Joining Technologies for Electric and Autonomous Vehicles

Jeff Ellis, PhD

Senior Technology Leader

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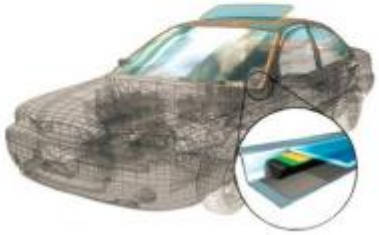
Joining Applications and Materials in Automotive

GLASS BONDING



- Glass
  - Front and back windshields
  - Attachment to side and top panels
- Steel

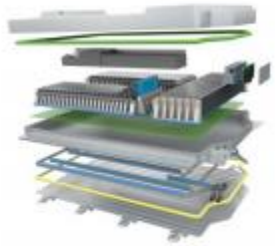
BODY

- Steel/Aluminum
- Polymer composites
- Structural reinforcements
  - Vehicle stiffness
  - Crash performance
- Multi-material combinations

CLOSURES

- Steel
- Aluminum
- Skins and substructure
- Combined with crimping

BATTERY

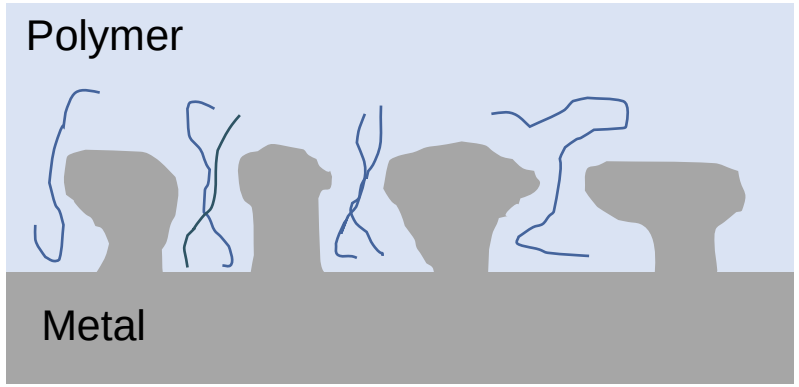


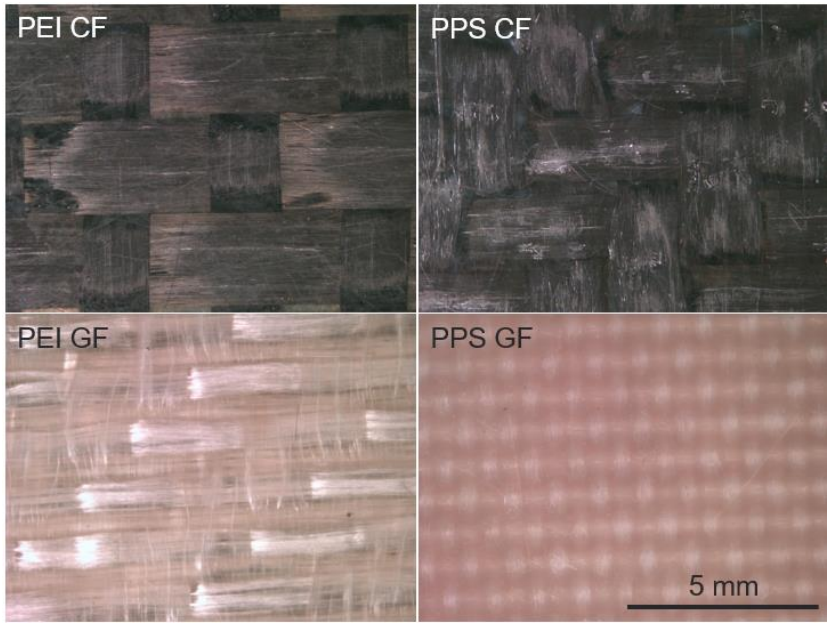
DUPONT

- Steel/Aluminum
- Plastics
  - PBT, Nylon
- Composites
- Multi-material combinations
- Reviserable joining

Outline

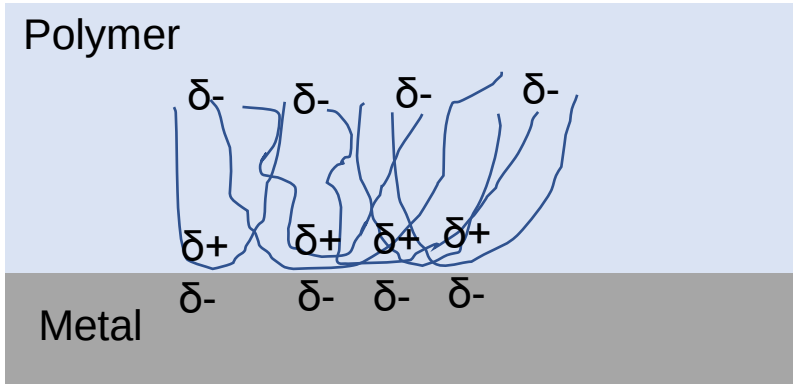
- Outline
  1. Background on Joining
  2. Battery Box Joining
  3. Thermoplastic Composite Joining



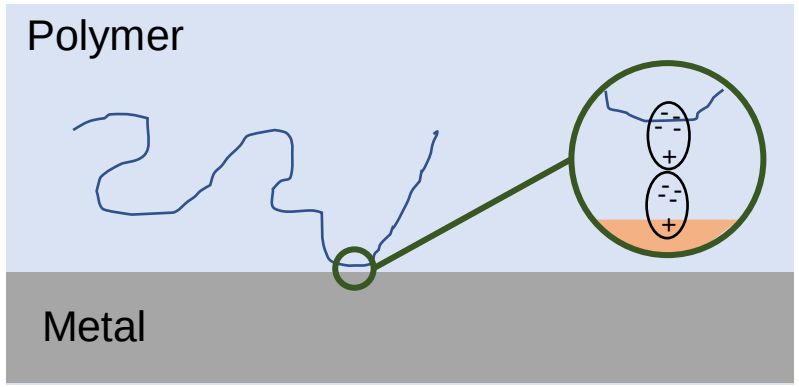


Background on Joining

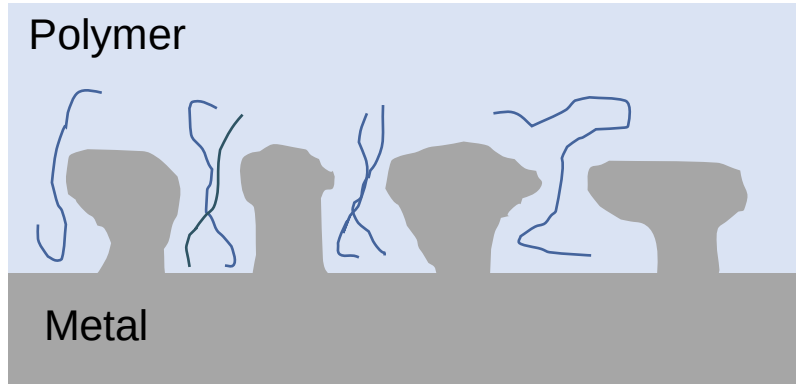
Polymer to Metal Joining



Electrostatic Adhesion
Charged Molecules



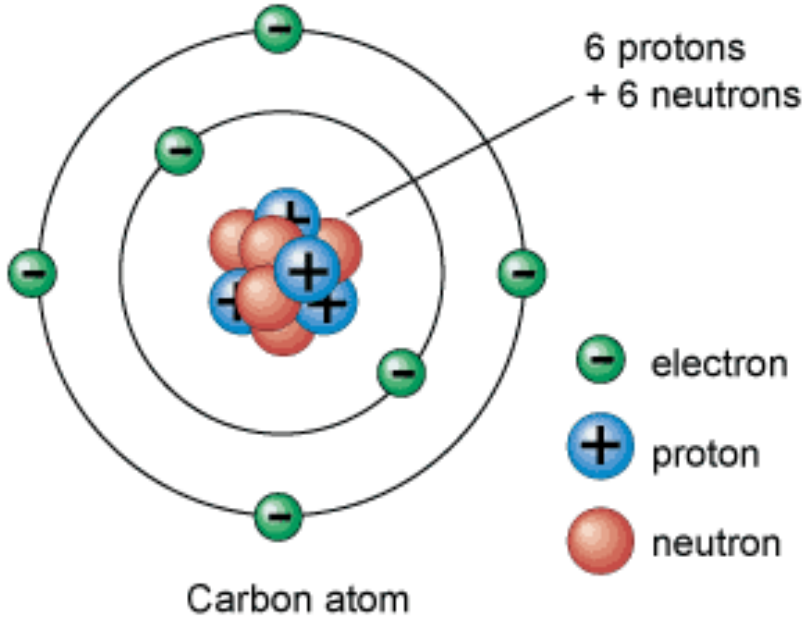
Van der Waals Forces
Induced Dipole Moment



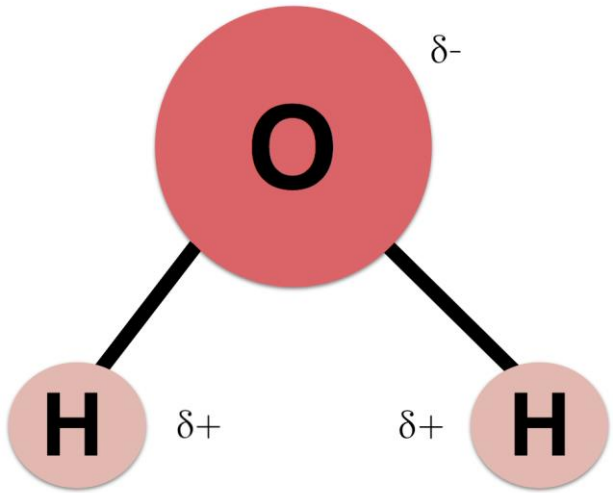
Mechanical Interlocking

Chemistry – Building Blocks of Materials

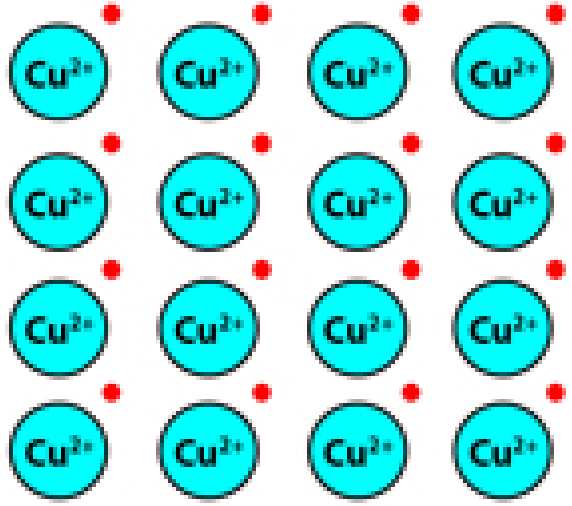
- **Atom** – Smallest unit of matter that can take part in a reaction
- **Molecule** – Two or more atoms joined together by covalent bonds
- **Metal** – Positive ions immersed in an electron cloud



Carbon atom



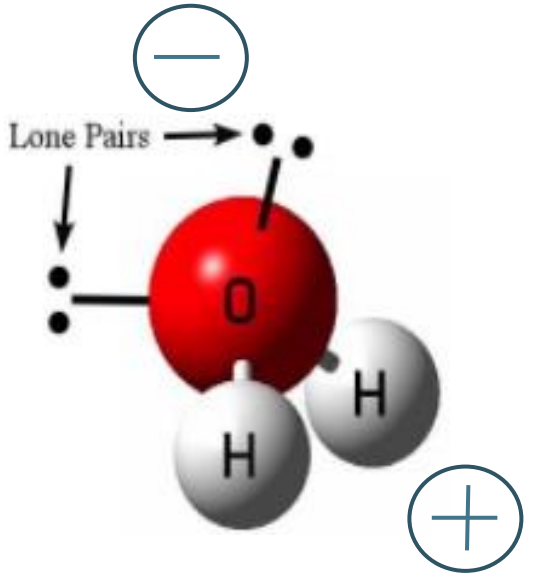
Water Molecule



Copper Metal

Surface Preparation of Plastics – Role of Polarity

- Must provide sufficient surface polarity for bonding
  - Polarity is the separation of electric charge leading to a molecule having a dipole moment, with a negatively charged end and a positively charged end
  - The polarity can be raised through oxidation as oxygen is highly electronegative



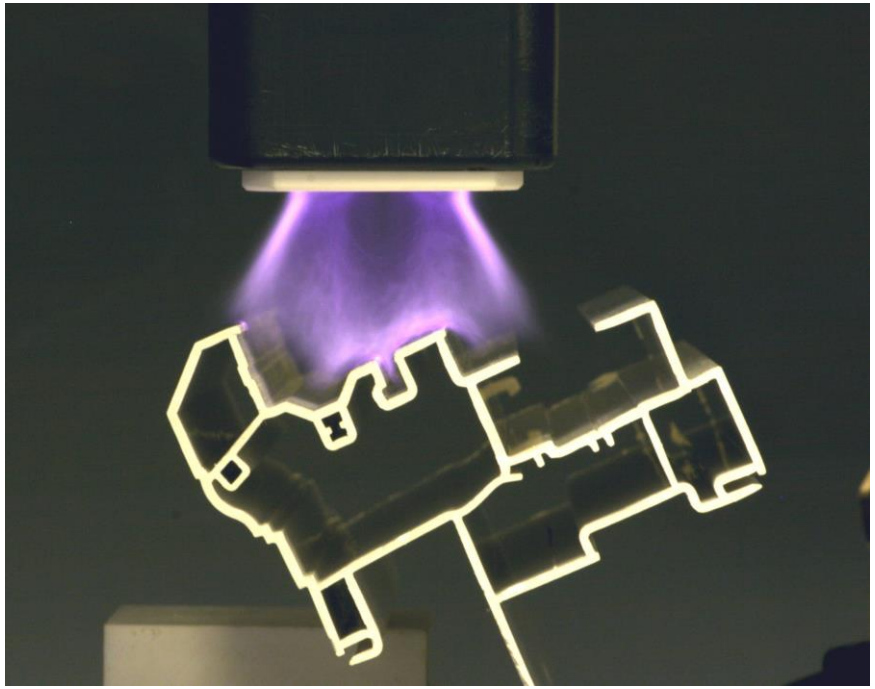
Water has positively charged hydrogen and negatively charged oxygen (4 electrons)

Polymer Surface Preparation – Etchants

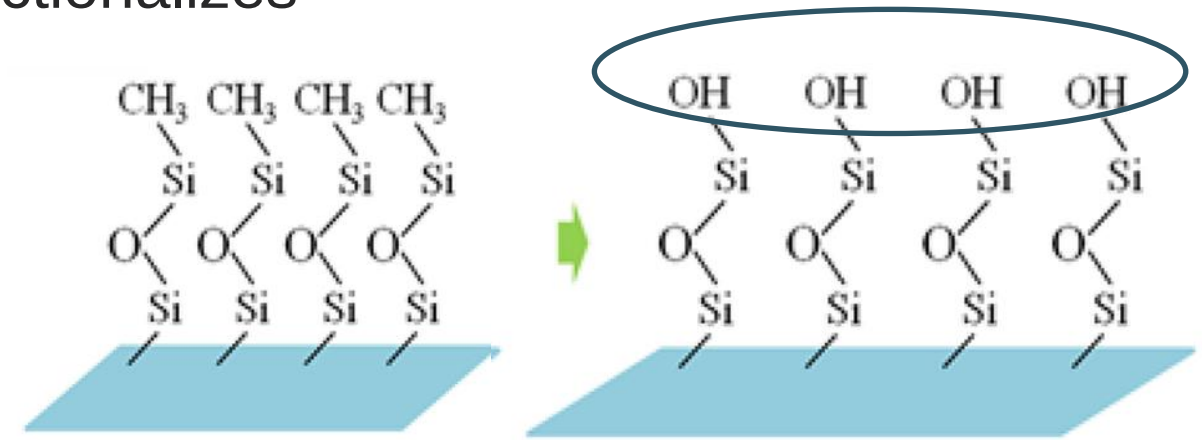
- Etchant – Alters the surface chemistry
  - PTFE tubing is placed in a sodium solution, which removes fluorine atoms from the carbon-fluorine backbone
  - Molecules from the air (oxygen, water, hydrogen) attach to the electron deficient carbon
  - The new surface has higher surface energy and is more reactive to bonding

Polymer Surface Preparation – Gas Ionization

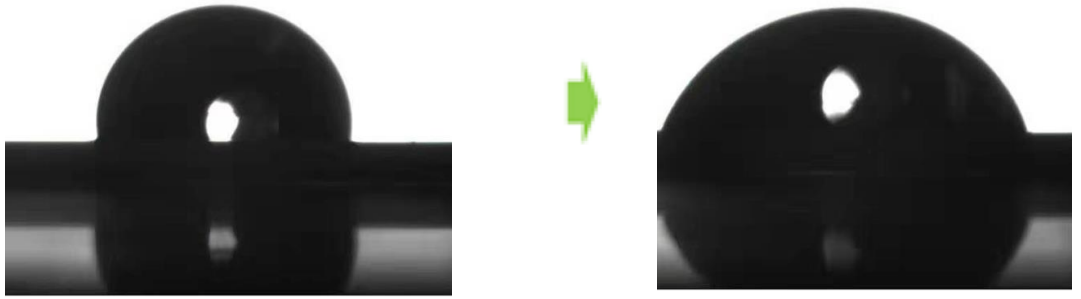
- Ionization of gas – cleans, etches, and functionalizes
  - Plasma – Ion, arc, or variable chemistry
  - Corona - Air



Plasma



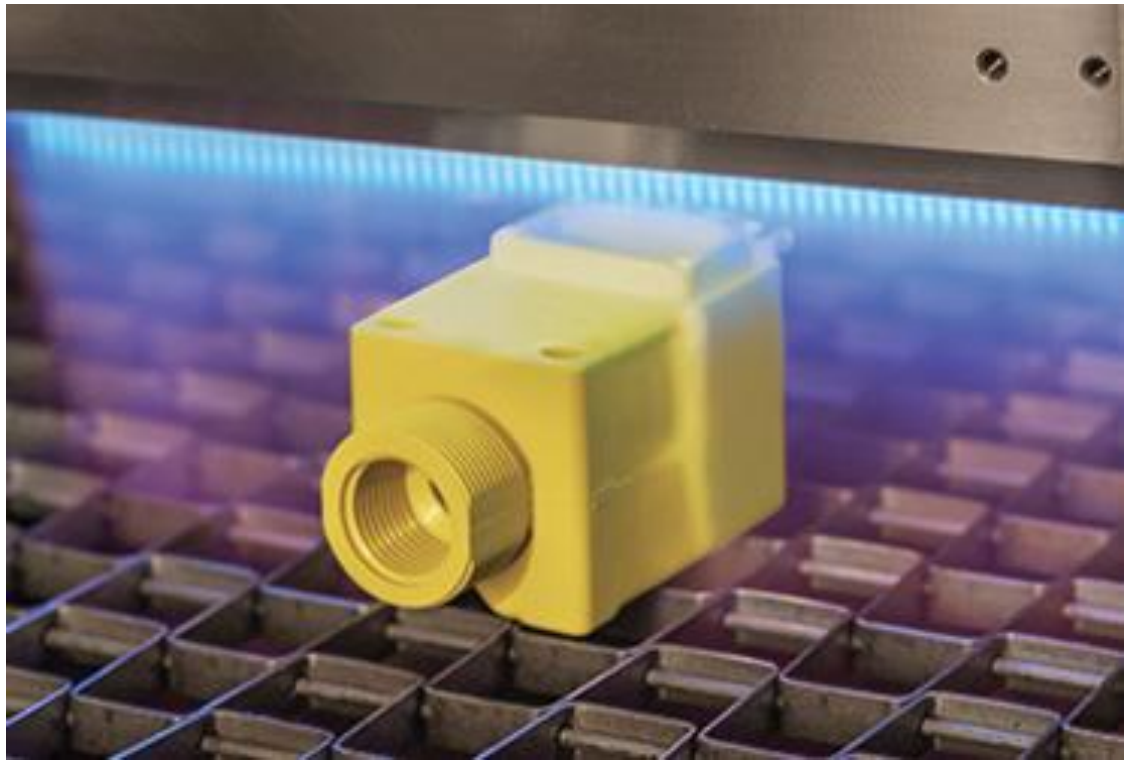
Silicone Silicone with Functionalized Surface



Lower contact Angle = Increased Wettability

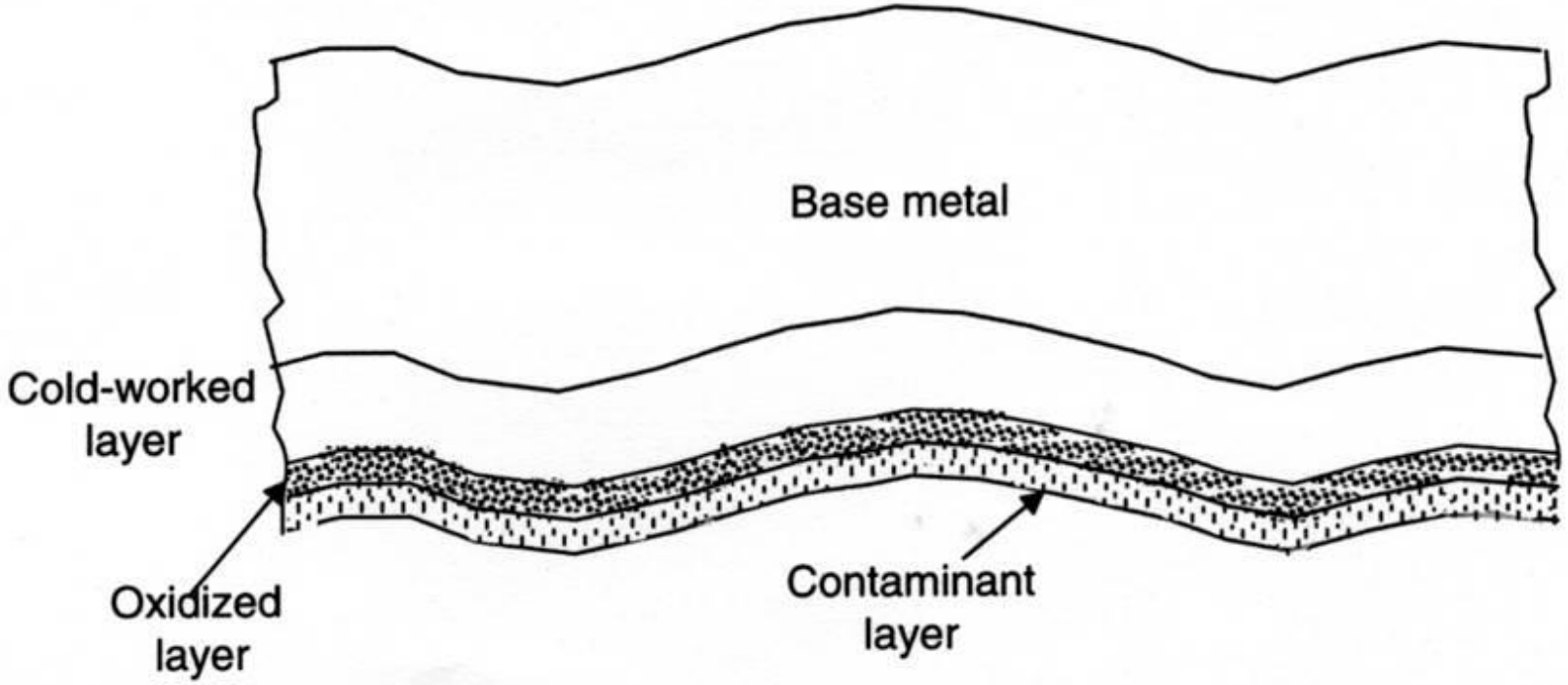
Polymer Surface Preparation – Other Techniques

- Plasma flame treatment
  - Flame plasma is formed when a flammable gas and atmospheric air are combined and combusted to form an intense blue flame
- Ultraviolet ozone
- Radio Frequency
- Laser Treatment
- Electron Beam Treatment
- Parts must be bonded shortly after any surface treatment
  - The new highly reactive surface reacts quickly with air (minutes to hours)
- Plasma treatment is also used on metals



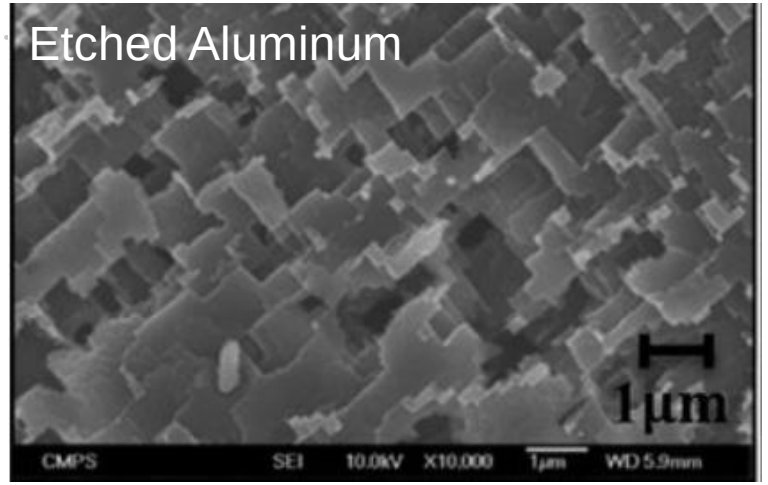
The Complexities of Metal Surfaces

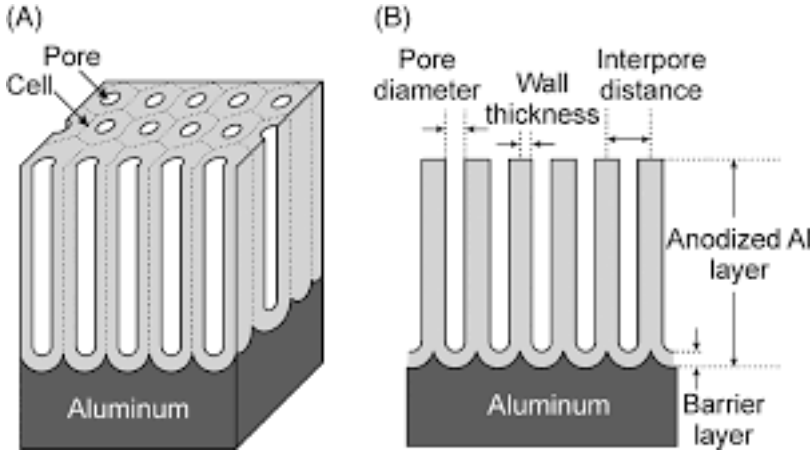
- Adhesives bond to the outer most layer (bottom of figure)
- Contaminant layers can be removed by cleaning
  - Solvents, Surfactants, Acid or base
- Different strategies are used to functionalize the surface
  - Etching – removes oxide
  - Anodizing – grows stable oxide
  - Galvanizing – adds stable coating
  - Nanoscale – adds stable coating
  - Laser Ablation – removes oxides



Metals Surface Preparation

- Etching – Removes an oxide
  - Heated acid in a dip tanks at 100-150°C for a few mins
  - Aluminum, Magnesium, Stainless Steels, Titanium
- Anodizing – Grows an oxide
  - Electrolytic passivation in heated acid bath
  - Voltage, current, and liquid pH are monitored
  - Aluminum, Titanium
- Galvanizing
  - Hot dip protective zinc coating to steel
- Galvannealing – addition of zinc alloy

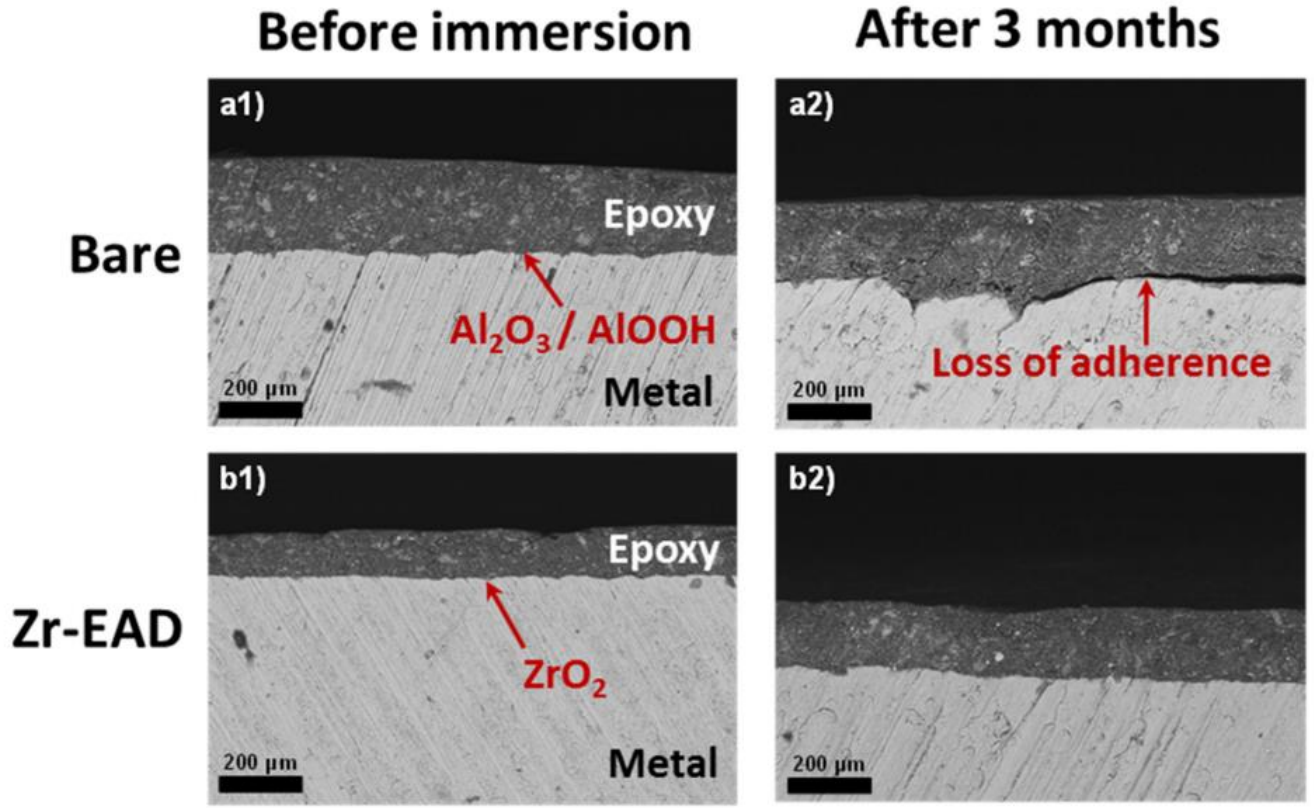




Anodized Aluminum

Nanoscale Coatings

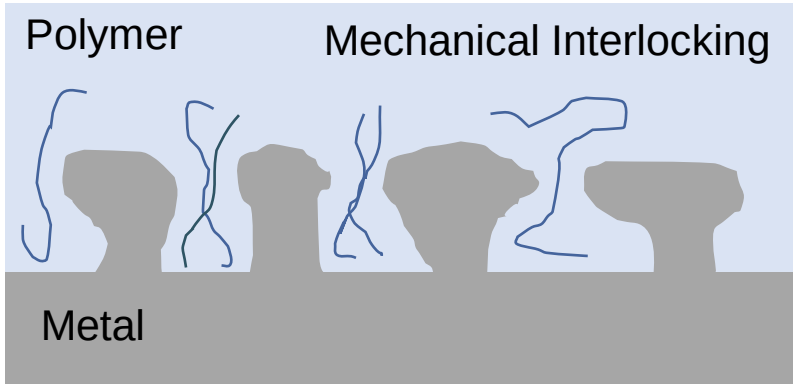
- Nano thick coating of ZrO_2
  - Electro-assisted deposition (Zr-EAD)
  - Hexafluorozirconic acid solution
  - Low porosity
- Typical Metals
  - Aluminum

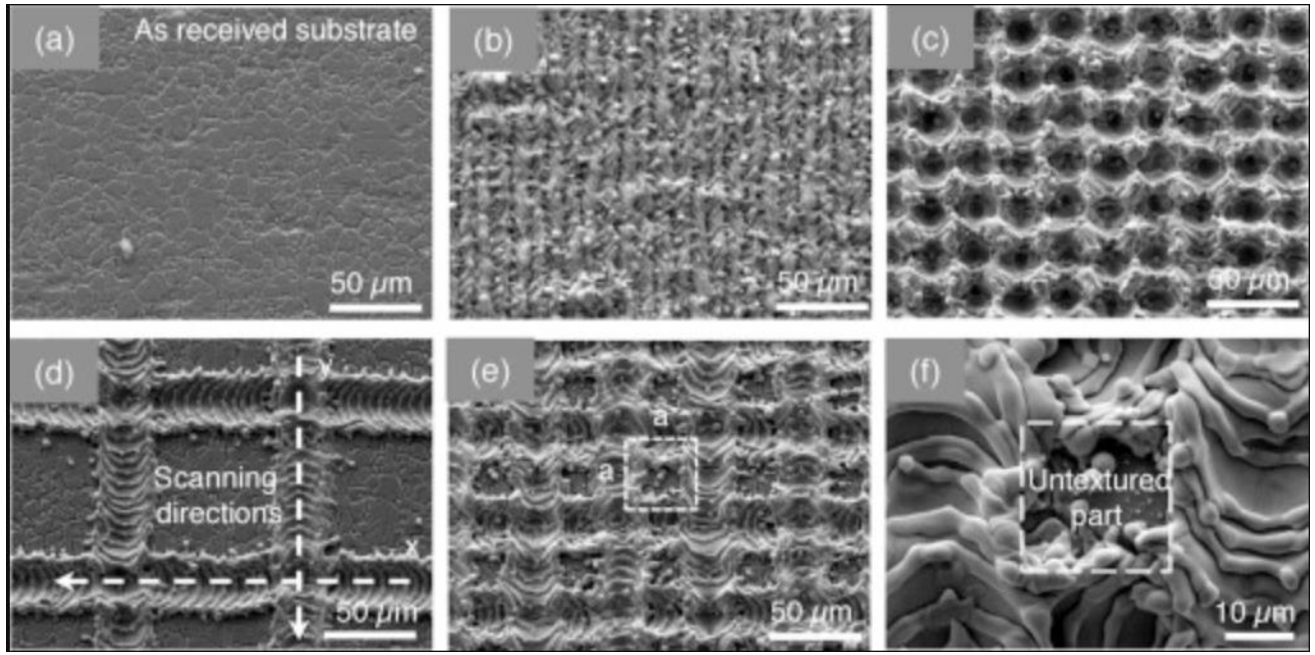


Source: Sustainability 2021, 13, 9688

Metals Surface Preparation – Patterned Laser Ablation

- Pulsed infrared fiber laser creates a porous surface
- Creates clean wettable surface
- Increases surface area
- Velcro-like surface
- Good for polymer bonding through mechanical interlocking





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Battery Box Joining

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Current Materials and Processing

- Boxes and covers are typically steel or aluminum
- Joining techniques
  - Form-in-place (FIP) gaskets – automation equipment necessary for application
  - Form-in-place die cut sheets
  - Cure-in-place, 1k and 2k adhesives/sealants
  - Extruded and spliced homogeneous rubber gaskets – placed in a machined groove
  - Mechanical fasteners + sealant
  - Hot melt adhesives

Photo: Sika Automotive

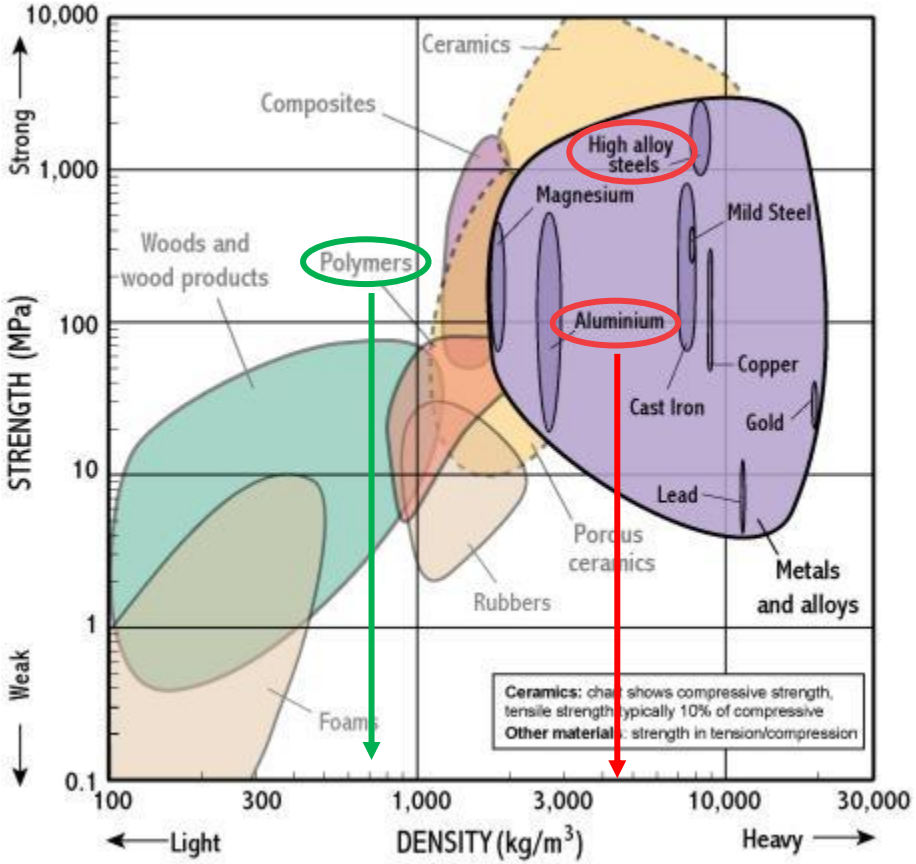
Current Battery Box Challenges and Polymer Advantages

Weight of Materials

- Aluminum and Steel are more dense than Polymers
- Adhesives and sealant add extra weight, direct bonding can eliminate these
- Up to 60 kg weight and 50% cost reduction with polymers

Storage and Handling

- Cross-linking or solvent drying liquids and solids require specific temperature and timing to remain active, while thermoplastics are stable at room temperature for years
- Solids can be handled more easily than pumping and purging tubing



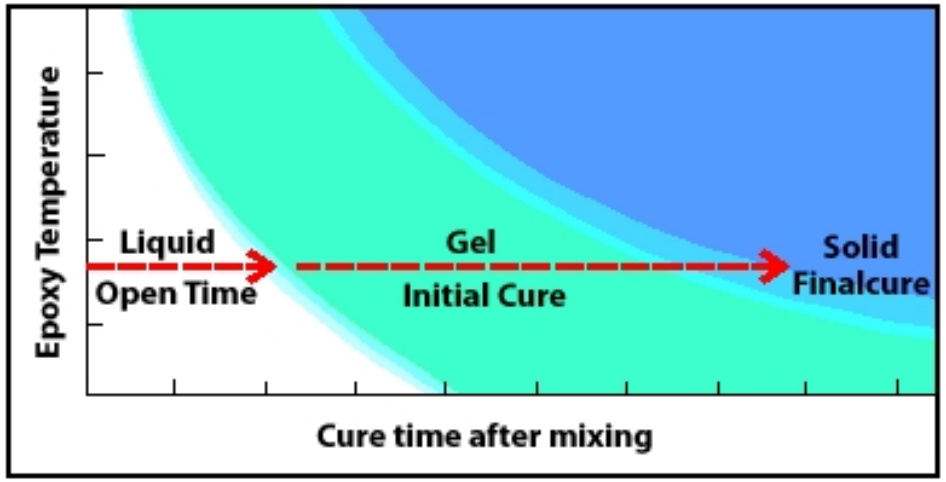
Current Battery Box Challenges and Polymer Advantages

Curing Time

- 1k and 2k system can take long time or high temperature to obtain final bond strength, while thermoplastics solidify in seconds

Serviceability

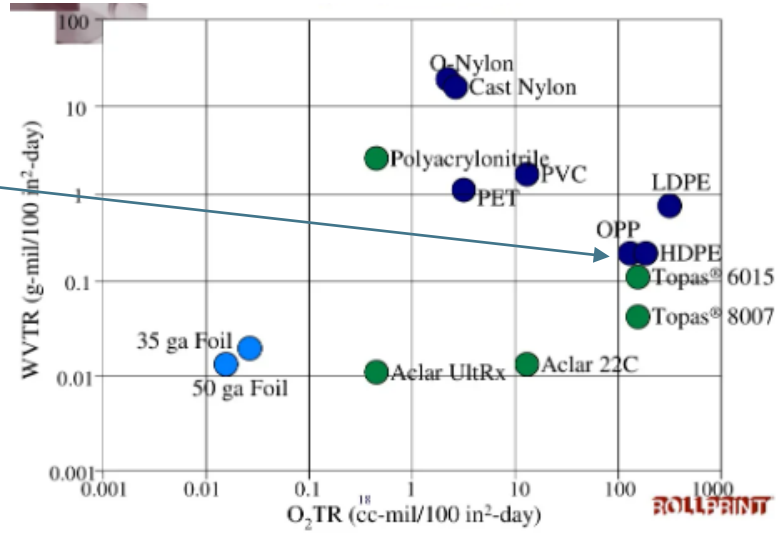
- Battery boxes with mechanical fasteners can be opened with a wrench, while polymer direct bonding would require specialized heating tools



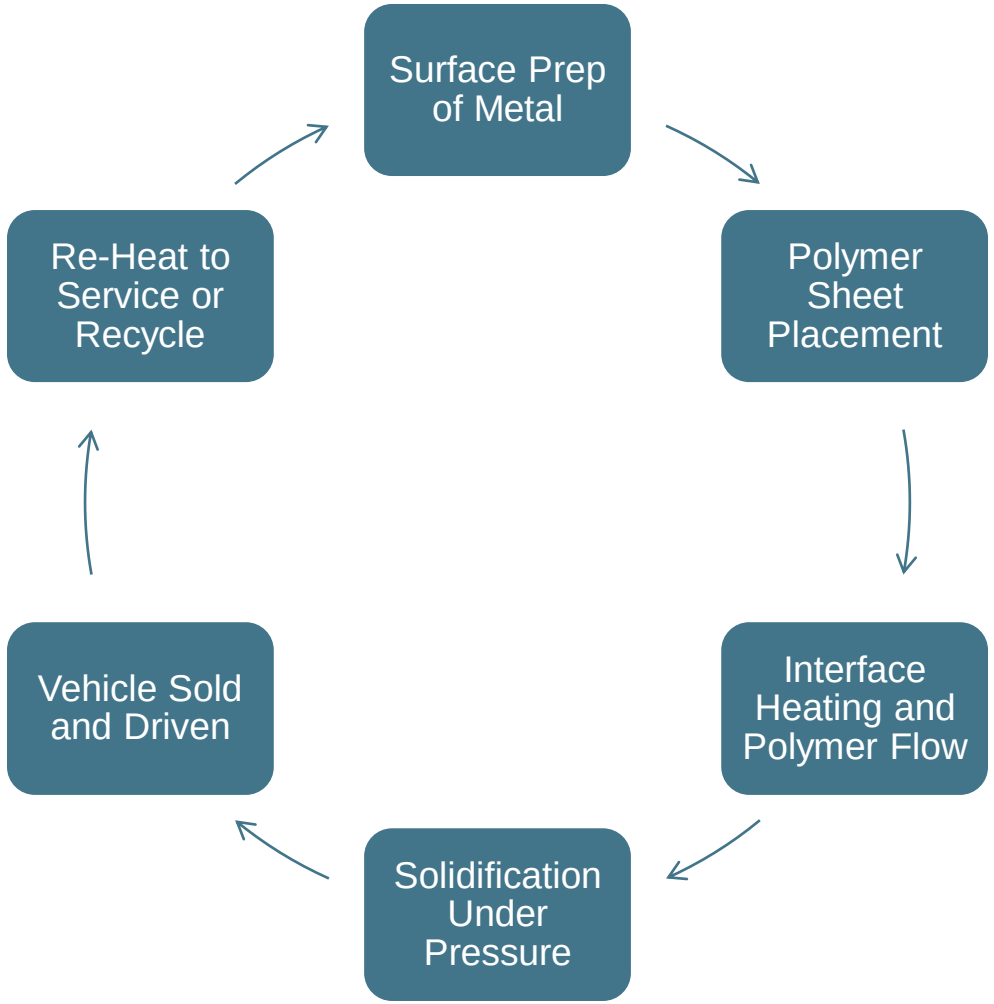
Battery Box Requirements

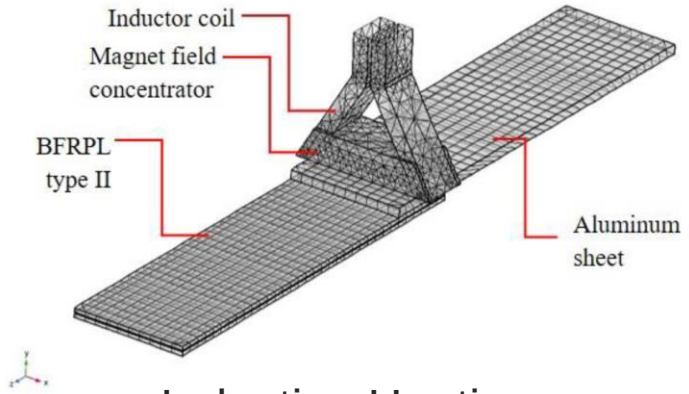
Requirement	Polymer-based Cover
Non-conductive seal, battery box to cover	Polymers are inherently good insulators
Low flammability rating (UL-94)	Many polymers (e.g., PEI, PES, PEEK) have good flame-resistant properties, while other commodity polymers (e.g., PP, PA6, PC) can be filled with additives to allow them to meet the requirements
Liquid and gas tight sealing	Polymers are a good barrier to liquid, and some are also a good barrier to humidity (e.g., HDPE)
Serviceable – cover removable from battery box	Thermoplastics can be repeatedly melted to make and break bonds for serviceability
Electrical Shielding (ESD, EMI, RFI)	Conductive additives can be added to polymers to meet these requirements

Neat vs Flame Retardant



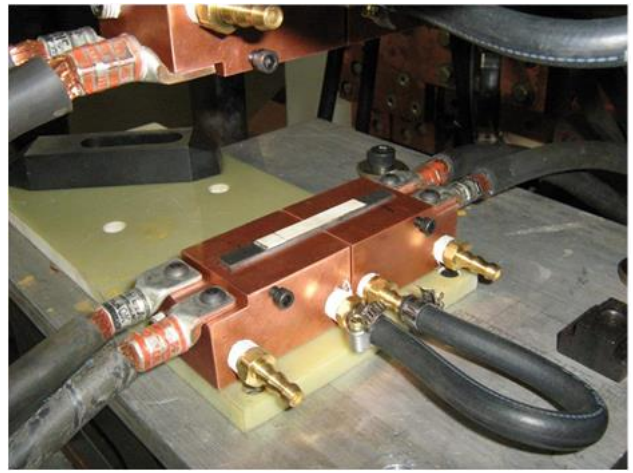
Joining Methods



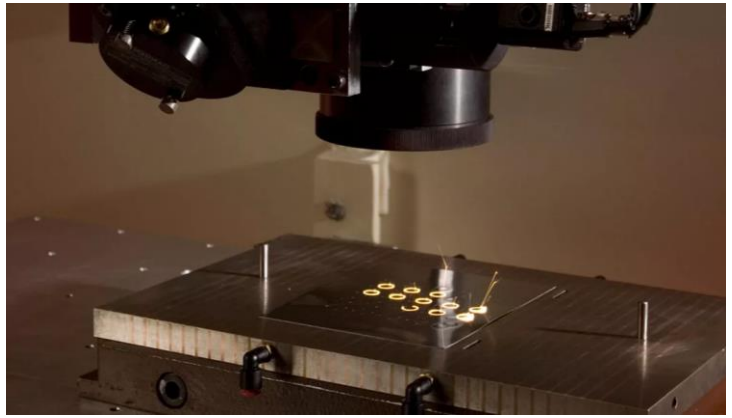


Induction Heating

J. Compos Sci. 2021, 5(1), 10



Resistance Heating



Through-Transmission Laser Heating

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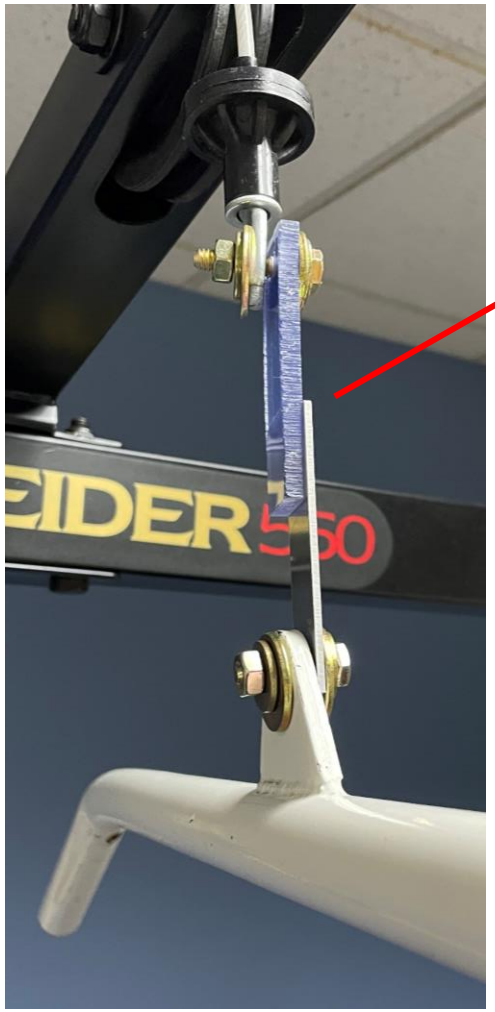
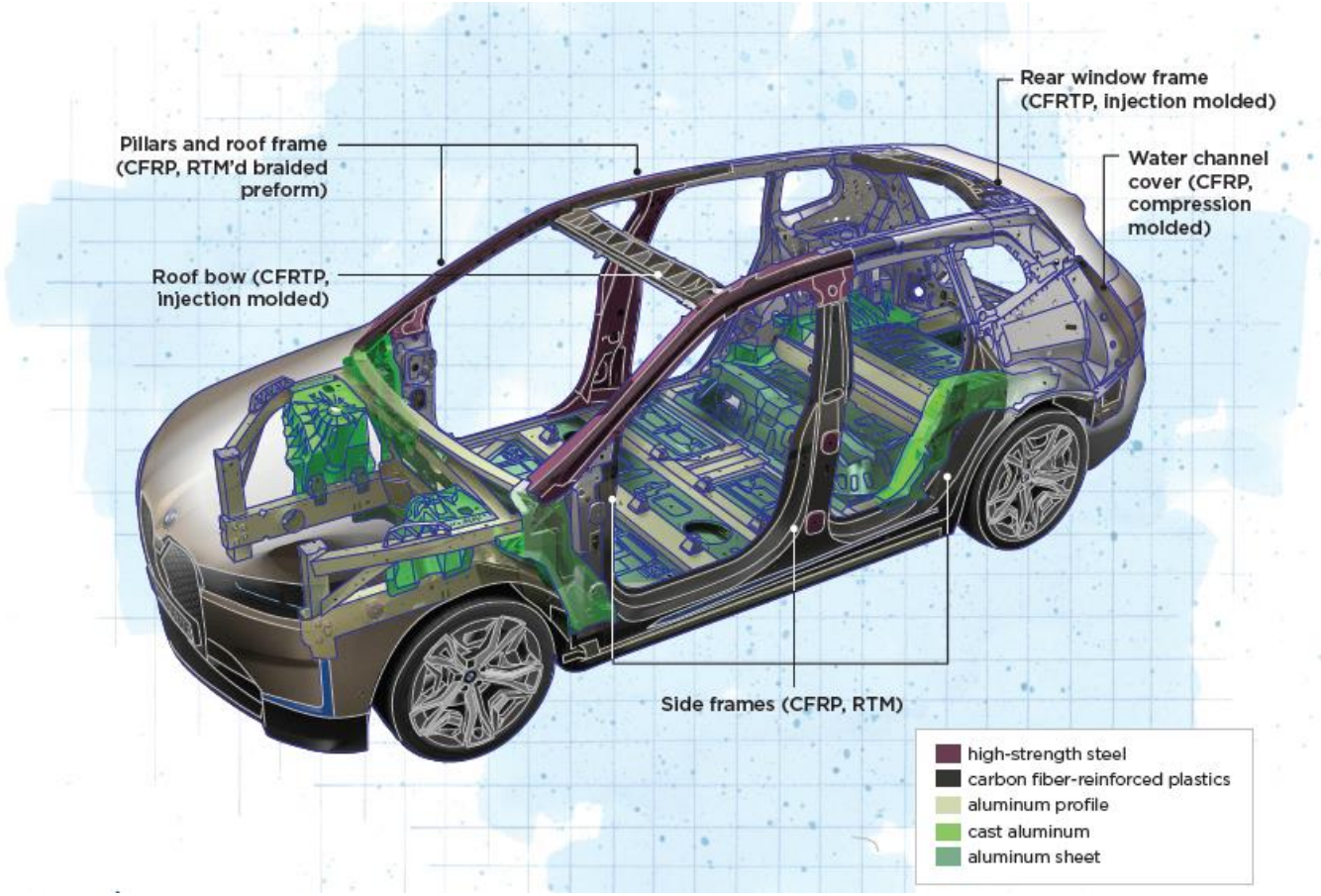
Polymer to Metal

- Aluminum 5052 – laser ablated
- PVC
- 1-in area joined with laser heating
- Thermally cycled from 65°C to 0°C
- Soaked in water
- Strong enough to hold my weight
  - Actually, they hold ~1000 lbs



Thermoplastic Composite Welding

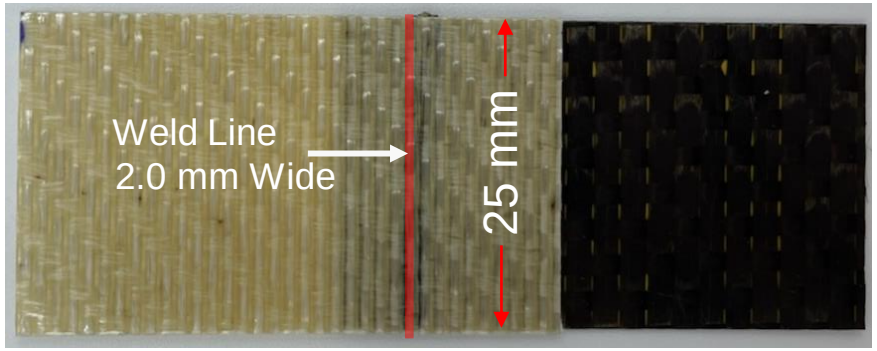
Carbon Fiber Reinforced Thermoplastic (CFRTP)



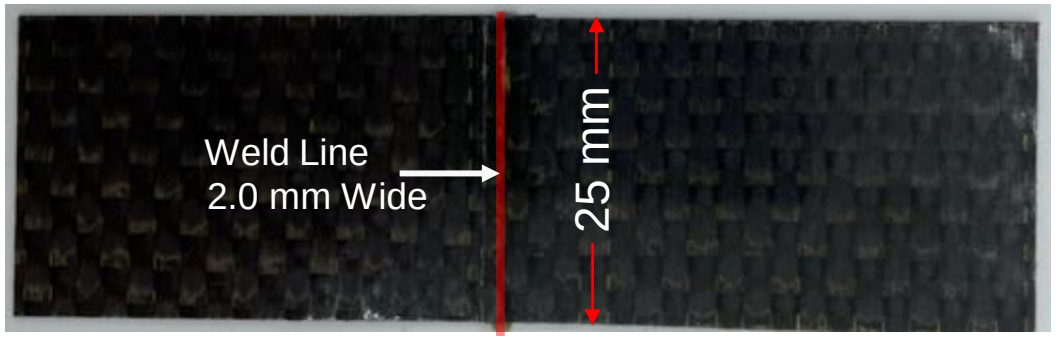
https://www.compositesworld.com/articles/bmw-rolls-out-multi-material-carbon-cage-with-2022-ix-vehicle-line

Welding

- Leister Novolas WS-AT Welder
- Diode Laser module 200 W 975 nm wavelength
- Linear velocity up to 750 mm/min
- Compaction pressure up to 100 psi
- Pyrometer measured the temperature on the top surface to regulate the power during welding



Lap Weld

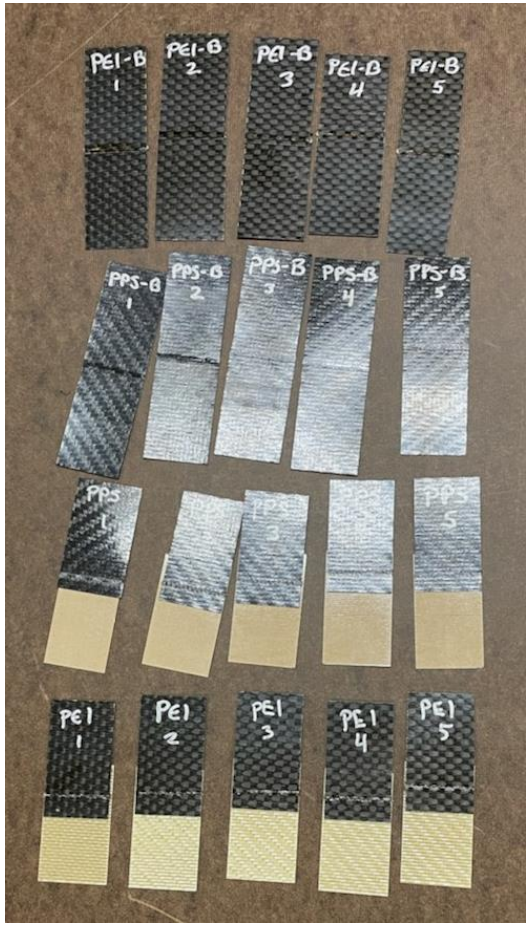


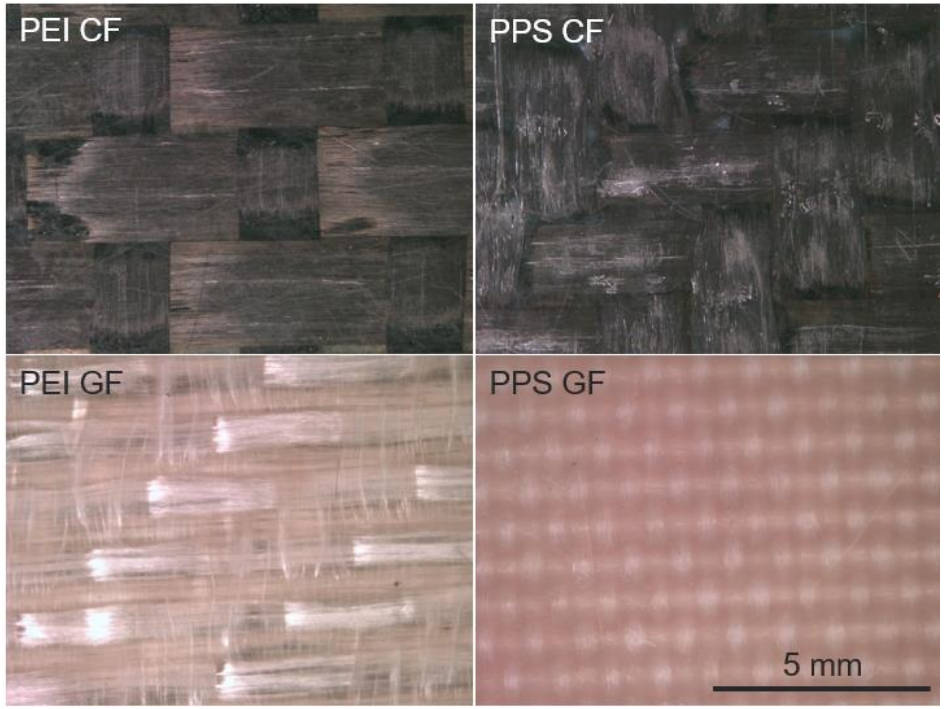
Butt Weld

Welded Ensigner Samples

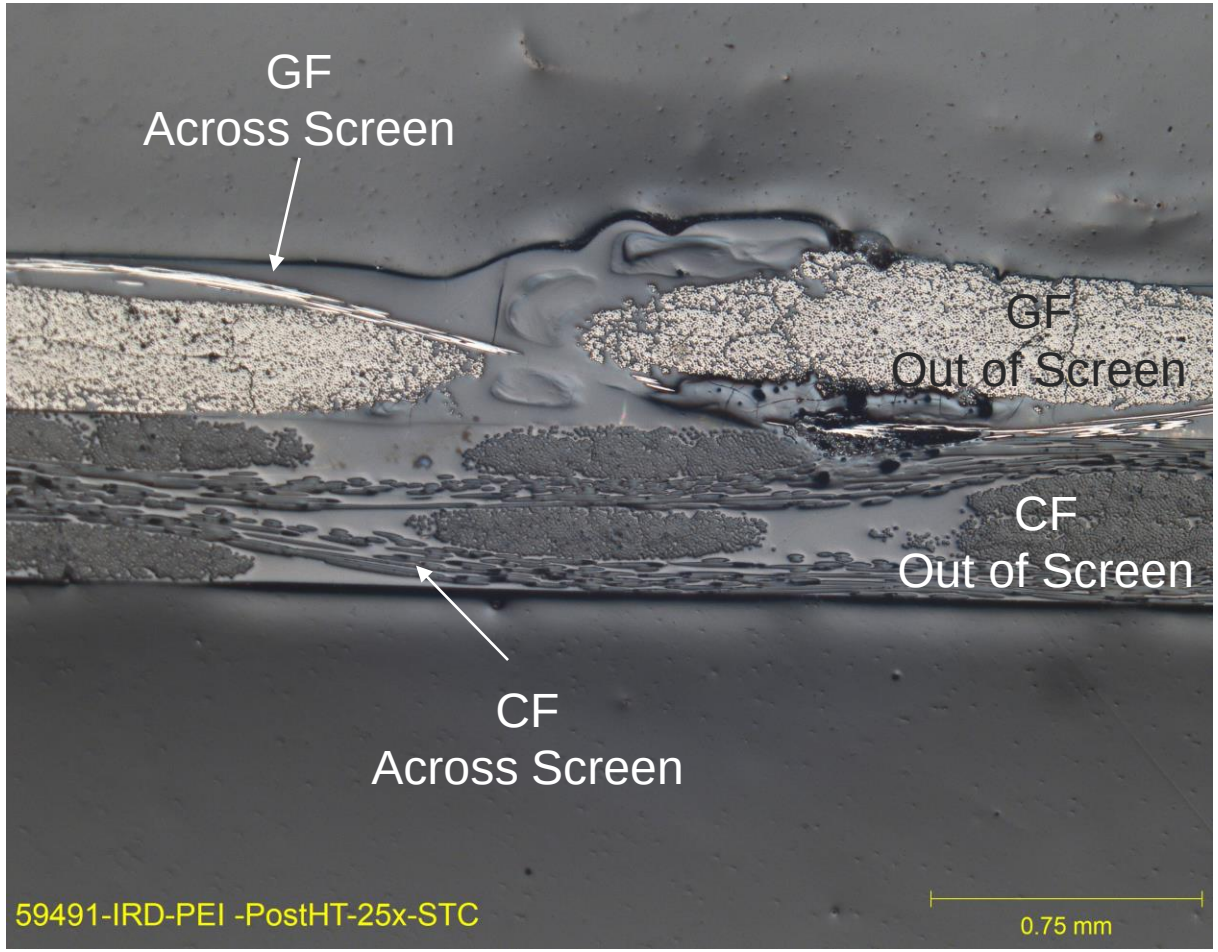
- Butt Welds (nearly edge to edge)
- Overlap Welds (1 inch overlap)

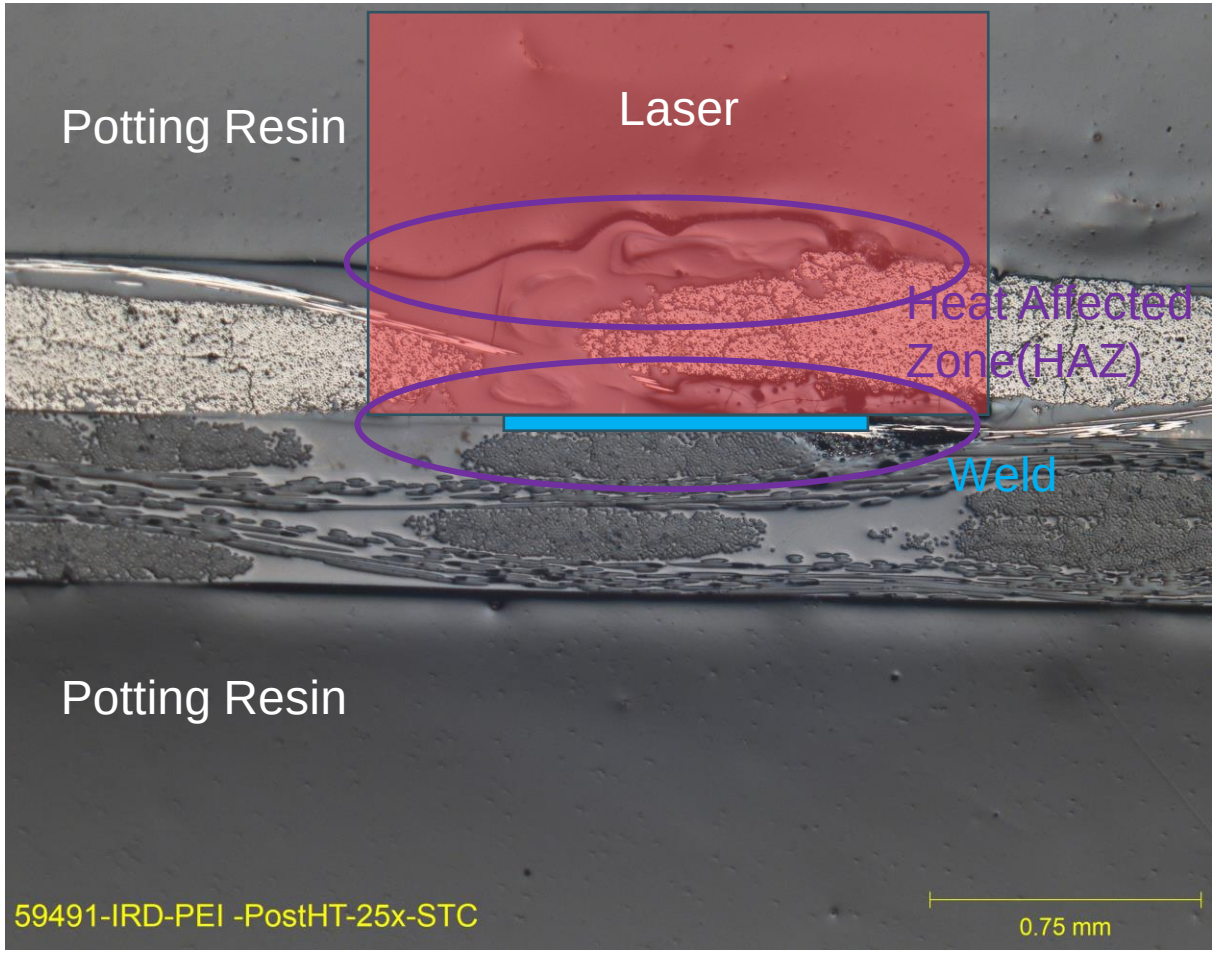
- CF = carbon fiber
- GF = glass fiber



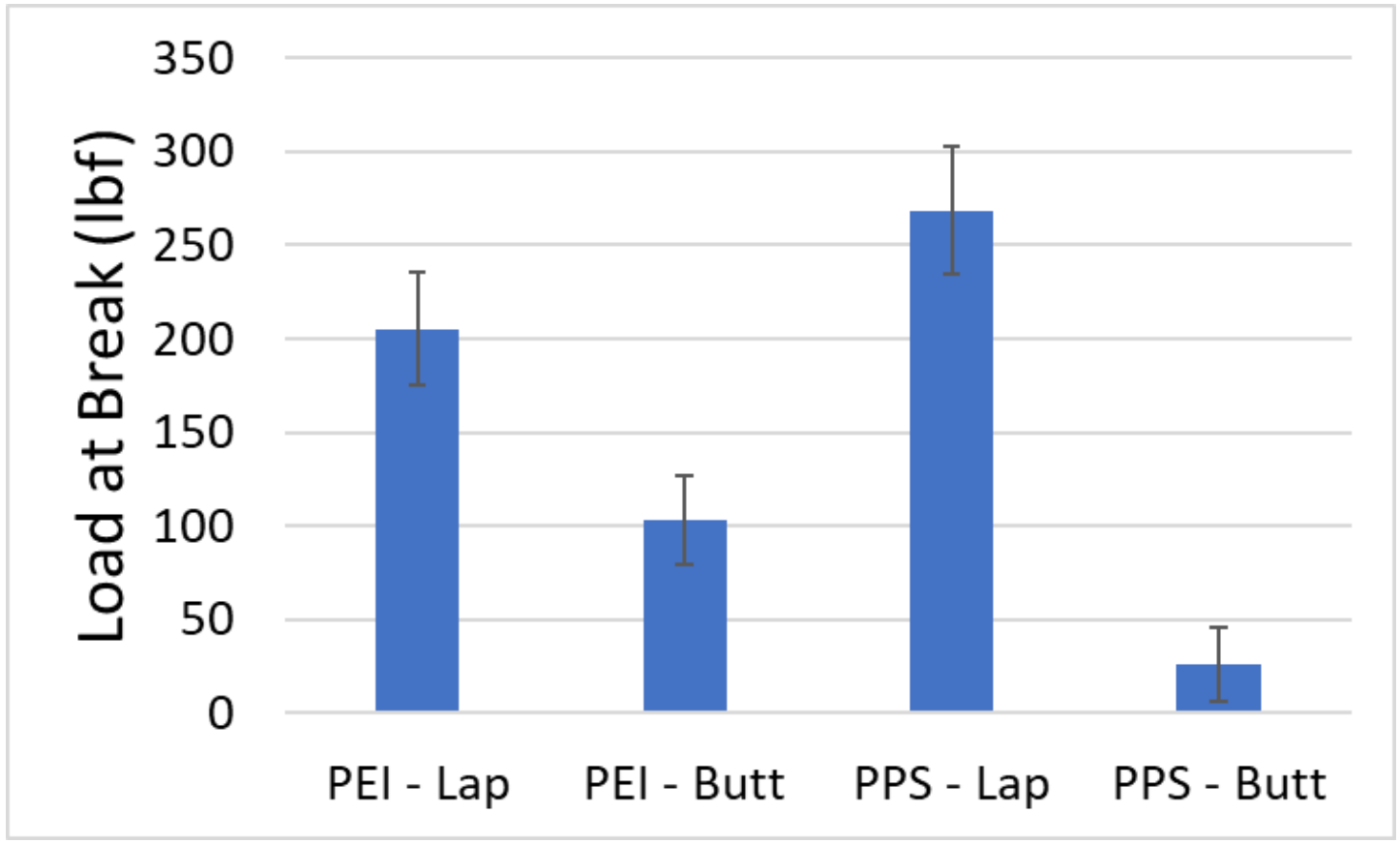


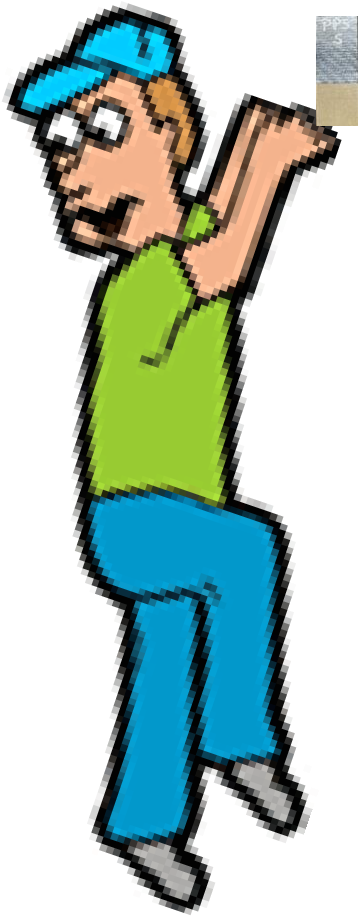
Cross-Section of Lap Shear Specimen - PEI





Lap Shear Strength

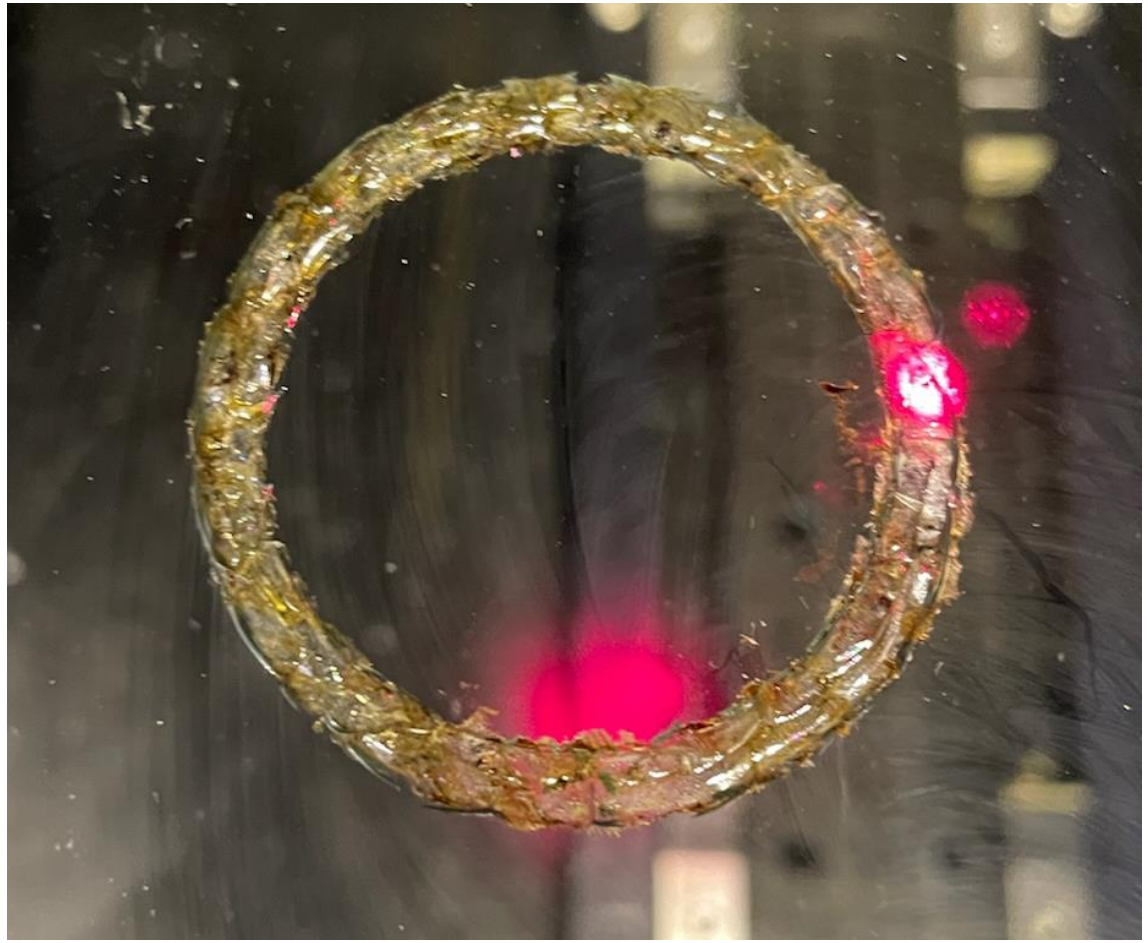




25.4 x 2.0 mm weld is strong enough to hold a person and has a shear strength of up to 24 MPa

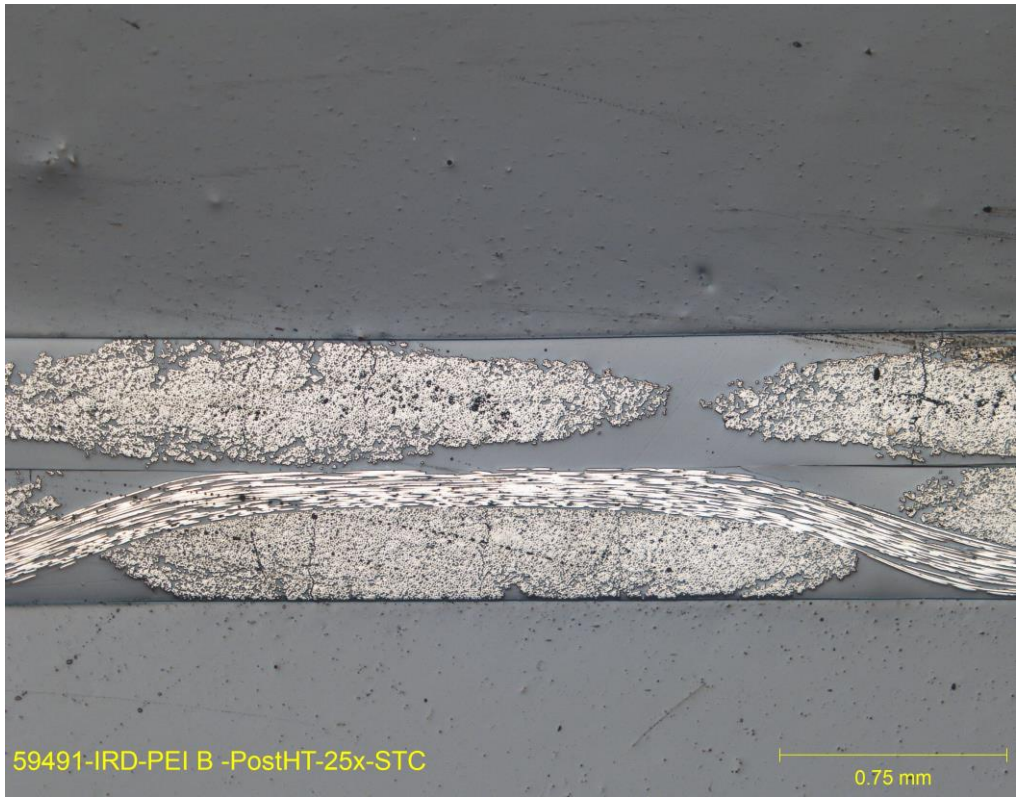
Opportunities

- Carbon filled PEI welded to glass when the power was increased.
- New applications for window seals



Conclusions

- There are many ways to join materials without adhesives or mechanical fasteners
- Direct polymer to metal joining could be a game changer for battery box manufacturing
- EWI has joined continuous fiber filled Nylon, PEI, and PPS composites using through transmission laser welding to yield **strong, lightweight, durable joints.**



Carbon fiber filled PEI welded to itself

Thank You!

JEFF ELLIS, PHD
Senior Technology Leader
JELLIS@EWI.ORG
614.688.5114

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