DEVELOPING THE NEXT GENERATION OF POLYETHYLENE BASED SINGLE POLYMER COMPOSITES

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UNIVERSITY OF LEEDS

FuturePlas

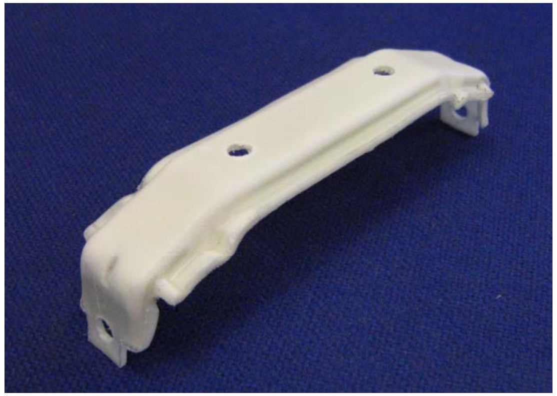
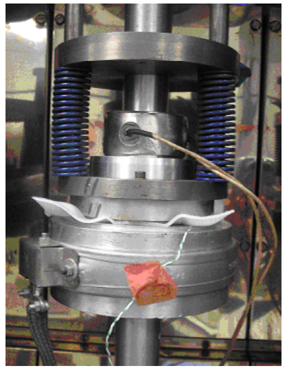
polymer IRC

IRC Meeting September 2009

OUTLINE

- What are self reinforced, single polymer composites.
- Previous studies on polyethylene
- Recent work on polyethylene FuturePlas

    The effect of weave style
    Thermoforming studies
    Production and testing of demonstrator component.

POLYMER/POLYMER COMPOSITES

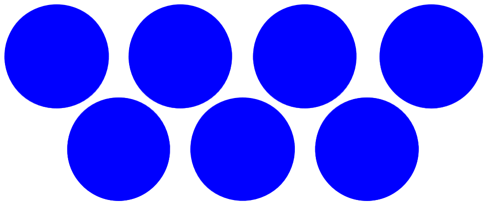
- Composites in which fibres and matrix are both polymers.
- The reinforcing element is usually an oriented polymer fibre or tape, made by drawing to a high level of molecular orientation.
- The term 'Single Polymer Composites' was first coined by Capiati and Porter in their work combining oriented polyethylene filaments with polyethylene powder of a lower melting point.

A variety of processing routes have been proposed for the production of these composite materials

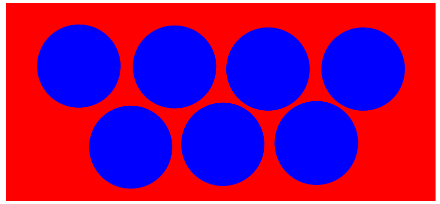
Film Stacking	Teishev/Marom and Marais/Feillard	PE
Bicomponent tapes	Peijs and colleagues	PP
Pressure controlled melting	Marom and colleagues	PE
Hot Compaction	Hine/Ward	PE/PP/PET/Nylon

Capiati, N. J. and R. S. Porter, "The concept of one polymer composites modelled with high density polyethylene." *J.Mat.Sci.* 10 (1975) 1671-1677

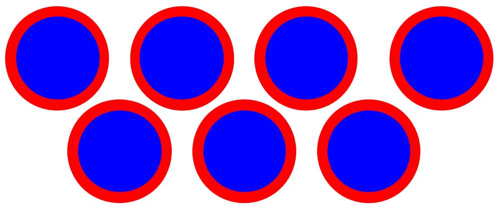
THE HOT COMPACTION PROCESS



Initial oriented element (fibre or tape) assembly



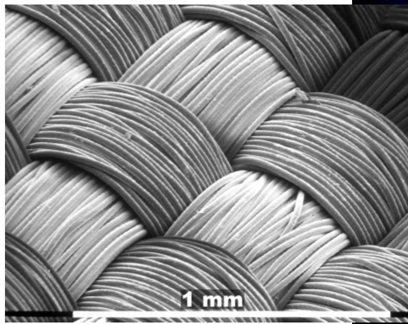
As the polymer cools, melted material forms a matrix around oriented elements –single polymer composite.

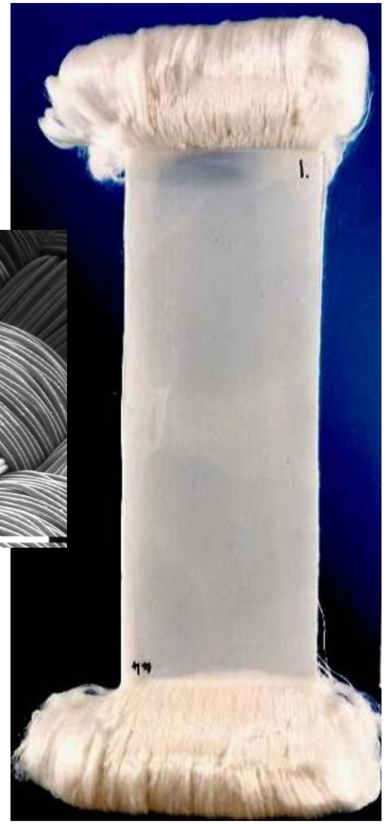


Under pressure and at compaction temperature, surface melting of the individual oriented elements occurs

Single polymer composite

MELT SPUN POLYETHYLENE





Fibre name: CERTRAN

M_w: 130,000

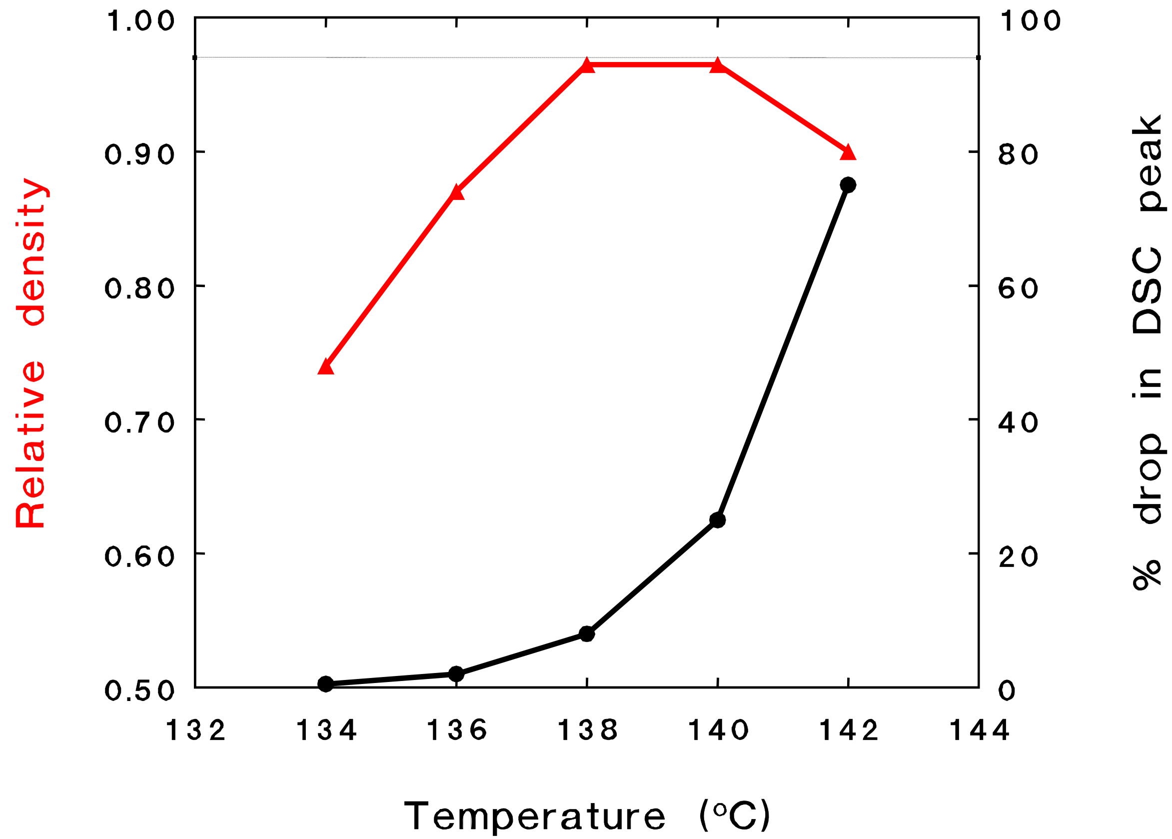
Modulus: 44 GPa

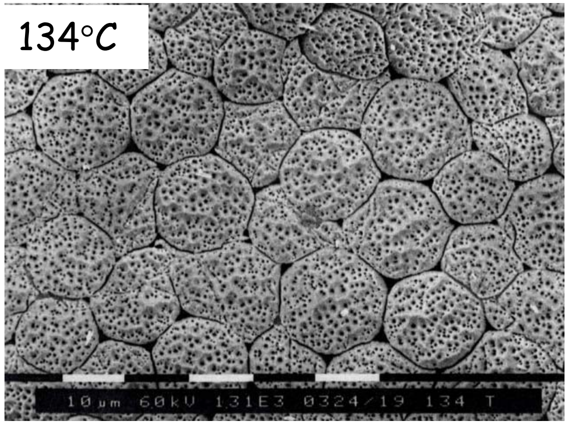
P.J.Hine, I.M.Ward, R.H.Olley and D.C.Bassett, 'The Hot Compaction of High Modulus Melt-Spun Polyethylene Fibers', J. Mat. Sci., 28 (1993) 316-324

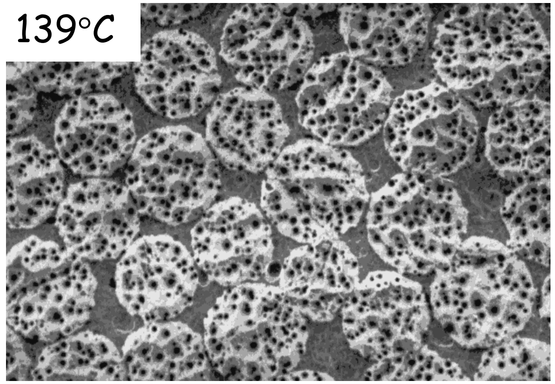
I.M.Ward, P.J.Hine and K.E.Norris, March 1992, Polymeric Materials, British Patent Office GB2253420

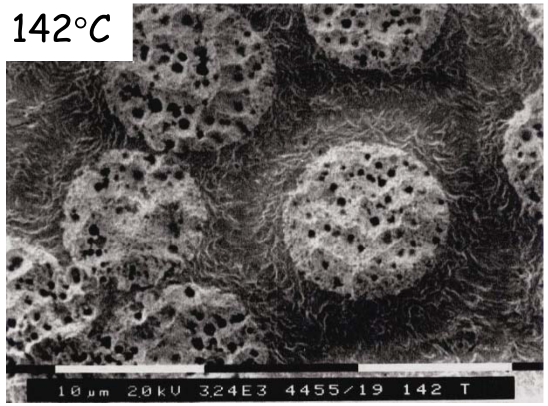
MELT SPUN PE

UNIDIRECTIONAL FIBRES (Certran)



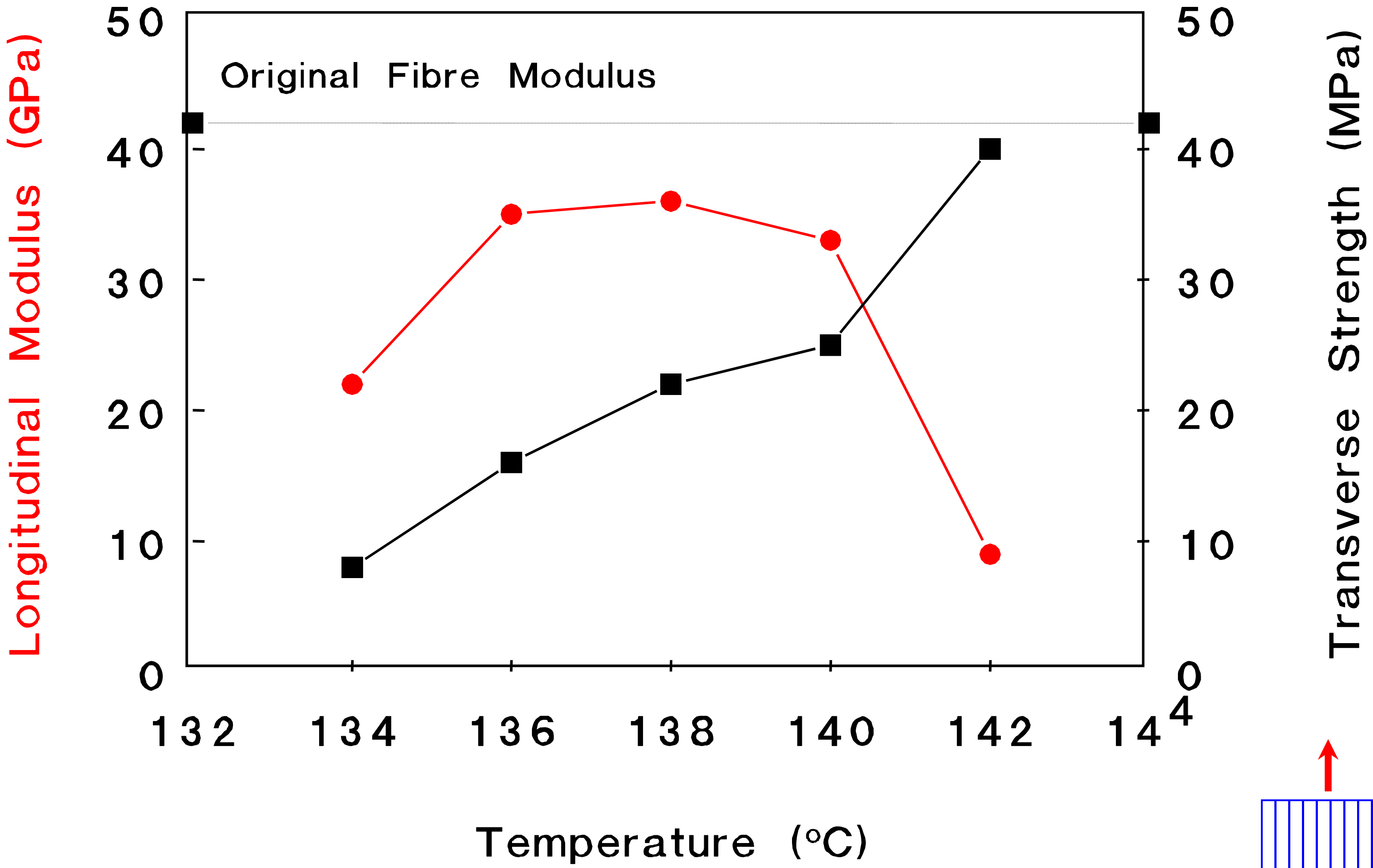


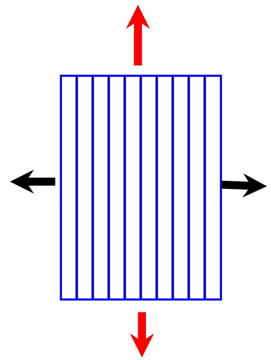




Single polymer composites
Very high reinforcement fraction
No impregnation problems

MELT SPUN PE





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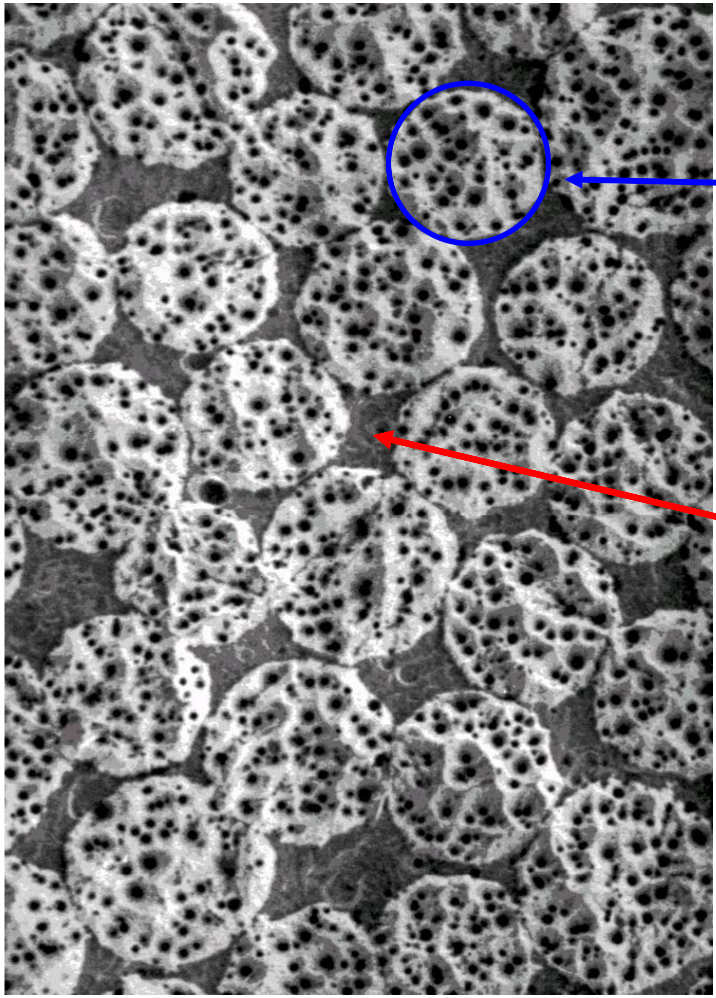
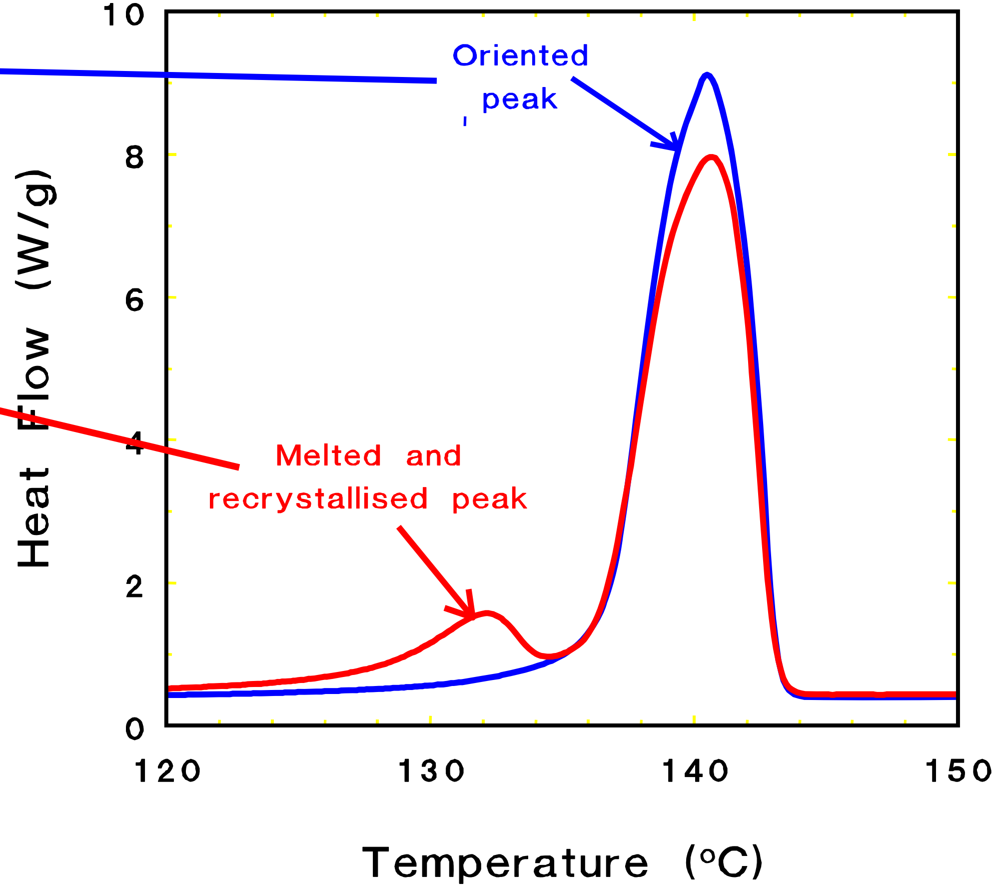


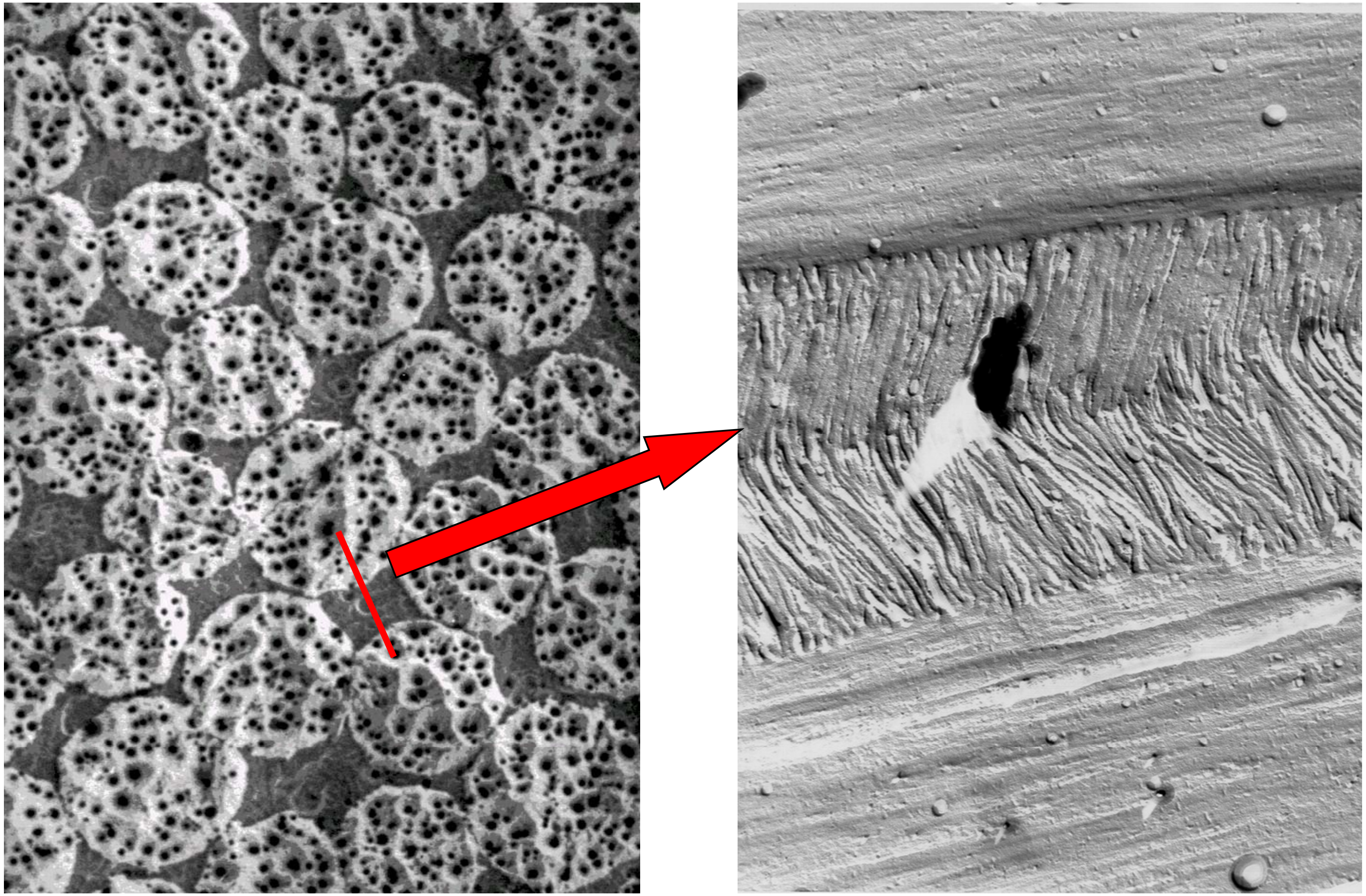
Morphology and melting behaviour.
(DSC) shows two distinct phases

Aligned PE fibres



Original oriented fibre   Compacted fibres

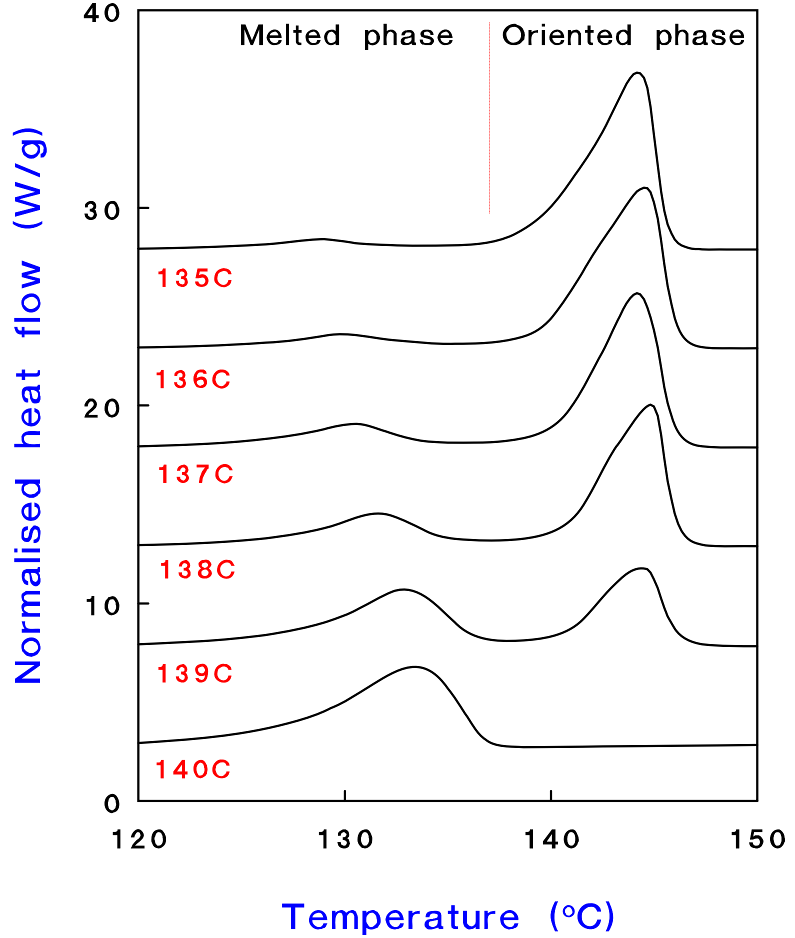
MELT SPUN PE

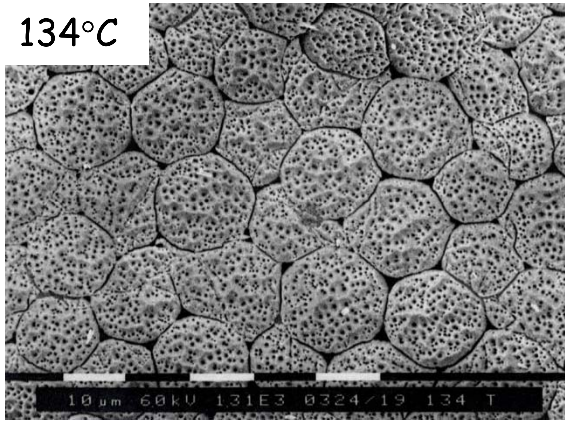


Optimum compacted polyethylene fibres - the transcrystalline layer

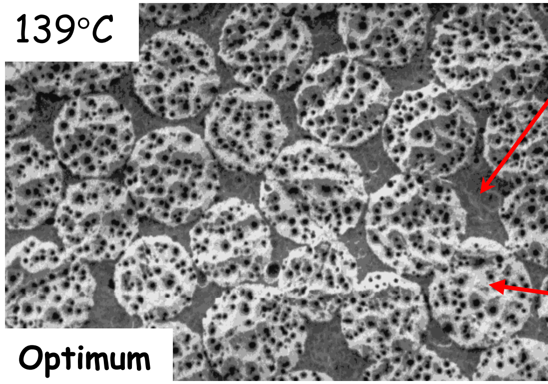
MELT SPUN PE

Temperature controls oriented phase fraction and hence mechanical properties



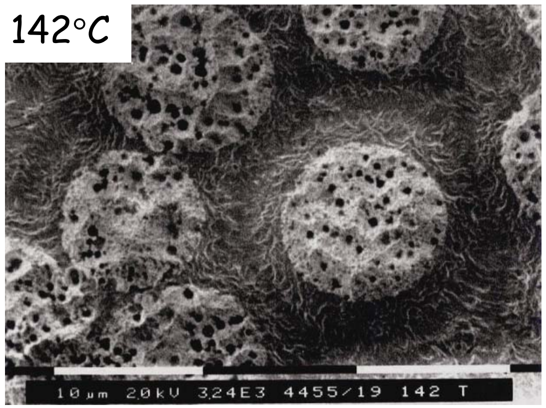


Professor David Basset and Dr Robert Olley



Recrystallised matrix phase

Original PE Fibres



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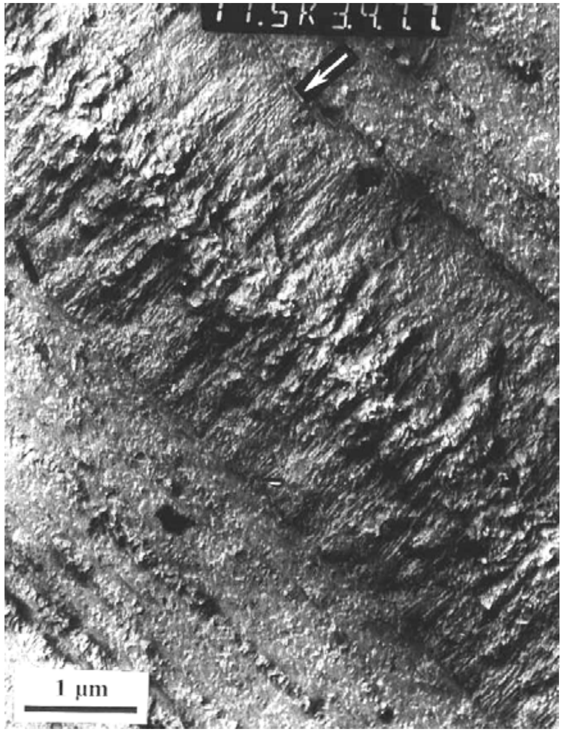
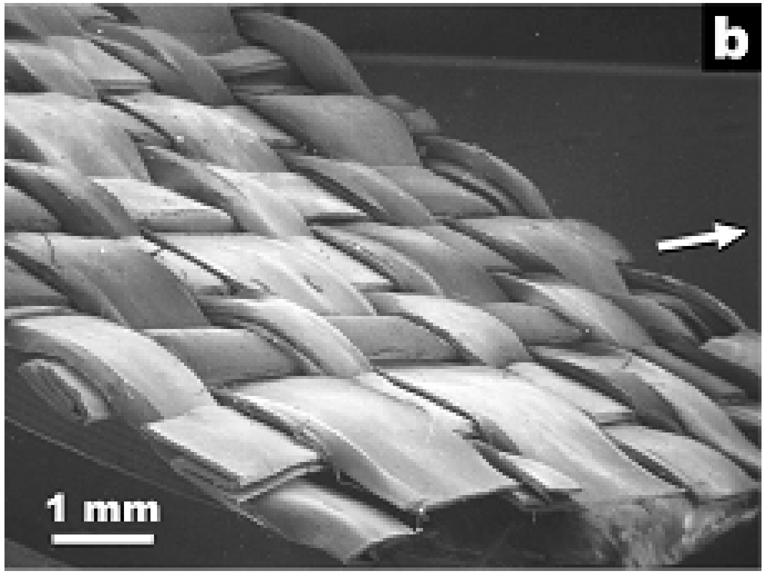
POLYPROPYLENE



Woven cloth: Geotextile

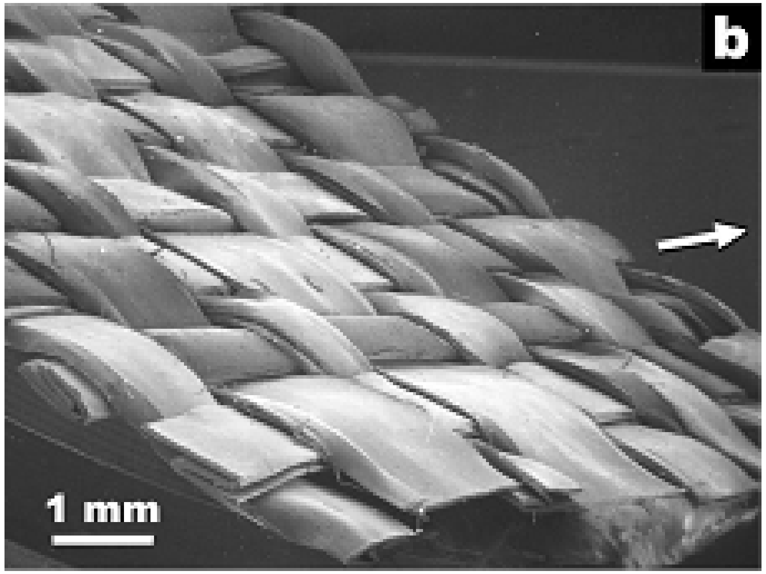
M_w: 360,000

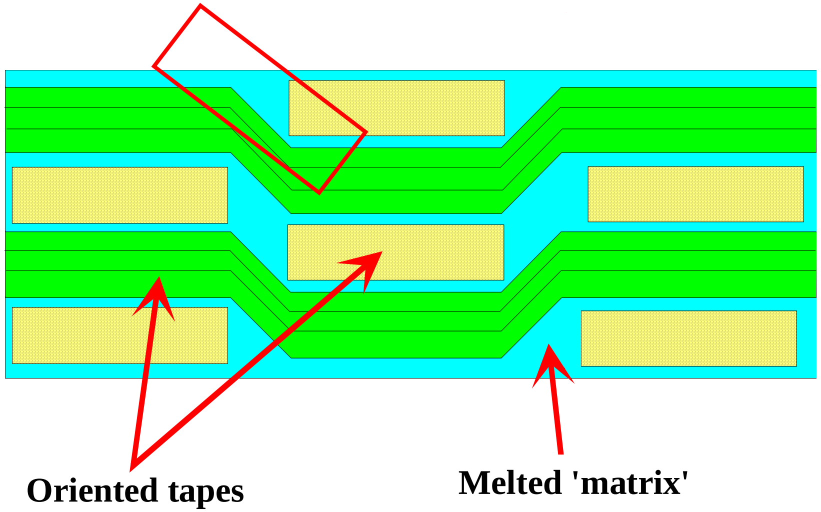
Modulus: 7GPa



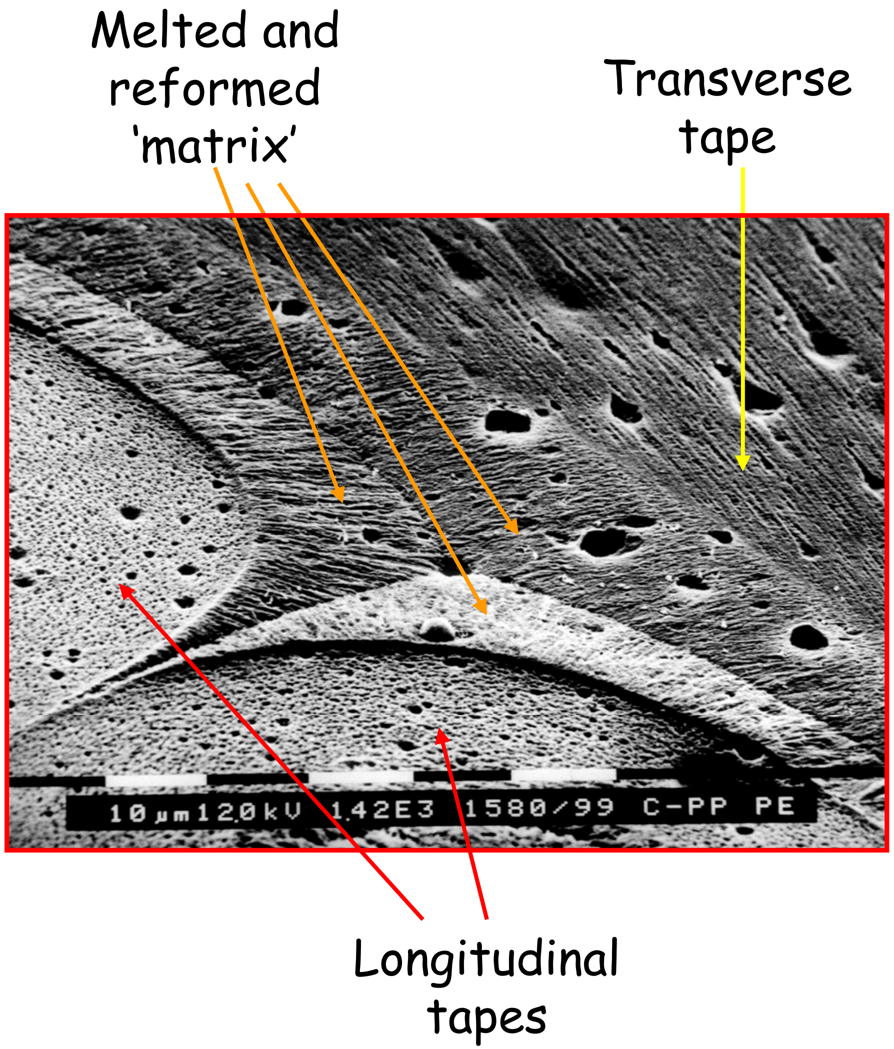
CURV™ - www.curvonline.com

MORPHOLOGY





Compacted woven PP tapes



- ***molecular continuity between phases***

MECHANICAL PROPERTIES - PP

PRELIMINARY DATA (ASTM Standards)	CURV PP sheet	Isotropic PP Homopolymer	Random mat Short glass/PP 40wt% fibre	Continuous Sheet glass/PP 60 wt% fibre
Density (kg/m3)	920	900	1185	1490
Notched Izod impact strength (J/m)	4750 (20ºC) 7500 (-40ºC)	200	672	1600
Tensile Strength (MPa)	180	27	99	340
Tensile Modulus (GPa)	5.0	1.12	3.5-5.8	13
Heat deflection °C, 455 KPa temperature °C, 1820 kPa	160 102	110 68	154	155
Thermal expansion (10^{-6}/°C)	41	96	27	21
Recyclability	EASY	EASY	DIFFICULT	DIFFICULT
Thermoforming	MEDIUM	EASY	MEDIUM	DIFFICULT
Surface appearance	GOOD	GOOD	POOR	POOR

Comparison data for other materials taken from www.matweb.com.
Quoted values are averages of all commercially available grades
Compacted PP made on a pilot plant.

CURV™ - www.curvonline.com

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- LIGHTWEIGHT

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- LIGHTWEIGHT
- MODULUS COMPARABLE TO GMT

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- LIGHTWEIGHT
- MODULUS COMPARABLE TO GMT
- OUTSTANDING IMPACT STRENGTH EVEN AT LOW TEMPERATURES

DEVELOPMENT OF THE HOT COMPACTION TECHNOLOGY

- **1990-1991** **INITIAL DISCOVERY**
  IRC project 1990-1997

- **1992-1995** **INVENTIONS EXTENDED TO MANY FIBRES**
  IRC and BTG funding

- 1995-2000 VANTAGE POLYMERS (University Spin-off)
  Initially a joint development project with Hoechst Celanese

- 2000-2009 FULL SCALE COMMERCIALISATION BY BP
  (now with Propex Fabrics Gmbh – Curv™).

- **1999-2009** **PARALLEL SCIENTIFIC STUDIES**
  EPSRC grant, BTG funding,
  BP funding, DTI funding

COMMERCIALISATION

www.curvonline.com

Hot compacted PP (Curv) successfully commercialised by Propex Fabrics (formerly BP)

Wilson Benesch Loudspeakers

Nike: Contour BPS Soccer shinguards

Samsonite X-Lite luggage range

Automotive undertray

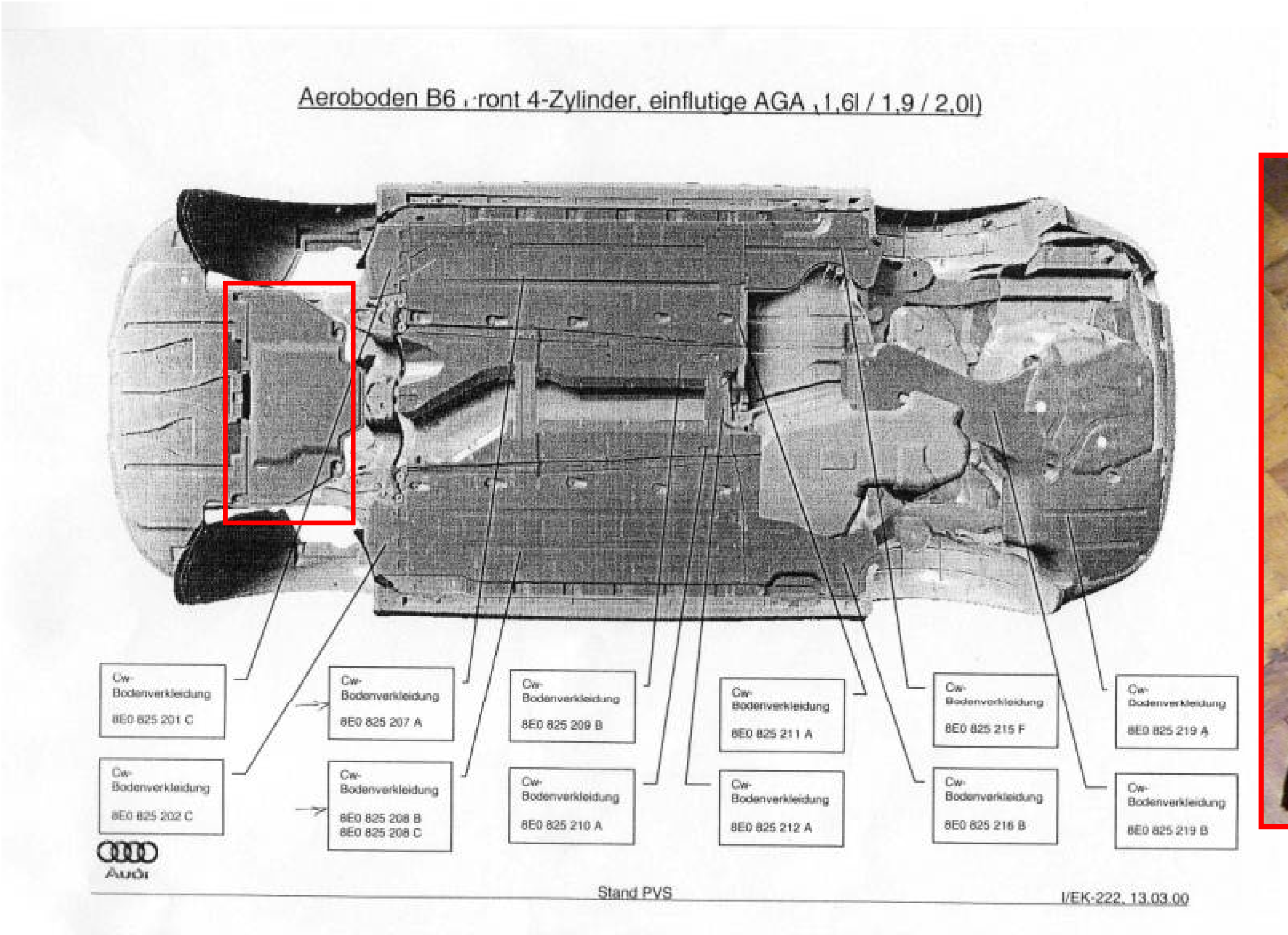
COMMERCIALISATION

SPORTS GOODS

A commercial application for hot compacted PP sheet (CURV™) is for NIKE soccer shinguards (Contour BPS).

The picture on the left shows hot compacted / foam PP shinguards which are now on the market.

AUTOMOTIVE APPLICATIONS



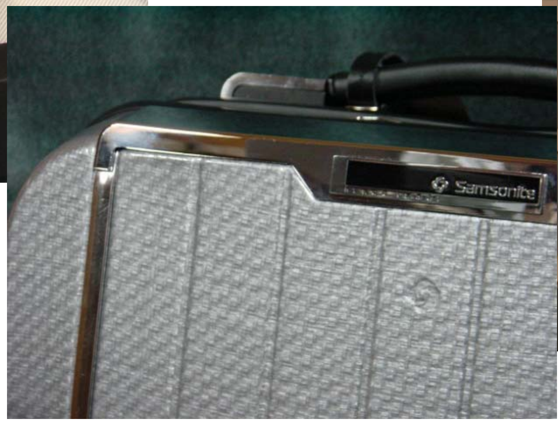
- **The combination of high impact strength, even at low temperatures, and good abrasion resistance, makes hot compacted PP an ideal material for under body shields.**

AUTOMOTIVE APPLICATIONS

	Hot Compacted PP	GMT
Weight	900 gms	1200 gms
Puncture impact energy @ + 20°C	14.5 J	9.6 J
Puncture impact energy @ - 40°C	14.1 J	10.5 J
Notched Izod @ + 20°C	4750 J/m	750 J/m
Notched Izod @ - 40°C	7500 J/m	Brittle
Abrasion resistance	> 3 hours	1 hour 40 mins

- CURV™ thermoformed undershield out performed GMT on all mechanical property requirements.

LUGGAGE



Samsonite suitcase (X-Lite range) from Curv™


Samsonite
BLACK LABEL
COLLECTIONS
SCOPE
X'LITE
VINTAGE
SIGNAT
PRO-DLX
Life's a Journey
Shopping bag
Joaquín Cortés
"I consider myself a nomad of the twenty-first century, though as a good Gypsy obviously I travel by plane. Before the Gypsies traveled in covered wagons with their cattle and horses. Now things have changed. I look at myself as an ambassador of my country and my culture."
about joaquin
travel tips
The X'Lite Collection
The lightest and strongest luggage Samsonite has ever created. Its distinction is in its unique construction. Made with the exclusive CURV® material – layers of woven synthetic fabric formed into self-reinforced, composite sheets – for the traveler who wants easy luxury with an edge.
tour the collection

FUTURE STUDIES

ADVANTAGES

- Lightweight
- Good mechanical properties
- Thermoformable
- High impact performance
- Recyclable

Nike Contour BPS shinguards

DISADVANTAGES

- Stiffness drops with increasing strain
- Stiffness drops with increasing temperature
- Poor creep resistance at elevated temperatures (target 120°C)
- High thermal expansion

Automotive undershield

FUTUREPLAS PROJECT

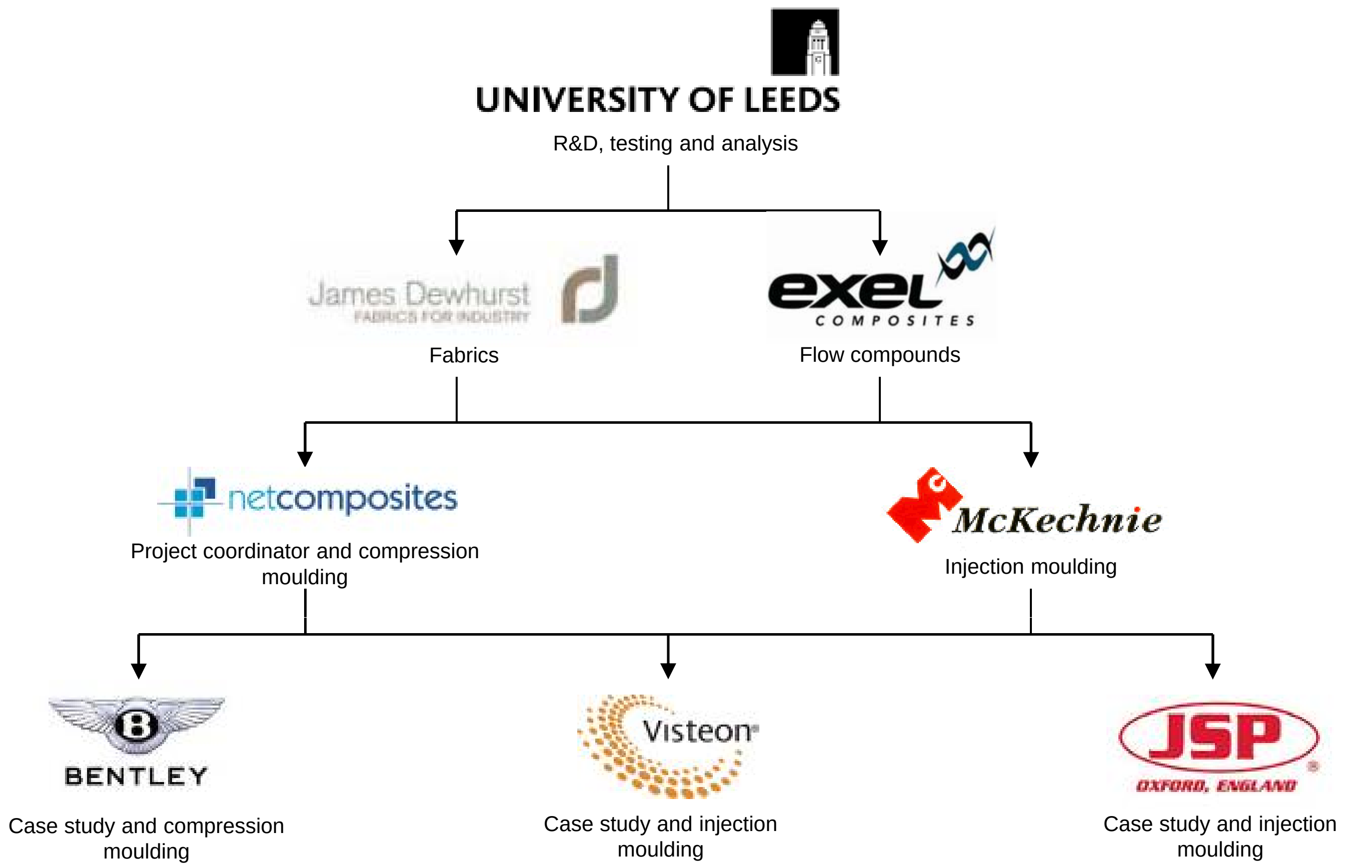
- TSB Technology Project.
- The aim is to develop the next generation of self reinforced polymer composites.

www.Futureplas.com

Key Targets

- Reduce the amount of plastic used to make a component by 30%.
- Reduce component weight by 30%.
- Improve the recyclability of reinforced plastics.
- Improve the design flexibility of self-reinforced plastics.

FUTUREPLAS – PROJECT PARTNERS



The project involves 8 UK partners representing the entire supply chain

RECENT PE RESEARCH

FuturePlas

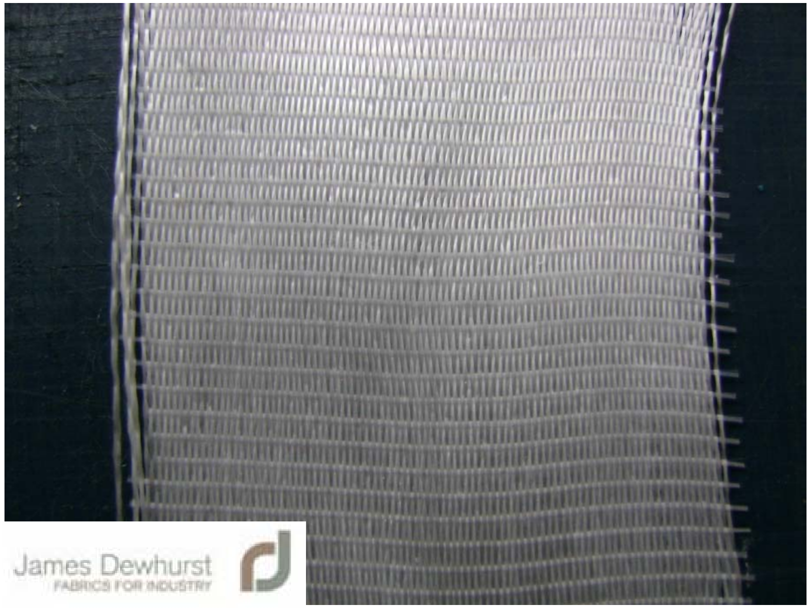
Fibre name: CERTRAN

M_w: 130,000

Modulus: 44 GPa

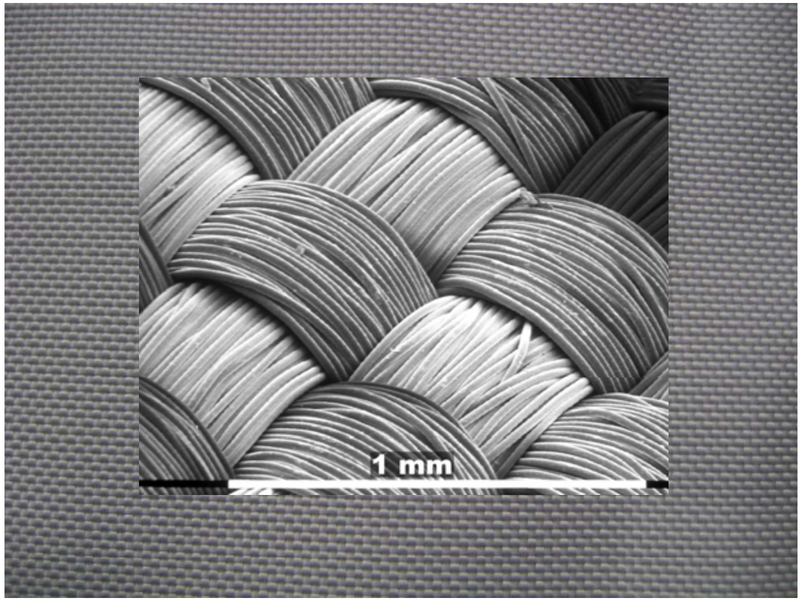
- Futureplas studies used the same PE fibre as the original hot compaction work.
- Two weave styles available:
  Plain weave
  Unidirectional weave made specially by James Dewhurst

Unidirectional cloth



PET carrier, low crimp but difficult to handle

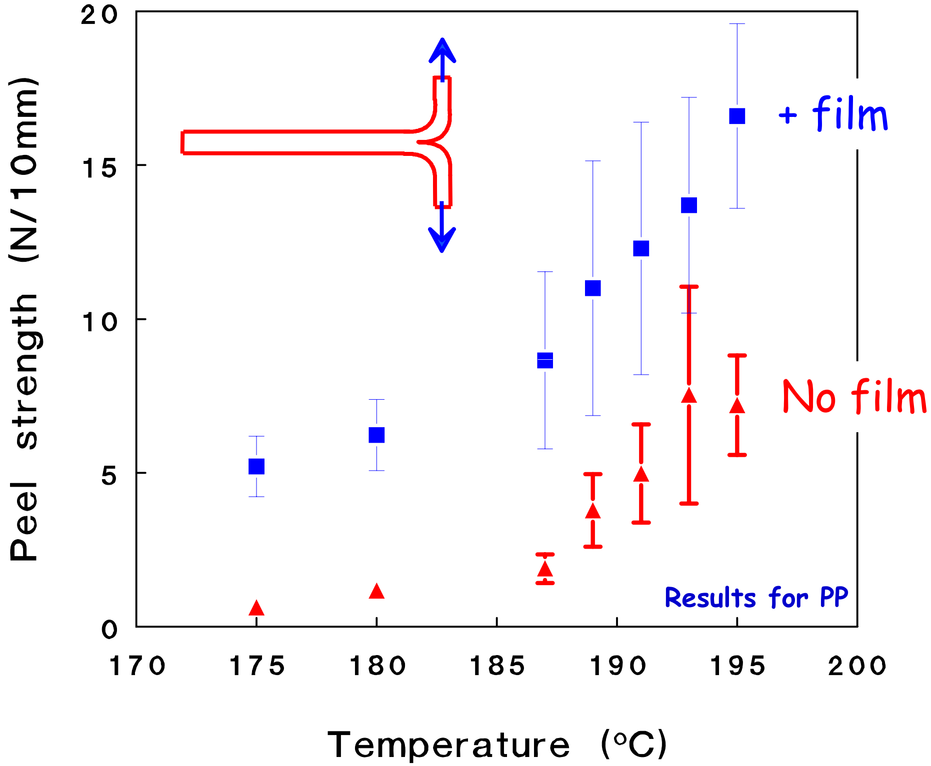
Plain weave

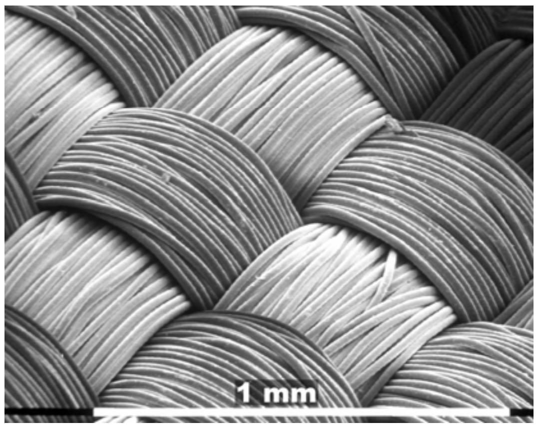


Balanced, conformable, high crimp.

INTERLEAVED FILMS

- A woven fabric is normally used to give balanced properties in the final single polymer composite.
- If the surface of the woven fabric is rough then more matrix material is required to bond the layers (~30% melted material) than between the fibres in each bundle (~10% only).
- This can require a compaction temperature close to the point where the whole crystalline structure melts.
- Using an interleaved film allows a lower compaction temperature to be used, thereby widening the processing window and increasing interlayer bonding (which can be crucial for thermoforming).



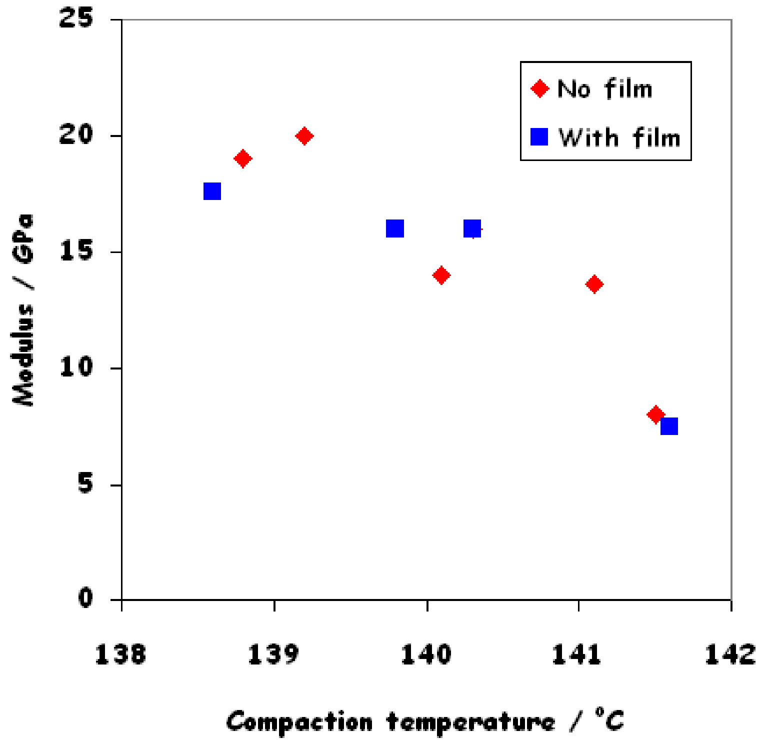


RECENT PE RESEARCH

Unidirectional cloth - 0/90 configuration

Made with and without an interleaved film

Samples 350mm x 300mm



- No significant effect on modulus with the introduction of an interleaved film.
- Balanced unidirectional weave gives a higher modulus compared to a high crimp plain weave (previous research showed a tensile modulus of 10GPa for a plain weave sample made without film).

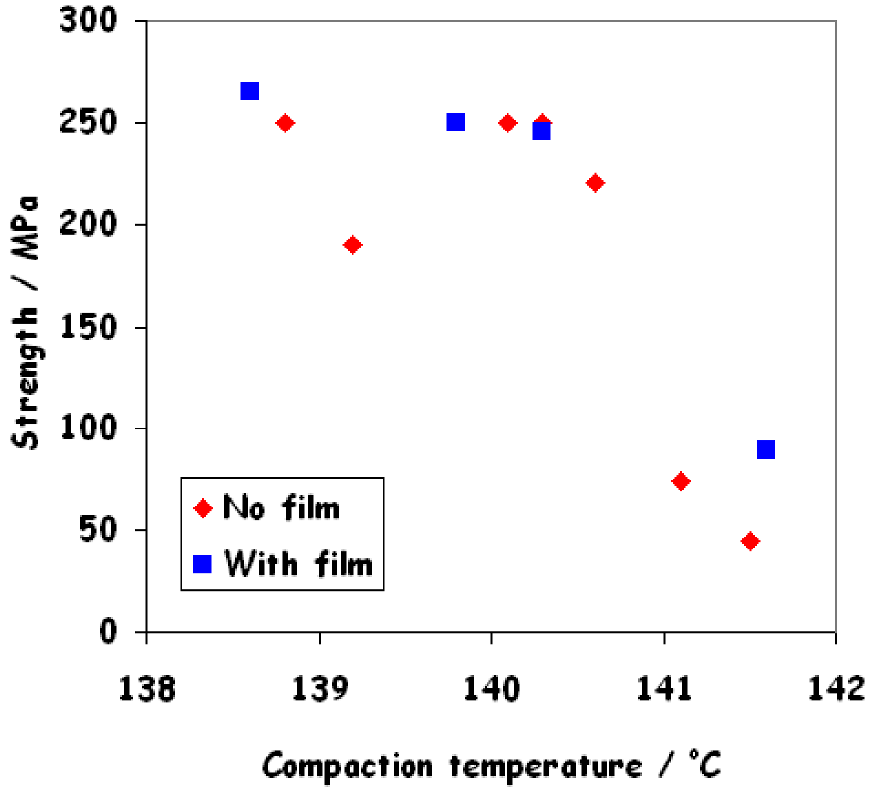
RECENT PE RESEARCH

FuturePlas

Unidirectional cloth - 0/90 configuration

Made with and without an interleaved film

Samples 350mm x 300mm

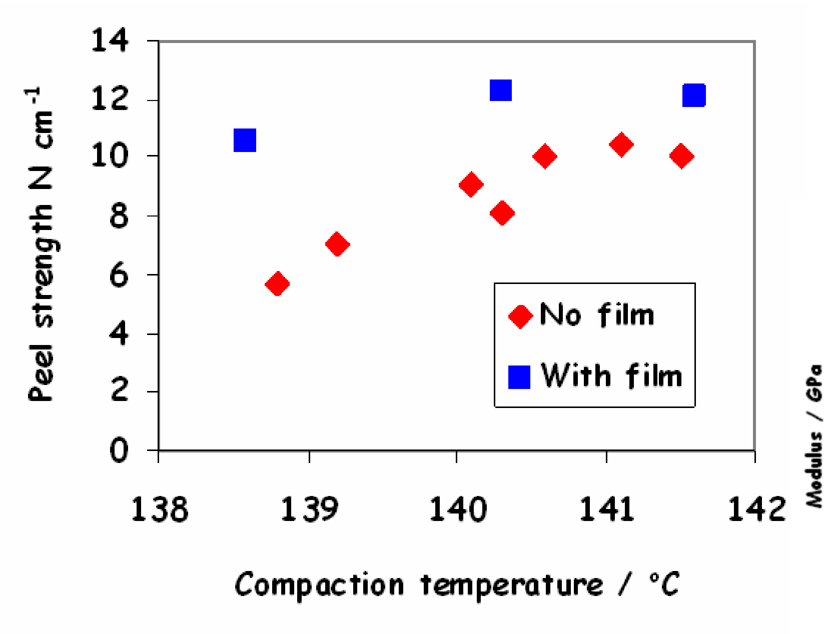


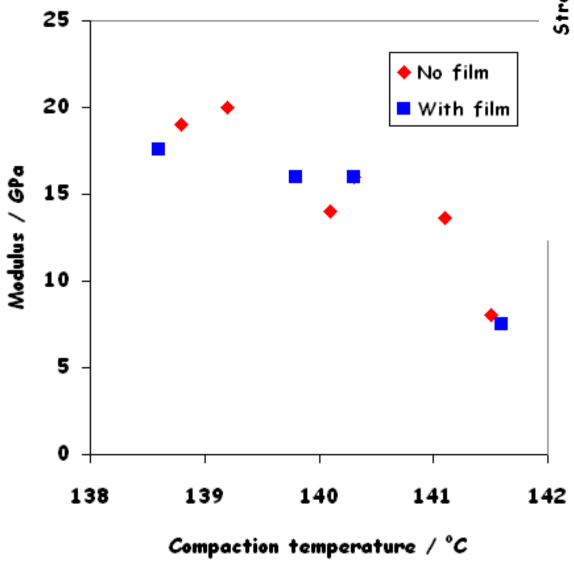
- Similar results for strength.
- Strength drops rapidly for a compaction temperature > 140.5°C

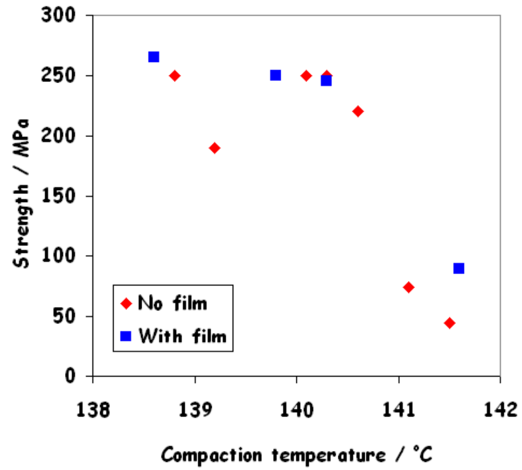
RECENT PE RESEARCH

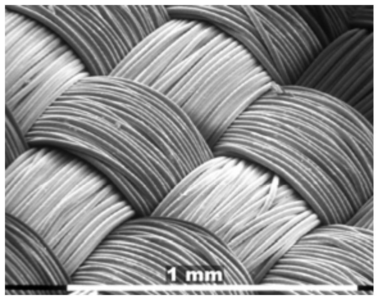
Unidirectional cloth - 0/90 configuration

Made with and without an interleaved film









- Peel strength higher with interleaved film and less sensitive to compaction temperature.
- The optimum temperature is therefore ~139°C with a film – good stiffness and strength but not risking significant fall in stiffness or strength with hot spots in processing (i.e. wider processing window). Samples can be made without film if preferred at ~140°C.

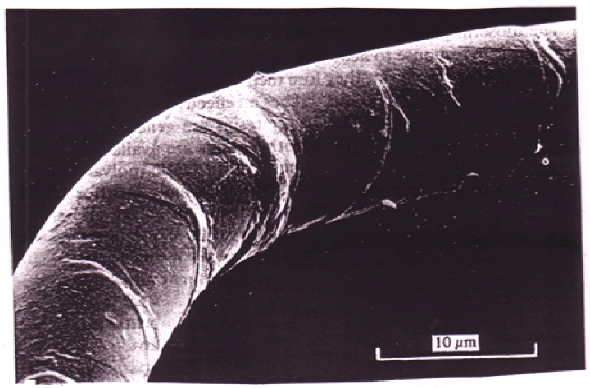
RECENT PE RESEARCH

FuturePlas

A comparison of properties tested in tension and bending

Weave Style	Test Type	Modulus (GPa)	Strength (MPa)
Uni (0/90) + film	Tensile	20	250
Uni (0/90) + film	Flexural	22	69
Plain + film	Flexural	9.4	68

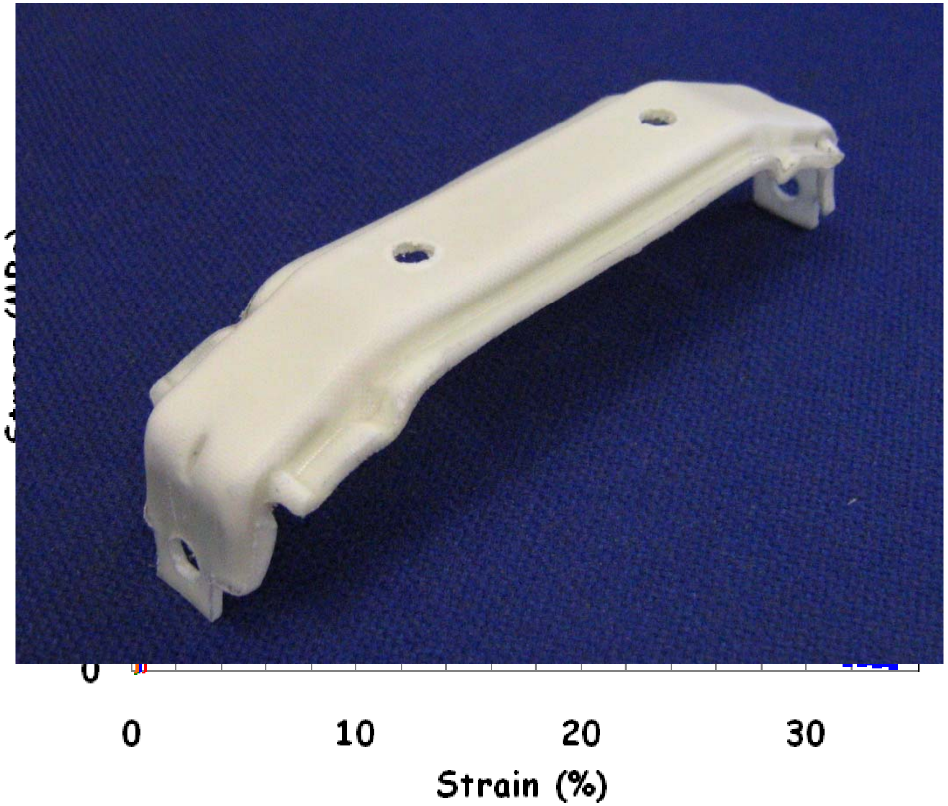
- Typical properties at the optimum compaction temperature of 139°C.
- The Unidirectional weave style (0/90) showed twice the stiffness of the plain weave style due to less crimp.
- The flexural strength was found to be significantly lower than the tensile strength and independent of weave style.

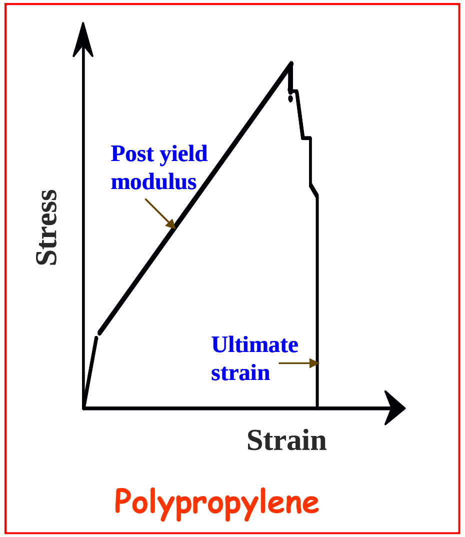


RECENT PE RESEARCH

FuturePlas

Hot tensile tests – UD 0/90 with film



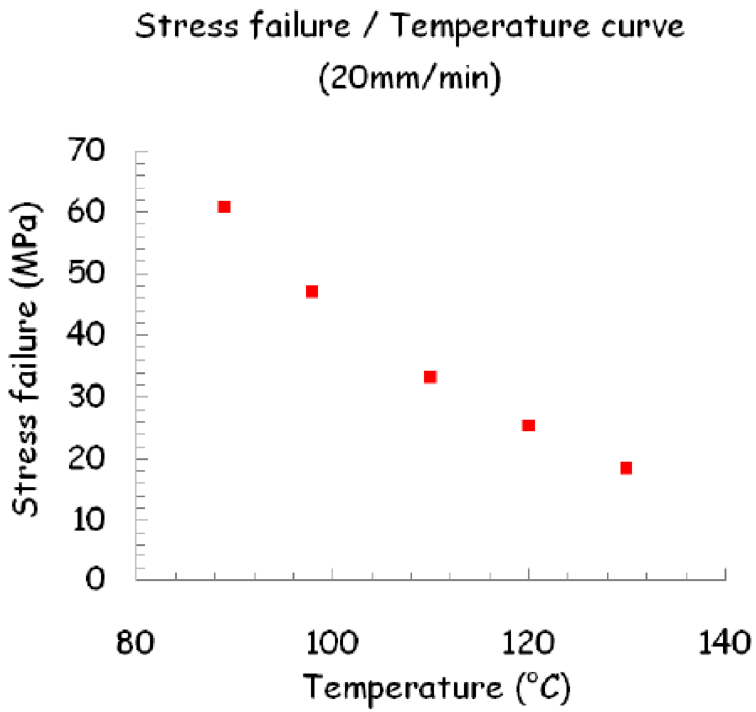


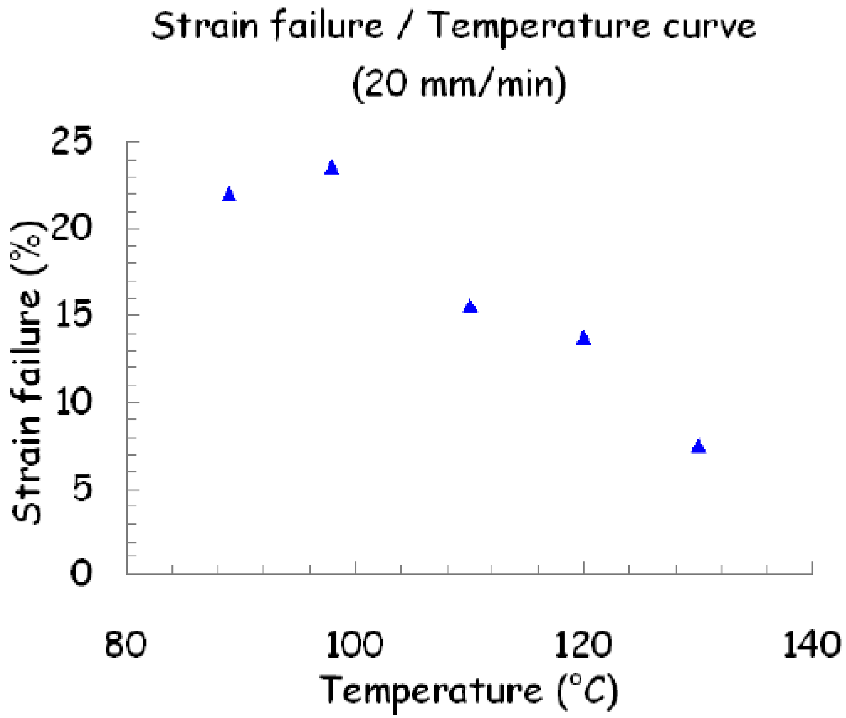
- Hot tensile behaviour quite different to previous work on PP.
- For PE, after yielding there is very little resistance to stretching.
- Stress (resistance to stretching) falls with post forming temperature.
- Maximum failure strain at 100°C (for PP the failure strain increased with post forming temperature).

RECENT PE RESEARCH

FuturePlas

Hot tensile tests – UD 0/90 with film



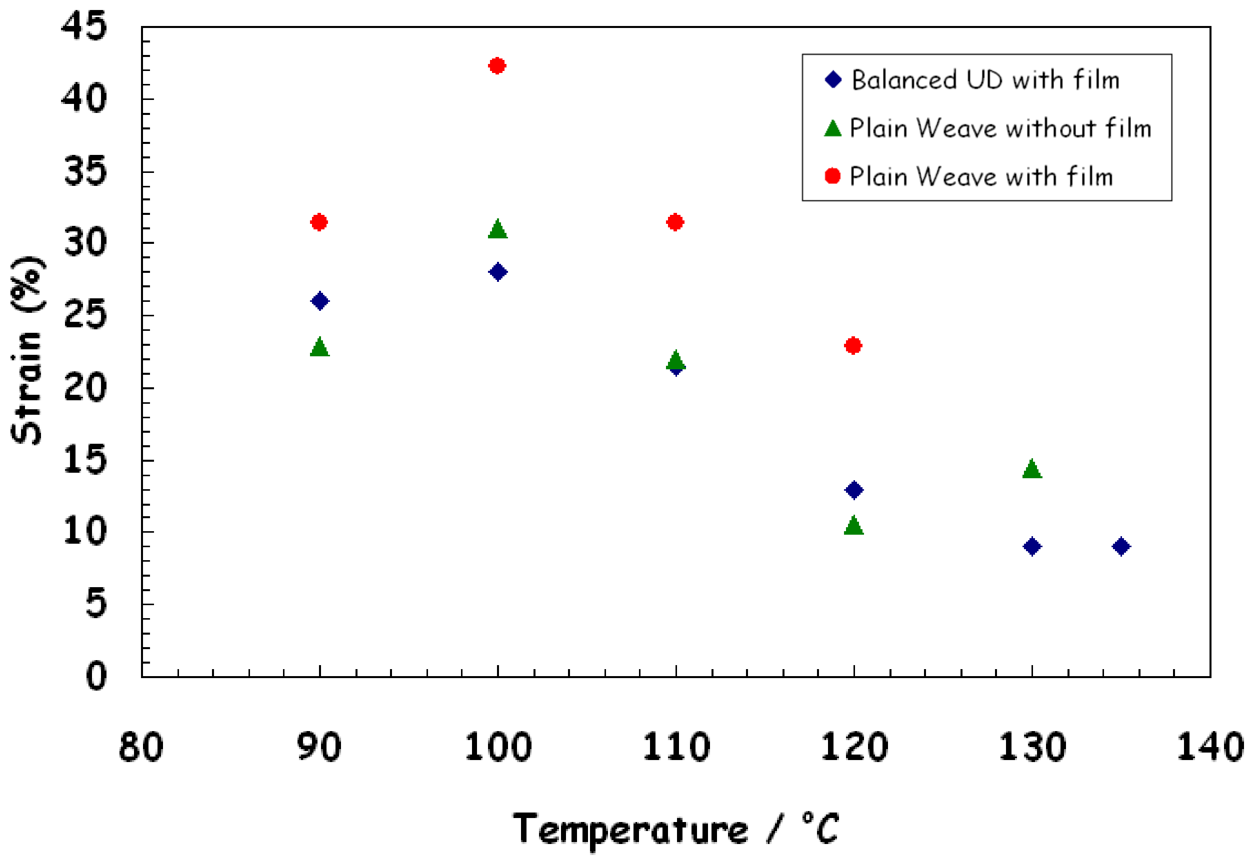


- For PP the strain to failure increases with temperature making it an advantage to get close to the melting point.
- For PE the strain to failure goes through a maximum and then falls significantly with temperature making it an advantage to be at a lower temperature for forming.

RECENT PE RESEARCH

FuturePlas

Hot tensile tests – all weave styles



- 100°C is a good choice for the post forming temperature as the failure strain passes through a maximum at this point for all weave styles.

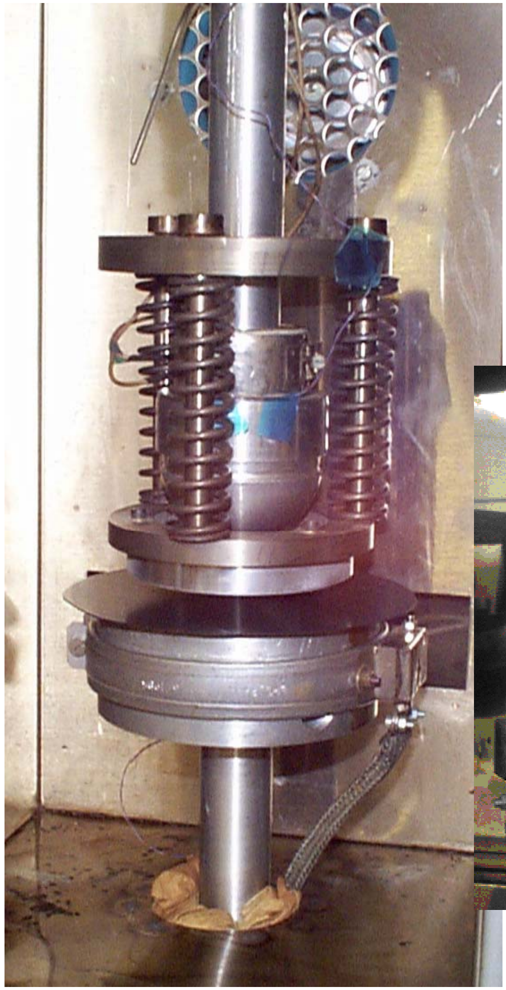
RECENT PE RESEARCH

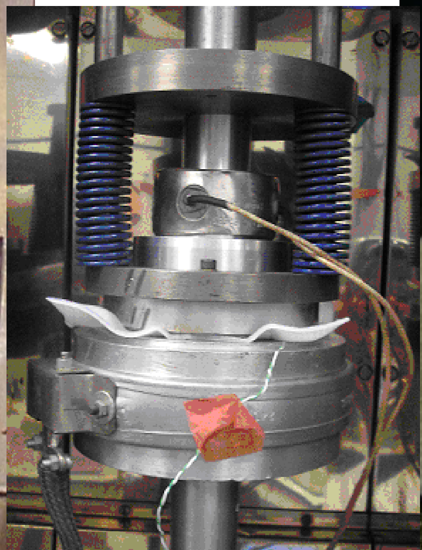
FuturePlas

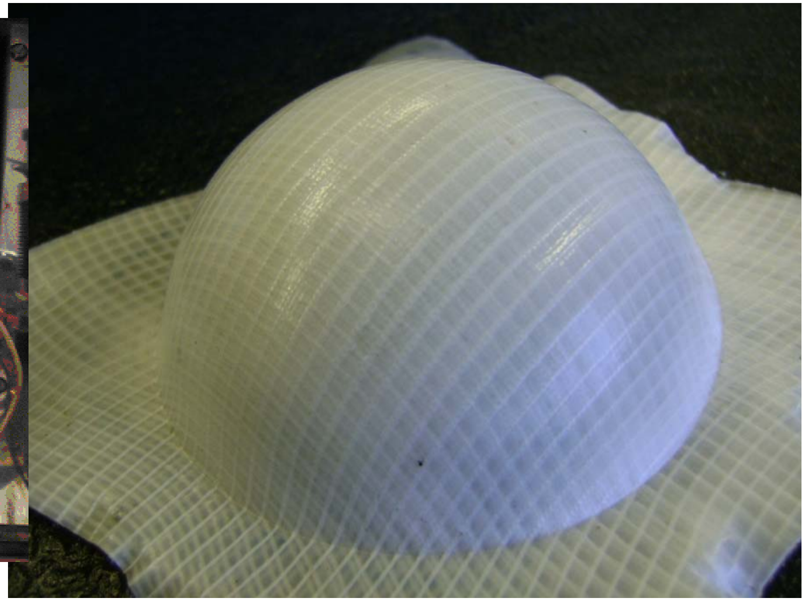
Thermoforming

Hemispherical Mould

- Hemispherical tool installed in an environmental chamber.
- Sheets were thermoformed for a range of temperatures, closing speeds and gripping arrangements.
- Excellent hemispheres made from both weave styles. The best samples were made at ~100°C, correlating well with the hot tensile tests. At higher temperatures the sheet was seen to tear on forming and at lower temperatures the sheet was difficult to form.





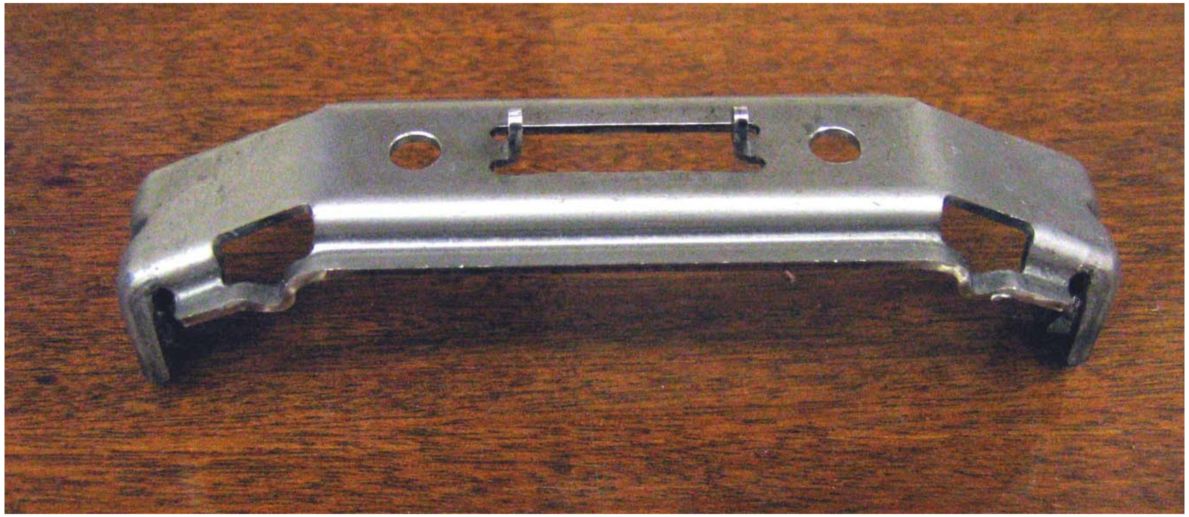


Hemisphere from the unidirectional sheet (note the PET carrier): formed at 100°C

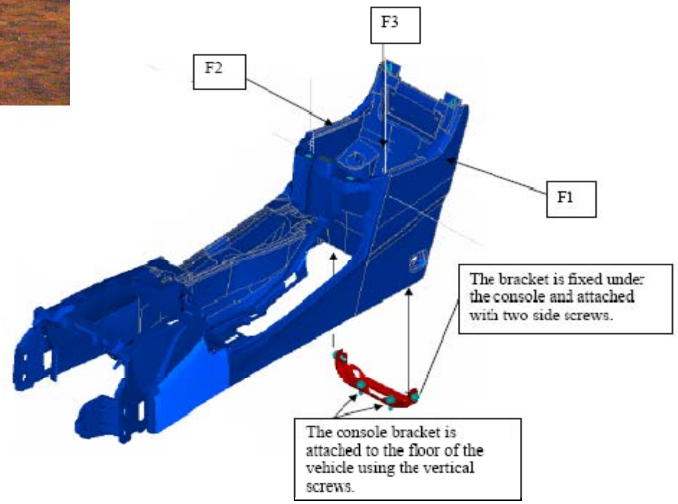
RECENT PE RESEARCH

FuturePlas

Thermoforming of a demonstrator component



Visteon

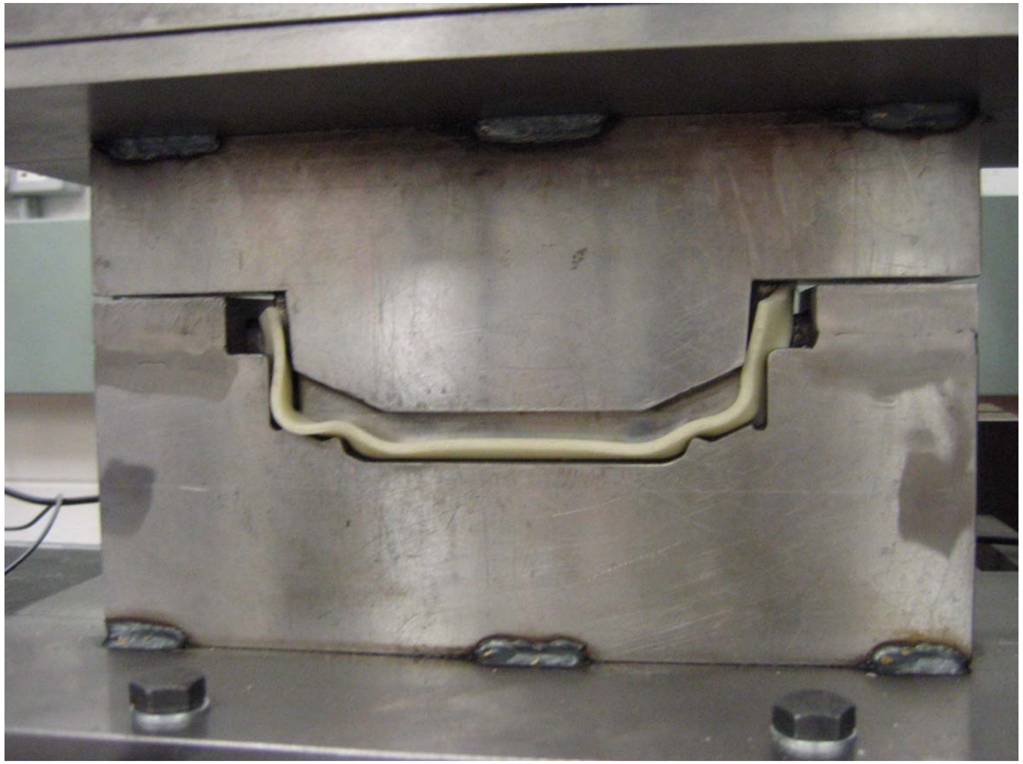


- Centre Console Bracket (part and matched metal tooling) supplied by Visteon.
- The aim is to evaluate the mechanical properties of a lighter weight thermoformed polymer/polymer composite in an application typically fabricated from a steel stamping.

RECENT PE RESEARCH

FuturePlas

Thermoforming of a demonstrator component



Simple component

Plain weave

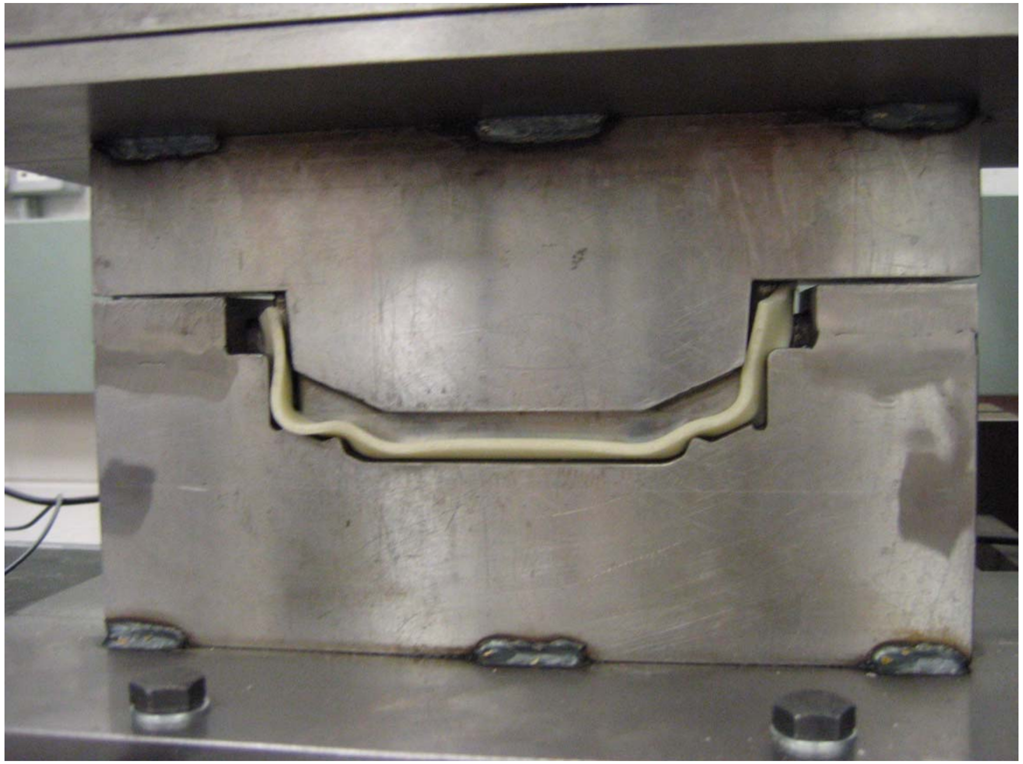
no film

- Matched tooling installed on tensile test machine.
- Mould heating by an air gun: samples heated in an oven (120°C).

RECENT PE RESEARCH

FuturePlas

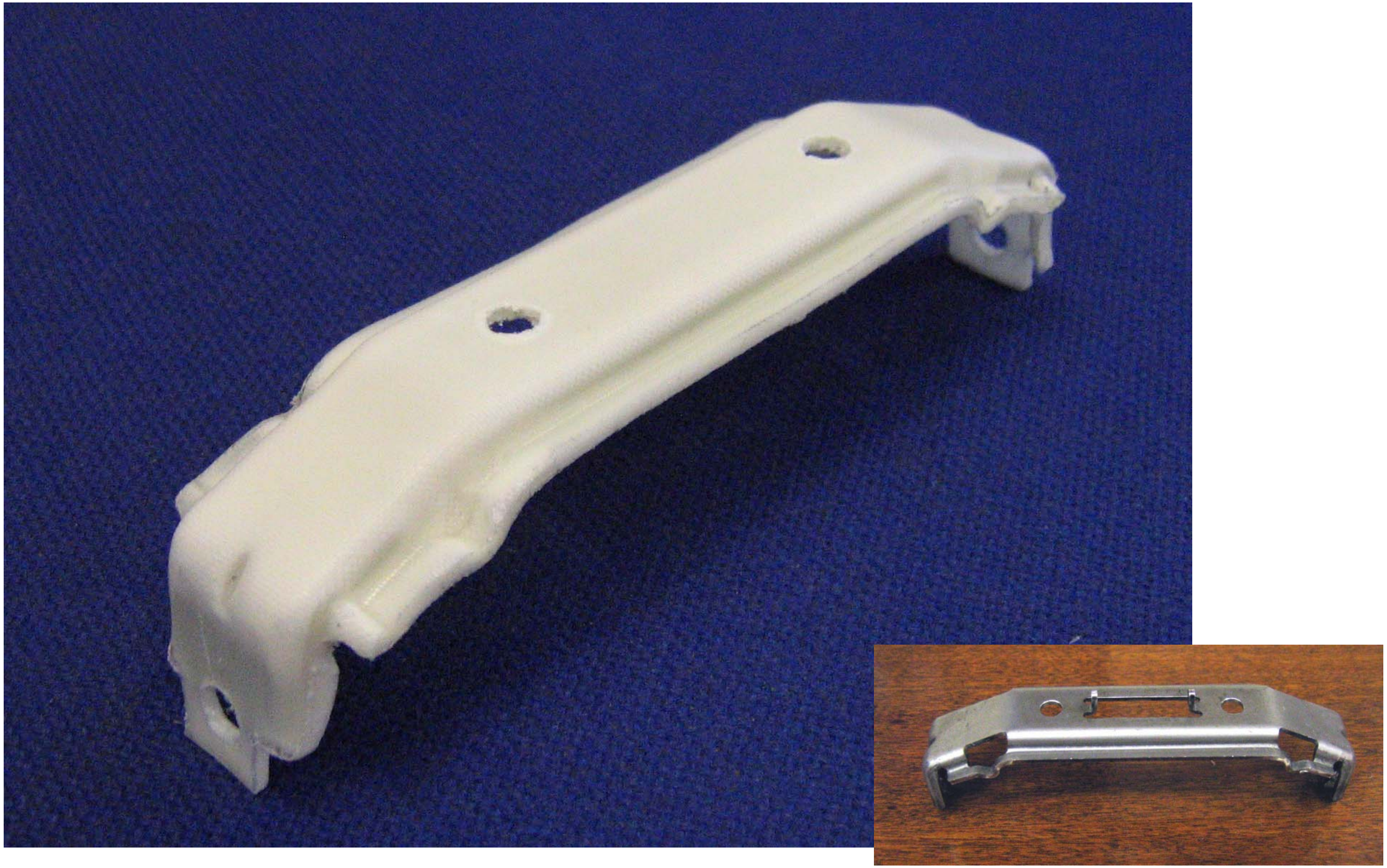
Thermoforming of a demonstrator component



- 2 stage procedure — close the mould at 200mm/min to 10kN
  compress the sheet at 10mm/minto 100kN.

RECENT PE RESEARCH

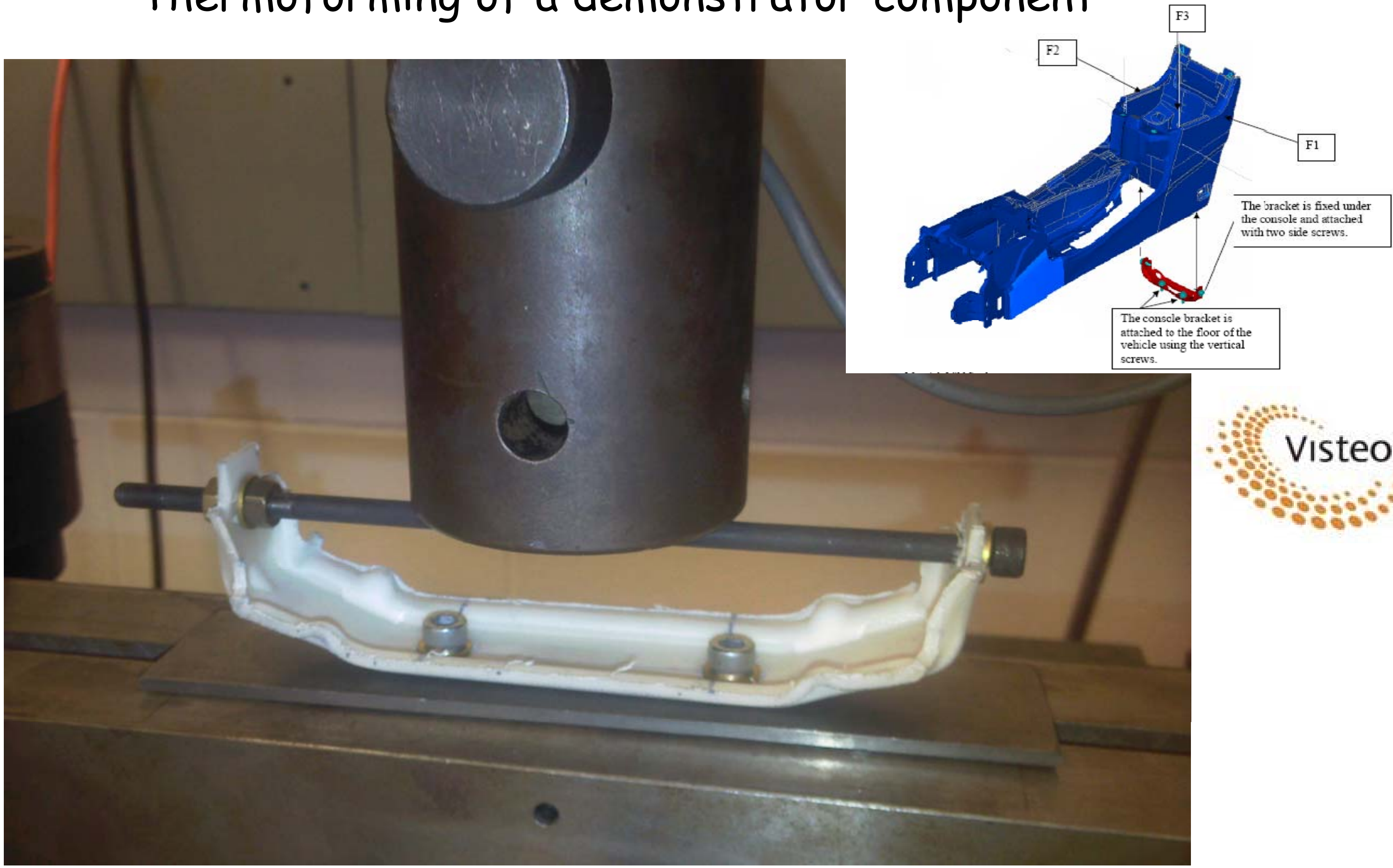
FuturePlas



- Trimmed and drilled to produce comparison with metal part.
- Metal part weight 115g   PE part weight 20g

RECENT PE RESEARCH

Thermoforming of a demonstrator component

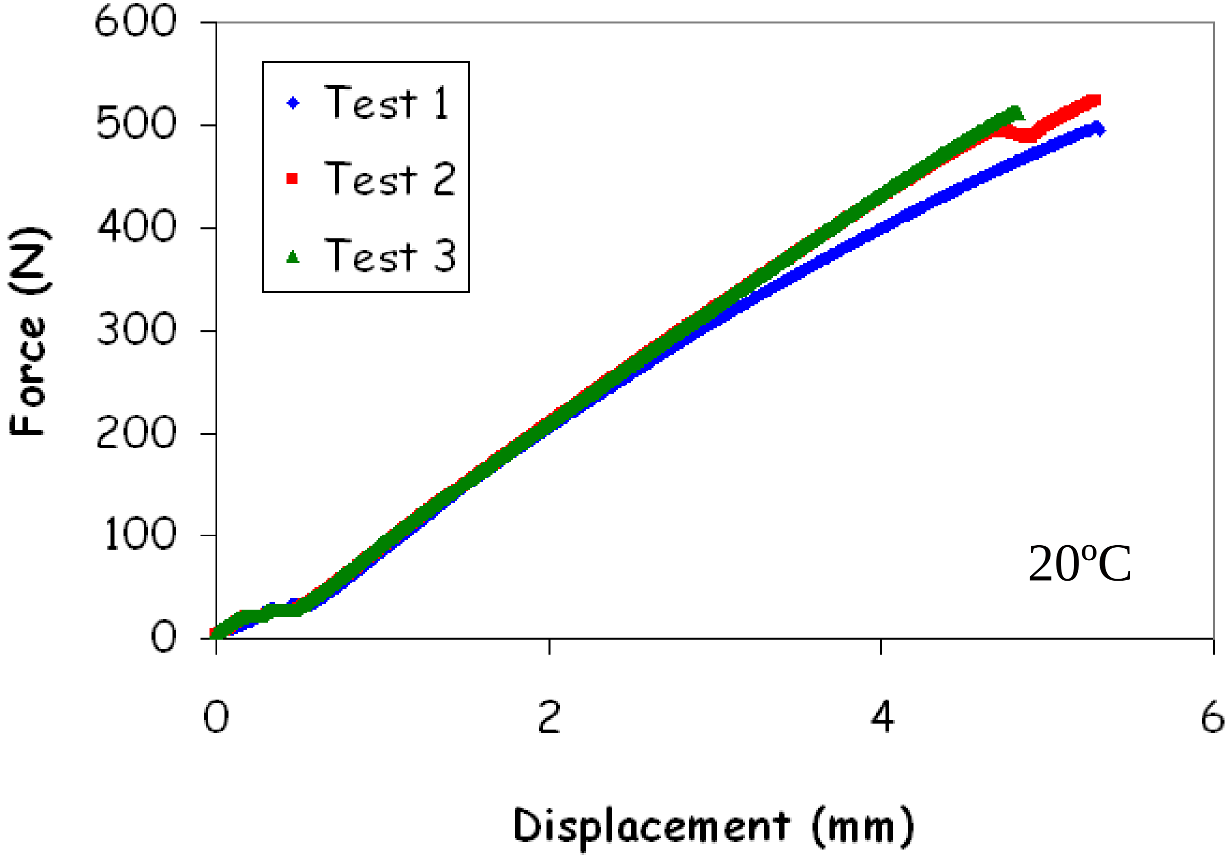


- Thermoformed samples were subjected to mechanical loading to simulate bracket function.

RECENT PE RESEARCH

Test Specification: Strength and Rigidity:

Application requires bracket to be free of damage and permanent deformation on application of a load of 500N



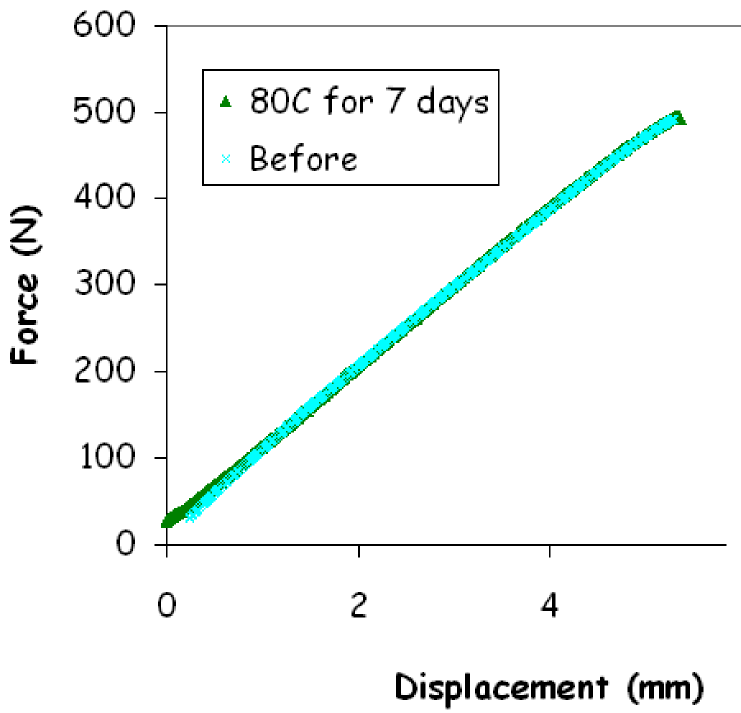
- No change in stress-strain behaviour after three applications of 500N at 20°C.

RECENT PE RESEARCH

FuturePlas

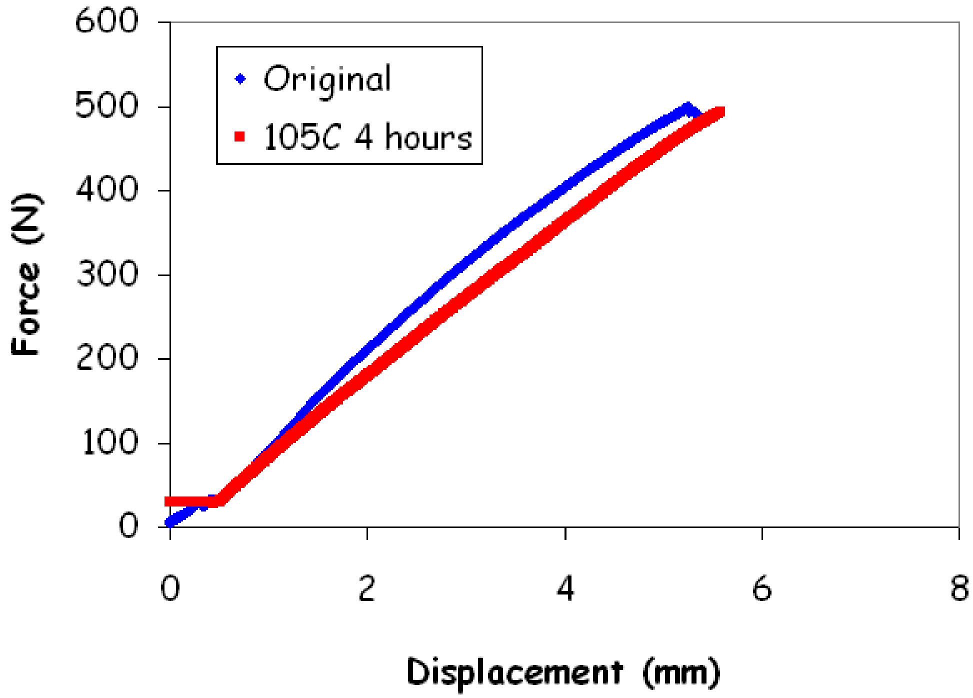
Test Specification: Strength and Rigidity:

Application requires bracket to be free of damage and permanent deformation on application of a load of 500N after spending 7 days at 80ºC or spending 4 hours at 105ºC.



- No change in stress-strain behaviour after 7 days at 80°C

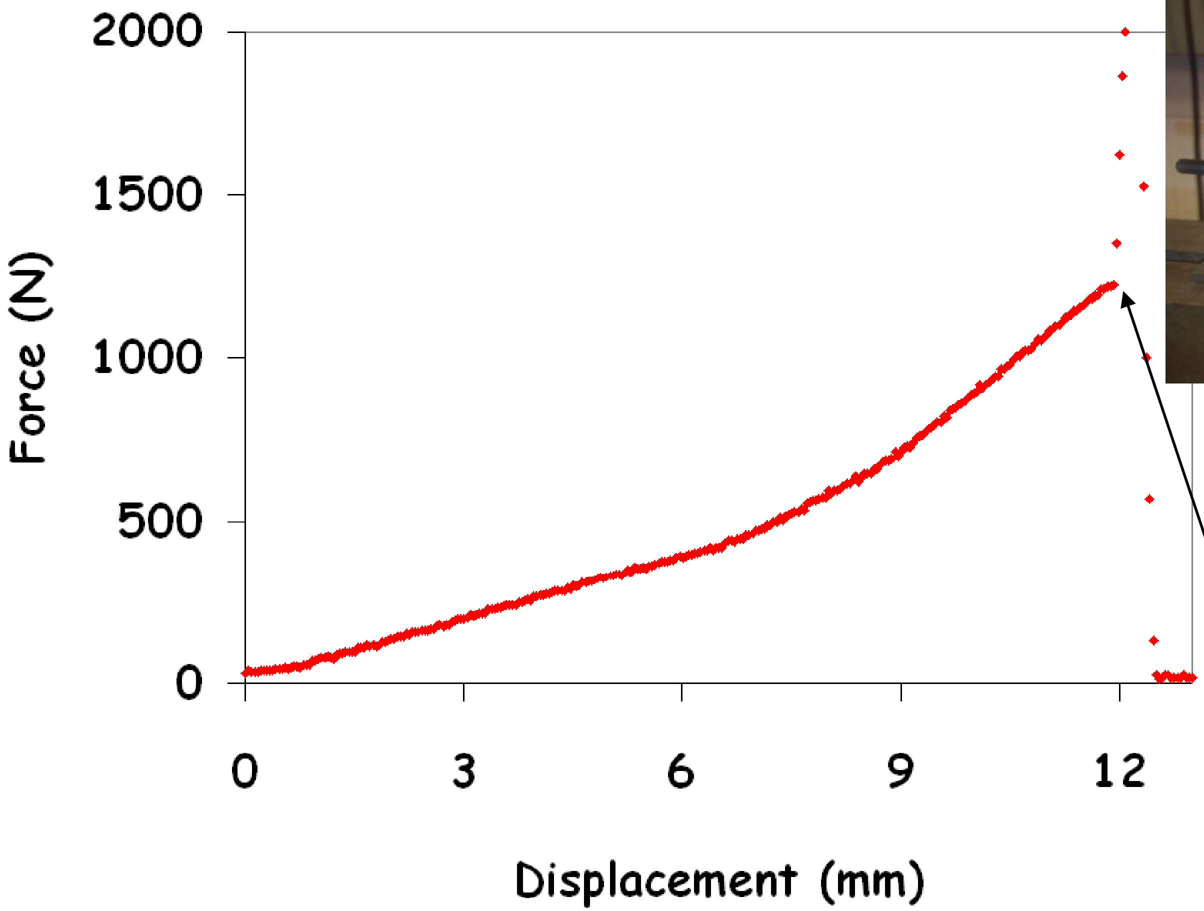
Small reduction in stiffness after 4 hours at 105°C

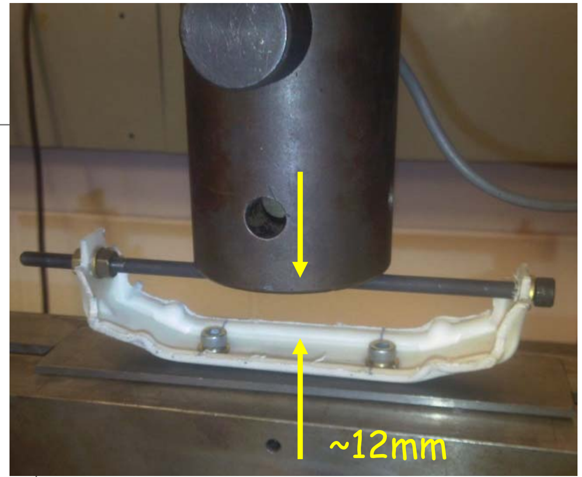


RECENT PE RESEARCH

FuturePlas

Test Specification: test to destruction





Rapid load increase when testing fixture goes metal to metal.

- Does not fracture, but buckles. Could be an advantage for this application.

CONCLUSIONS

FuturePlas

- An interleaved film widens the processing window and improves interlayer strength.
- A unidirectional weave style gives twice the sheet stiffness and strength compared to a plain weave.
- The flexural strength is much lower than the tensile strength and independent of weave style.
- The best thermoforming temperature is 100°C. At higher temperatures, the resistance to forming decreases, but so does the strain to failure.
- A demonstrator component was successfully thermoformed using matched metal tooling from hot compacted PE sheet. The single polyethylene composite part weighed one fifth of the equivalent metal part and has passed the specified test

ACKNOWLEDGEMENTS

- FuturePlas colleagues.

James Dewhurst FABRICS FOR INDUSTRY

exel COMPOSITES

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The Futureplas project is co-funded by the Technology Strategy Board's Collaborative Research and Development programme, following an open competition. The Technology Strategy Board is an executive body established by the Government to drive innovation. It promotes and invests in research, development and the exploitation of science, technology and new ideas for the benefit of business - increasing sustainable economic growth in the UK and improving quality of life.

UNIVERSITY OF LEEDS

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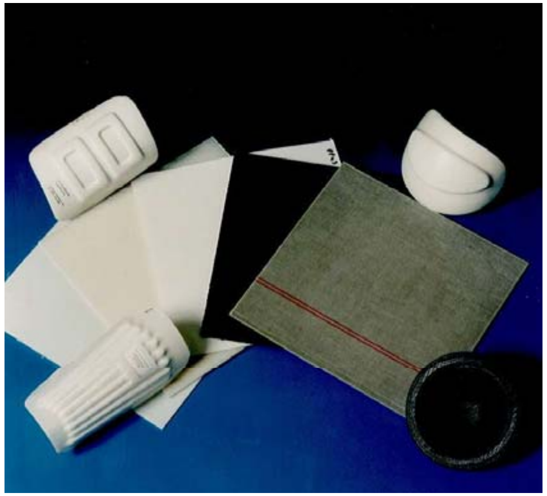
- Hoechst Celanese
- BP (BP Amoco Fabrics Gmbh), Propex Fabrics

WHY SINGLE POLYMER COMPOSITES?



- Lightweight.
- Recyclable (no glass fibres).
- Thermoformable.
- Lower energy consumption when making parts.
- Outstanding impact: ductile under all conditions.
- Forms a bridge between isotropic and glass filled polymers.
- Enhanced properties compared to isotropic PP at the same density.
- Versatility of isotropic PP with the properties of fibre reinforced PP (GMT).

OTHER POLYMERS

	PE	PP	PET	Nylon (Wet)
Oriented modulus (GPa)	88	11	14	5.8
Matrix modulus (GPa)	0.5	1.2	2.8	1.9
Initial sheet modulus 20°C (GPa)	30	5	5.8	2.8
Compacted sheet strength (MPa)	400	182	130	150