for 460 adhesive

Baseline: No laser structuring

Clean fracture surfaces indicate poor adhesive adherence

Baseline joints: 620 adhesive



Baseline joints: 460 adhesive

Laser structured joints

Both surfaces have residual adhesive

Laser-structured joints: 620 adhesive

Failure in the composite

Laser-structured joints: 460 - adhesive

Response to Previous Year Reviewers' Comments

This project was not reviewed last year

Technical Collaboration
Industry identified and provided materials

- Based on a review of industrial practice at Magna International and Plasan Carbon Composite, Inc. the following materials were identified to be used in this project:
  - Al 5182 samples of 1.5mm gauge, 100mm width, and 300mm long were supplied by Cosma International, Inc.
  - Al 5182 as the 5xxx Al alloy series is being used in inner vehicle body structure and it doesn't age on the shelf like Al 6xxx series.
  - The CFPC specimens were supplied by Plasan Carbon Composites, Inc. as 12 inch x 12 inch, 4 ply thick plaques.
  - CF Composite Prepreg - T83 resin (epoxy), T700S Carbon Fiber; as it is commonly used in the automotive industry and Plasan has several parts in production using this material.
- Three adhesives were selected at 3M for this project to be compatible to the Al alloy and CFPC selected for this project:
  - DP460 - an epoxy,
  - DP620 - a polyurethane, and
  - DP810 - a low-odor acrylic.
- 3M recommended procedures for joining the Al and CFPC.

Proposed Future Work

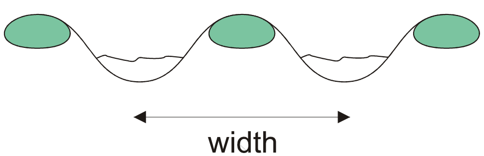
- Assessment of corrosion for the laser structured Al-CFPC joints
- Make and test double lap-shear Al-CF joints,
- Dynamic shear lap testing of joints (different loading rates)
- Next steps:
  - A follow-on effort is needed to demonstrate the laser-assisted joining technology of composite and aluminum in an production environment.

Technical Accomplishment

A breakthrough surface-preparation for CFPC and Al joints has been demonstrated

Relevance: Successful Al-CF joining in this project will enable high-volume, high-yield joining for lightweight and dissimilar materials leading to an increase in CF use in automotive and thus to significant weight vehicle reduction.

Approach: Alternating, high-power and low-power profile created by wave interference yields localized surface structuring.



Future work: Assessment of corrosion for the laser structured Al-CFPC joints.

Technical Accomplishments:

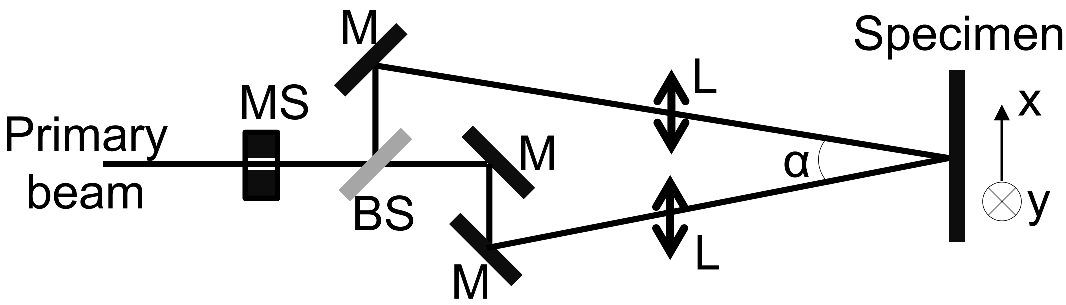
- Shear-lap strength of Al-CFPC joints has increased by 12-35% using laser-interference structuring.
- Laser-structured joints are more ductile, indicating an enhanced bonding of adhesive to both Al and CFPC.
- The Al surface roughness increased through laser-interference structuring.
- Laser-interference structuring is effective at removing surface contaminants,
- All results obtained without empirical, labor-intensive surface preparation methods that are incompatible with automation required by automotive manufacturing.

Tech. Collaboration: Magna Intl, Plasan Carbon Composite, Inc. and 3M identified and provided materials.

Technical Back-Up Slides

Background

Principle of the laser interference technique



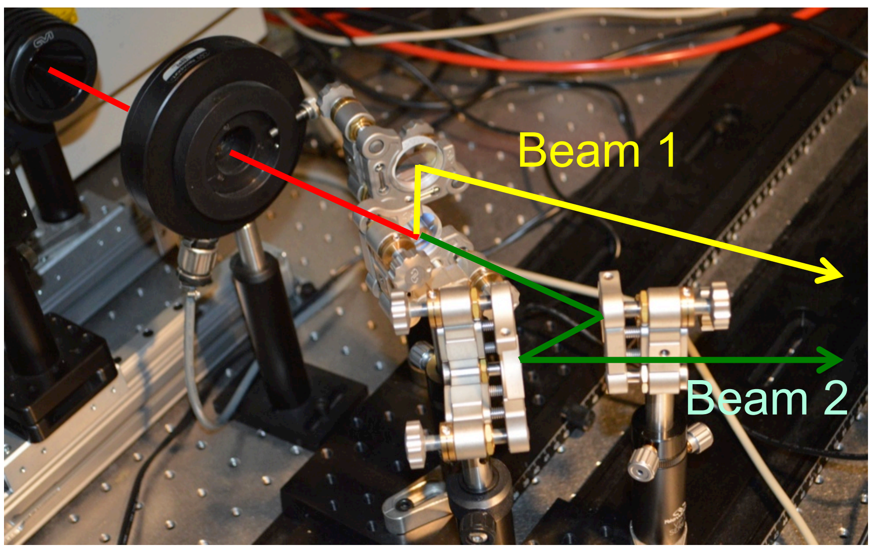
- *Wavelength λ*
- *Pulse frequency 10Hz*

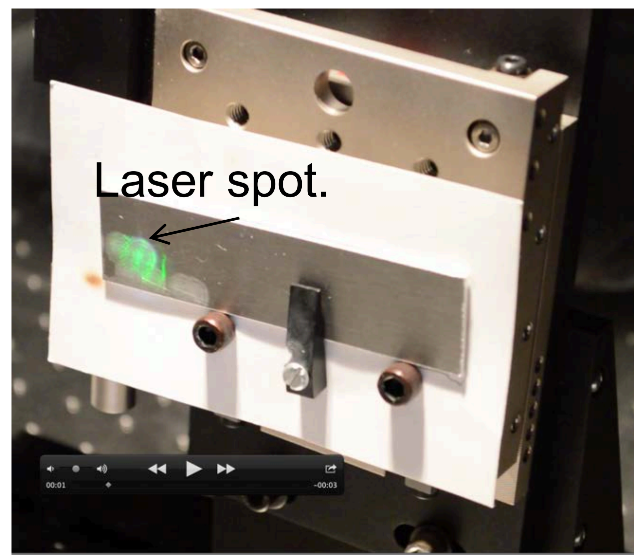
Periodic spacing formed by 2 beam interference

$$d = \frac{\lambda}{2\sin(\alpha/2)}$$

MS – mechanical shutter
BS – beam splitter

M – mirror
L – lens

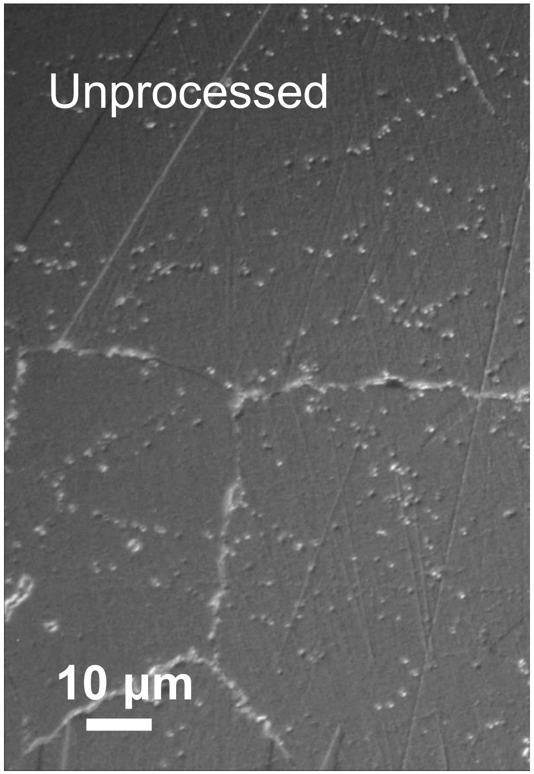


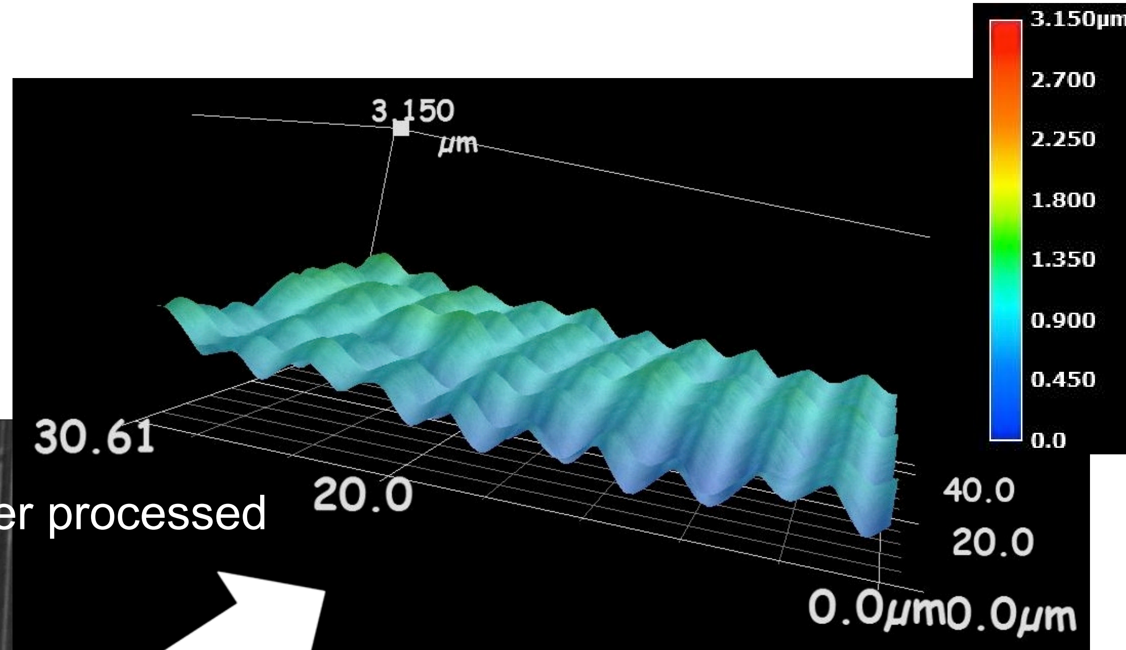


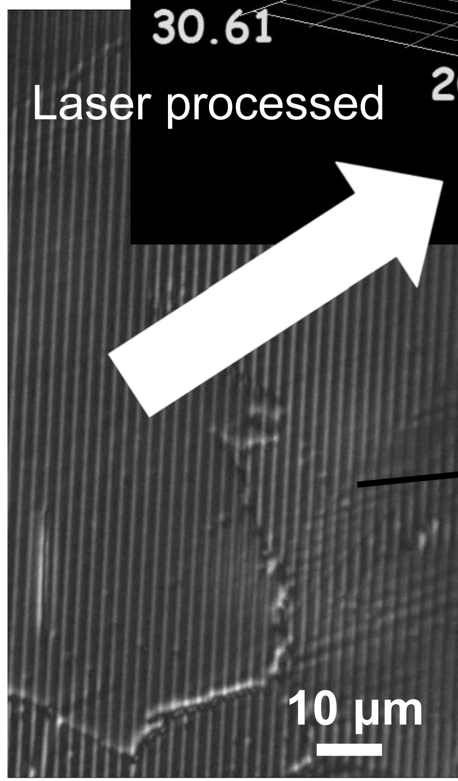
Sample mounted on a translational stage controlled by Labview.

- Q-switched Nd:YAG laser system with an harmonic generator enabling the selection of one very sharp wavelengths of 1064, 532, 355, or 266nm.
- Pulse duration 10ns (heating and cooling rates above 10^{12}K/s, frequency = 10Hz

Laser texturing on a polished steel surface







Vertical lines indicate “ridges and valleys” produced by the wave interference

Due to low its thermal conductivity, laser-interference structuring of steel surfaces is attained at low powers.

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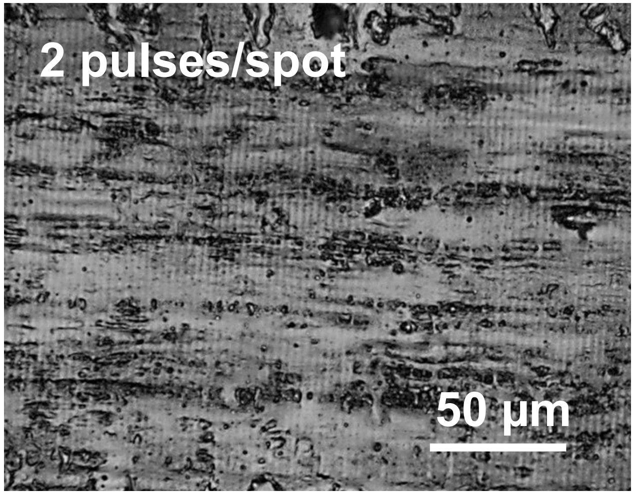
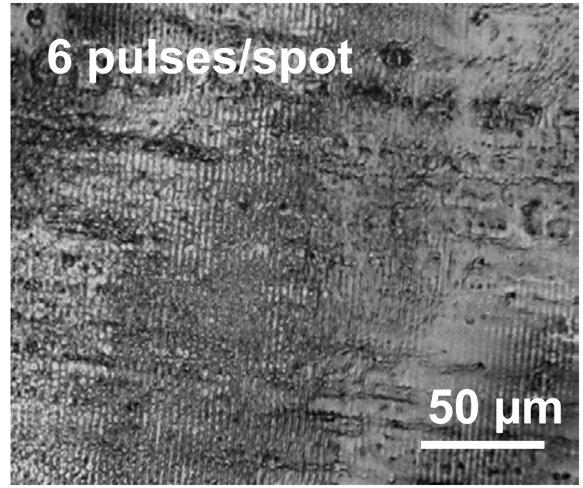
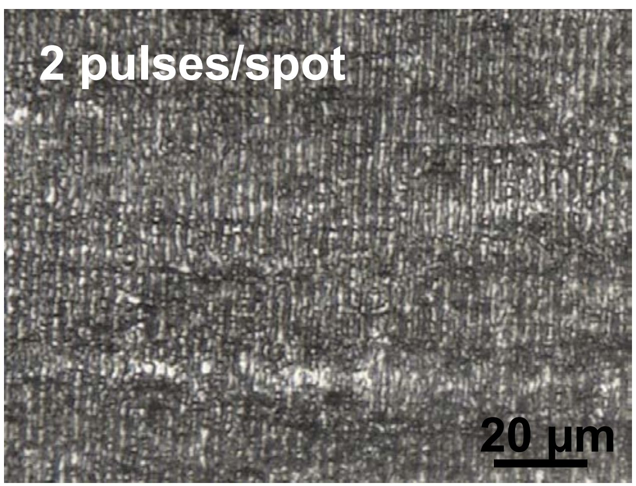
Influence of laser wavelength

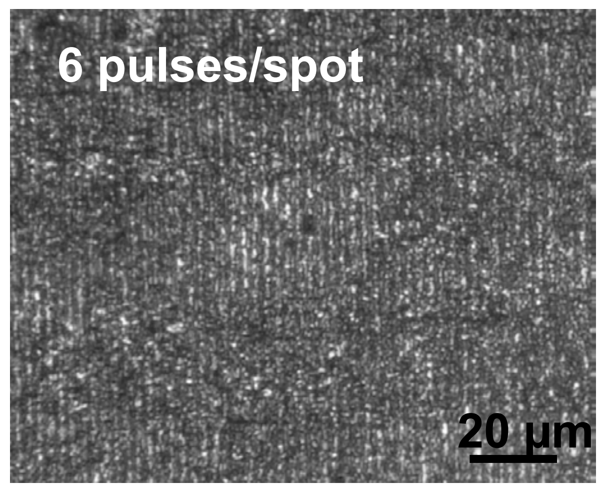
λ=266 nm and pulse fluences of 1.2 J/cm^2





λ=355 nm and pulse fluences of 1.2 J/cm^2





Collaboration with Tier1 Suppliers

- Magna International houses product engineering and prototype-build facilities in Troy, Michigan and Brampton, Ontario.
  - production scale prototype capability: metal stamping, robotic welding, rivet bonding, laser cutting and CMM dimensional inspection equipment.
  - metallography & metrology materials characterization laboratory, x-ray, production scale rivet, bonding and welding, laser cutting.
- 3M's Corporate Materials Research Laboratory is capable of formulating the appropriate adhesive and testing:
  - 3M is engaged with external vendors for the raw materials and have access to the appropriate mixing and processing equipment to manufacture adhesives.
- Plasan Carbon Composites (PCC) is the leading Tier I supplier of carbon fiber parts and assemblies in the United States:
  - PCC has developed a new high volume, out-of-autoclave process for Class A, structural and semi-structural components for mainstream automotive.
  - PCC is the manufacturer and supplier of the hood, roof and liftgate of the new SRT Viper, and the hood and roof for 2014MY and 2015MY Corvette.
  - Past parts include: fenders (Corvette Z06); hood, fenders, roof, roof bow, lower rocker moldings and front splitter (2009 Corvette ZRI); rear spoilers, front splitters, and front dive planes (2008 Viper SRT-1 0 ACR); and the splitter, hood assembly and mirror caps (2008 Ford Shelby GT500KR).