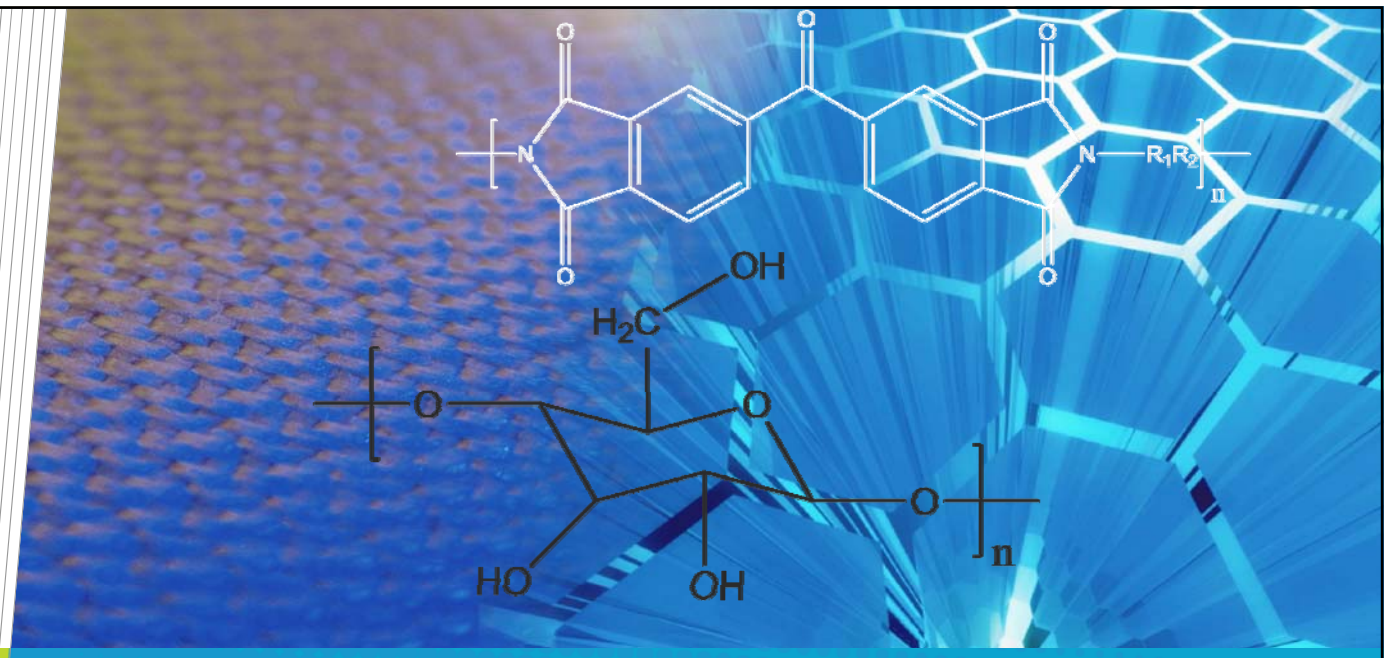

www.csiro.au

Welding Technology for Joining Textile Media

Tony Pierlot

October 2011

International Fibre Centre — Supporting Training & Education in Textiles

Filtration & Separation Association

Ramsay McDonald Pty Ltd

EMCO — ELIZABETH MACHINES CO. Incorporating... LIGHTNING AUSTRALIA PTY LTD

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Outline

- Background
  - Polymers
  - Seams
  - Welding mechanism
  - Bond testing
- Welding Methods
  - Hot Air & Hot Wedge welding
  - Ultrasonic welding
  - RF welding
  - Induction welding
  - Laser welding
- Summary
  - Poster

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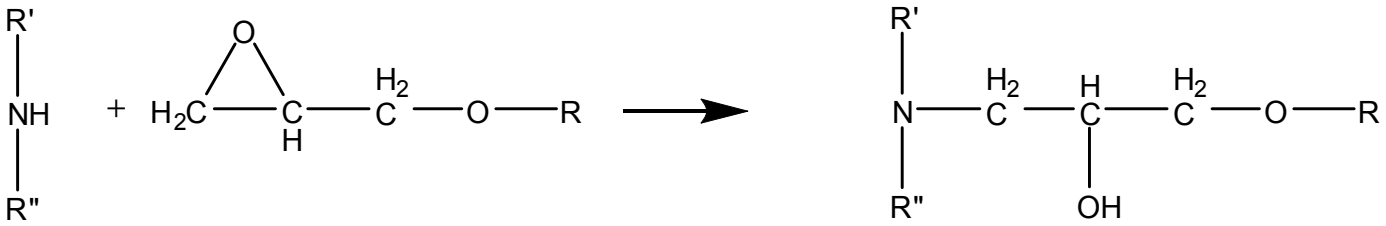
Background

Background/Polymers

Polymers – Two general types

- Thermosets
  - Undergo a chemical reaction or “cure” (when heated) to produce a crosslinked polymer
  - When reheated they tend to decompose rather than melt
  - Examples: Epoxy, Bakelite, Melamine, some Polyurethanes

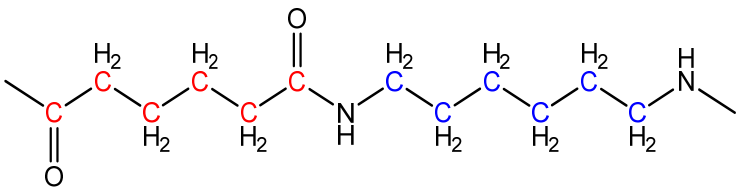


- Natural fibres e.g. cotton, wool, egg behave similarly

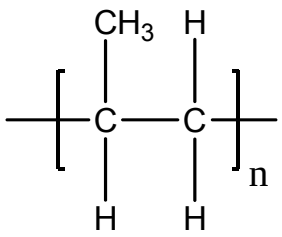
Background/Polymers

Polymers – Two general types

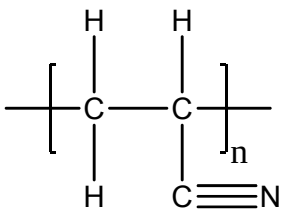
- Thermoplastic Polymers
  - Soften and melt when heated
  - But heat causes some degradation and change in structure e.g. fibres may shrink
  - Examples: nylon, polyester, acrylic



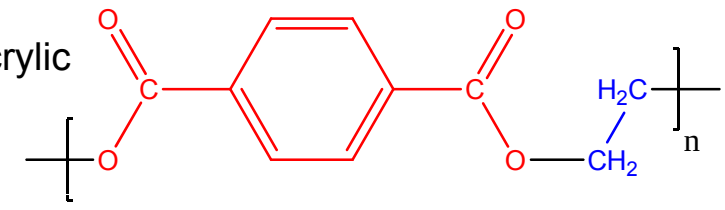
Nylon 6,6



Polypropylene



Polyacrylonitrile



Polyester

Background/Polymers

Thermoplastic Polymers

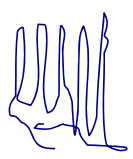
- Amorphous - glass transition temperature (T_g)
  - Above T_g rubber like, below T_g glass like

    Polyvinylchloride T_g~ 85°C

    Polymethylmethacrylate (perspex) T_g~ 100°C

- Semicrystalline - composed of both a crystalline component with melting temperature (T_m)

  and an amorphous component with a T_g



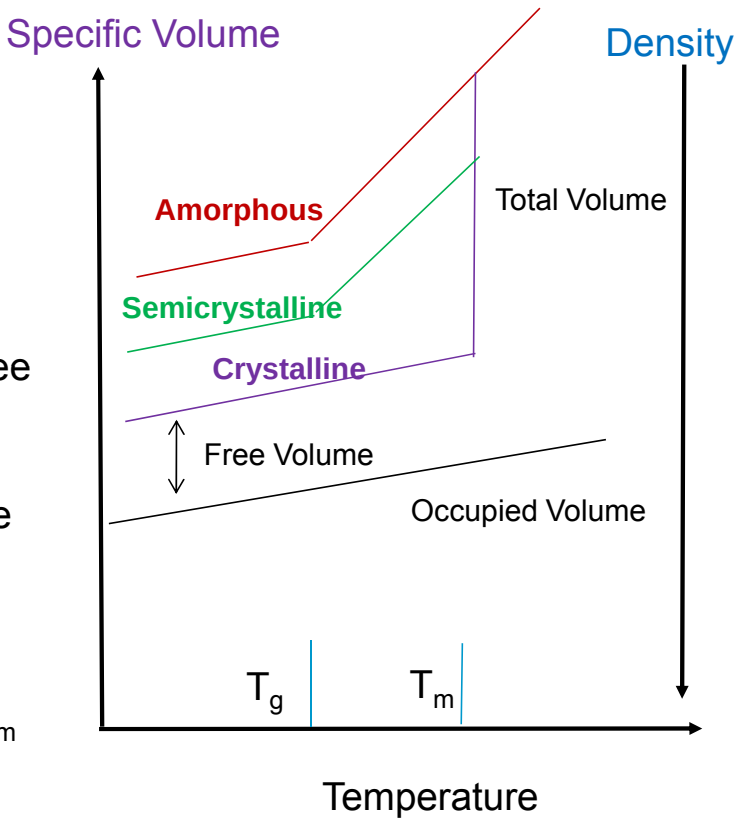
- T_g<T_m - transition through either results in changes to mechanical properties
- Mechanical properties of fibres improved by crystalline fraction

  Polypropylene: 70-80% crystalline T_g~ -10°C, T_m~ 170°C

Background/Polymers

Thermoplastic Polymers

- Heating
  - Materials (polymers) expand when heated
  - Density becomes lower at higher temperature
  - Lower density means more free volume – greater mobility of polymer chains (softening)
  - Semicrystalline polymers have both T_g and T_m
  - Gradual change in volume above T_g - softening
  - Abrupt change in volume at T_m polymer melts – liquid like



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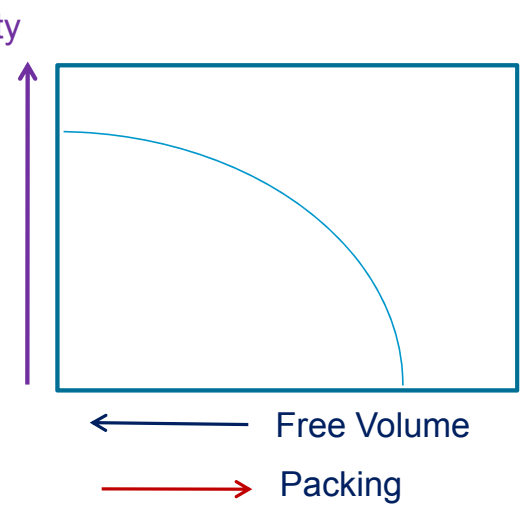
Background/Polymers

Free Volume

- Mobility in close packed systems depends primarily on degree of packing or free volume.
- With increasing packing, mobility decreases, slowly at first then at increasing rate



- Consider exiting a packed elevator or moving offices when there are none spare

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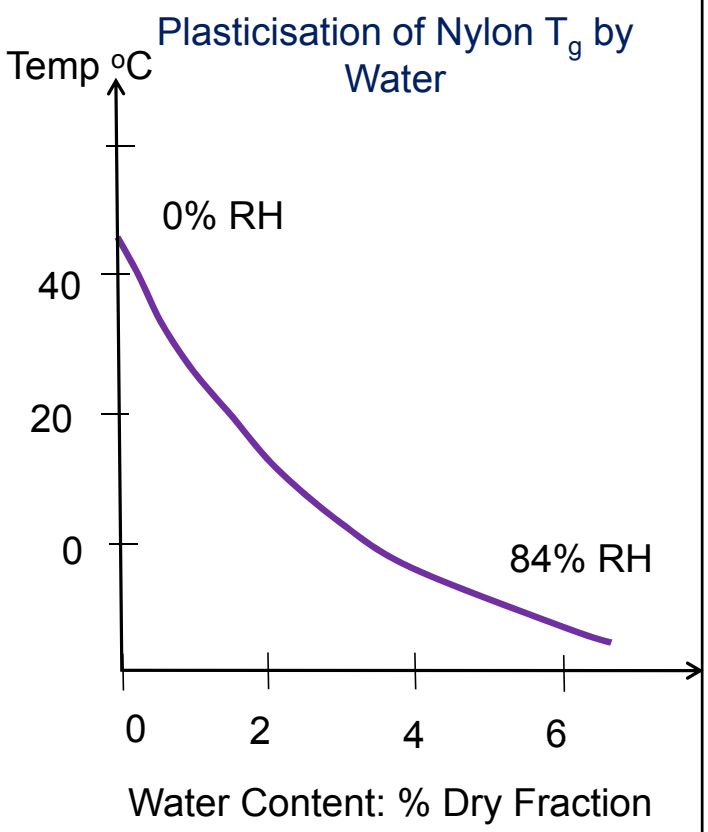
Background/Polymers

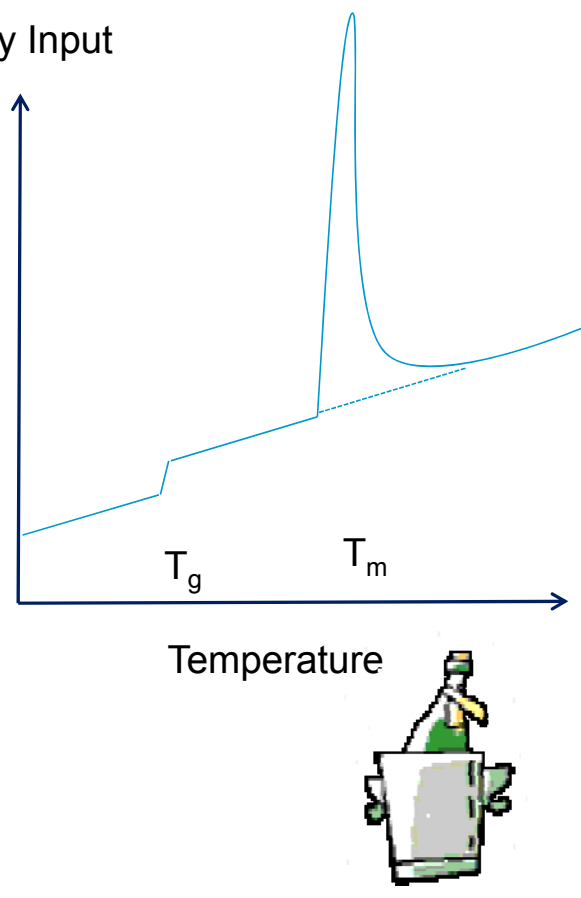
- Plasticisation
  - T_g of amorphous polymers can be lowered by incorporation of a low molecular weight compound that softens and makes more flexible
  - PVC is normally hard T_g~85^{o}C
  - Plasticised PVC <0^{o}C
    - eg with dioctyl phthalate
  - Adding carrier to dyebath improves dyeing of polyester
  - Some plasticisers can evaporate/migrate over time
    - New car smell



See Lim et al; J App Poly Sci, 71, 197, 1999

Background/Polymers

- Heating
  - **At T_g**
    - Some change in heat capacity i.e. more energy required to heat material by a similar amount
    - Heat Capacity (J/gK) Cu=0.4; Al=0.9; Water = 4.2; Polyethylene = 2.3
    - Welding ~100^{o}C above Tg
  - **At T_m**
    - Large input of energy required
    - Temperature only increases once everything has melted (good mixing)
    - Compare with ice in water: temperature remains at 0^{o}C until all ice is melted
    - Rapid solidification of melt outside of heated area
    - Welding ~50^{o}C above Tm

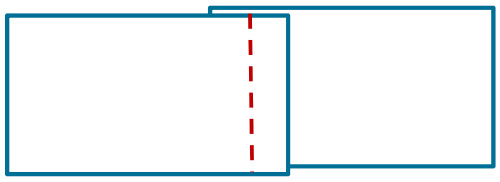


Background/Seams

Seam Geometry

- When sewing need to consider seam geometry for application
- e.g. superimposed or lapped, functional or aesthetic
- Same applies for welding

Superimposed



Lapped

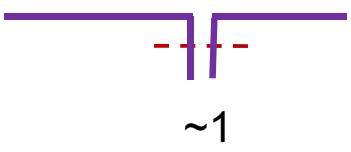
Flat

Background/Seams

Effect of Geometry on Relative Seam Strength

Strength also determined by number of threads carrying load

increase number or yarn strength



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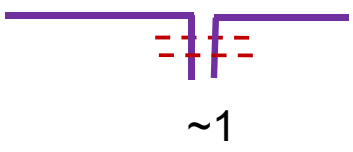

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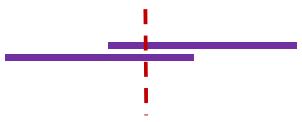

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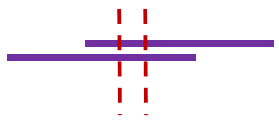

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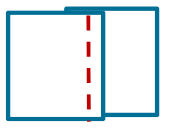

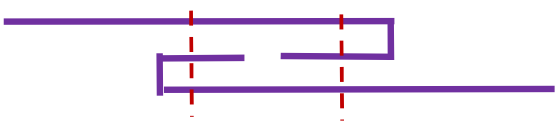

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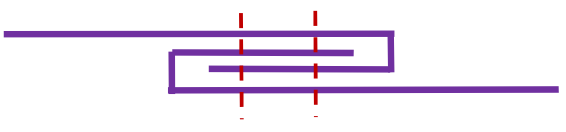

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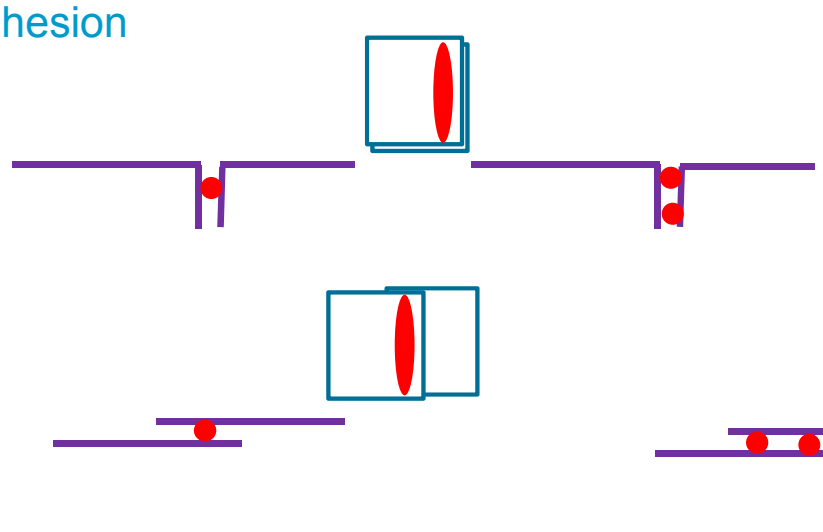
Background/Seams

Effect of Geometry on Relative Seam Strength: Weld Adhesion



Try with postit notes

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Background/Seams

- Example of Peel and Shear
- Gecko foot
  - Covered in hairs
  - Each hair splits into 100's of spatula shaped ends
  - Van der Waals attraction between hairs and surface
  - Need strong shear strength when climbing
  - Curl toe to easily remove by peeling

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Background/Seams

- Sewing
  - Stitching – strong
  - Creates holes in fabric - cannot use for water proof seal (tape to seal)
  - Holes may also lead to stress concentration/tearing
  - Difficult to join fabric to solid material
  - Need skilled operators/training
- Adhesive bonding
  - Relatively slow process
  - Relatively long curing times-optimum strength develops over time
  - Good joint preparation required (e.g. surface activation treatment, solvent cleaning, roughening)
  - Poor wetting/adhesion for some polymers e.g. Polypropylene

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Background/Seams

- Fabric Welding Advantages
  - Fast
  - More tolerant of surface contamination and preparation than adhesive bonding
  - Useful for joining polymers with low surface energies e.g. Polypropylene (poor wetting/adhesion)
  - Liquid/air tight seals can be produced
  - Variety of heating techniques can be used for complex applications for optimum performance/efficiency

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Background/Welding Mechanism

- Welding Requirements: Heat (energy), pressure, time, cooling (pressure)
- Two general options for heating

- External Heating
  - Use convection or conduction to heat the weld surface
  - **Hot wedge**
  - **Hot air**
  - Relatively inexpensive machines
  - High welding speeds 10's m/min – 100 m/min in factory
  - Wide seams up to 50 mm
  - Works better with thicker material (~0.5 mm/layer)
  - Can be used in field/site applications
  - Hot wedge – no noise or fumes compared to hot air
  - Hot air– can weld irregular shape seams e.g. circles
  - Interchangeable heads on some machines

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Background/Welding Mechanism

- Internal Heating
  - Mechanical
    - Conversion of mechanical energy into heat through surface friction and intermolecular friction
    - (Vibration – linear, orbital)
    - (Spin)
    - **Ultrasonic**

- Equipment cost higher but energy use lower, high speed
- Cut and seal edges
- Bond fabrics to formed parts
- Curved, complex patterns possible
- Embossing of fabrics
- Bond nonwoven materials
- Minimal fibre degradation

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Background/Welding Mechanism

- Internal Heating
  - Electromagnetic
    - Conversion of electromagnetic radiation into heat
    - **Induction**
    - **Radio Frequency**
    - **Laser**
    - (Infrared)
    - (Microwave)
  - Equipment cost much higher, particularly Laser
  - Good control over power level, useful for thin materials
  - Minimal fibre degradation
  - Induction – can bond incompatible materials e.g. thermoplastic to aluminium
  - RF – easily automated
  - Laser – automation, complex & intricate parts, deep, narrow and precise

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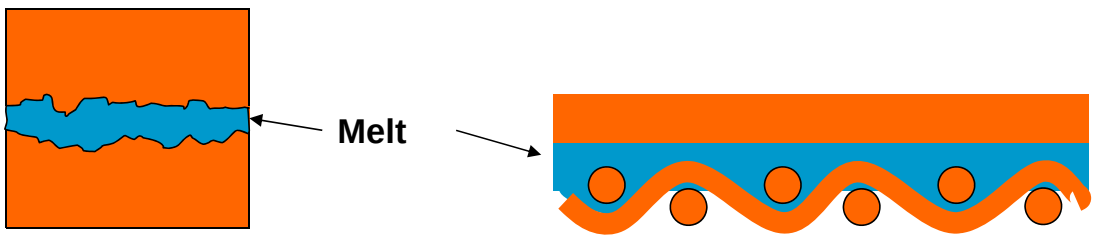
Background/Welding Mechanism

- Mechanical Interlocking
  - Melt enters irregularities in the surface before solidifying
  - Keys into the surface to form a strong bond
  - Potentially more effective with fabric substrate
  - Use bonding tape



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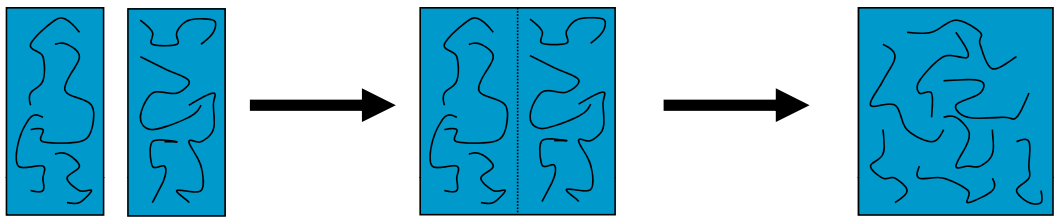
Background/Welding Mechanism

- Interdiffusion
  - Polymer molecules at boundary interdiffuse and entangle
  - Boundary between components is eliminated
  - Requires mobile polymer chains ($T>T_g$ or T_m)
  - Requires compatibility between polymers
    - Same polymer
    - Polyethylene and polypropylene are not compatible
  - Forms a good strong bond



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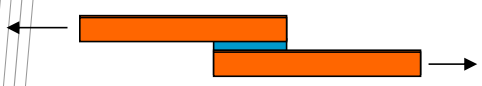
Background/Bond Testing

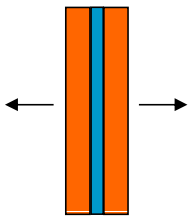
- Bond
  - Type of stress
  - Types of joints

Previously melted region or bonding tape

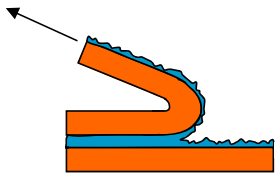
Unmelted substrate



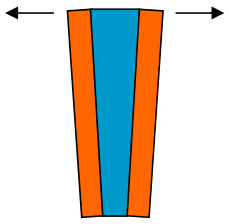
Shear



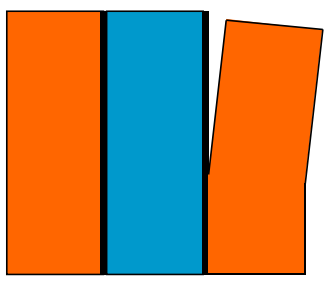
Tension



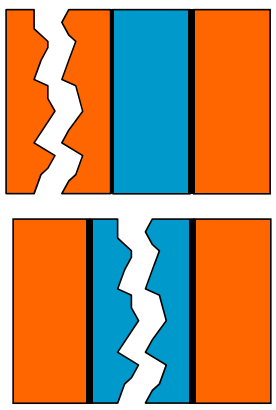
Peel



Cleavage



Adhesive failure



Cohesive failure

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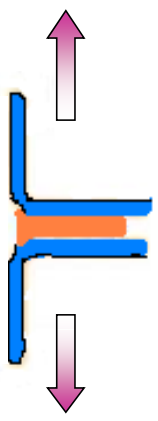
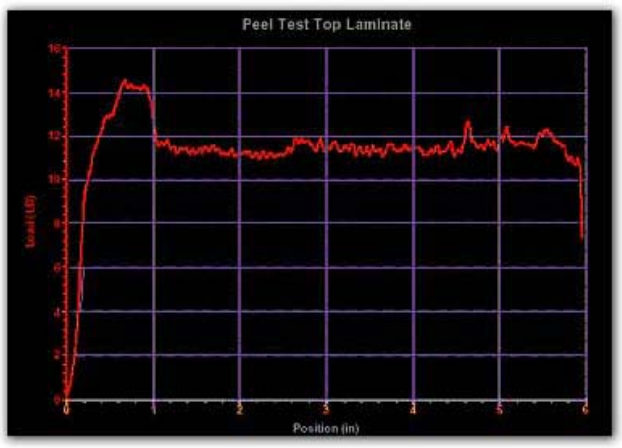
Background/Bond Testing

- Peel Force
  - Resistance of a bonded joint to stripping force applied at a predetermined angle and rate.
  - Test applies line loads, acting at the joint's end
  - Only a fraction of the bond surface is exposed to stress; bond surface is unevenly stressed
- Results depend on
  - strength of the bond
  - evenness of bond
  - width of sample
  - rate of test





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Background/Bond Testing

- Shear Force
  - Resistance to forces acting parallel to the join
  - Join surface is evenly stressed.
  - Generally referred to as "tensile shear strength", since the force is characterized by tensile effects

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Background/Bond Testing

- Fatigue Testing
  - Repeated application of a given load or stress to the joint
    - Flex
    - Deformation
    - Wash performance
    - Dry-clean
    - Environmental exposure
  - Applied loads are less than the failure load
  - Fatigue failure dependent on
    - Frequency and Amplitude
    - Mode of stressing
    - Environment: temperature; moisture, UV exposure, chemical/solvent

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Hot Wedge & Hot Air Welding

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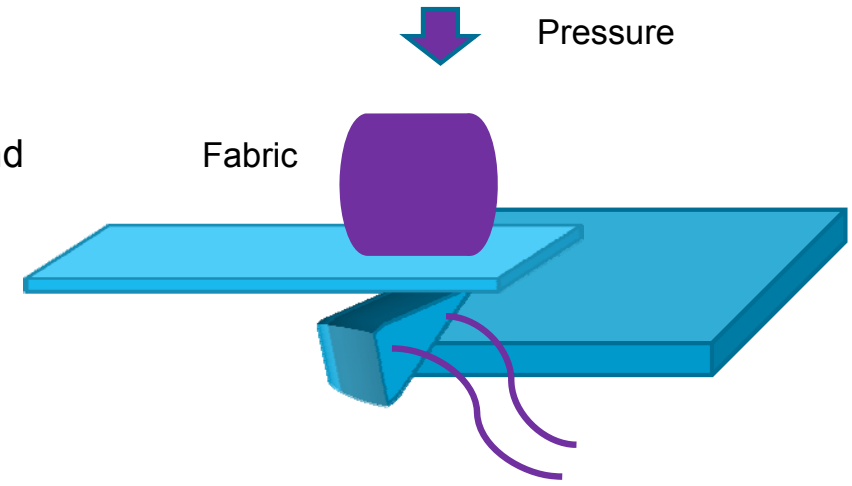
Hot Wedge & Hot Air Welding

- Heated wedge is inserted between the layers of fabric. Fabric surface is softened and pressure is used to form the seal.
- Hot Air– heat is provided by air blowing across electrical heating elements and is injected at the welding point
- Could also use nitrogen gas for materials that are prone to degradation in air



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Hot Wedge & Hot Air Welding

- Relatively inexpensive machines
- High welding speeds 10's m/min – 100 m/min in factory
- Can be used in field/site applications
- Hot wedge – no noise or fumes compared to hot air

Hot Air Welder

http://www.leister.com/uploads/pdf/en/leister-billboards-tarpaulins-eng.pdf

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Hot Wedge & Hot Air Welding

- Wedge and nozzles can be structured to form a double seam e.g. 40 mm wide wedge with 2 x15 mm welded seams with 10 mm pocket for testing

http://www.geomembrane.com/Tech Papers/GeoCongress2008FPR.htm

Split Wedge Welder

http://www.leister.com/uploads/pdf/en/leister-civil-engineering-tunnel-eng.pdf

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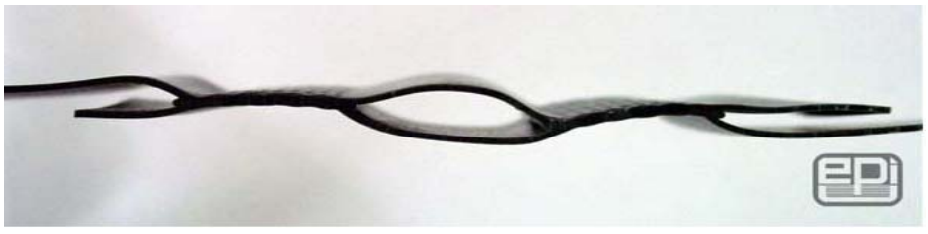
Hot Wedge & Hot Air Welding

- PVC geomembrane seams separated by an unwelded air channel that can be pressurised to ensure good strong join with no leaks
- verify a minimum of 2.6 kN/M (15 lb/in) peel strength (ASTM D 7177)



http://www.geomembrane.com/Testing/airtest.htm

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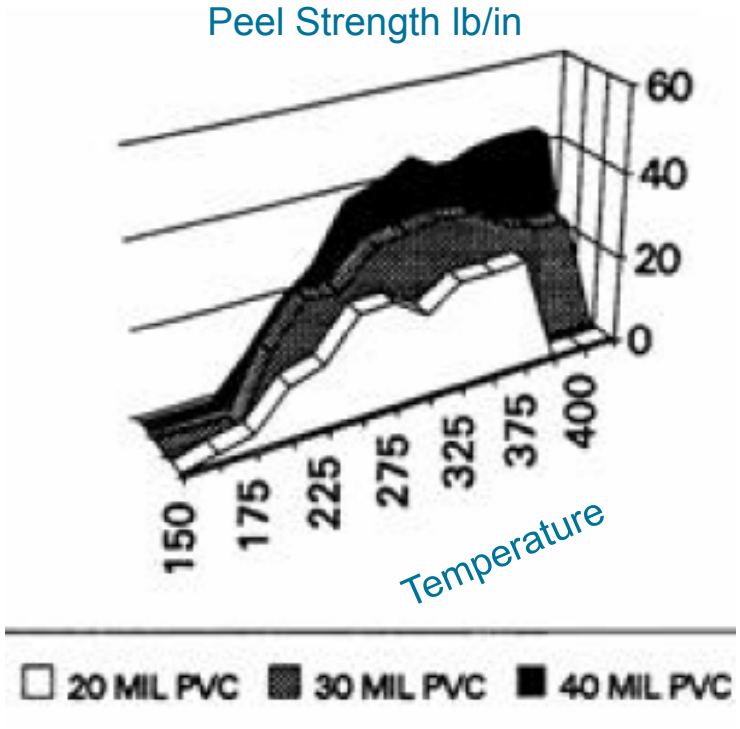
Hot Wedge & Hot Air Welding

- Split wedge welding PVC membrane
- Welding window for all three thickness is 250-375^{o}C
- Can overheat seams if not careful reducing strength
- Delamination of PVC coating from scrim
- If overheated, fabric often weakened adjacent to seam



http://www.geomembrane.com/thermal_welding/wwtemp.html

Hot Wedge & Hot Gas Welding

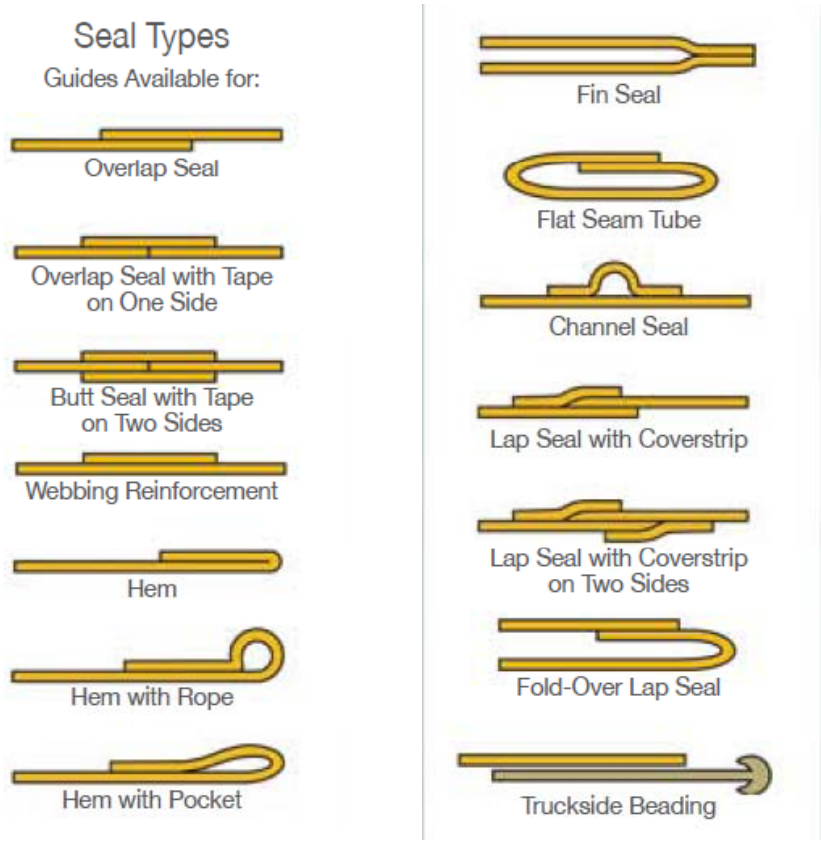
- Acrylic fabrics
  - Awnings, boat covers etc
  - Cannot be directly welded to produce a strong seam
  - Possible using a tape (e.g. polyurethane) inserted between the seam
  - Melts on heating to form the seam/join
  - Process can also be used for joining materials that are not thermoplastic or different materials using compatible tape

Acrylic Wedge Welder

http://www.sineqco.com/products/SpecWedgeWelderDescription.asp

Hot Wedge & Hot Air Welding

- Variety of seams and seal are possible



see http://www.weldmaster.com/

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Hot Wedge & Hot Air Welding

- Applications
  - PVC laminated and coated fabrics
  - Polyurethane films
  - Polypropylene coated fabrics
  - Polyethylene non woven
  - Thermoplastic rubber fabrics
  - Polyester non woven
  - Acrylics for awnings and marine
  - Fusing tapes, weldable velcro, webbings

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Hot Wedge & Hot Air Welding

- Automated/industrial systems available

http://www.elizabethmachines.com.au/Products/T-300.aspx

Ultrasonic Welding

Ultrasonic Welding

- Competes with thermal bonding
- Equipment cost is higher but energy use is lower
- Reasonably high speeds
  - 10's metres/minute
  - Shortest welding times
- No consumables (possible)
- Reduced fibre degradation– energy/heat generated within the fibres at joint site
- (thermal bonding: heat is conducted through fibres to soften)
- Impermeable seam if required

http://www.branson-plasticsjoin.com/pdf/Chase%20FS-90%20sell%20sheet.pdf

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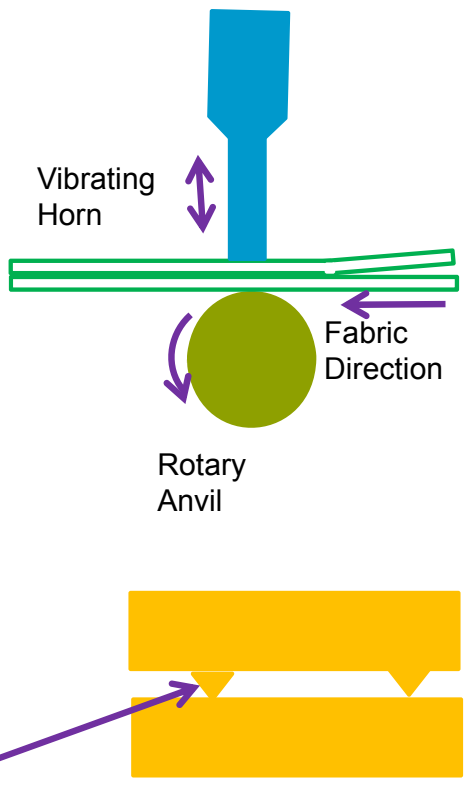
Ultrasonic Welding/Process

- Ultrasonic: beyond audible sound >18 kHz
- Vibrations and compression produced in region between horn and anvil create intermolecular and boundary friction (heat) at material interface.
- Frequency 20 - 40 kHz:
  - Higher frequencies smaller and quieter equipment, reduced wavelength, amplitude, power and working distance (near field)
- Polymer softens locally then greater dampening causes acceleration of melting
- Heat generated is highest at joint surface due to surface asperities (greater strain & friction)
- Pressure maintained between horn and anvil



•If solid materials use energy director to initiate softening

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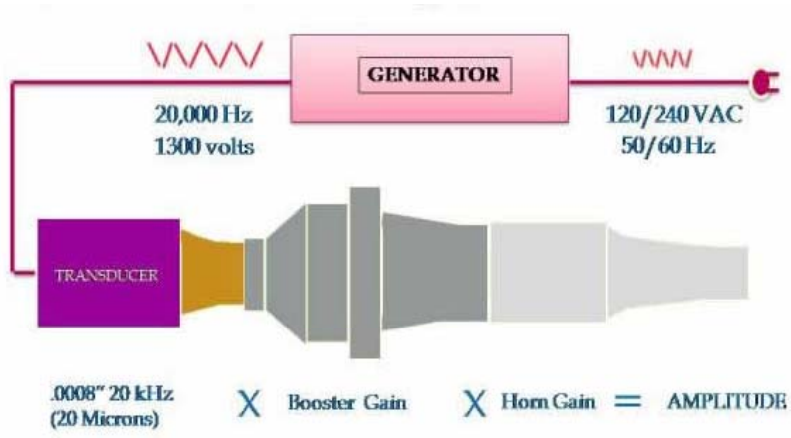
Ultrasonic Welding/Equipment

- Power Supply/Generator
- Converter or Transducer
  - converts electrical energy into high frequency vibrations via a piezoelectric ceramic
- Booster
  - Increase or decrease the amplitude of the vibrations (e.g. 0.5 to 2.5 times)
- Horn or Sonotrode
  - Transfers mechanical vibration to the work piece (high strength aluminium alloy, hardened steel, titanium).
  - Amplitude 10's microns



http://www.eina.es/english/Technologies/Welding-ultrasonics.html

Ultrasonic Welding/Equipment

- Anvil
  - Supports the material (opposing force), patterned to intensify energy and form seam, or cut and seal
  - http://www.branson-plasticsjoin.com/pdf/PW-45_FS-90.pdf
- Stand/Fixtures
  - Ultrasonic cutting/slitting, sealing, seaming, tacking
  - Plunge mode
  - Rotary/continuous welding – machine fixed, fabric moves
  - Traversing – fabric fixed, machine moves
  - With bonding tape

Ultrasonic Welding/Equipment

- The closer the horn can be located to the join the greater the efficiency
  - <6 mm near field; >6 mm far field
- Transmission of ultrasonic vibrations from horn to joint is more efficient (less energy loss) if ;
  - Amorphous polymer
  - Stiff/rigid polymer
- Joining dissimilar materials
  - Need Tg difference less than 20^{o}C between two materials e.g. different acrylics
  - Must be chemically compatible (e.g. acrylic and polycarbonate compatible for interdiffusion of polymer chains)
  - Different semicrystaliline polymers generally not compatible

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Ultrasonic Welding/Equipment

- Bond integrity governed by amount of energy provided
- Only three variables
  - Amplitude (booster, horn design and power supply control)
  - Pressure (pneumatic press)
  - Time (throughput speed)

- Simplified power formula

$$E = P \times t$$

E = energy; P = power;
t = time or throughput speed

$$P = F \times V$$

F = force; V = velocity, frequency, & amplitude,

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Ultrasonic Welding/Materials

- Polyester
  - Good material for ultrasonic applications
- Nylon
  - Nylon 6 and 6,6 can produce strong, neat seams
- Polyolefin
  - Good ultrasonic welding properties; polypropylene preferred over polyethylene
- PVC
  - Difficult to predict due to broad range of additives e.g. plasticisers to increase flexibility (plasticisers can inhibit)
- Polyurethane
  - Both thermosetting (e.g. ether base) and thermoplastic (e.g. ester base) are possible
  - Ultrasonic only useful for thermoplastic polyurethane

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Ultrasonic Welding/Materials

- Acrylic
  - Copolymer containing > 85% polyacrylonitrile polymer
  - Can be ultrasonically cut or tacked but due to embrittlement bonding strength is low
- Modacrylics
  - Copolymer (containing < 85% polyacrylonitrile) with other polymers e.g. PVC
  - Good bonds possible depending on fabric construction and seam selection
- Blends
  - >60% thermoplastic polymer – other can be wool, cotton, linen, rayon etc
  - > thermoplastic content the greater bond strength
  - Use bonding tape

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Ultrasonic Welding/Materials

Relative ease of ultrasonic welding polymers
Do not relate to strength of weld obtained
****Easiest; *Difficult - Material not generally in this form

	Woven	Nonwoven	Knitted	Coated	Laminates
Polyester	****	****	***	****	****
Nylon	***	***	***	***	***
Polypropylene	****	****	***	***	***
Polyethylene	-	****	-	****	***
Acrylic	*	-	*	-	-
PVC	**	-	-	**	**
Polyurethane	-	-	-	****	-

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Ultrasonic Welding/Applications

- Polyester
  - Conveyer belts, filters, mattress pads, quilts
- Polyethylene
  - Laminates, resealable bags, disposable garments
- Polypropylene
  - Carpet backing, tents, upholstery, disposable garments
- Nylon
  - Carpets, filters, garments, seat belts, lingerie
- Acrylic
  - Filters, awnings, blankets, knits
- Polyurethane
  - Rainwear, coated materials
- PVC
  - tarpaulins

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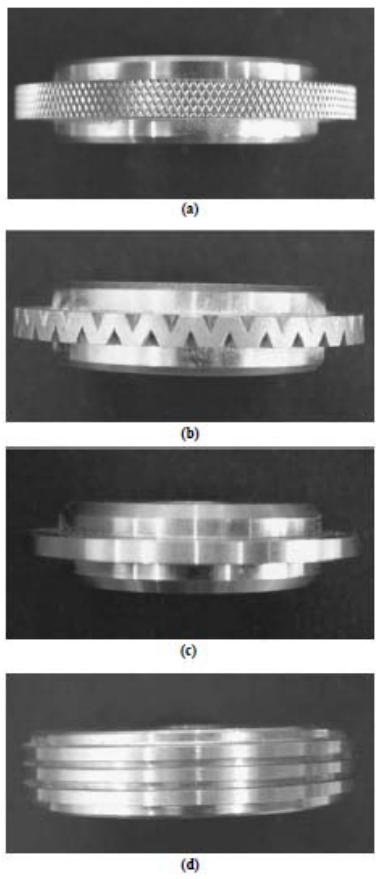
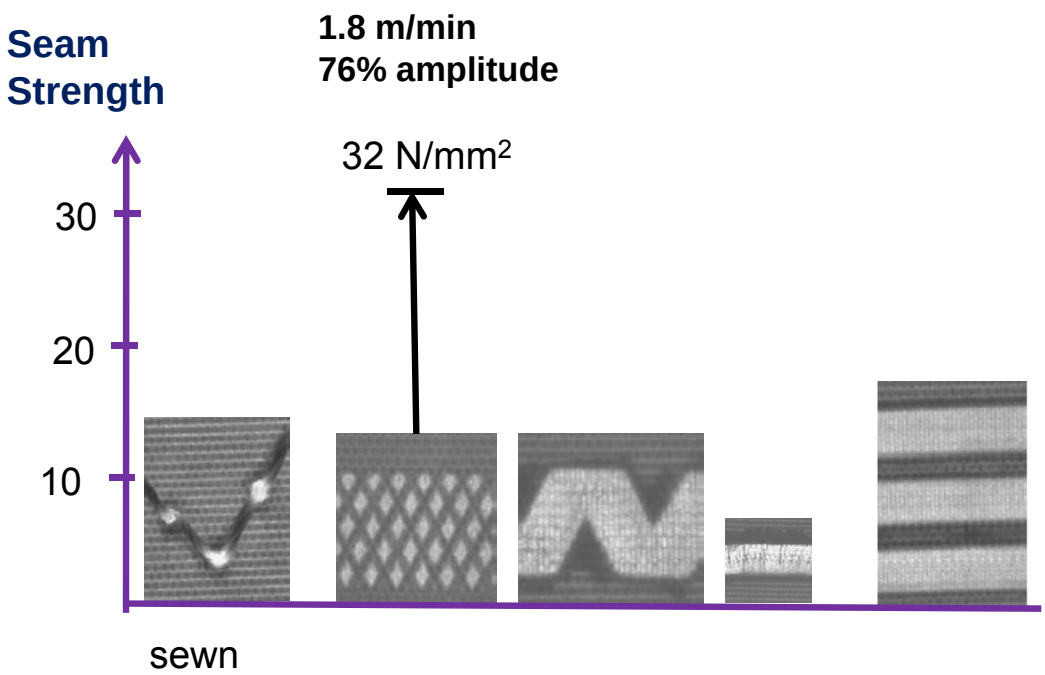
Ultrasonic Welding/Example

- Ultrasonic welding of a sail
  - Polyester woven fabric 40 g/m^2
  - 2D cloth -> 3D sail
  - Seam/bond tensile strength and impermeability important
  - 400 W, 30 kHz ultrasonic welding machine
  - Variables
    - Speed 0.6, 1.8, 3 m/min
    - Amplitude 50, 76, 100%
    - Various anvil wheels
    - 0.18 mm gap and 2.4 bar pressure between sonotrode and anvil wheel
  - Comparison with sewing



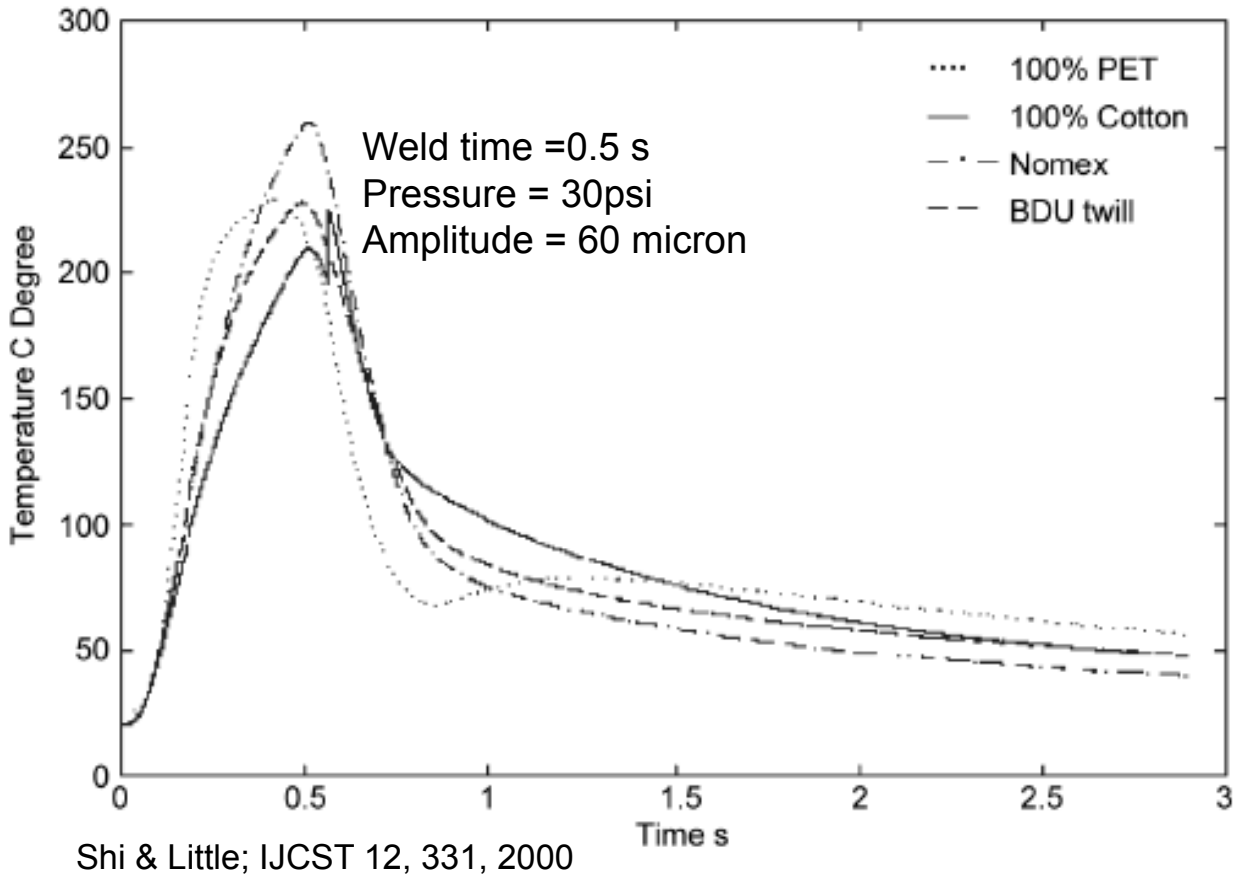
Vujasinovic et al, IJCST 19, 204, 2007

Ultrasonic Welding/Example



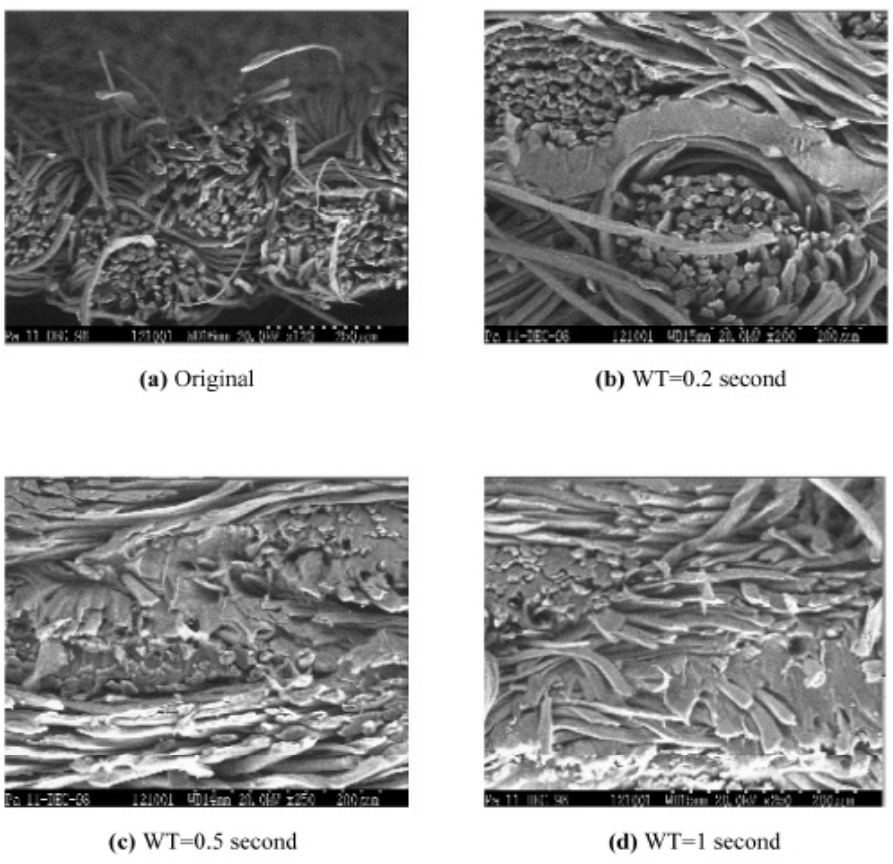
See Vujasinovic et al, IJCST 19, 204, 2007

Ultrasonic Welding/ Further Example



Shi & Little; IJCST 12, 331, 2000

Ultrasonic Welding/ Further Example



Pressure = 30 psi
Amplitude = 60 μm
Polyurethane film
50/50Nylon/cotton twill

Shi & Little; IJCST 12, 331, 2000

Ultrasonic Welding/Example

http://www.sonobondultrasonic.com/welders-bonders-nonwovens.asp

http://www.youtube.com/watch?v=wpoWoq-yr4I&feature=related

http://www.youtube.com/watch?v=V90DatJYc4c&feature=related

http://www.youtube.com/watch?v=TmMmgsIvoS4&NR=1

http://www.youtube.com/watch?v=Lm9oKbrgcbc&feature=related

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Radio Frequency Welding

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Radio Frequency Welding

http://www.nemeth-engineering.com/index_files/Automatic_Plastic_Welders.htm

Also called high frequency welding or dielectric welding

KLR-3000CW,High frequency welding machine

www.keepleader.com

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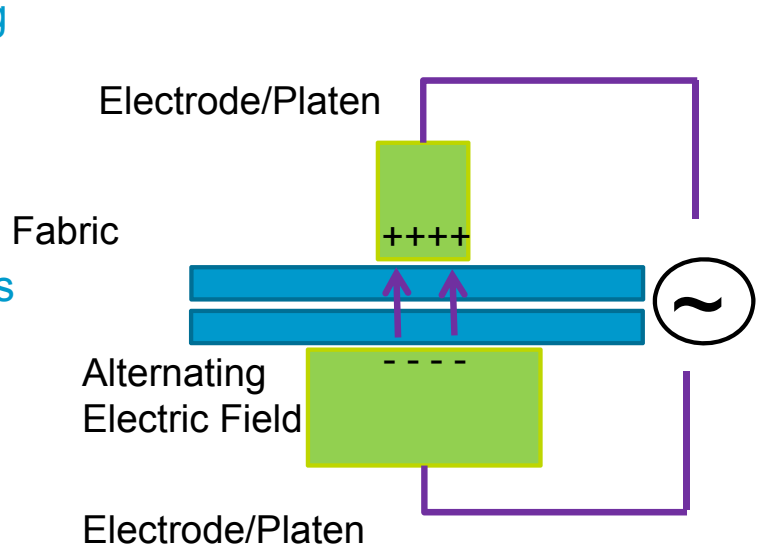
Radio Frequency Welding

- Uses high frequency alternating electromagnetic energy for heating
- Need strong (alternating) electric field between electrodes
- Only for thin sheets, films, coated fabrics
- Heat generated by dielectric hysteresis/loss in polymer



Typically 27 MHz (13-100 MHz)
1-1.5 kV AC

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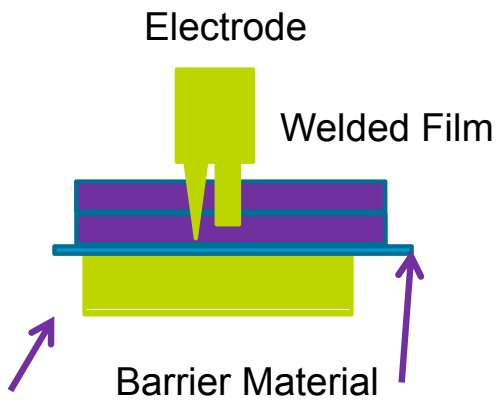
Radio Frequency Welding

- Advantages
  - Fast, (2-5s)
  - Can weld multiple layers simultaneously
  - Easily automated
  - Good weld appearance
  - Also used for tear seals or score marks for hinges
- Disadvantages
  - Material restriction –not all polymers can be RF welded
  - Limited thickness of materials – need high electric field strength

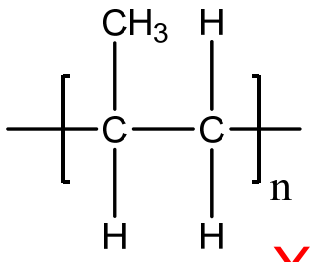


Radio Frequency Welding

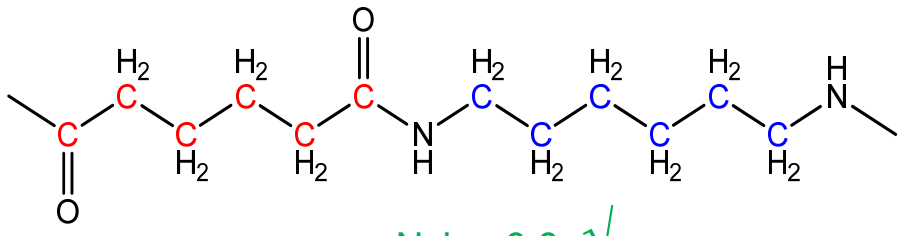
- Material must have required electrical properties
  - High relative dielectric constant (relative permittivity)
    - Ratio of the amount of electrical energy stored in a material by an applied voltage, relative to that stored in a vacuum
    - Typically greater than 2: vacuum =1 by definition, air = 1.0006
  - High dielectric loss (major requirement)
    - Measure of loss of energy and heating when dielectric material is in alternating field
  - High dielectric breakdown
    - Minimise “short circuit” through material
    - Most polymers for RF welding have good inherent properties

Radio Frequency Welding

- Requires Polymer with Polar groups (dipole moment)



Polypropylene X



Nylon 6,6 √

- Heating related to field strength and frequency but also
  - Size of dipole moment
  - Molecular freedom
  - As material is heated, more free volume and more molecular movement
  - For most thermoplastics, dielectric loss is proportional to temperature
    - Can lead to thermal runaway (rapid temperature rise)

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Radio Frequency Welding/Polymer Suitability

- Suitable Polymers
  - PVC and polyurethanes most common for RF welding
  - Nylon (need heated platen)
  - Polyester (need heated platen)
  - Special grades PP and PE
  - Cellulose acetate

- Not suitable
  - PTFE
  - Polystyrene
  - Standard grade PP and PE

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Radio Frequency Welding

- Power Requirements
  - Type of material: higher loss factor, lower power
  - Thickness: thicker materials require lower power, less heat loss
  - Seam length: long narrow require more power than short wide of same area
  - Barrier or buffer material: e.g. polyester, PTFE, use reduces heat loss
  - 10 - 30 cm^2 requires 1 kW of RF power

- Equipment Features
  - Platen temperature may need to be controlled – minimise cooling time
  - Heated platen – for nylon or polyester
  - Third bonding material / seam tape

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Radio Frequency Welding/Applications

- Chair upholstery
- Quilting
- Table mats
- Tarpaulins
- Awnings
- Tents
- Pool liners,
- Transportation (truck) covers
- Air bags
- Bonding vinyl pads to automotive carpets

Polymer	Ease
Polyester	***
Nylon	***
Polypropylene	*
Polyethylene	*
Acrylic	*
PVC	****
Polyurethane	****

**** Easiest * Difficult

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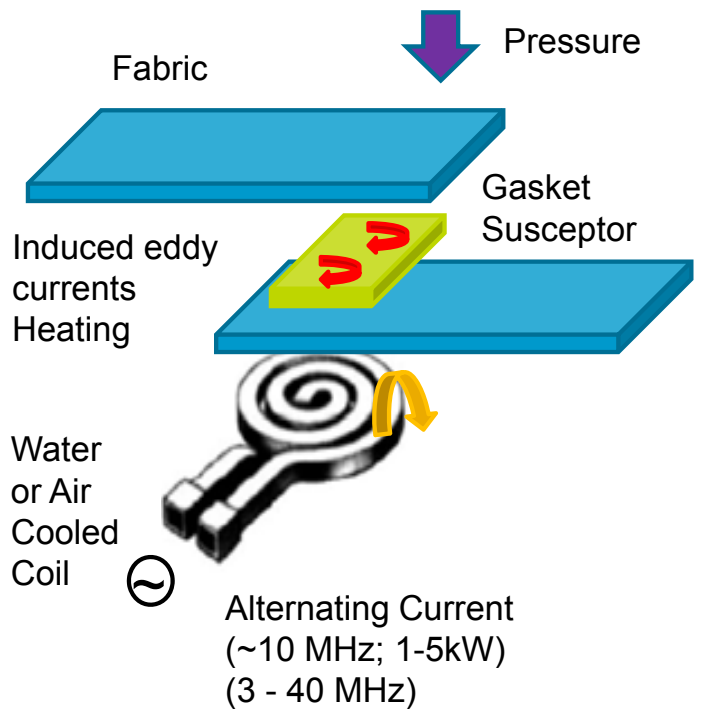
Induction Welding

Induction Welding

- Also called electromagnetic welding
- Uses an alternating electromagnetic field to inductively heat material;
  - eddy currents
  - magnetic hysteresis



Induction Welding

- Advantages
  - Remote heating of joint area
  - Good control of heating and cooling (power level)
  - Complex joints with multiple curvatures can be welded
  - Joining dissimilar materials e.g. thermoplastics to ceramics, aluminium
  - Less dependent on properties of materials being welded
  - Rapid, long joins possible
- Material that gets heated needs to be
  - Non-magnetic electrical conductor
    - e.g. aluminium, stainless steel –closed loop e.g. mesh
  - Ferromagnetic
    - e.g. iron, carbon steel, special ceramics
  - Thermoplastic polymers do not fit either category

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Induction Welding

- Requires suitable implant or gasket
  - Susceptor: material that absorbs electromagnetic energy
  - Usually a composite of thermoplastic polymer being welded, or compatible with
    - containing metal fibres (mesh, foil)
    - micron sized ferromagnetic powders (<15%), iron, stainless steel, ferrite, ceramics
    - may require a custom made material e.g. a blend of the two thermoplastics to be joined
    - can also be a liquid with electromagnetic material
  - Process melts implant that fuses with surrounding material
  - Sheets, extruded profiles, injection moulded parts, tapes, strands etc

http://www.emabond.com/pdf/Assembly%20Tech%20Expo%202003.pdf

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Induction Welding

- Disadvantage
  - Consumable gasket/susceptor adds to cost
  - Gasket remains at the joint interface (may be dismantled)
  - Coil design is important (custom designed for each application)
  - Cost of equipment and development of optimal coil design can be high
  - Coupling distance must be small - field strength drops rapidly with distance between coil and susceptor
  - Potential rusting of metal particles in susceptor

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Induction Welding

- Examples of coils
  - Single turn, multiturn, hairpin, split
  - Coils need to follow contours of join
  - Magnetic field strength greatest within perimeter of coils – joints placed in centre of coil
  - Coils may be embedded in PTFE or ceramic block to apply pressure
  - Water or air cooled
  - Flexible cables

Ahmed et al; Composites A37, 1638, 2006

Hairpin coil

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Induction Welding/Example

*www.kse-oettle.de/**emabond**praesentation.ppt*

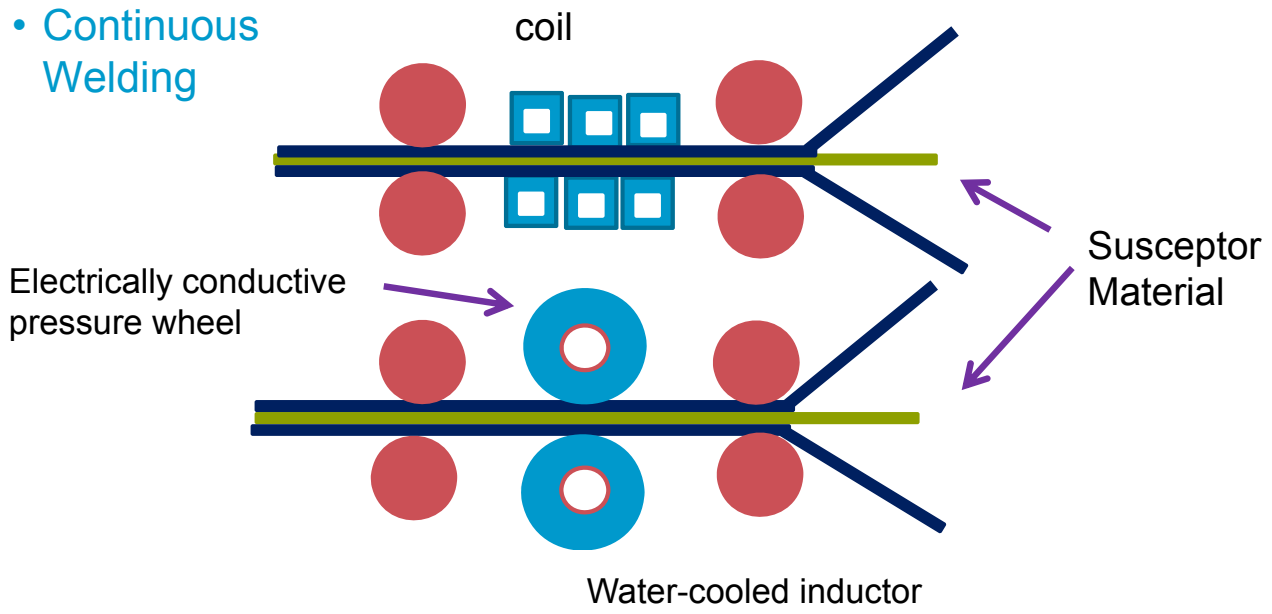
Induction Welding

- Susceptor material important for operating frequency
  - equipment frequency range 3 - 40 MHz
- Low frequencies - conductive fillers best
- High frequencies - ferromagnetic better
- Setup - measure temperature of gasket - cannot use thermocouple need optical sensors

- Carbon fibre reinforced thermoplastics may be directly welded
  - Electrically conductive
  - Cross ply not unidirectional as require closed current loop

Induction Welding

- Continuous Welding

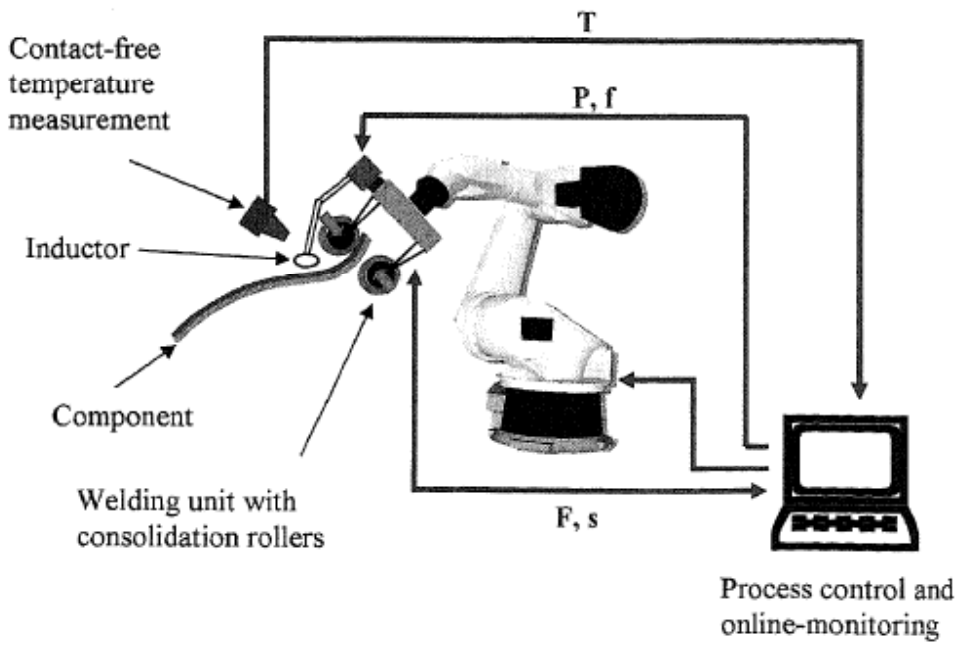


- Sealing

http://www.youtube.com/watch?v=xrFatizavH4&feature=related

Induction Welding

- Robotic Welding System



Moser et al; SAMPE Journal, 44,43,2008

Laser Welding

Laser Welding

- Infrared (IR) heating using a laser
- Two approaches

- Direct Welding
  - Laser used to heat surface, melt polymer similar to hot welding
  - Technique does not offer the major benefits of laser welding

Robotic manipulation of diode laser welding upholstery to polyvinyl chloride-coated wooden divan drawer.

http://www.clearweld.com/datasheets/TTIArticleMay05.pdf

Laser Welding

- Through Transmission IR Laser Welding
  - Main laser welding approach
  - Top layer transparent to IR, lower or intermediate layer absorbs IR energy
  - Non contact welding (part held by transparent (glass) plate)
  - Weld occurs at interface (no melting of external fabric structure)
  - Minimal heat affected regions
  - Can be used to weld elastomeric or difficult materials
    - polyetheretherketone PEEK
    - polyetherimide PEI
  - Good control over power levels
  - Water proof flexible seam
  - Outer surface texture retained

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Laser Welding

- Disadvantages
  - High equipment cost
  - One material needs to be laser transparent the other absorbs laser energy
  - Coating or carbon black can be applied at interface to increase range of options (additional cost)
- Equipment
  - Laser:
    - Carbon dioxide (CO_2): gas
    - Diode laser (high power): semiconductor
    - Nd:YAG neodyniumyttrium-aluminium-garnet: solid state
- Applications
  - Bed assemblies
  - Medical furniture
  - Clothing
  - Airbags

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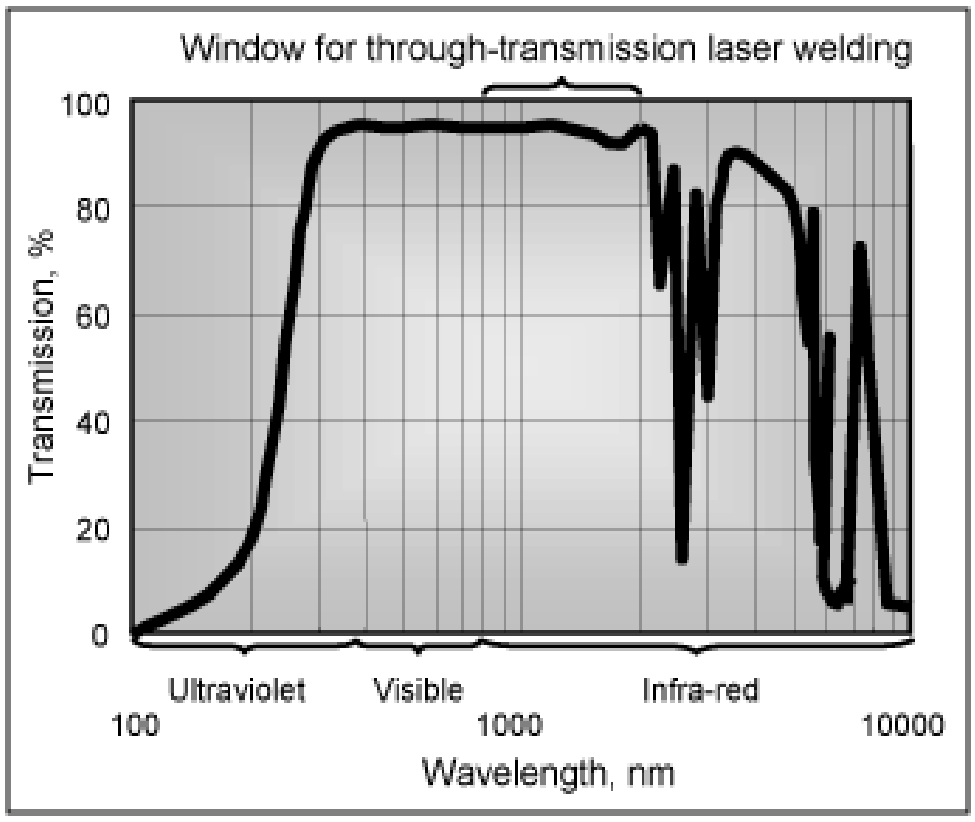
Laser Welding

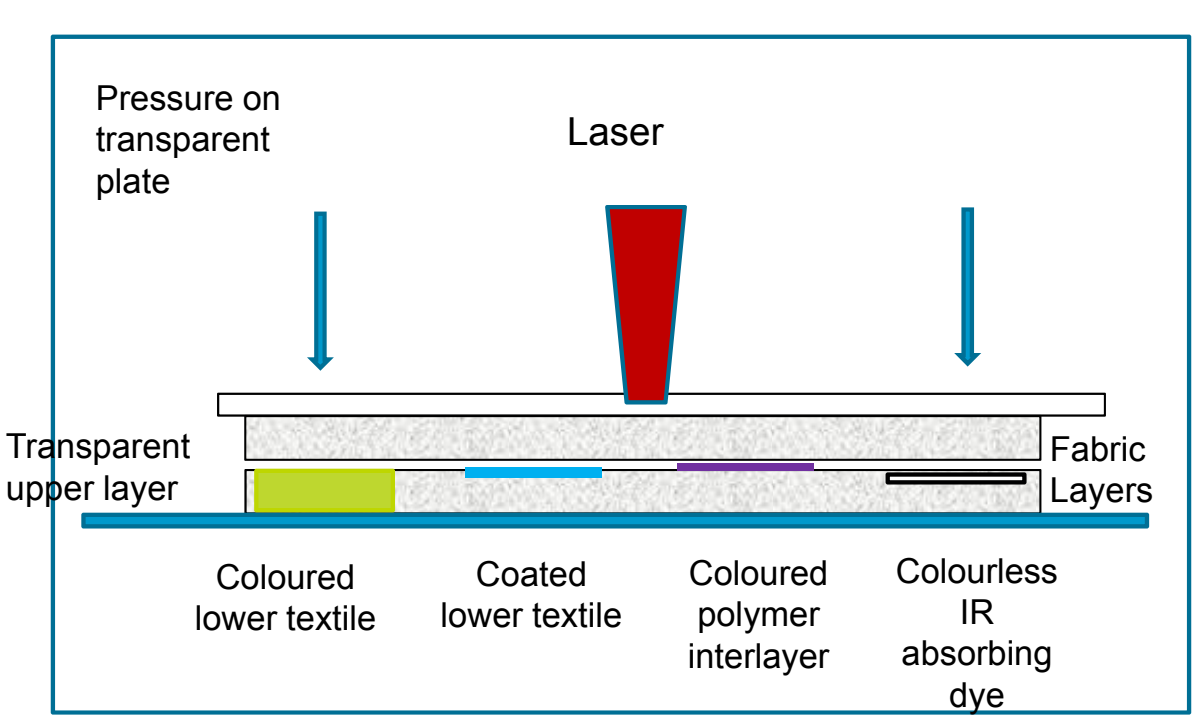


Absorption of typical thermoplastic polymers

http://www.twi.co.uk/content/spcmwapr2006.html

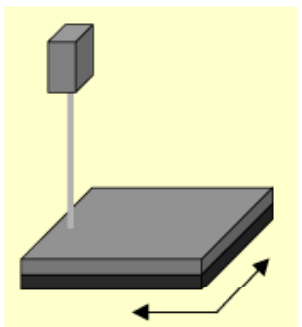
Laser Welding

Options for producing a transmission laser welded seam

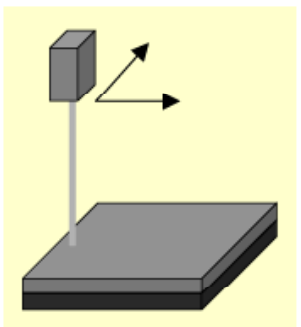


Laser Welding

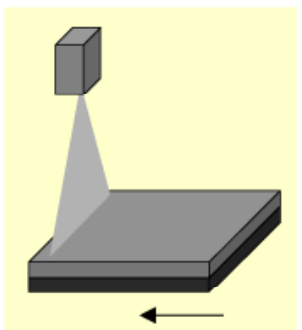
a) Moving workpiece;



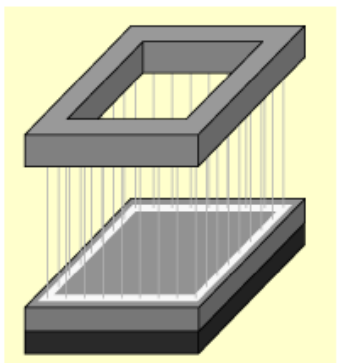
b) Moving laser;



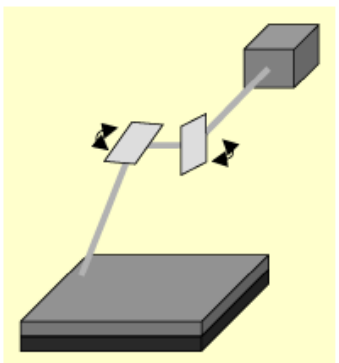
c) Curtain laser;



d) Simultaneous welding;



e) Scanning laser



http://www.twi.co.uk/content/spcmwapr2006.html

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Laser Welding/An Example

- Automotive airbag production
  - Frequent product changes, short innovation cycles
  - Intense cost pressure – machinery flexibility
  - High product quality and seam strengths (1000 N/5cm)
  - Woven fabrics of Nylon 6,6 or polyester

http://en.wikipedia.org/wiki/Airbag

Hustedt et al, Third World Automotive Congress Plastics-in-Motion 2008, Prague, 14 – 16 May, 2008

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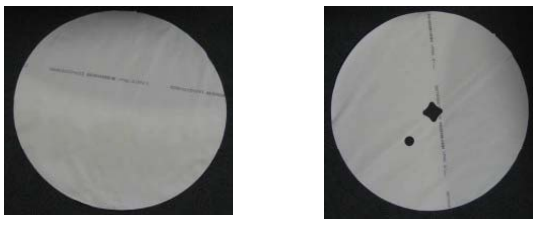
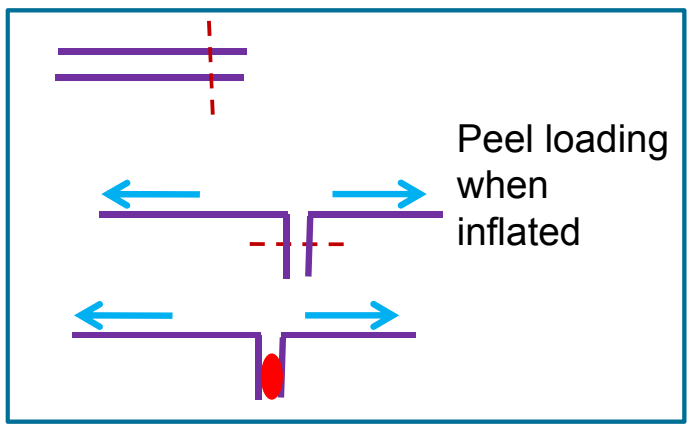
Laser Welding/An Example

- Seam Geometry
  - Seam normally sewn
  - top and bottom plate



http://www.lmba.de/temp/explorer/files/forschung/Airbag_welding_Prague_May_2008.pdf

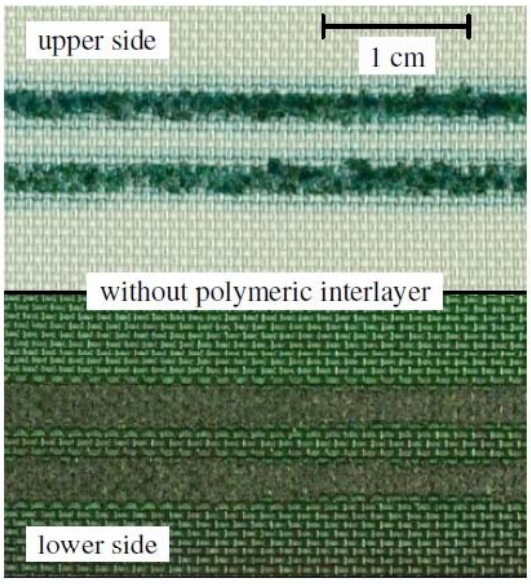


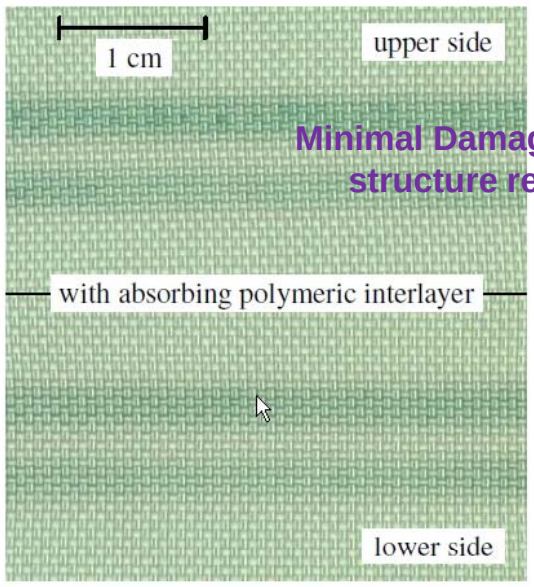
Laser Welding/An Example

- Experimental Approach
  - Nylon 6,6 woven fabric, 370 μm thickness, 700dtex yarn count
  - Fabric tensile strength > 3kN/5 cm
  - Diode laser 940 nm wavelength
  - Dyed bottom textile layer or coloured interlayer
    - Nylon films or calendered thin woven textile
    - Thickness 30-230 μm

- Best results
  - Calendered thin woven Nylon 6,6 interlayer
  - Peel Seam Strength: ~300 N/5cm no interlayer, ~550 N/5cm with
  - Lap Seam Strength: ~500 N/5cm no interlayer, ~1200 N/5cm with
  - Lap seam with interlayer meets strength requirements

Laser Welding/An Example





Minimal Damage: Textile structure retained

Appearance of Welded Seam under Optimum Conditions

Hustedt et al, Third World Automotive Congress Plastics-in-Motion 2008, Prague, 14 – 16 May, 2008

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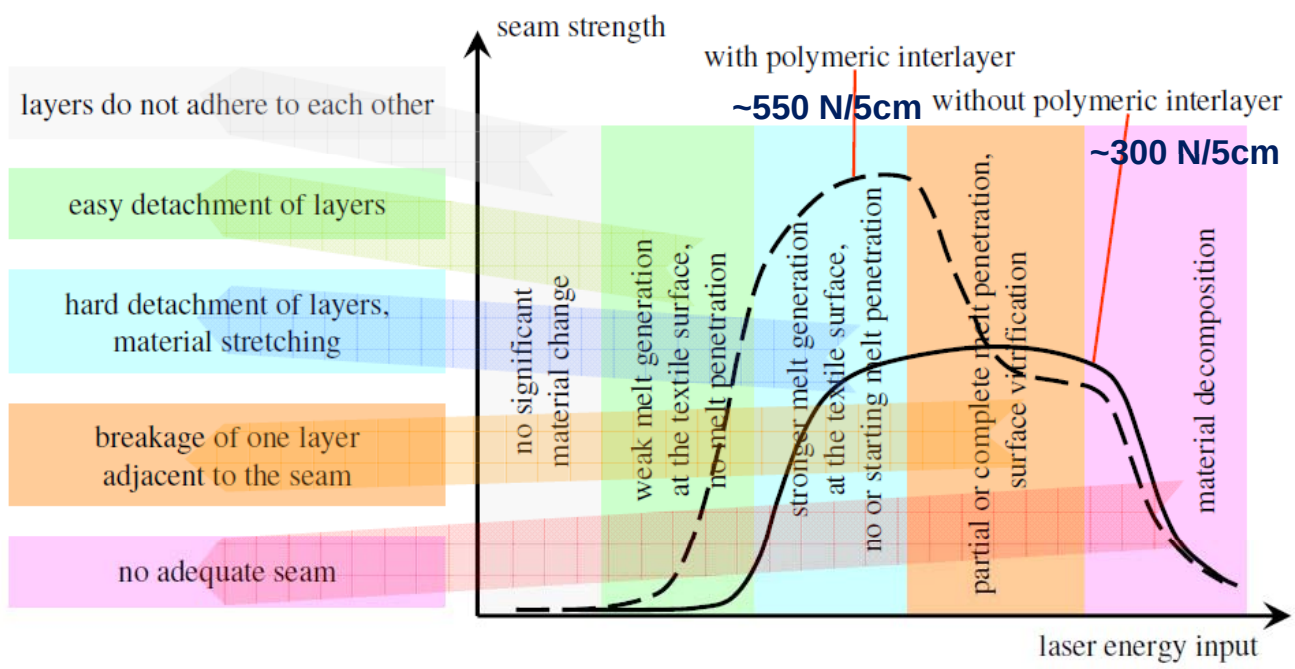
Laser Welding/An Example



Seam Strength (Peel) as a Function of Laser Energy

Hustedt et al, Third World Automotive Congress Plastics-in-Motion 2008, Prague, 14 – 16 May, 2008

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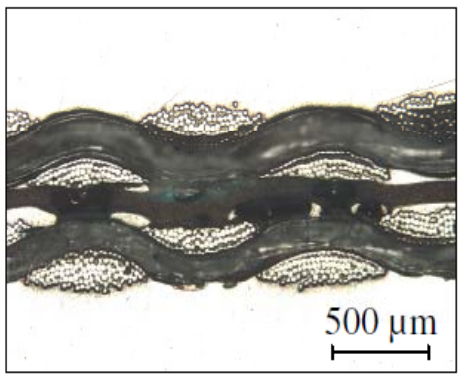
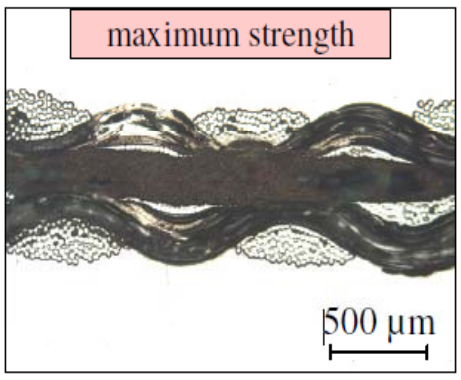
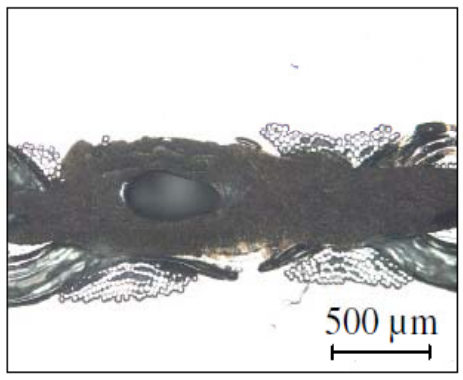
Laser Welding/An Example



molten interlayer material (textile layers are stuck up), fibre structure almost completely preserved



molten interlayer material (mixture in the peripheral zone of the textile layers), fibre structure preserved to a large extent



interlayer material mixed with the textile layers in the seam centre, fibre structure widely destroyed

increasing average laser power

Hustedt et al, Third World Automotive Congress Plastics-in-Motion 2008, Prague, 14 – 16 May, 2008

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Polymer	Hot Air & Hot Wedge Welding	Ultrasonic Welding	RF Welding (Dielectric)	Laser Welding (Through Transmission)	Induction Welding
Polyethylene	****	****	*	The top fabric layer must be transparent to IR radiation while the second layer or an intermediate bonding layer absorbs the radiation.	A conducting or ferromagnetic susceptor, gasket or tape is necessary generally moulded from the same polymer. Method allows flexibility in joining dissimilar materials.
Polypropylene	****	****	*		
Polyester	b***	****	***		
Polyamide	b***	***	***		
Polyacrylonitrile	c*	*	*		
Polyvinylchloride	****	**	****		
Polyurethane	****	****	****		
Polyphenylene sulfide	**	**	*		
Natural Fibres	Possible for fabrics with greater than 50% thermoplastic fibre or use thermoplastic bonding tape: ***				

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****Easiest; *Difficult; Related to ease of welding not bond strength, polymer fillers and additives may impact welding ease and performance.

Useful References

Joining of Plastics: Handbook for Designers and Engineers

Handbook of Plastics Joining: A Practical Guide

Plastics and Composites Welding Handbook

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Acknowledgments

International Fibre Centre

Supporting Training & Education in Textiles

Filtration & Separation Association

EMCO ELIZABETH MACHINES CO.
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