TWI Seminar:
Recent Advances in Composite Technology at TWI
Asuka Conference Room No.303C
Dia-Yaesu-Guchi Building, Yaesu 2-2-1, Chuo-Ku, Tokyo

19 November 2013

09:45 – 10:00	**Coffee/Registration**	
10:00 – 10:05	Welcome and introductory remarks	T Fukuda, UKD
10:05 – 10:20	Introduction to TWI Services	F Delany
10:20 – 10:40	TWI activities on Adhesives, Composites and Sealants	A Kapadia
10: 40 – 11:00	Overview of Composite Joining Technologies	A. Kapadia
11:00 – 11:10	**Coffee/tea**	
11:10 – 11:40	Introduction to Thermoplastic Composites	C Worrall
11:40 – 12:00	Thermoplastics Composites Joining	C Worrall
12:00 – 12:20	Joining Innovations at TWI in Thermoplastic Composites	C Worrall
12:20 – 12:30	Discussion	
12:30 – 13:30	**Lunch**	

An Introduction to TWI

Fred Delany

TWI
Technology
Engineering

Our Expertise

- Joining and welding processes
- Structural performance
- Materials engineering
- Corrosion management
- Modelling/simulation
- Inspection
- Quality and safety
- Surface engineering

TWI Technology Engineering

TWI in 2013

- £80m of R&D in materials joining and related technologies
- 700 Members operating in over 4500 locations worldwide
- More than 800 staff

TWI Technology Engineering

UK Network

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Global Network

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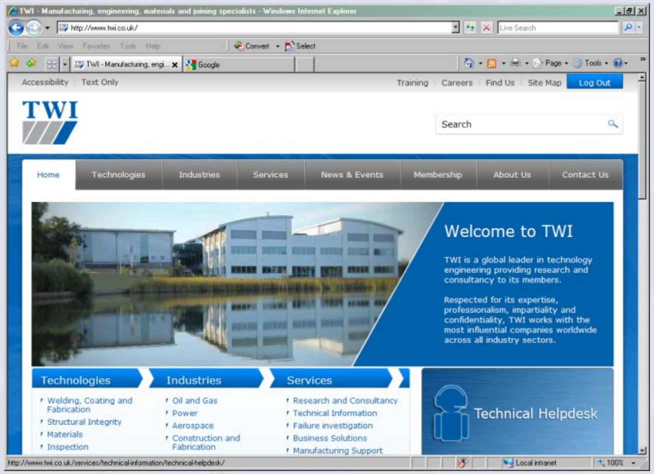
Benefits for Members

- Technical helpdesk
- Confidential R&D projects
- Detailed technical discussions
- Access to Core Research Reports
- Access to online technical information
- Discount on training courses
- Networking opportunities
- Help to reduce organisational risk

TWI Technology Engineering

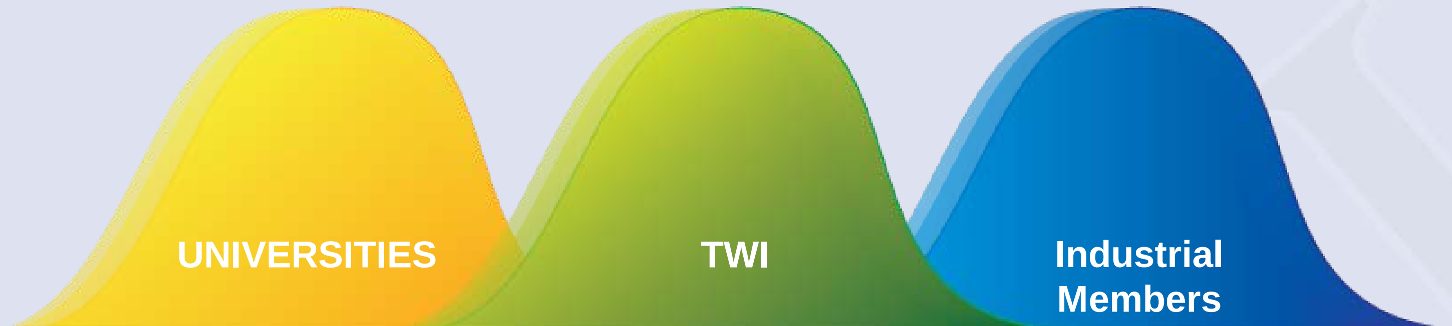
Providing Information

- Our website
  - Direct access to TWI’s expertise via ‘Who Knows’
- Best practice guides
- Industrial Member Reports
- Published papers
- More than 1,000 FAQs
- Knowledge summaries
- Weldasearch



Technology Engineering

Technology Readiness Level



TRL / MCRL SCALE	1	2	3	4	5	6	7	8	9
	UNIVERSITIES			TWI			BUSINESS		
	Basic Idea	Concept Developed	Experimentl Proof of Concept	Process Validated in Laboratory	Process Validated on Production Equipment	Process Capability Validated on Production Equipment	Capability Validated on Economic Runs	Capability Validated over Range of Parts	Capability Validated on Full Range of Parts over Long Periods

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Services we Provide

- Research and development
  - Single Client Projects
  - Group Sponsored Projects
  - Collaborative Programmes
  - Core Research Programme
- Consultancy
  - Design, materials, inspection, performance testing
  - Technology evaluation
  - Manufacturing
  - Surface engineering
  - Fabrication and repair
- Failure investigations
- Technology transfer
- Training and certification
- Software

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Why TWI?

- Scientific reputation since 1946
- Main source of technical information
- Strict independence
- Ensured confidentiality
- Track record of innovations
- Multi sector international networking opportunities
- We have Members not Shareholders

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Adhesives, Composites and Sealants Group

Ajay Kapadia

Section Manager

Adhesives, Composites and Sealants

Technology
Engineering

TWI Capabilities and Expertise

- Materials Selection, Design and Modelling
- Processing
- Repair
- Joining
- NDT and inspection
- Added functionality – Coatings
- Training
- Testing
- Failure Analysis
- Network Management – Materials KTN

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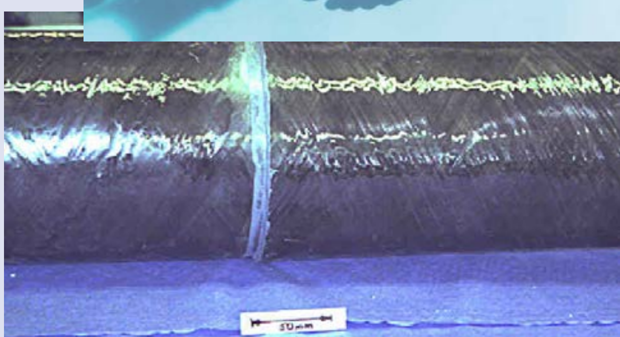
Industry sectors



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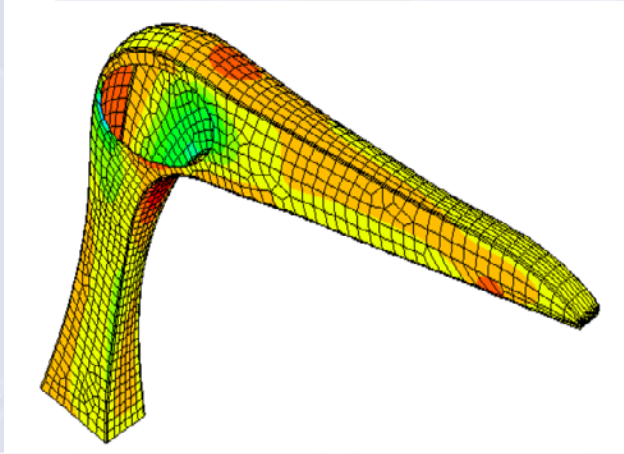
Materials Selection, Design and Modelling

- Knowledge of properties, uses and processing of:
  - Fibres (Carbon, Glass, Aramid, ….)
  - Resins (Epoxy, Vinyl and polyester, phenolic, …)
- Design:
  - In house FEA capability using ABAQUS
  - Ability to:
    - optimise lay up for weight and cost saving
    - Run test scenarios to optimise process



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Processing

- Standard composite processing equipment at TWI:
  - -18°C 428 ltr Chest Freezer (Adcock Refrigeration)
  - 225°C Air Circulation Oven 1220 x 1220 x 1220mm (Hedinair Ovens)
  - Filto-bench - Dust Extraction Bench 1900 x 1000 x 900mm (Horizon Int.)
  - Smog-Mobile - Mobile Air Filter (Horizon Int.)
  - Digital Vacuum Oven (Euro Tech)
  - Welch Dry Piston Pump (Euro Tech)
  - Dual Zone Hot Bonder (Aeroform)
  - Vacuum Resin Infusion kits

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Rapid Processing - Microwave

- Rapid processing through novel microwave processing
- Heats part not oven
- Saves energy and reduces cycle times
- Better control of heat transfer and exotherm
- Novel design enables metal tooling
- Can be modularised

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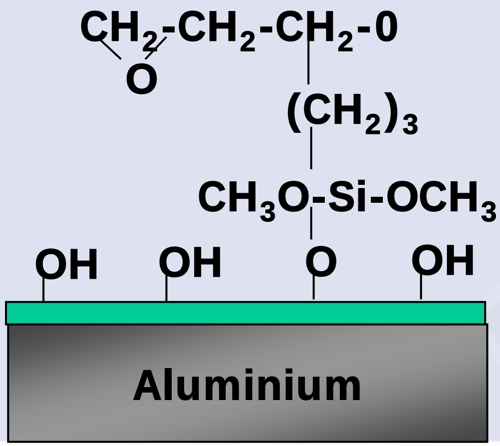
Repair

- Composite on metal and composite on composite
- Expertise in:
  - Damage detection through NDT
  - Surface preparation and damage removal techniques
  - Characterisation of surface after preparation (FTIR and Contact Angle)
  - Repair application, cure and NDT



Joining - Thermosets

- **Expertise in:**
  - **Composite on metal and composite on composite**
  - **Surface preparation – materials and process**
  - **Surface cleanliness and energy evaluation**
  - **Material selection – adhesives films**
  - **Joining through:**
    - Co curing
    - Bonding
  - **Training**
  - **NDT – quality of joining - kissing bond detection (under investigation)**

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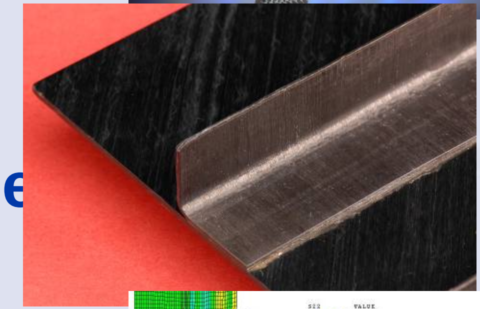
Joining -Thermoplastic

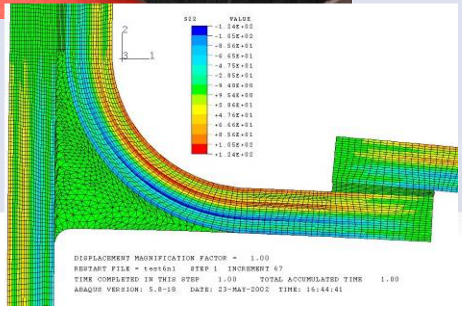
- **Twintex Welding**

- **Advanced aerospace materials**

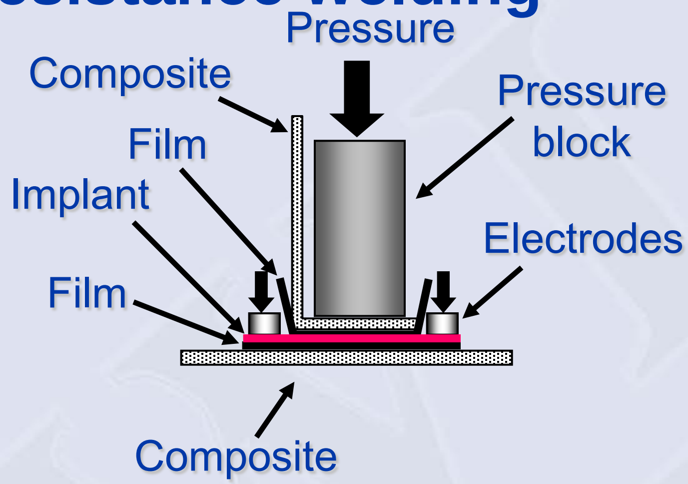
- **PEEK resistance welding**



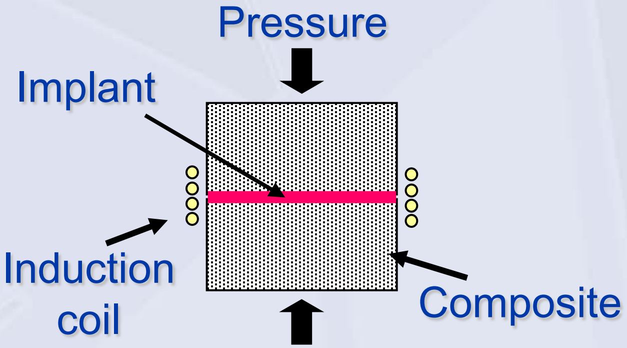
- **Modelling**



Resistance welding



Induction welding



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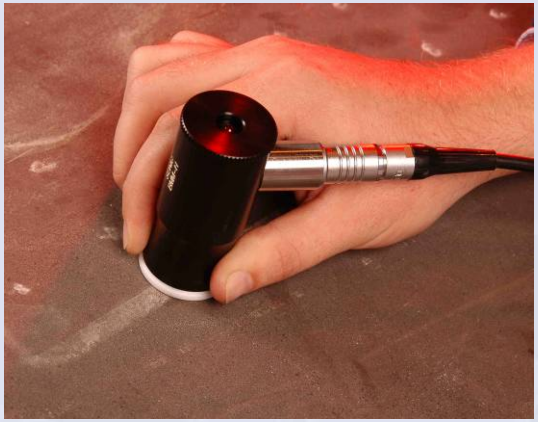
NDT and Inspection

- TWI Expertise in:
  - Ultrasonic
    (Including phased array)
  - Laser shearography
  - Thermography
  - Computed tomography
  - Automatic detection of defects



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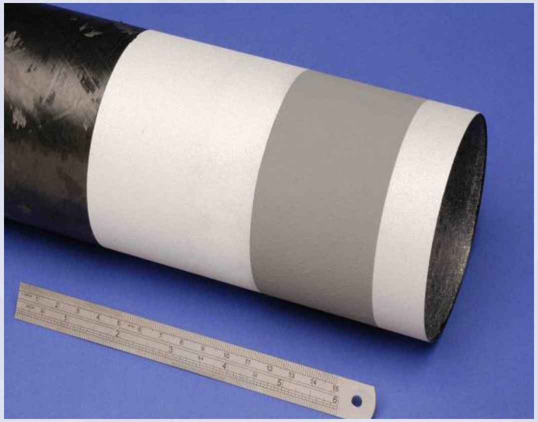
Added Functionality - Coatings

- An example of the use of coatings:

- De icing systems
- Electromagnetic screening
- Thermal barrier
- Heat reflective
- Lightning strike protection



- Applied to composite by spraying

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Composites Training

- **TWI Offers the following Composites Courses**
  - **1 and 5 Day Introduction to Composites**
    - Material selection and properties (fibre, resin, cores), layup and orientation and manufacturing process selection
  - **1 Day Repair of Composites**
    - Damage detection, techniques for cutting out damage, material selection for repair, lay up, cure and inspection

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Composites Testing

- **TWI capability in:**
  - **Large-scale – pipe, plate, can do custom testing**
  - **Impact – up to 50KJ**
  - **Static:**
    - Load: 0.5kN to 1750kN,
    - Temp: -196°C to +400°C
  - **Fatigue – numerous machines 10kN to 1000kN**

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Failure Analysis

- Full complement analysis equipment:
  - SEM
  - Chemical Laboratory
- Material Science expertise
- Can recreate scenarios for testing and validation
- Expert Witness work undertaken

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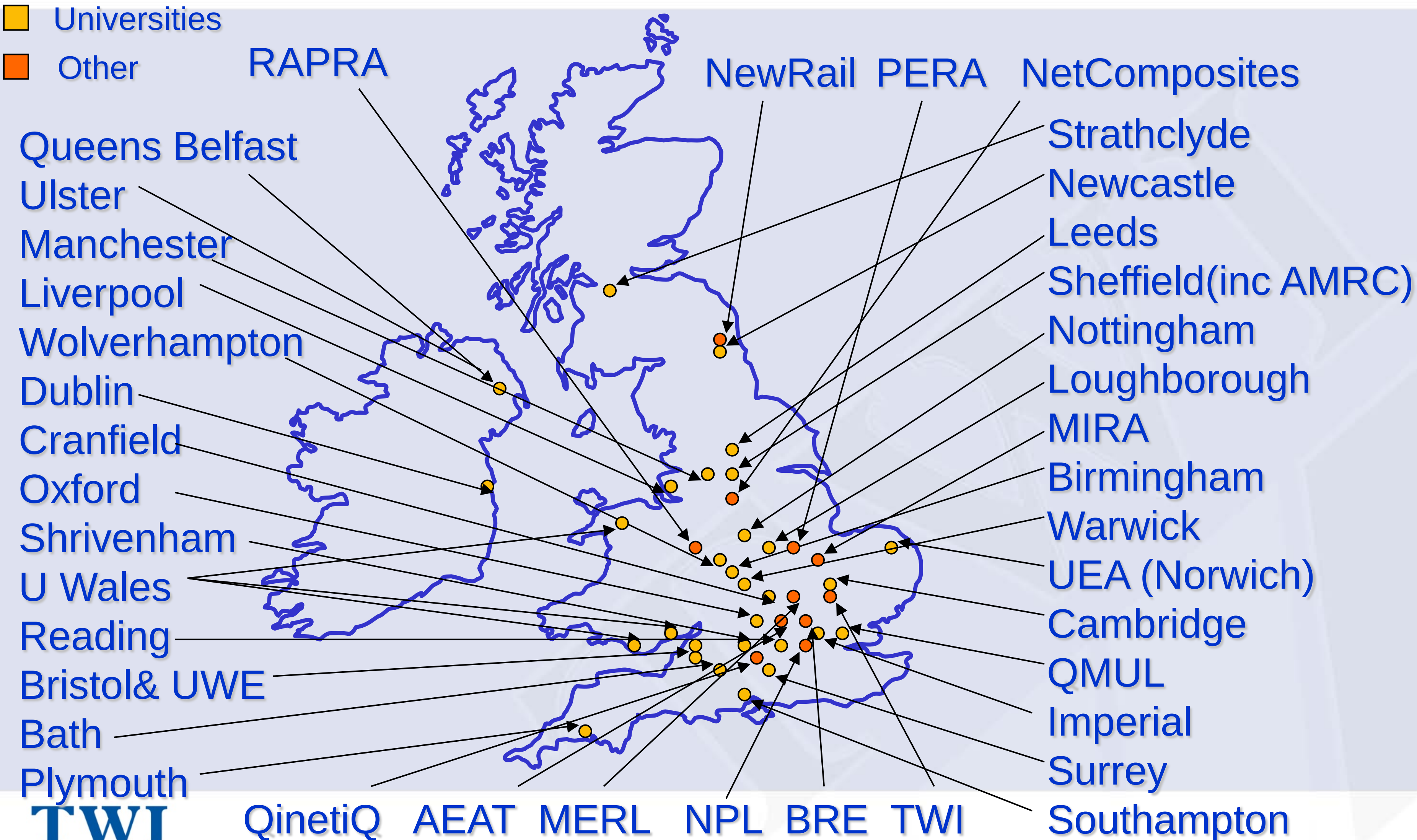
Materials KTN

- Composites delivered by NCN via TWI Ltd
- Brings together the materials supply chain to improve industrial innovation and the global competitiveness of UK business
- Delivers the key themes of the TSB Advanced Materials Strategy by:
  - News and advice on research and funding
  - Technology and strategy reports
  - Events organisation and netyworking opportunities
  - Signposting to the right facilities and people
  - Finding partners for projects

UK Composites R&D Capability



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Conclusions

- TWI can help you in a number of ways with composite materials
- From the initial stages of design and materials selection, processing & manufacture, testing (large and small), inspection and through using our Network of experts and Centres
- Give TWI a try to get you the best composite for you

Thank you for listening.

I welcome your questions

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Overview of Composites Joining Techniques

Ajay Kapadia

Section Manager

Adhesives, Composites and Sealants

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Contents

- Thermoset Composites
  - Adhesive Bonding
  - Mechanical Fastening
- Thermoplastic Composites
  - Welding/Fusion Bonding
  - Mechanical Fastening
- Metal to Thermoset Composites
  - Comeld
  - Adhesive Bonding and Co curing

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Contents (Continued)

- Metal to Thermoplastic Composites
  - PCM
- Metal Surface Pre-treatment
  - Wet Processes
  - Plasma
- Surface Assessment
- Non Destructive Examination

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Thermoset Composites – Adhesive Bonding

- Types of Adhesive
  - Film Adhesives – tight tolerances e.g. Epoxy
  - Paste Adhesive – gap filling
- Temperature
  - Heat Cure
  - Room Temperature Cure
  - Post Cure
- Pressure
- Surface Pre treatment
  - Peel ply
  - Abrade

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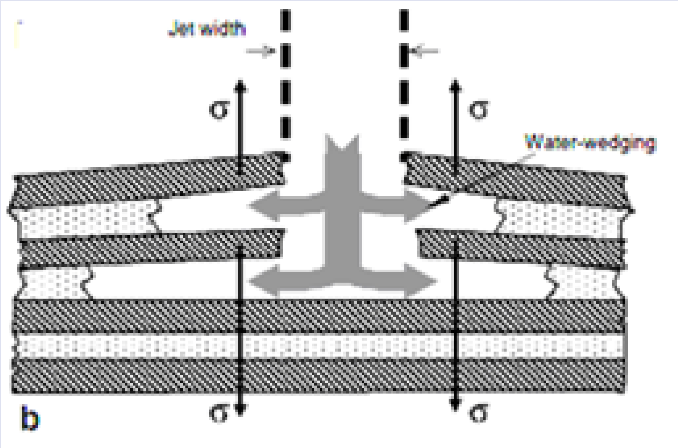
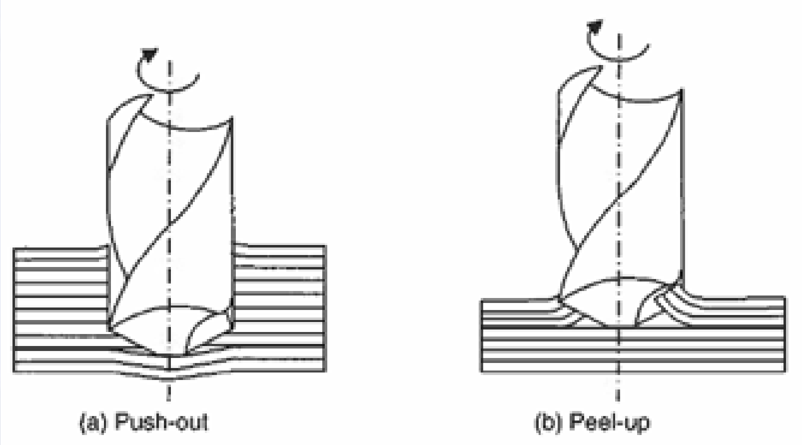
Thermoset Composites
- Machining for Mechanical Fastening

- Machining Techniques
  - Mechanical – drilling
  - Orbital drilling
  - Abrasive water jet
  - Laser
  - Water jet guided laser
  - Electrical discharge
  - Ultrasonic





Thermoplastic Composites – Welding/Fusion Bonding

- **Heating joint interface**
- **Common techniques**
  - **Induction**
  - **Ultrasonic**
  - **Resistance**
- **TWI SCRIM technology**

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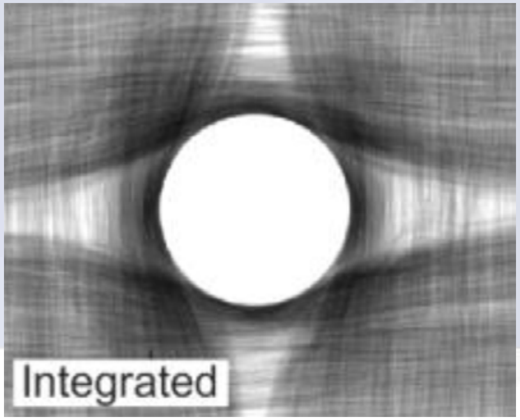
Thermoplastic Composites - Machining for Mechanical Fastening

- Thermoplastic composites allow for piercing
- Matrix can be heated to allow pin to be inserted
- Fibres move around pin rather than being cut
- Improvement in mechanical properties
- No carbon fibre dust from machining



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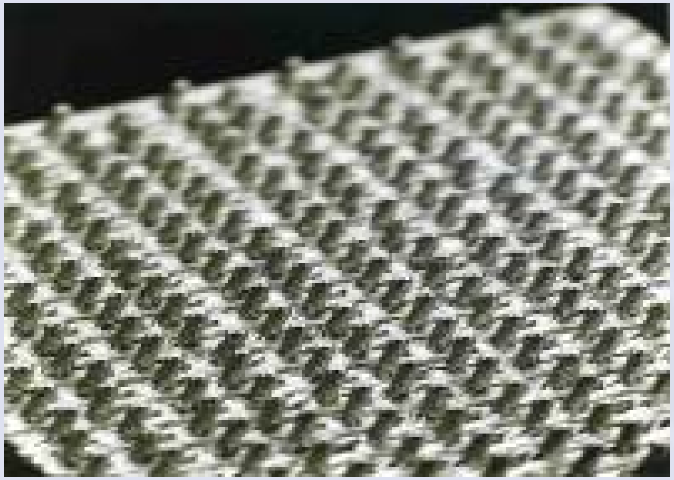
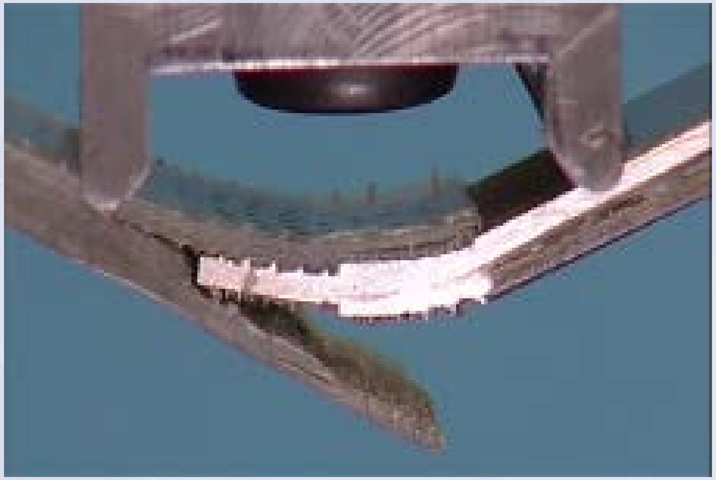
Metal to Thermoset Composites - Comeld

- Electron beam process provide texture for surfaces
- Composites laid up uncured and mechanical locked once cured





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Metal to Thermoset Composites Adhesive Bonding and Co Curing

- Bonding pre cured composite
- Co curing and simultaneous bonding
  - The adhesive properties of the polymer/resin are used to bond the composite onto the metal
  - The composite forms to the exact shape of the metal
  - Post cure is sometimes required to achieve maximum properties depending on the resin used
  - Bond line thickness is limited – can be increased using CSM (with poly/vinyl esters only)

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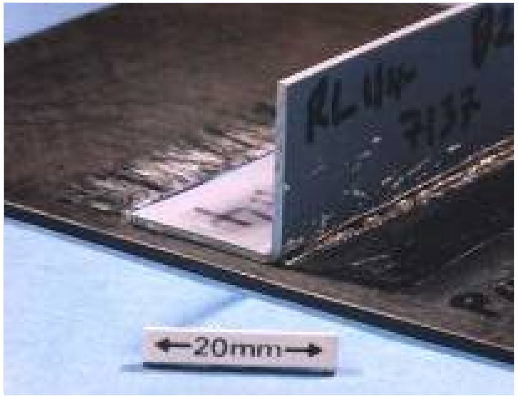
Metal to Thermoplastic Composites - Polymer Coated Material

- Join APC-2 (Carbon PEEK) L113 Aluminium Alloy
- Technique developed at TWI – “PCM Welding”
- European Patent EP0495 655B1 “Joining method”
- Involves coating dissimilar material components
- Then join using conventional thermoplastic welding
- Lap shear strength: ~30 MPa



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Metal Surface Pre-treatment
Wet Processes

SPM by FLP

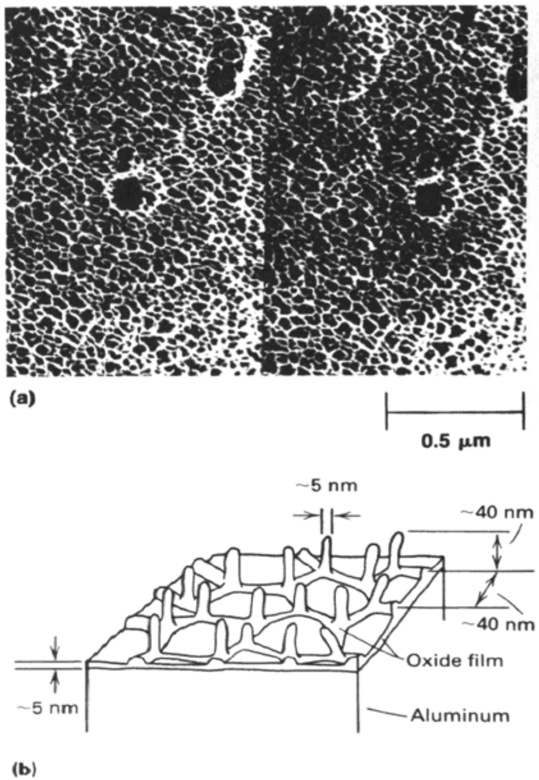

Fig. 1 FPL 2024 aluminum surface. (a) High-resolution stereo electron micrograph. (b) Isometric drawing

Phosphoric Acid Anodising

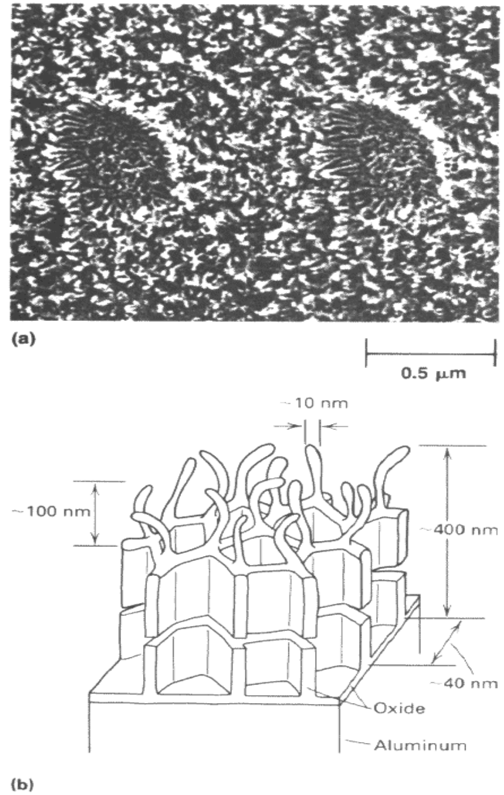

Fig. 2 PAA 2024 aluminum surface. (a) Stereo micrograph. (b) Isometric drawing

Chromic Acid Anodising

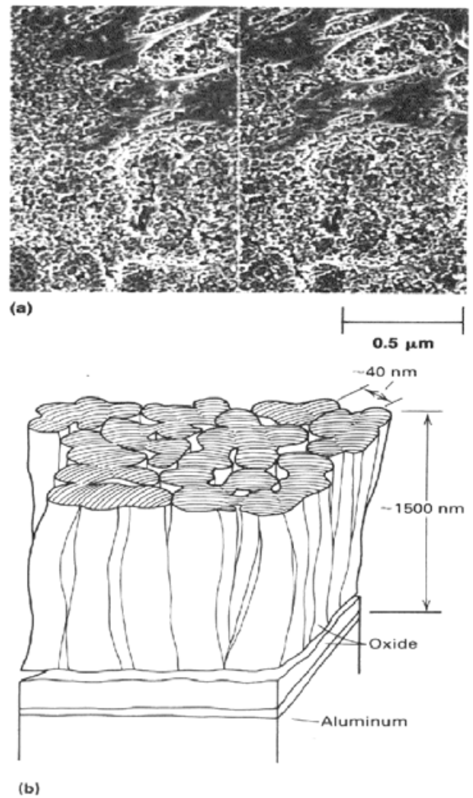

Fig. 3 CAA 2024 aluminum surface. (a) Stereo micrograph. (b) Isometric drawing

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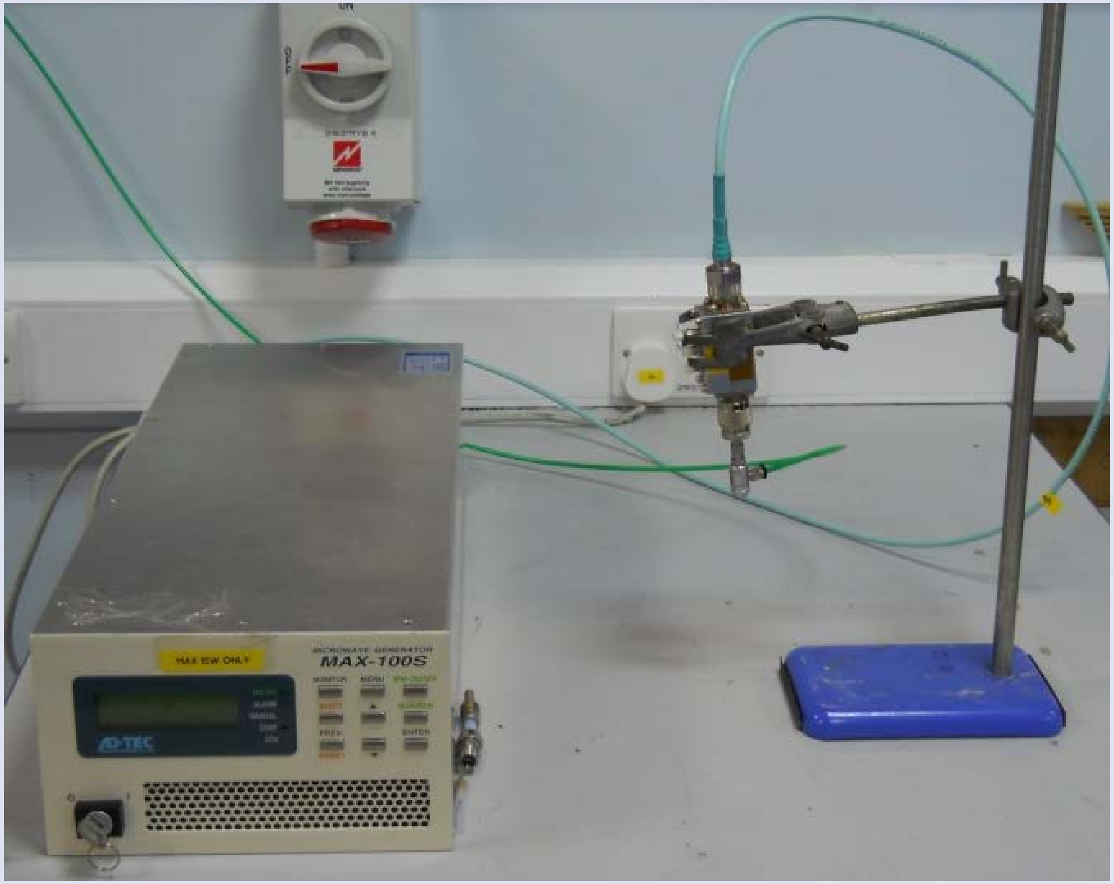
Metal Surface Pre-treatment Plasma

- **Increases surface energy and wettability**



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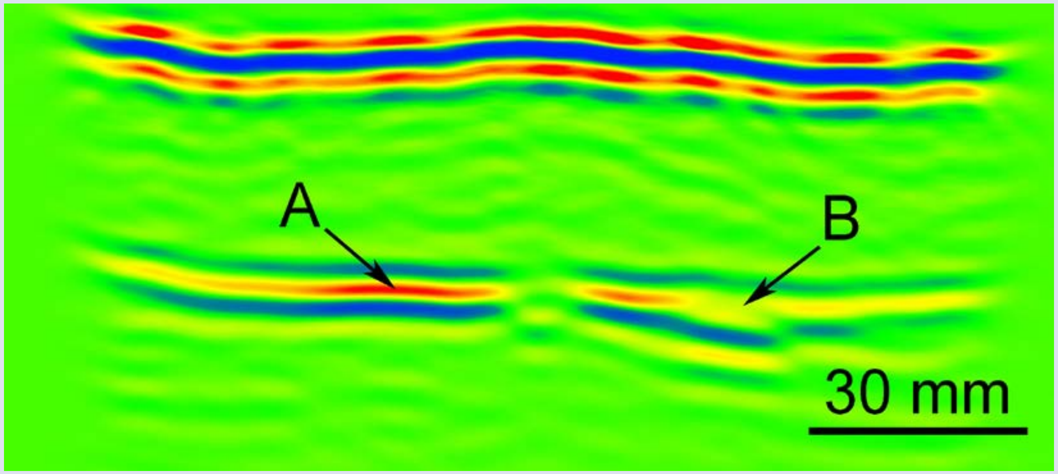
Surface Assessment

- Surface energy assessment
- Surface chemistry using FTIR

Contact Angle Analyser DSA100

Non Destructive Examination



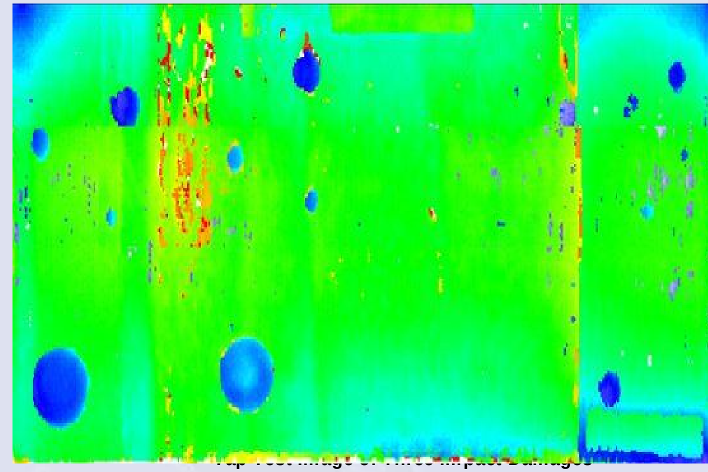
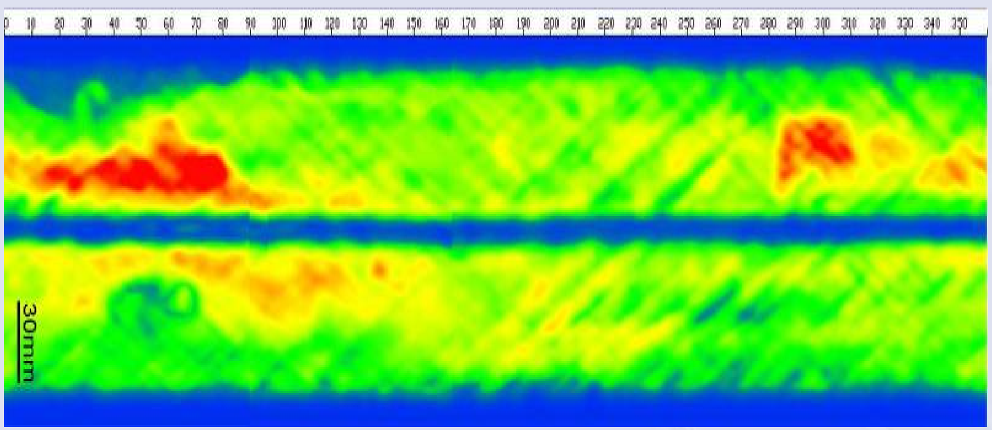
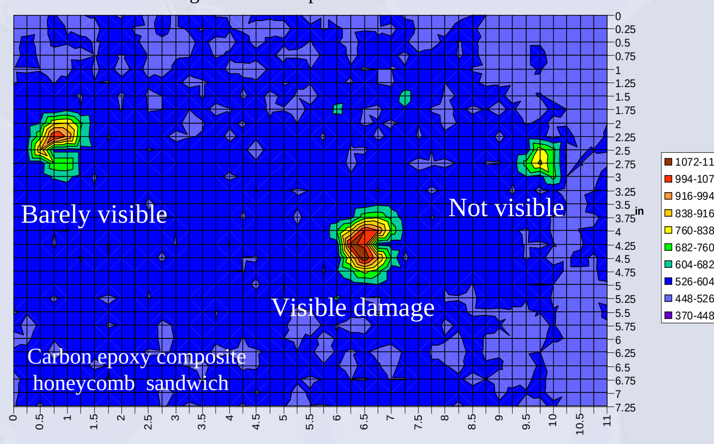


Image based on impact duration in microsceonds.





Specimen is carbon composite panel with 1” Nomex core. Tap test image generated with 1/4” tap spacing.

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Conclusions

- Joining of composites is a complex area
- Much overdesign exists due to lack of understanding
- Number of TWI technologies in joining composite materials to themselves and to other materials
- Best practice expert advice and validation also undertaken

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An Introduction to Thermoplastic Composites

Chris Worrall

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Thermoset & Thermoplastic

Thermosets:

- Strong primary chemical bonds (Covalent) between atoms in chain
- Strong secondary covalent bonds between molecular chains – Due to cross-linking
- Chemical cure reaction
- Cannot be reformed by heating
- Established materials

Thermoplastics:

- Strong primary chemical bonds (Covalent) between atoms in chain
- Weaker secondary bonds between chains that break down on heating causing softening
- No chemical cure reaction
- Can be reformed by heating
- New materials

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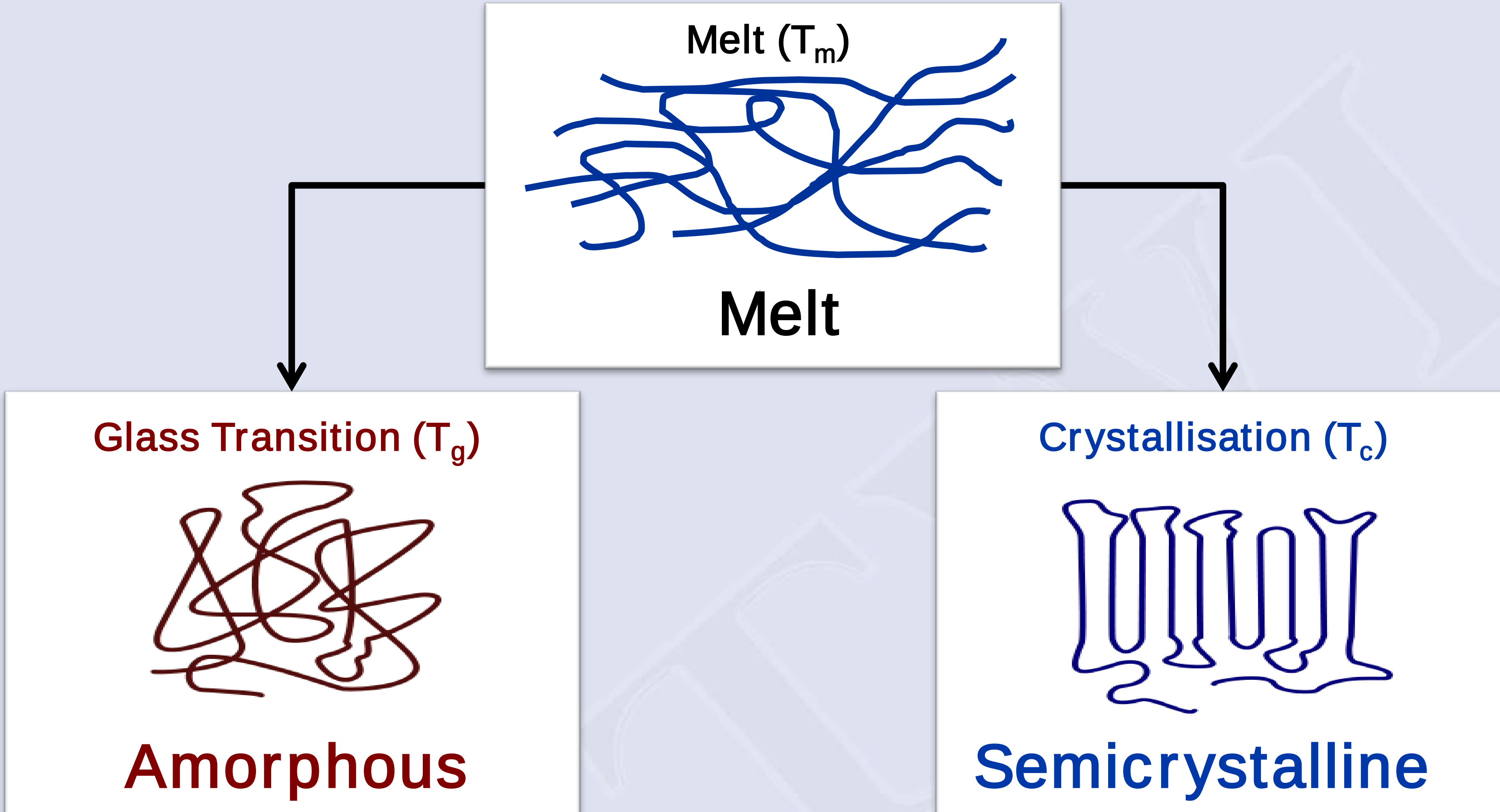
Polymer Structure and Temperature



Thermoplastics: Advantages

- Faster processing – minutes no hours
- Re-workability – possible recycling
- Room temperature storage - indefinite
- Greater damage tolerance
- Potential for higher temperature resistance
- Can be welded
- Low moisture uptake
- Low micro cracking
- Vibration damping
- Corrosion resistant
- Potential for low cost

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Thermoplastics: Disadvantages ☹

- High temperature and pressure processing
- Rapid processing may not be achieved
- Expensive processing equipment
- Expensive materials
- Limited material supply (limited choice)
- Prepreg processing more difficult
- Limited design database (new)
- Creep
- Difficult to bond

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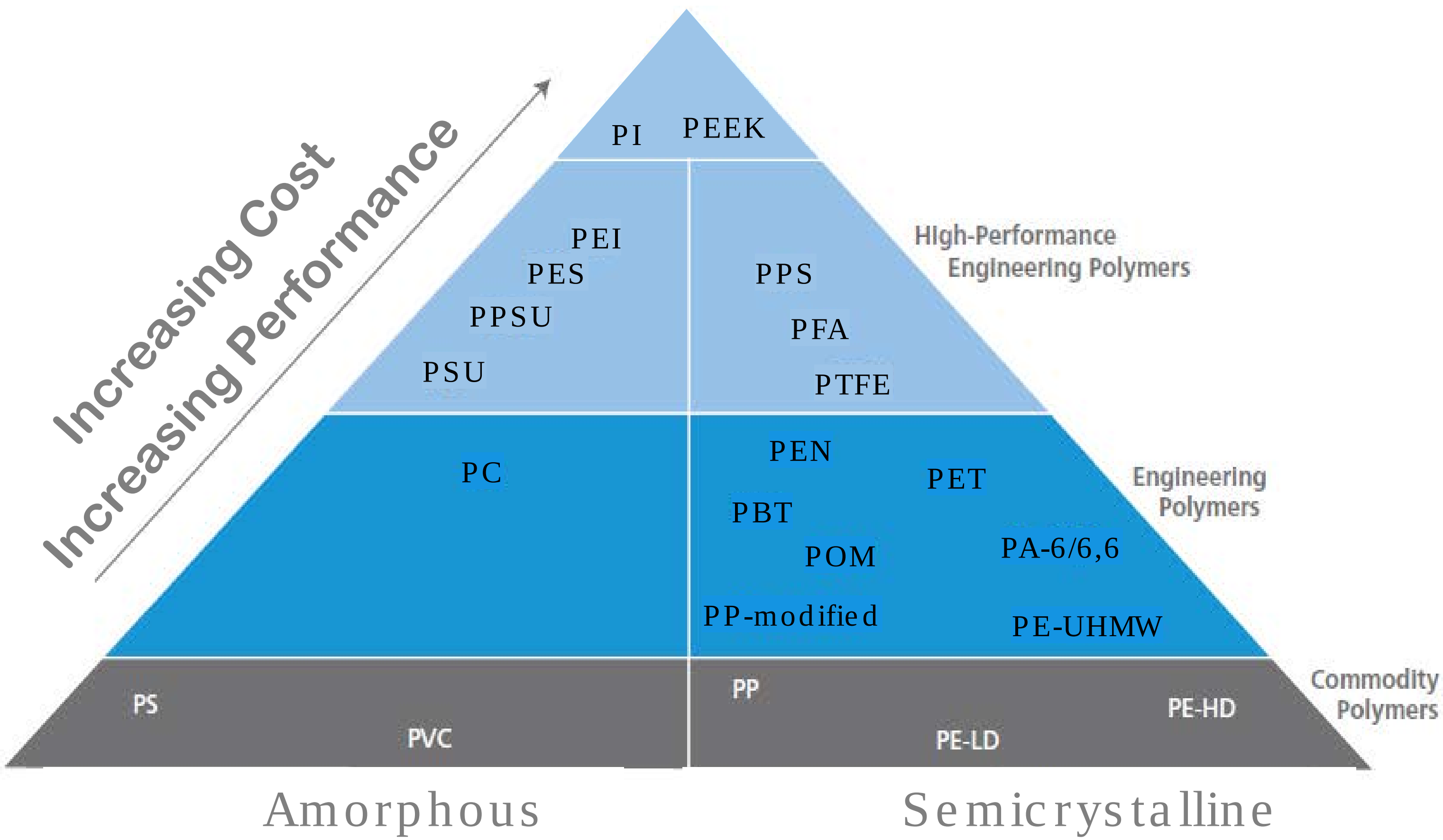
Polymer Pyramid



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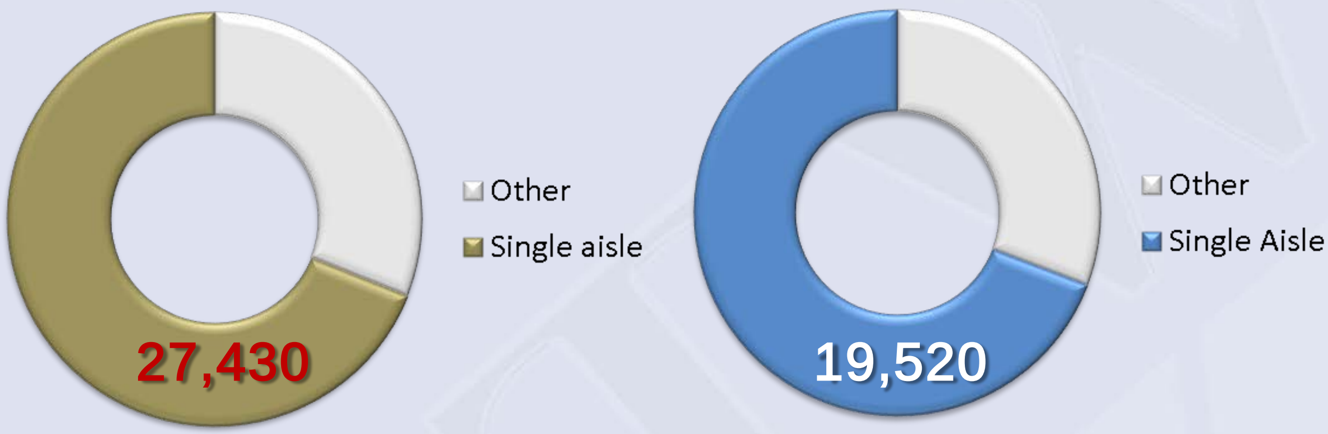
Driving Force for Thermoplastic Composites

- Single Aisle aircraft production expected >40/month
- Too rapid for thermosets (Autoclave)
- OOA solution required
- OOA thermosets – performance?
- Thermoplastics could be the answer



Boeing & Airbus 2031 Single Aisle Aircraft Forecast

Data from Airbus & Boeing, 2012

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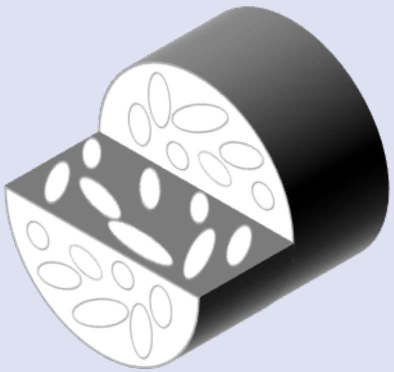
Driving Force for Thermoplastic Composites

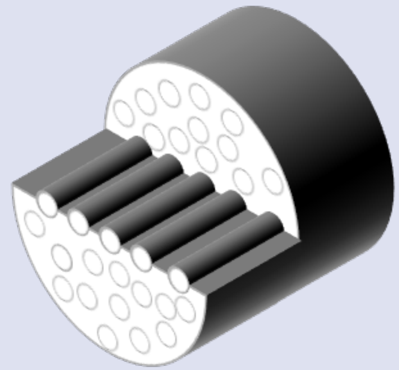
- Light weight automotive requirement (mpg)
- Production currently >10,000/year
- Require "Parts per Minute"!
- Not possible with thermosets (BMW?)
- Simple/complex geometry (Bonnet vs Chassis)
- Thermoplastics could be the answer

Thermoplastic CFRP: Transforming the Future, Reducing Automobile Chassis Weight by 80%, TEIJIN CSR Report 2012

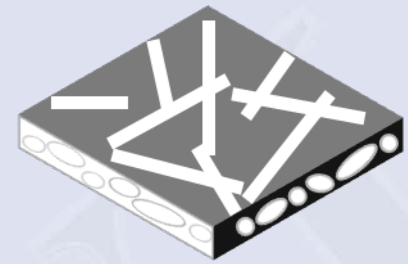
Material Forms



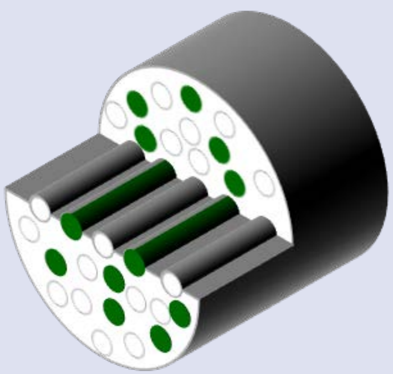
Typical short fibre thermoplastic material



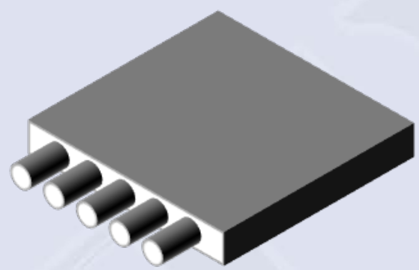
Long fibre thermoplastic material



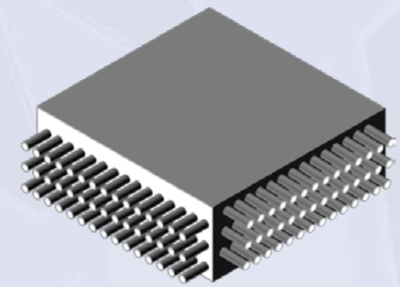
Long fibre thermoplastic material



Commingled yarn



Continuous reinforced thermoplastic material



Continuous reinforced thermoplastic material

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Applications of Continuous Fibre Thermoplastic Composites

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Aerospace - Commercial

- A340/A380 Fixed Leading Edge
- Autoclaved Glass/PPS (TenCate CETEX®)

http://www.fokker.com/Current-Thermoplastic-Applications

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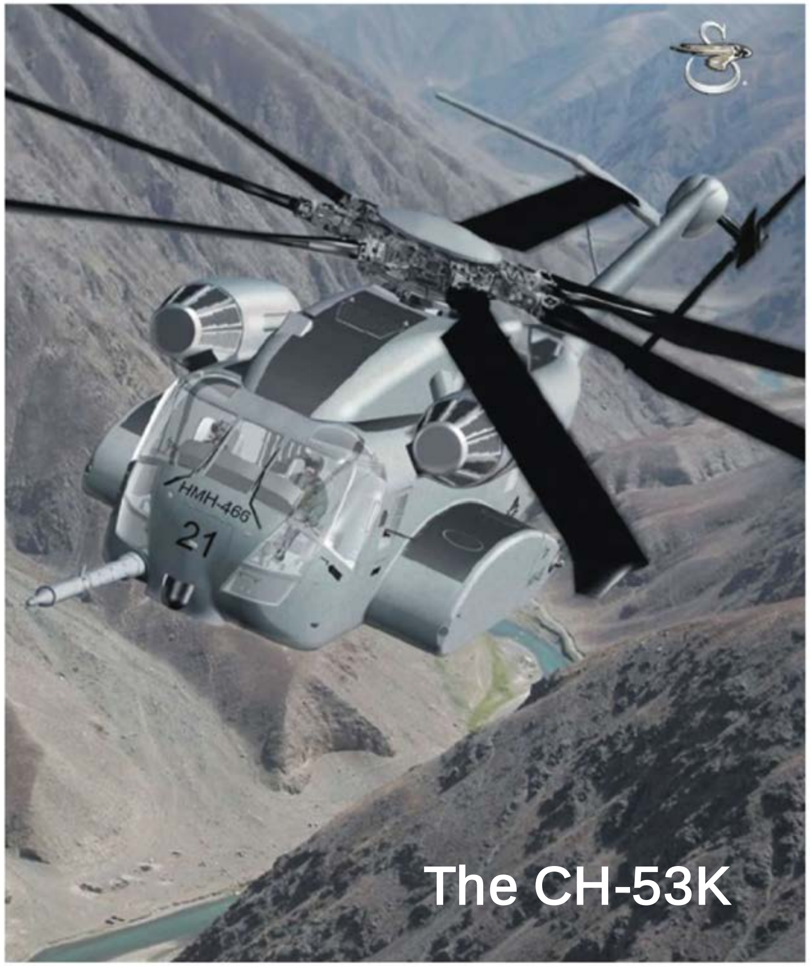
Aerospace - Defence

Carbon/PEEK helicopter cargo bay floor panel has toughness benefits thanks to its thermoplastic matrix



http://www.automateddynamics.com/content/what_difference_between_thermoset_and_thermoplastic_composites

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Automotive

- Beam and crush columns manufactured using Hexcel TowFlex PA6
- Roll formed
- Parts welded by high frequency vibrational welding
- 2 versions:
  - glass (~40 cars / day) and carbon (limited to 1600 cars total)

Source: Jacob Kunststofftechnik GmbH & Co. KG www.jacob-kunststofftechnik.de

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Oil and Gas

- Made from a combination of carbon fibre and PEEK
- Light weight / high strength – typically 1/10th of the weight in water of the equivalent steel
- Laser thermoplastic filament winding

http://www.magmaglobal.com/m-pipe/design-notes
http://www.magmaglobal.com/m-pipe/end-fittings

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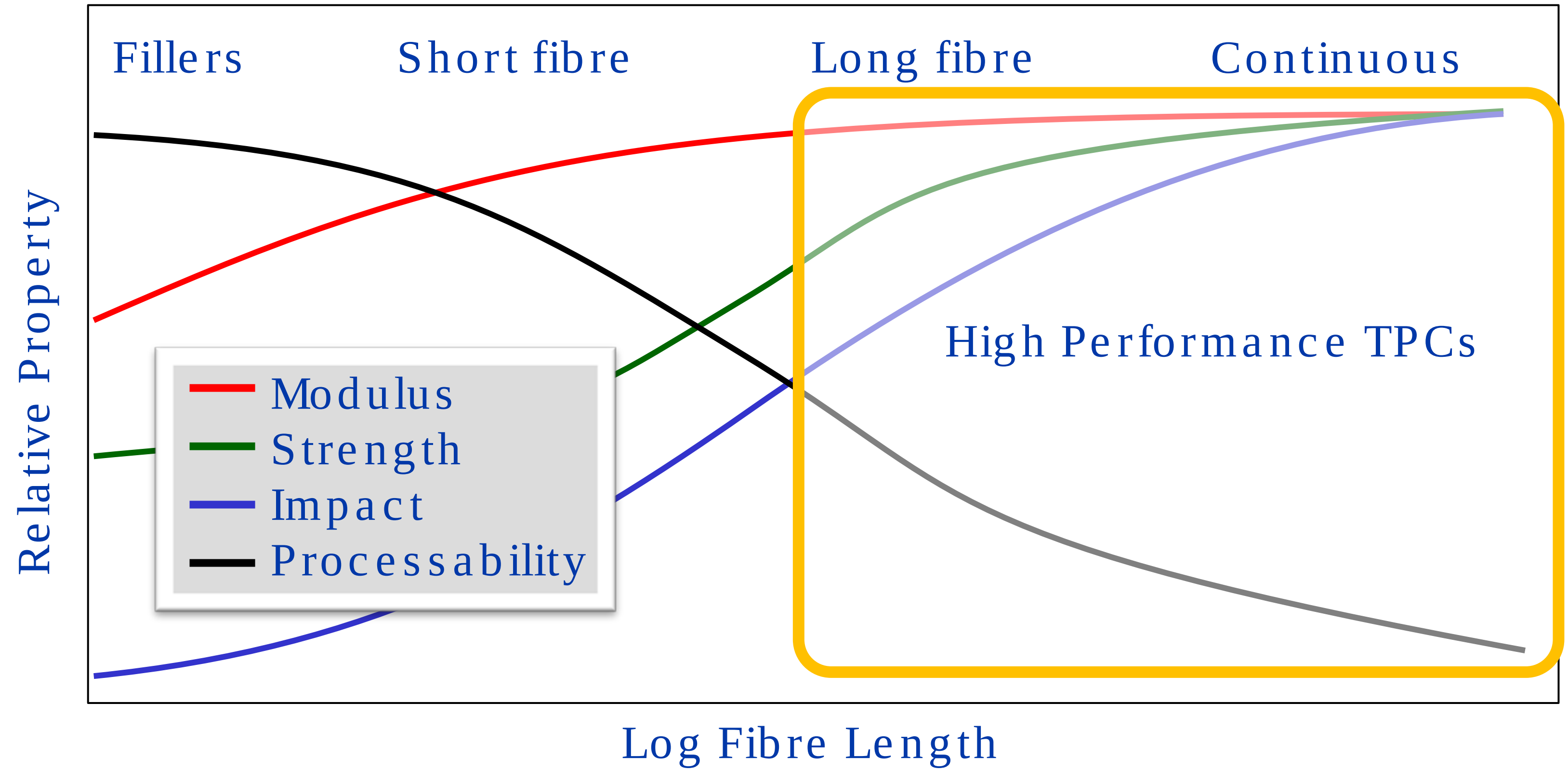
Forming of Thermoplastic Composites

Composite Processability vs Fibre Length



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From: OCV

Current Composite Production Processes

Injection moulding

Compression moulding

Thermoforming, pultrusion, LRI

ATL, AFP, hand lay-up, vacuum bag/autoclave

Low structural performance components

Semi-structural performance components

Structural performance components

Increasing fibre length

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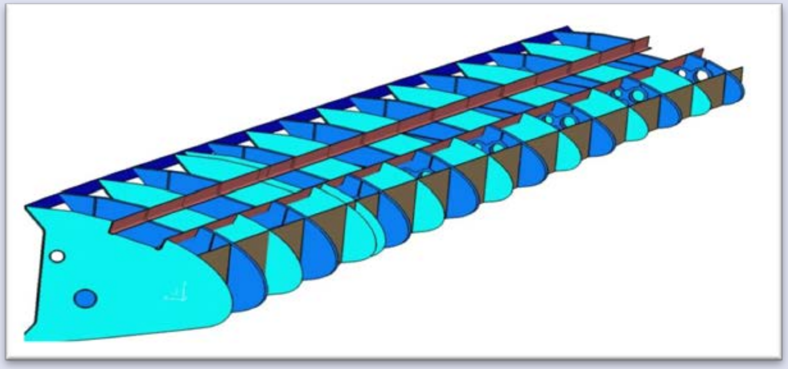
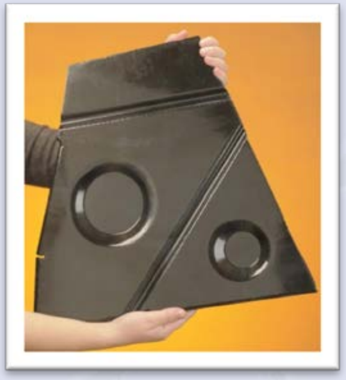
Thermoforming





Advanced Composites Development Project (ADCOMP), http://www.adcomp.co.uk

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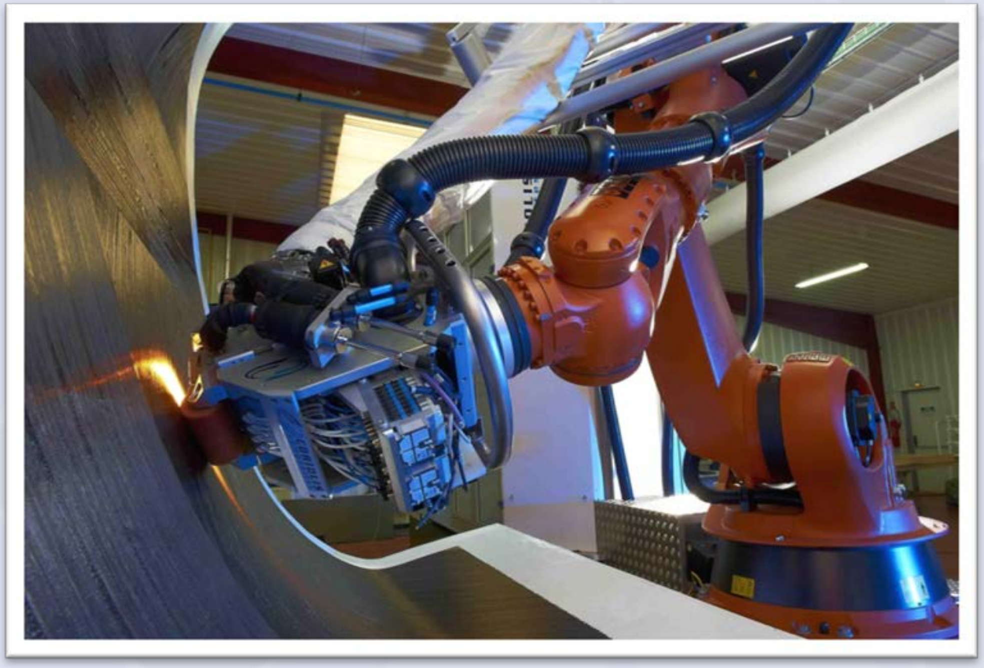
Automated Tape Lay - ATL

- Similar to thermoset ATL
- Requires heat and higher pressure
- In-situ consolidation or autoclave?
- Slow? (kg/hour)
- Fully automated
- High quality
- Aerospace



http://www.compositesworld.com/news/coriolis-composites-enters-long-term-partnership-with-dutch-tprc

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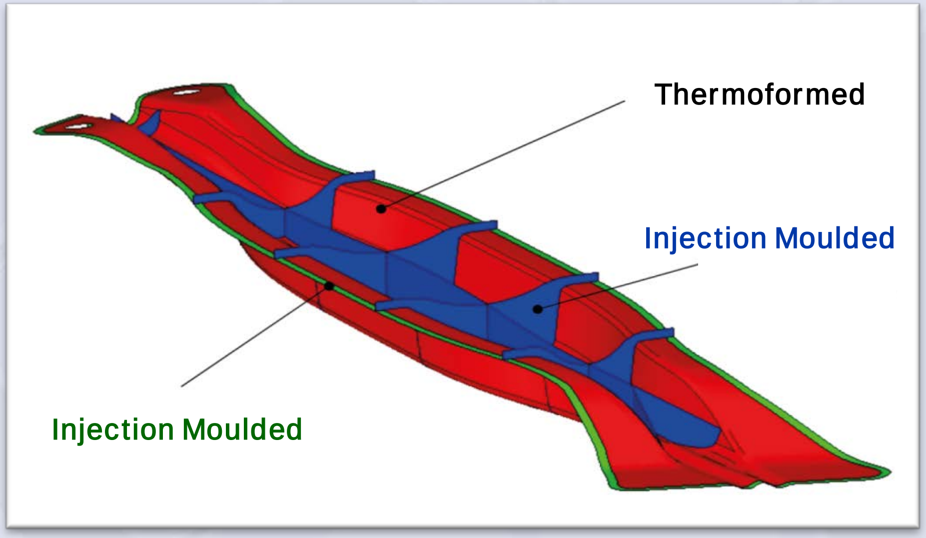
Filament Winding

- Thermoplastic ATL technique but tool rotates
- Principal heat sources are:
  - LASER
  - Directed hot inert gas
  - Induction
  - Heated compaction roller

Thermoforming + Injection Moulding

- New hybrid manufacturing involves thermoforming and injection moulding
- Audi AG teamed up with Bond Laminates
- Individual sheets are thermoformed and inserted into an injection mould by robots



http://www.sunrisethermoforming.com/hybrid-manufacturing-involves-thermoforming-injection-molding/
M. Würtele, "Fully Automated Injection Molding Production of Textile Reinforced Parts", ITHEC 2012

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Forming Summary

- Potential for rapid forming (no cure)
- But ATL can be very slow
- Impregnation/consolidation
- More automated techniques
- Expensive tooling
- High quality
- Problems due to fibre movement
- Simulation important
- Cooling rate important

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The Future of Thermoplastic Composites?

Materials Property Improvements

- One of the strengths of TPC's is the spectrum of properties available to the manufacturer
  - high strength, temperature resistance, toughness, ease of forming
- New materials take a long time to be developed, and the present range adequate, some property improvements are desirable, such as:
  - reduced processing temperatures with minimal loss in mechanical properties (particularly creep)
  - improved formability
  - reduced cost of the more commodity resins such as the PA's and PETs for the automotive industry

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Joining of Thermoplastic Composites

Chris Worrall

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Why Do We Need To Join?

- Often can’t fabricate product or structure as one piece
- Join detail parts, components, or structural elements

•**Achieve large size**:

+*Fabrication or erection of structures on site*

•**Provide geometric complexity**:

+*Function not possible by other processing methods*

•**Achieve structural efficiency**:

+*By joining extra material only where required*

•**Optimize material use**:

+*By adding rather than removing material*

•**Create hybrid structures with dissimilar materials**:

+*Using the right material in just the right location*

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"How do I join thee? Let me count the ways.."

Joining Techniques

- **Adhesive Bonding**
  - Solvent Bonding
  - Adhesive Agglutination
- **Welding**
  - Vibration
  - Rotational
  - Ultrasonic
  - Heated Tool
  - Laser
  - High Frequency
  - Induction
  - Resistive Implant
- **Mechanical Fastening**
  - Riveting
  - Clamping
  - Bolting

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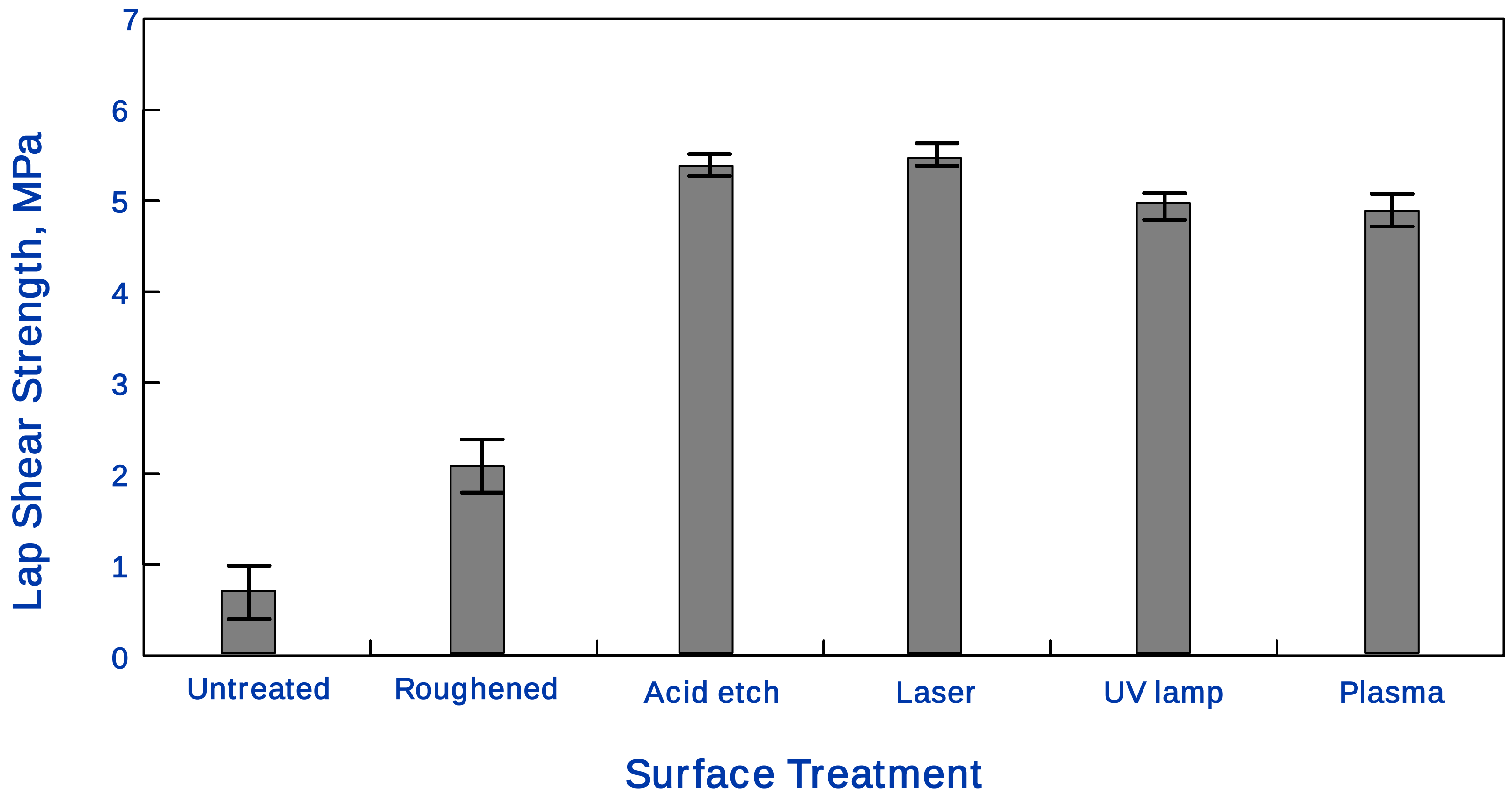
Before We Start…

Surface Preparation
Surface Evaluation

Surface Treatment Effect



From: Victrex

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Portable FTIR

Composite and Metal Applications include:

- Determine coating identification, thickness, uniformity
- Detect contaminants/ensure surface cleanliness
- Verify, determine thickness and uniformity of surface oxidation processes
- Ensure quality of surface preparation
- Link molecular information with physical properties of materials
- Use with adhesives, primers/paints, oxide coatings etc

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Adhesive Bonding

- Joining Techniques
  - Adhesive Bonding
  - Welding
  - Mechanical Fastening

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Adhesive Bonding

- Adhesive joints
  - Spread load over more uniform area (compared to fasteners)
  - Can result in a lower stress concentration
- Good joint design
  - Essential for high-stress applications
- Joints
  - Best loaded in compression
  - Can give acceptable performance in shear
  - Avoid peel and cleavage loading (tension)

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Adhesive Bonding

Advantages provided by adhesive bonding are:

- Established technology
- Uniform stress distribution
- Use with different materials, different thicknesses
- Clean-looking joints
- Easy to automate

Disadvantages:

- Surface pre-treatment is usually required
- Difficult to inspect the quality of bonded joints, destructive testing required
- Degradation, aging
- Limited heat resistance

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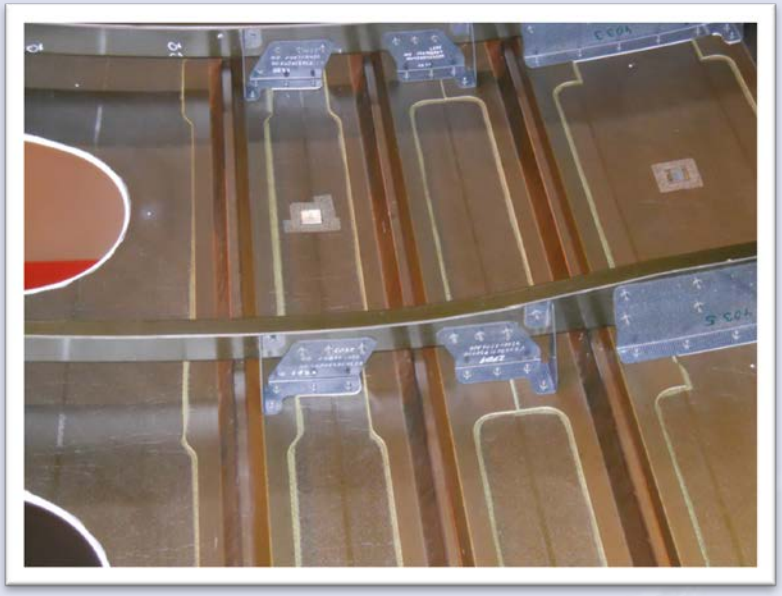
Mechanical Fastening

Joining Techniques

- Adhesive Bonding
- Welding
- Mechanical Fastening

Mechanical Fastening

Rivets and bolts are usually used to form the mechanical joints for composite materials



How Many Fasteners?

- **Airbus A340 - 2.5 million rivets[1]**

http://www.airbus.com/aircraftfamilies/passengeraircraft/a340family/a340-300/

[1] J. R. Wilson, “Making composites competitive: experience from non-aerospace sectors has significantly boosted cost-efficiency”. Interavia Business & Technology , November 2001

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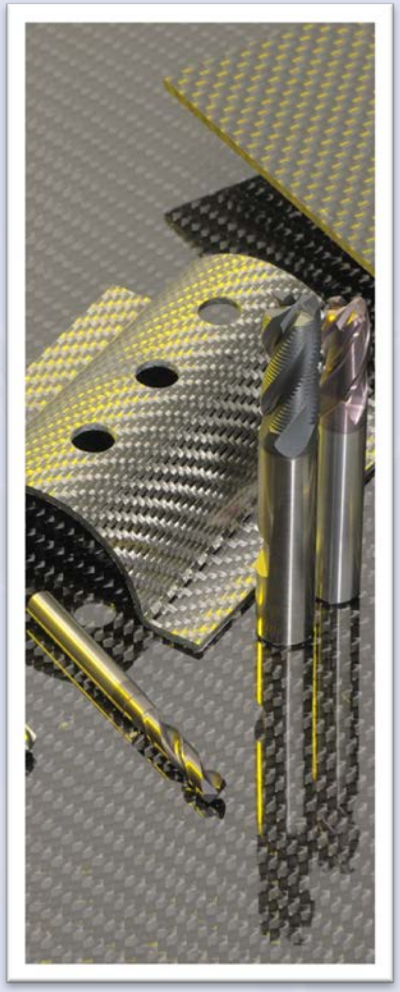
Mechanical Fasteners Need Holes

- Mechanical machining prevalent in industry
- Cutting fibres reduces performance
- Key drivers: cost vs speed vs finish quality

- Promising technologies
  - Orbital drilling (TRL higher than alternative technologies)
  - Laser (significant technical challenges need to be tackled to be industry-ready)
  - Hybrid Laser-Waterjet a possibility, but not demonstrated for composites



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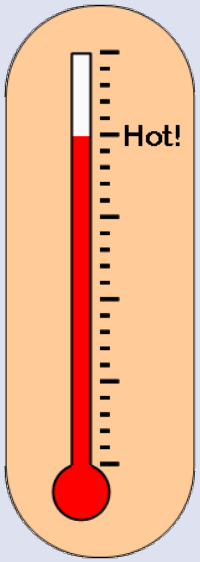
Welding

Joining Techniques		
Adhesive Bonding	Welding	Mechanical Fastening

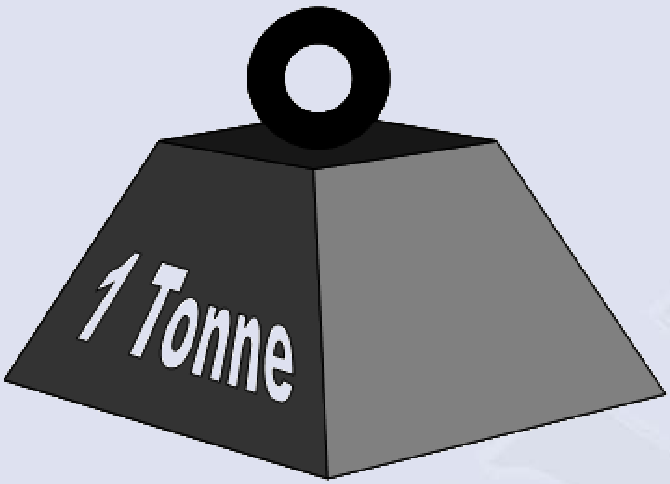
Welding Processes

- Joining Techniques
  - Welding
    - Mechanical
      - Spin
      - Vibration
      - Ultrasonic
      - Orbital
      - Friction Stir
    - Electromagnetic
      - Resistive Implant
      - Induction
      - Dielectric
      - Microwave
      - Infrared
    - Externally Heated
      - Hot Plate
      - Hot Bar
      - Impulse
      - Hot Gas
      - Extrusion

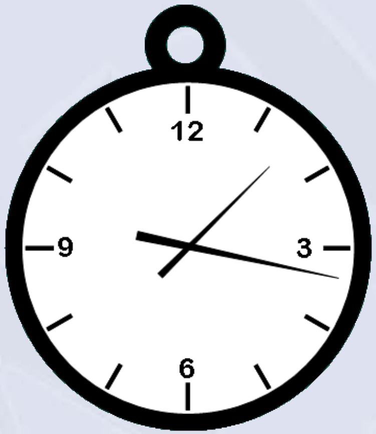
Welding Thermoplastics Requires…



Heat

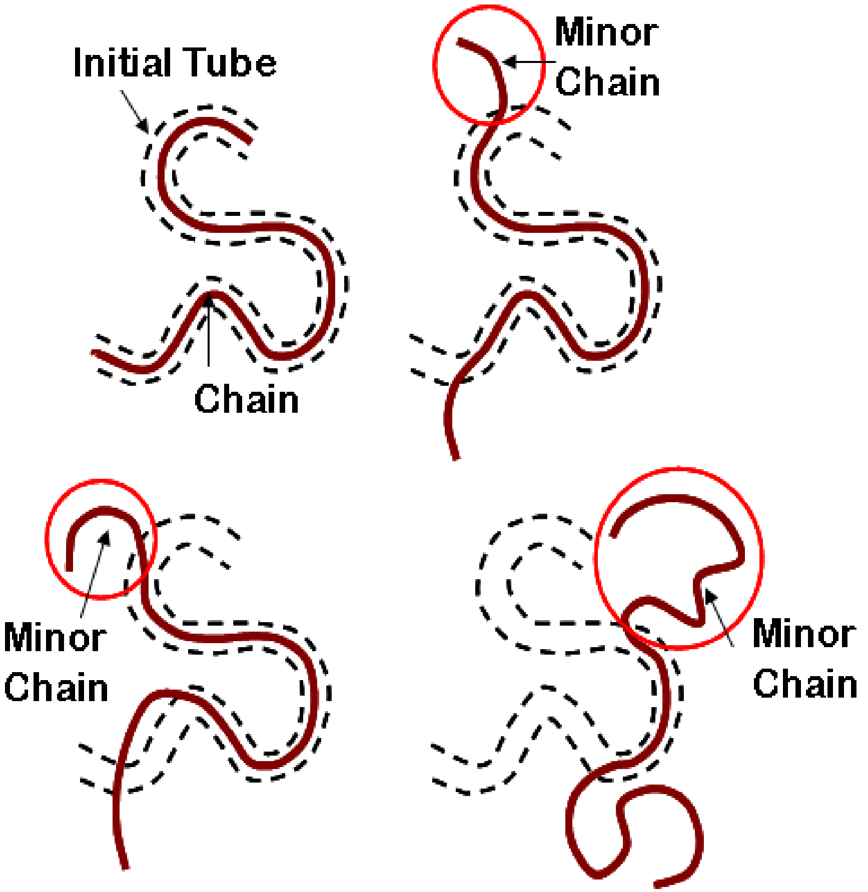


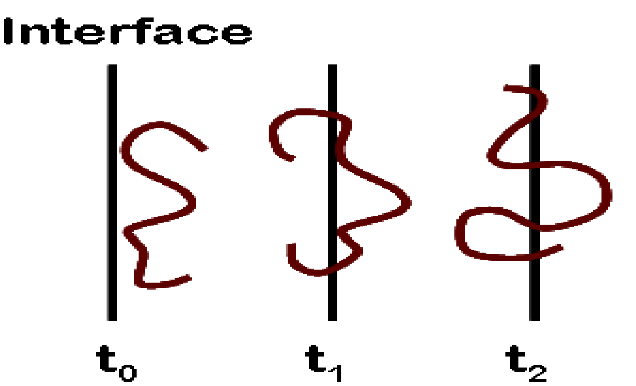
Pressure



Time

Welding Thermoplastics - Reptation





Kim and Wool (1983)

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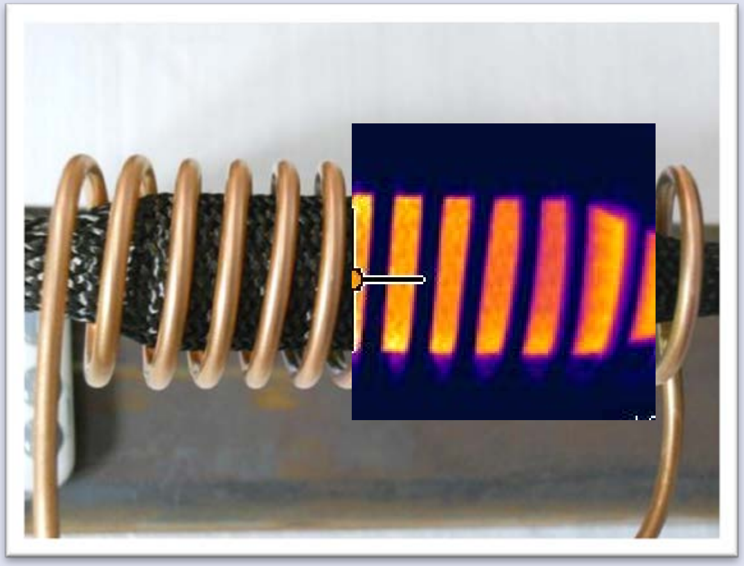
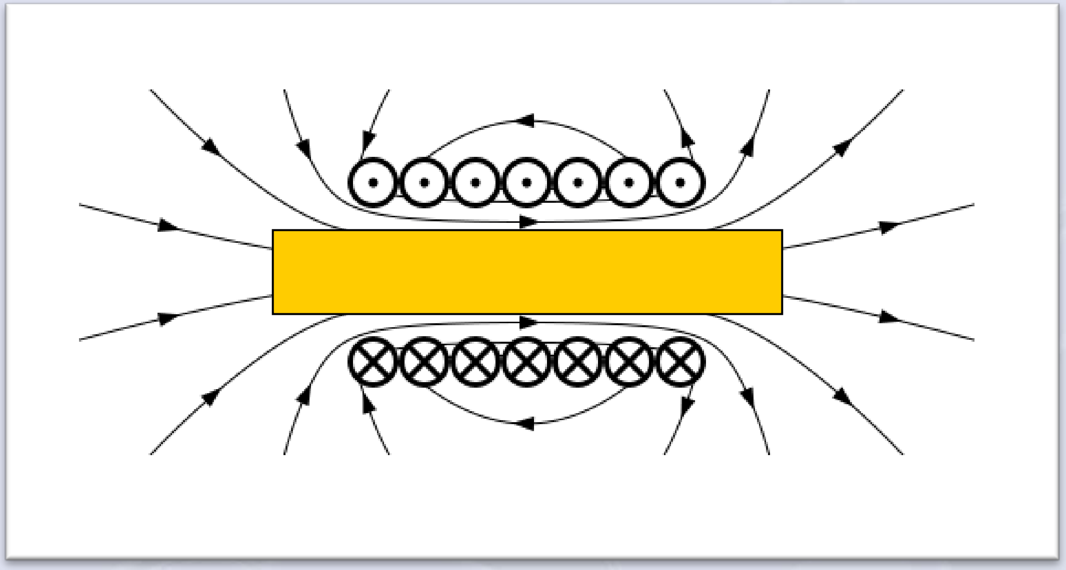
Induction Welding

What is Induction Welding?

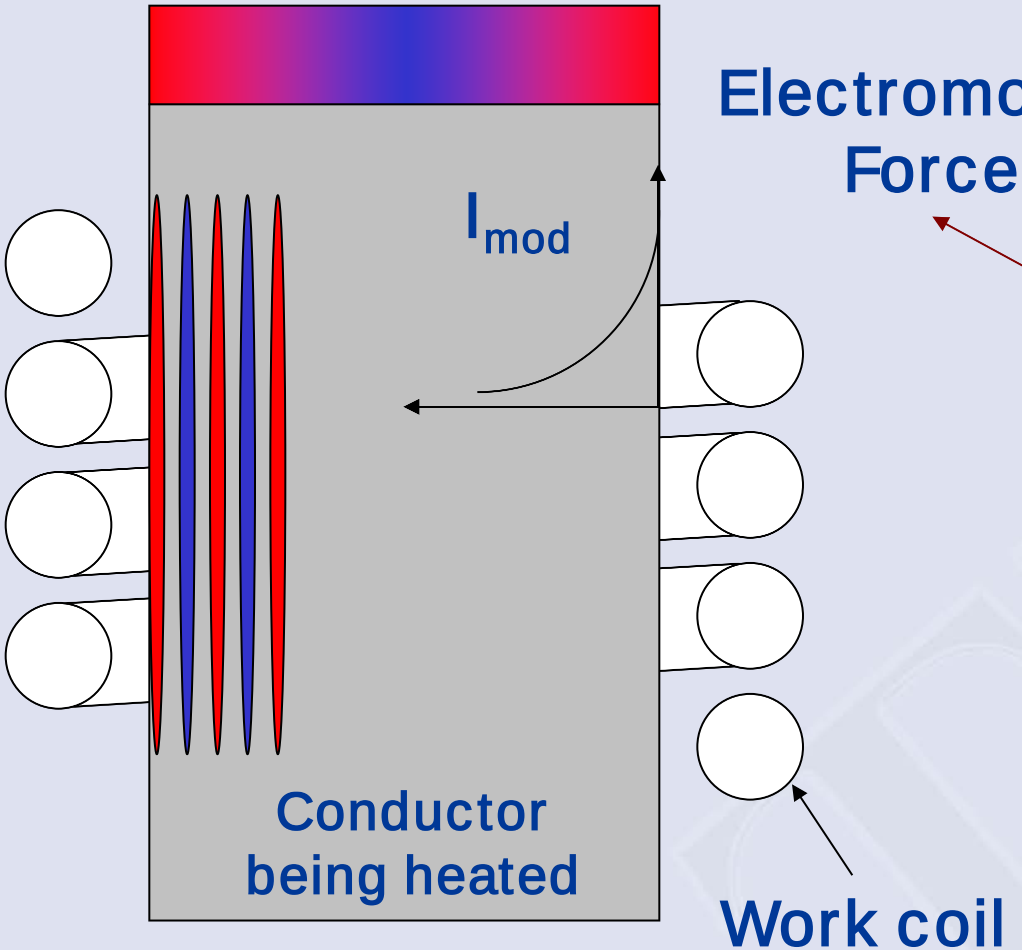
Induction heating of 15mm carbon fibre braid





- High frequency alternating field induces eddy current in conductor
- Current in conductor produces heat by Joule heating
- Conductor can be carbon fibre in composite

What is Induction Welding?



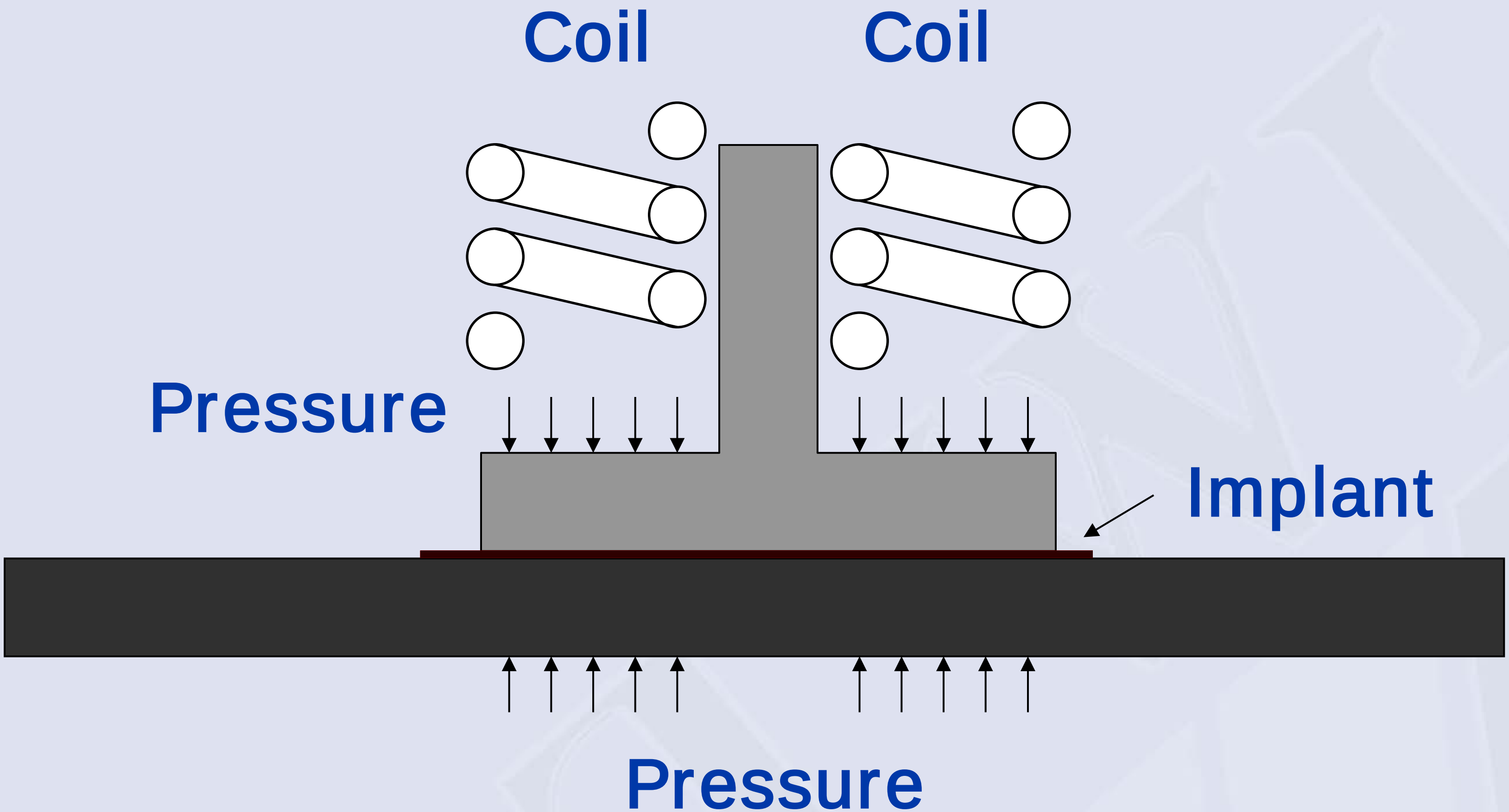
Electromotive Force

Inductance

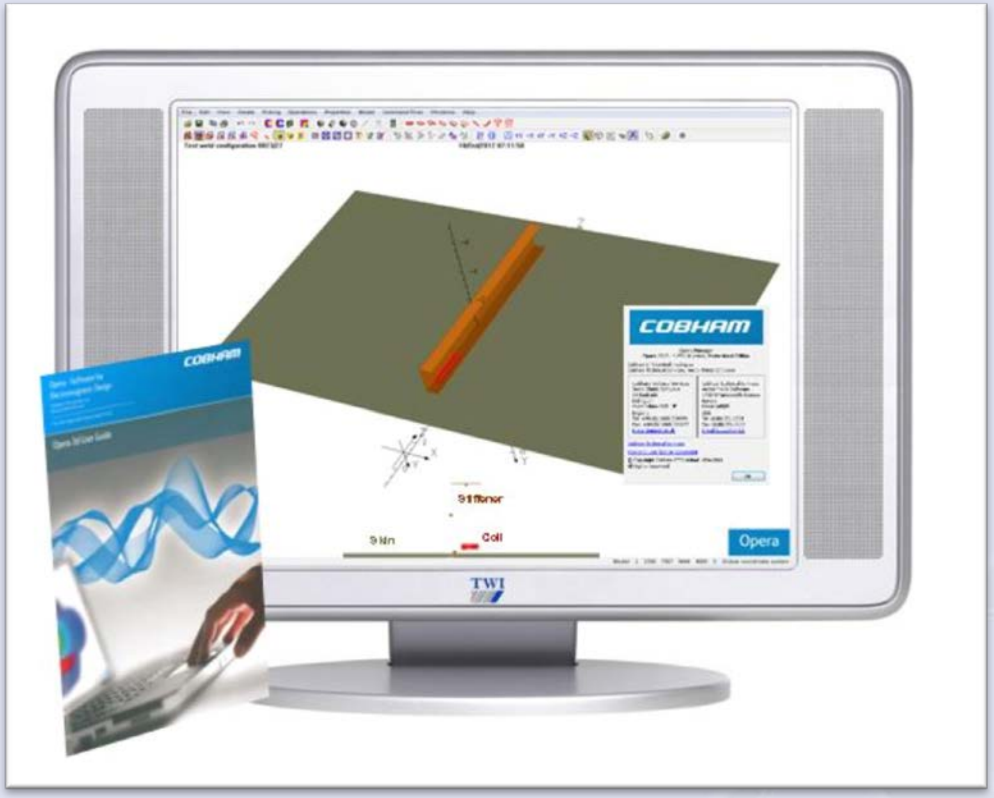
$$E = -L\frac{di}{dt}$$

Rate of change of current

Induction Implant Welding



Electromagnetic Simulation



- Electromagnetic simulation
- Cobham OPERA 3D
- ELEKTRA/SS
- Predict eddy currents
- Can couple with TEMPO/TR
- Predict temperature
- Model induction welding
- Work coil optimisation
- Process optimisation
- Edge Effects

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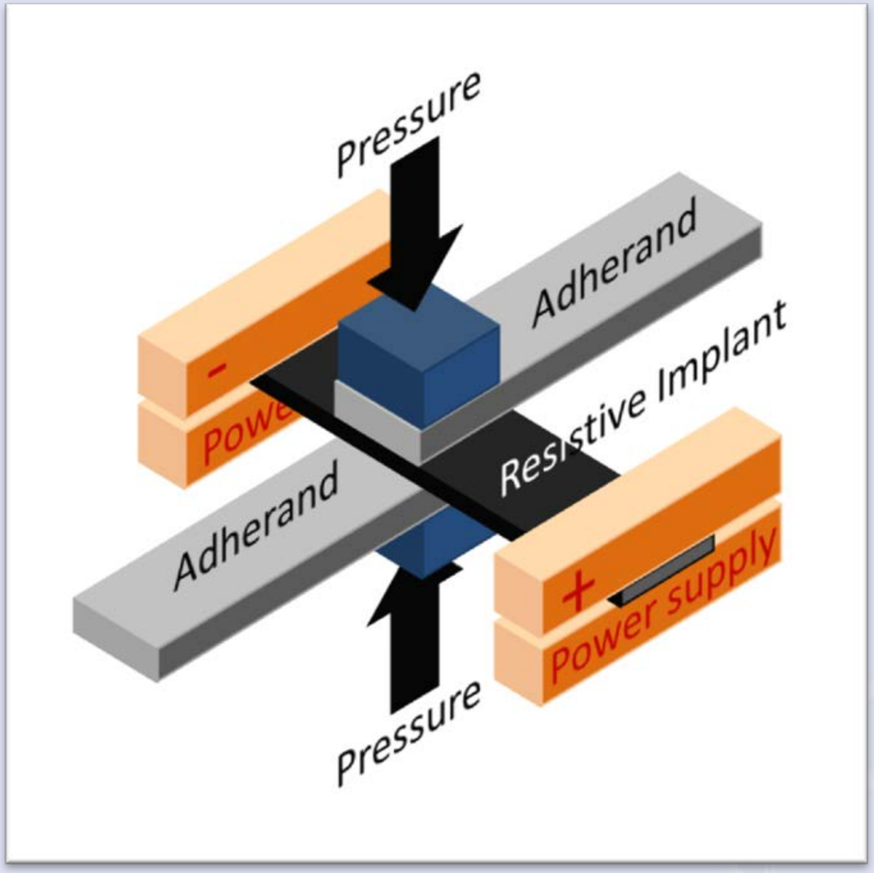
Resistive Implant Welding

Resistive Implant Welding



- Implant placed at the joint
- Can be metal wire, mesh or braid, carbon fibre
- Can intermingle substrate fibres in braid form
- Use polymer films to aid wetting at the joint
- Implant stays in-situ
- Can use metallic components as implants
- Process tends to be stepwise

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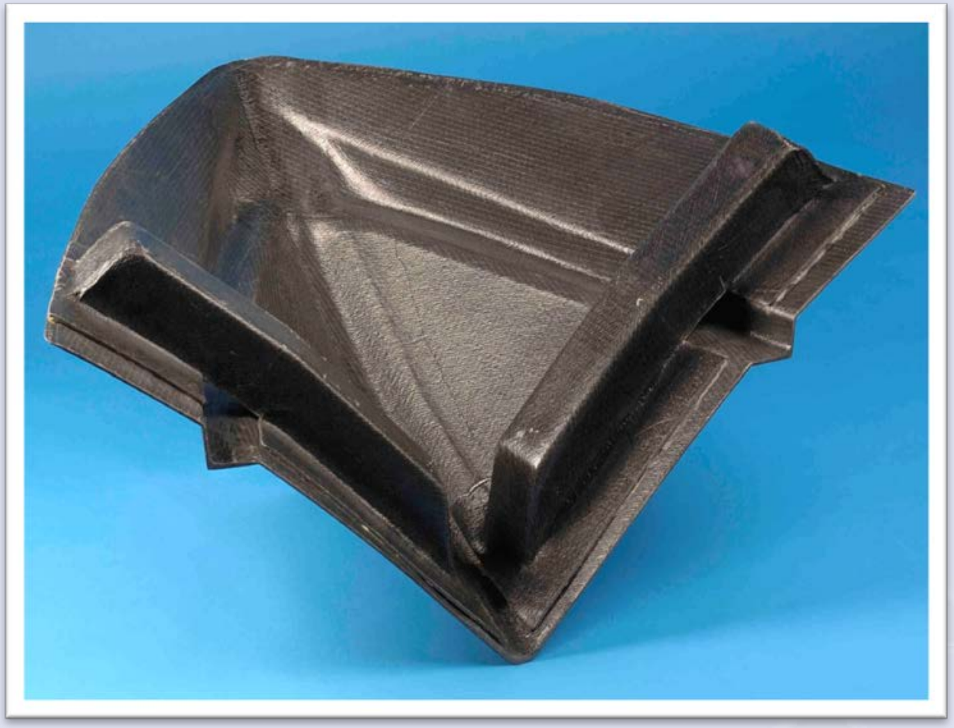
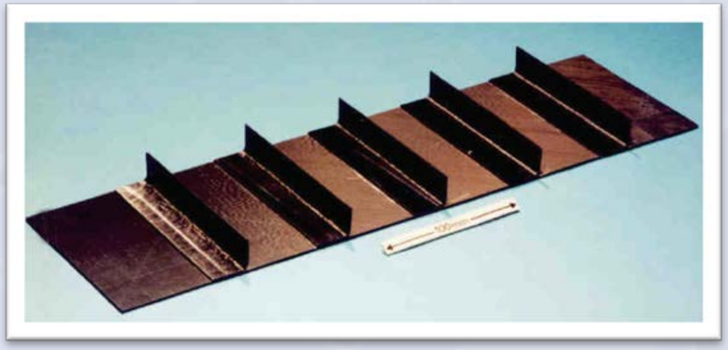
Resistive Implant Welding





Resistive Implant Welding of Thermoplastic Composites
Carbon PEEK, Twintex®

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Joining Summary

- Three main categories
- Only TPCs can be welded
- Many techniques
- Depends on geometry, speed etc
- No one solution fits all
- Cooling rate issues?
- High performance TPC welding not widely used (limited to aerospace)

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Joining Innovations at TWI in Thermoplastic Composites

Chris Worrall

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Background

- Renewed interest in thermoplastic composites
- Attractive option but as yet there has not been a significant uptake of TPCs Joining/problem
- One reason is lack of joining technology
- TPCs can be joined by fusion bonding (welding)
- Interface is heated without a foreign material left at the bond line
- Three types; induction, resistive implant and ultrasonic
- Invention - TWI had developed a new induction heating process that focusses the heat at the weld interface

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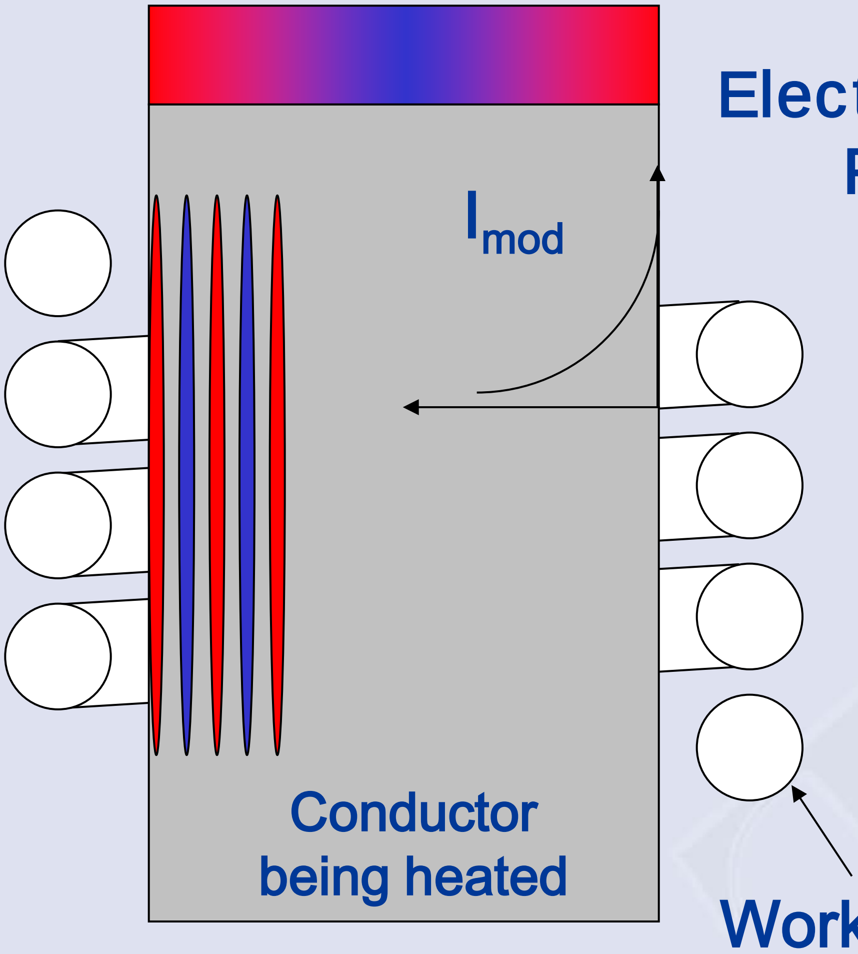
Induction Basics



Electromotive Force

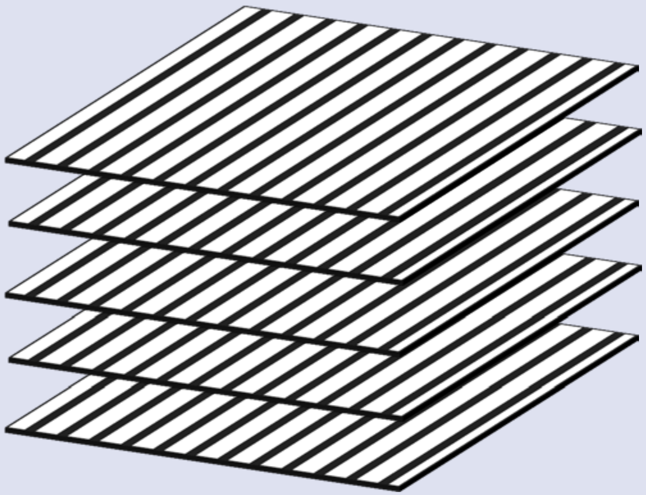
Inductance

$$E = -L\frac{di}{dt}$$

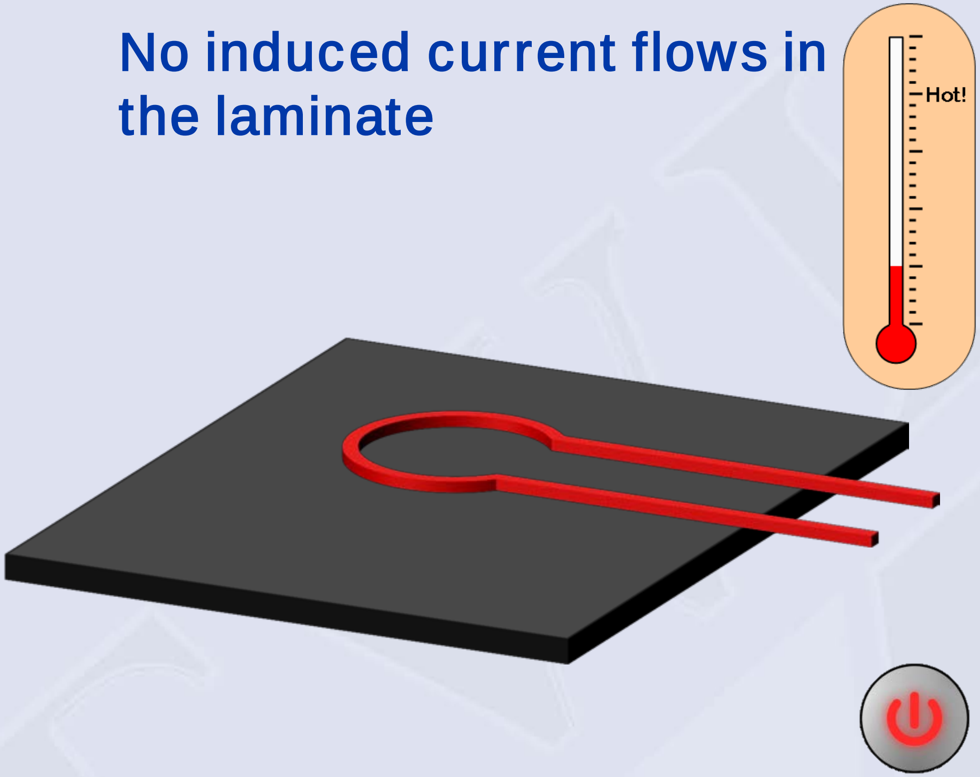
Rate of change of current

Induction Heating of UD Laminates

Touching layers have same fibre orientation

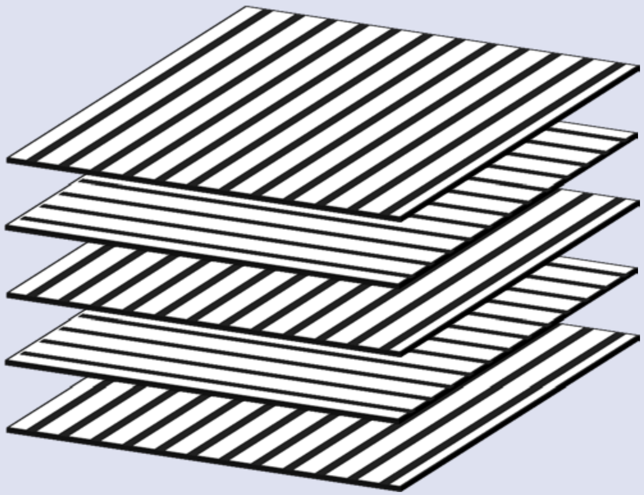


No induced current flows in the laminate

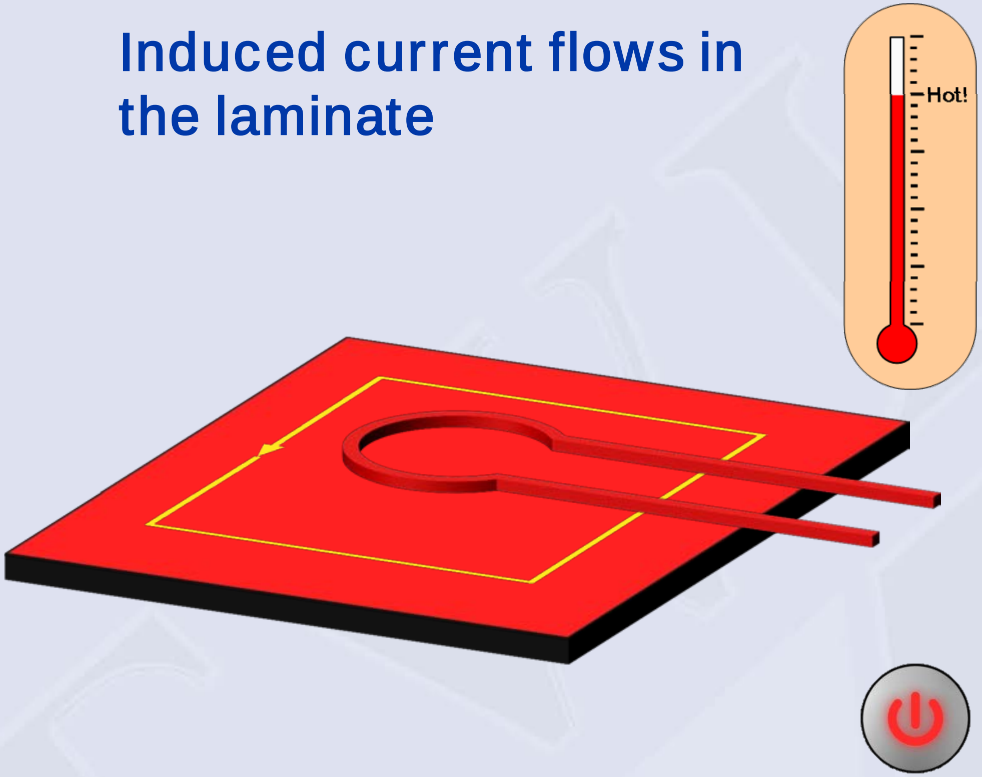


Induction Heating of Cross-ply Laminates

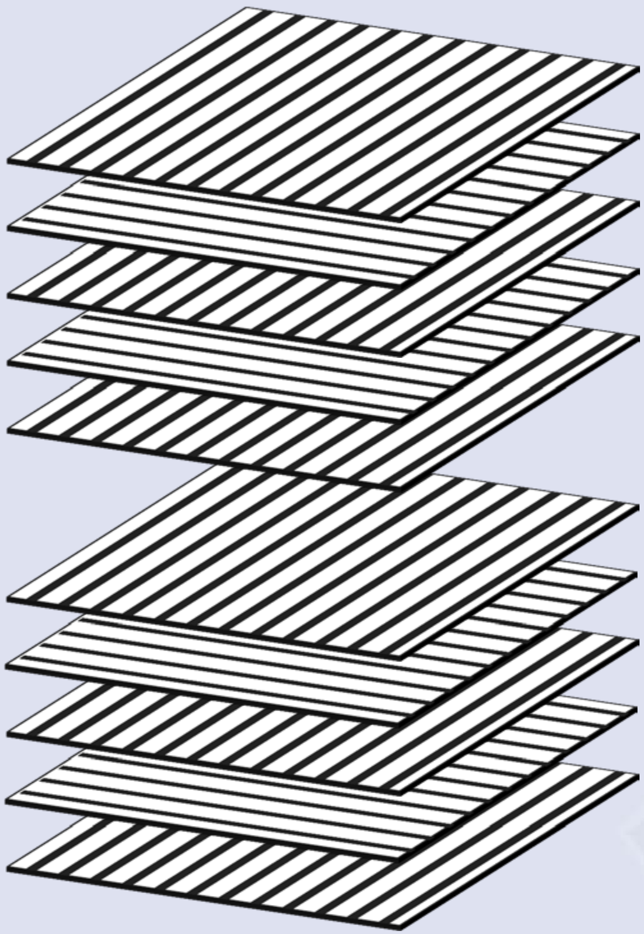
Touching layers have different fibre orientation



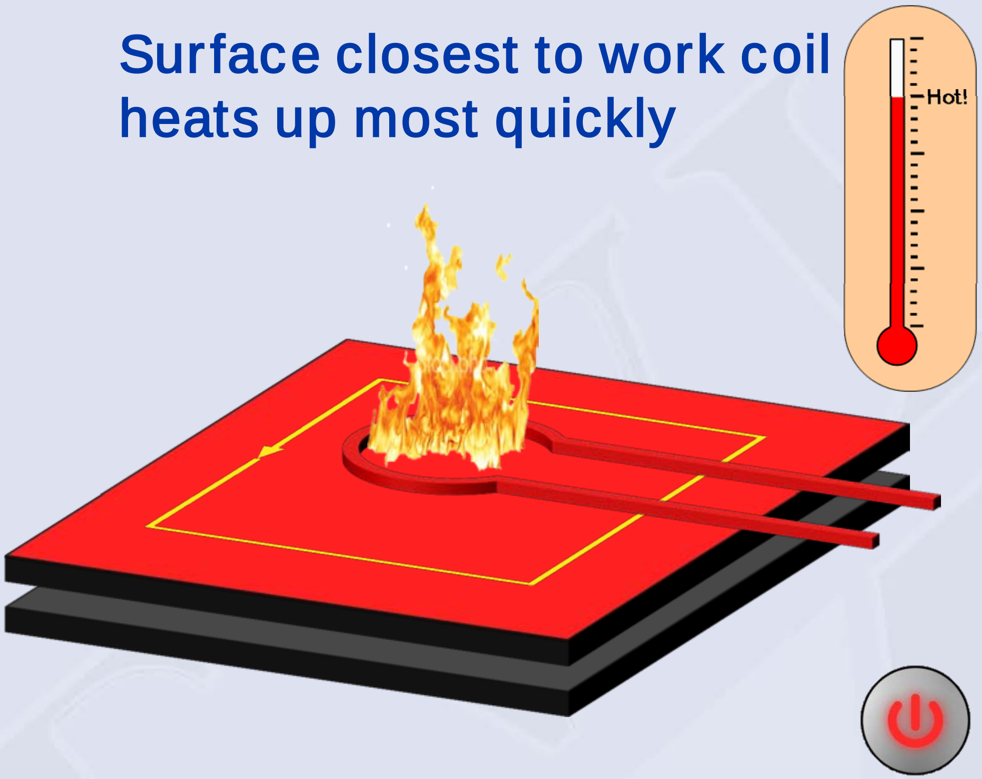
Induced current flows in the laminate



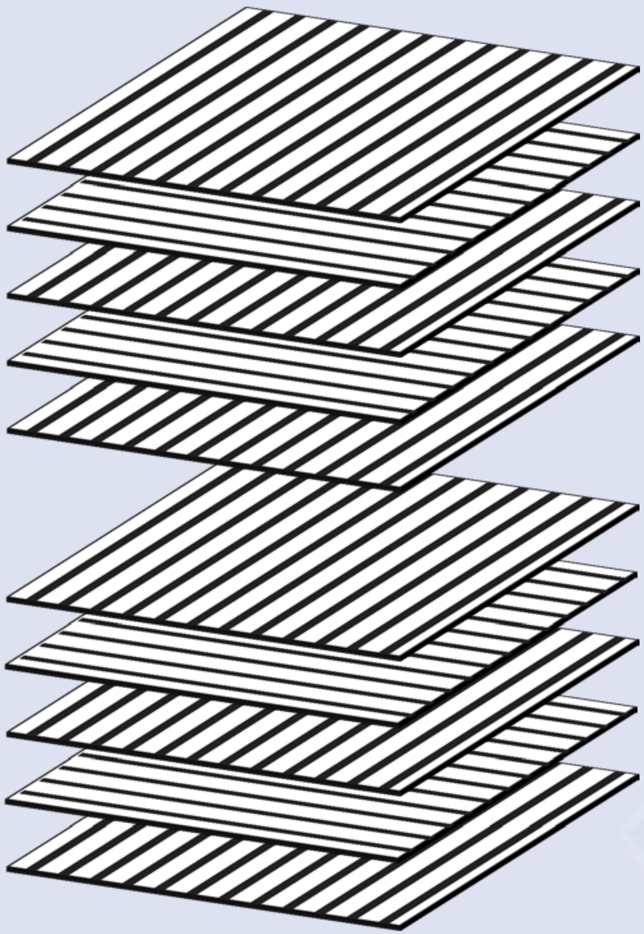
Induction Welding of Cross-ply Laminates



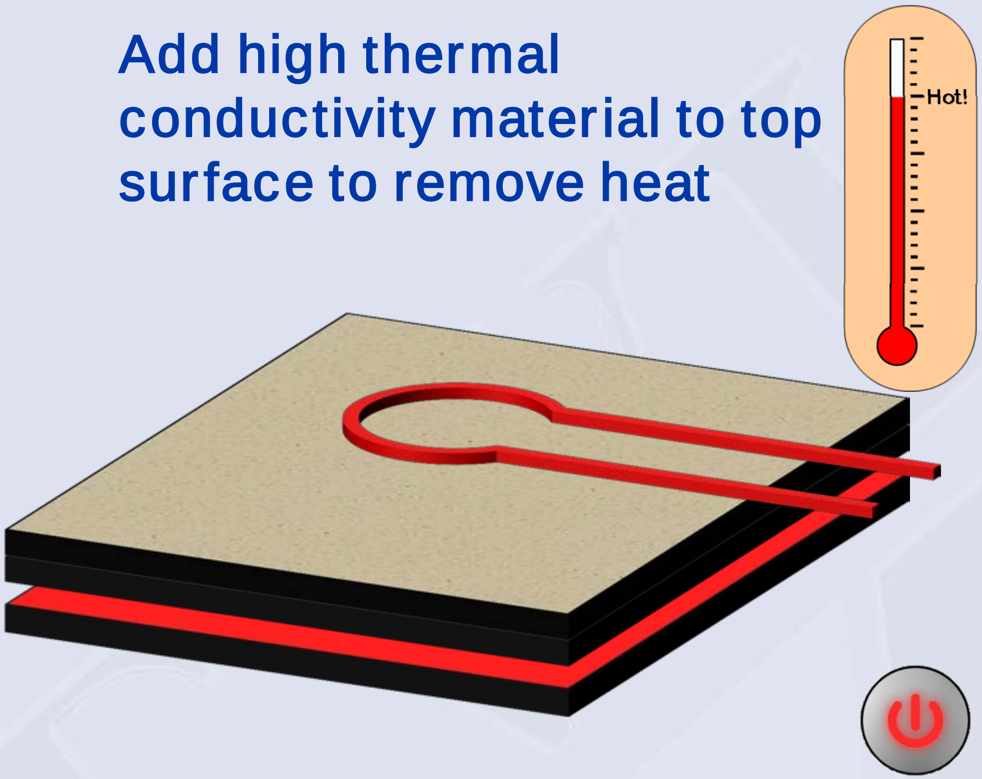
Surface closest to work coil heats up most quickly



KVE Approach (Patented)



Add high thermal conductivity material to top surface to remove heat



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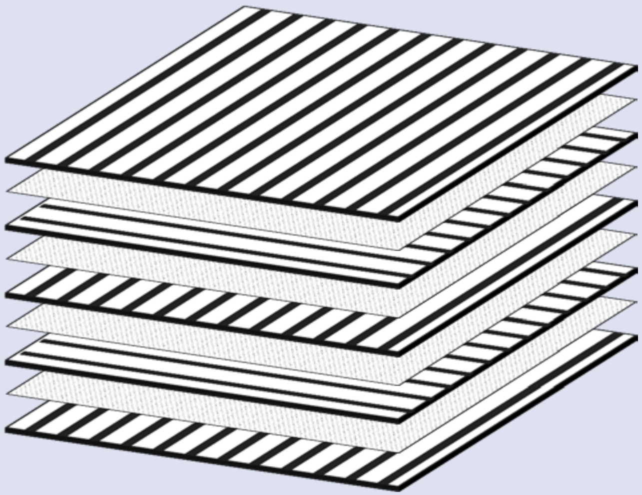
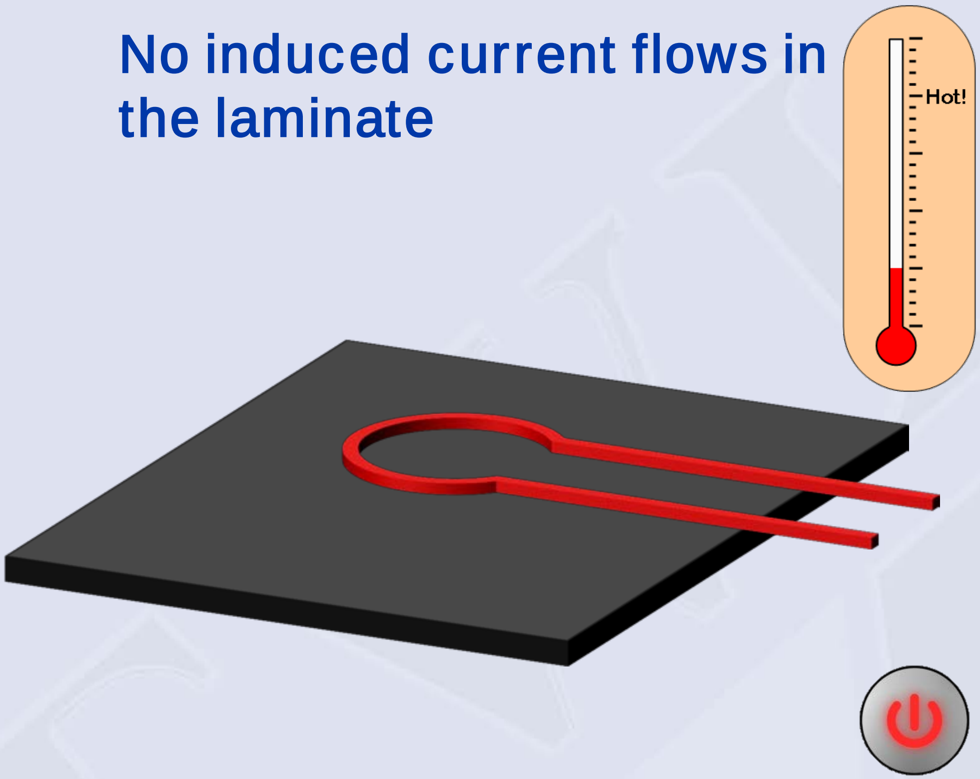
TWI Scrim Induction Welding Technique

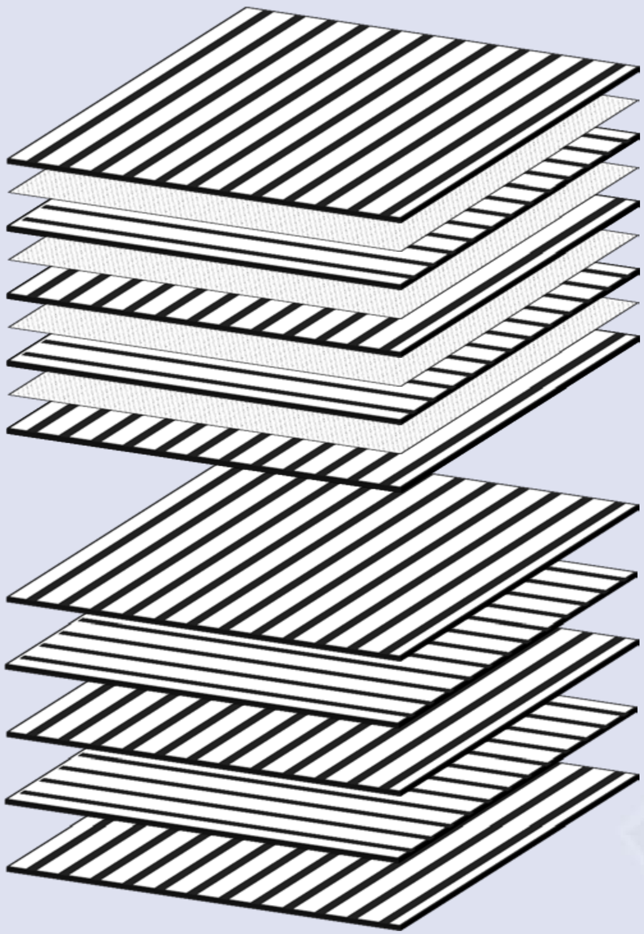
Introduce insulating scrim between alternate layers



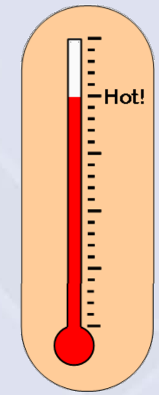
No induced current flows in the laminate

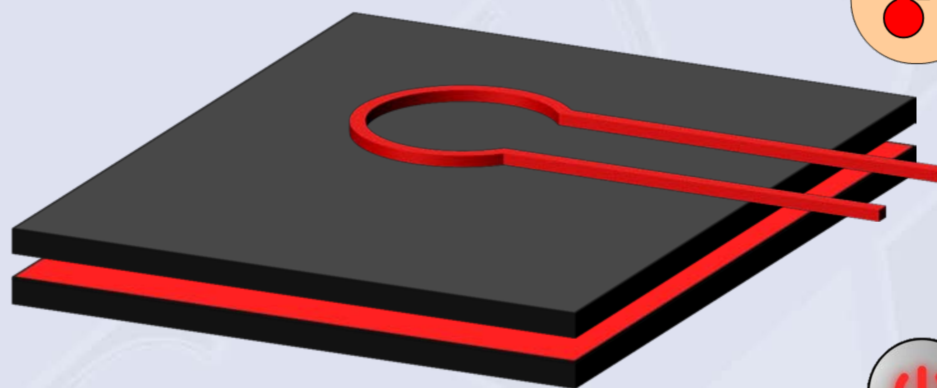


Scrim Induction Welding of Cross-ply Laminates



- Heat focussed at weld interface
- No extra material required
- No heat wasted





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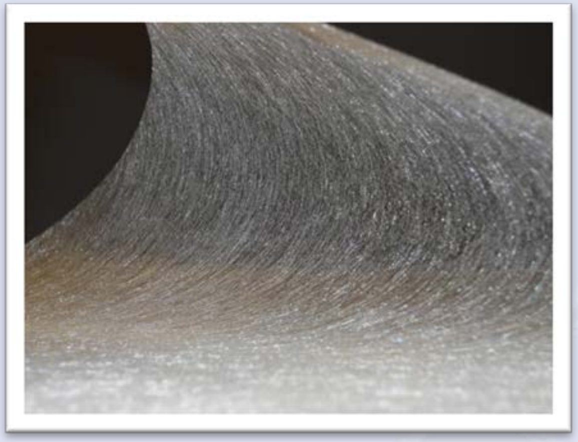
Materials

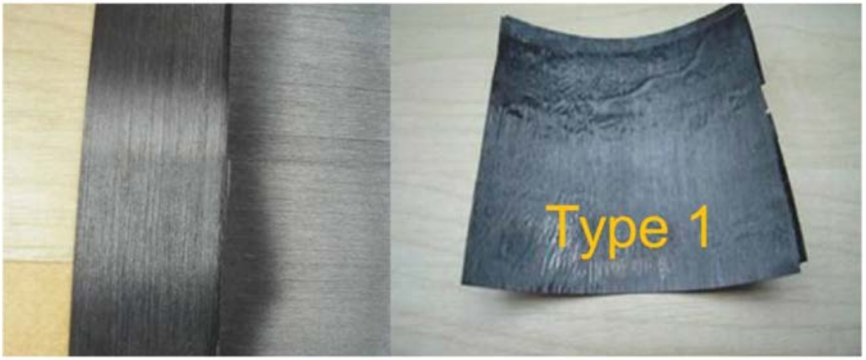


Carbon PEEK Prepreg (APC-2)

Glass Scrim (10gsm)

PEEK Film (12μm)

Lay-up



APC-2, 0°

APC-2, 90°

conductor

APC-2, 0°

PEEK

Scrim

PEEK

APC-2, 90°

insulator

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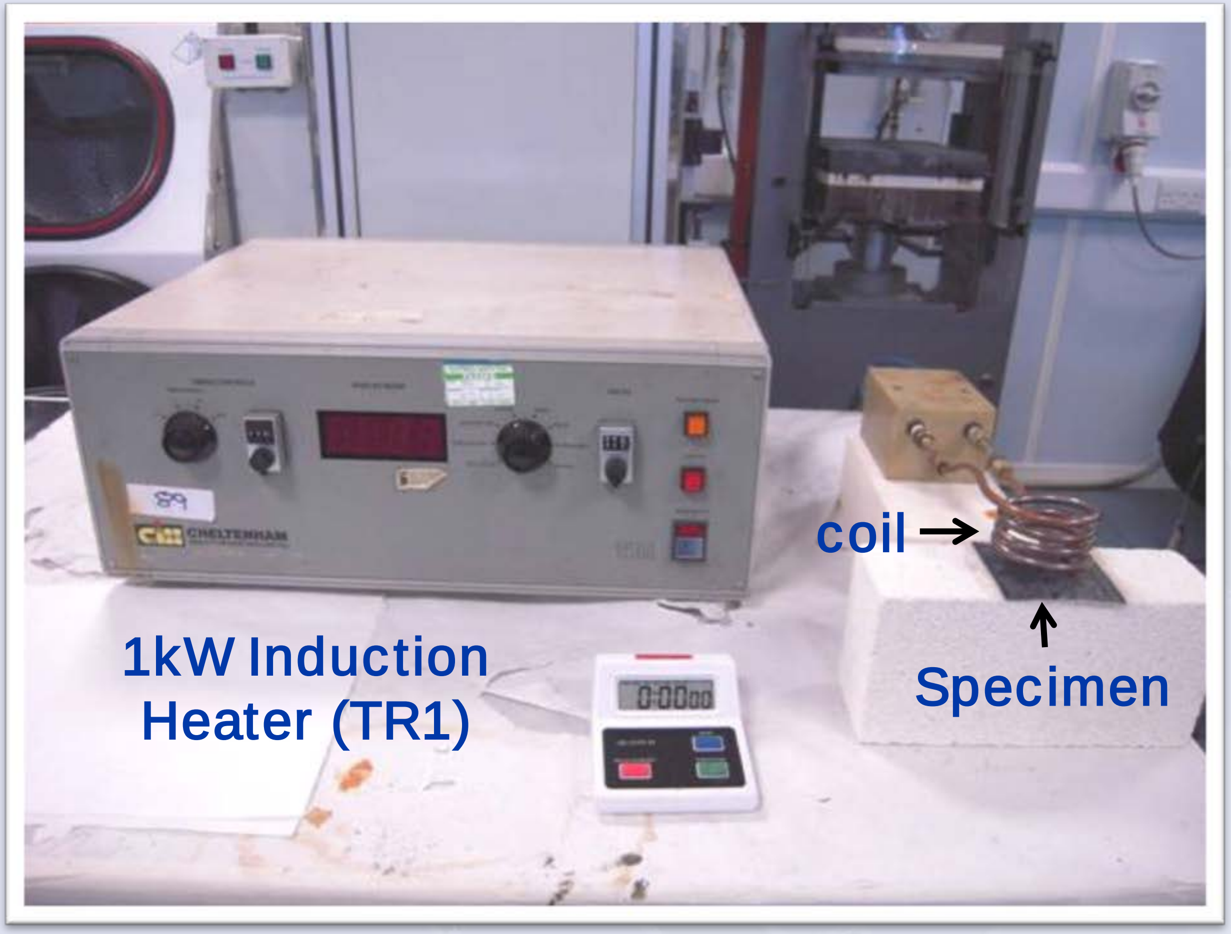
Induction Heating Trials



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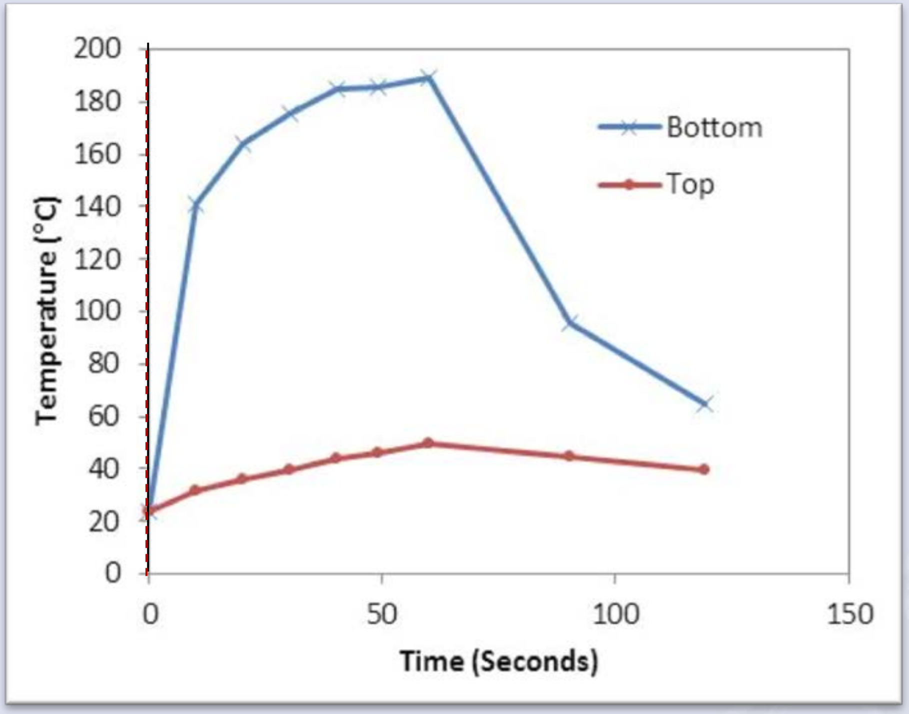
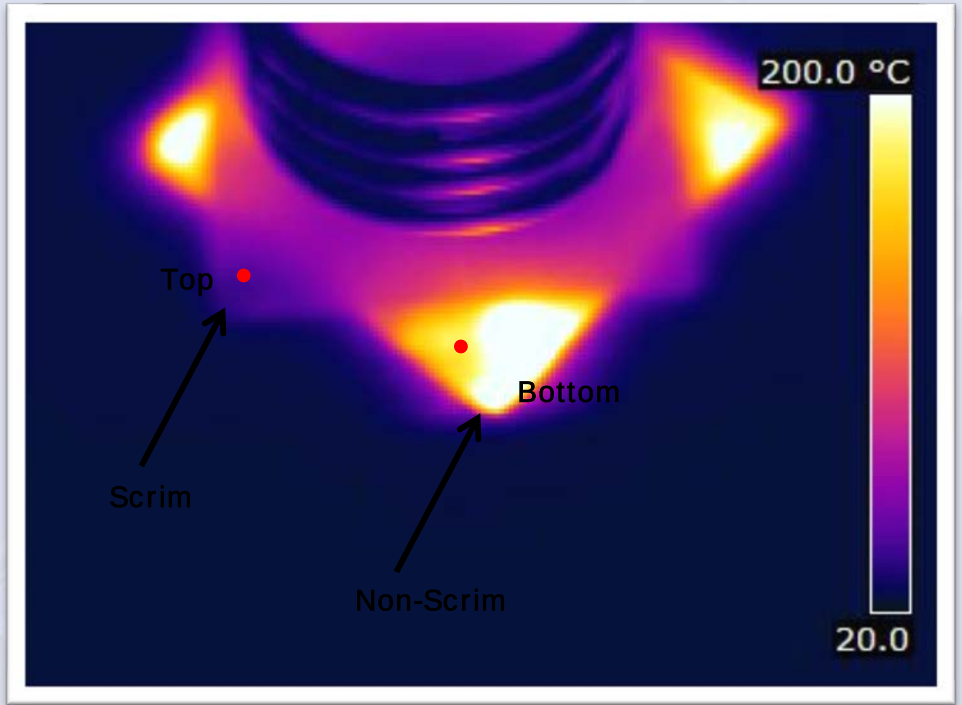
Demonstration of Effect





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Concluding Remarks

- New method to control depth of focus for induction heating of composites
- Advantages over the current state-of-the-art processes
- Especially where thick parts are involved
- Tooling costs are minimised (flexible process)
- Technique can also be used for adhesive bonding thermoset composites

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