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Evolution of Nonwovens in Clothing: Hydroentangled Impact Protection

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Overview

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- Brief review of nonwoven fabric utilisation in garments.
- Hydroentangled clothing fabrics based on mechanical property comparisons (with woven & knitted materials).
- Structure and properties of experimental hydroentangled HMPE (polyethylene) fabrics - low and high velocity impact and puncture resistance in clothing.

Nonwovens in Clothing

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- Nonwovens for shoes, leather goods, interlinings & garments >65K tonnes p.a.
- **Durables**: linings, interlinings, synthetic leather, stiffening fabrics, high-loft waddings.
- Limited penetration in outerwear clothing - despite many attempts.
- **Single use**: disposable personal protective clothing (PPE), travel-clothing (including under-wear in Japan).

Elastic PU-PP spunbond, hydroentangled fabric garment set
(School of Design, Leeds, 2005)

European Textile and Clothing Industry

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- 215 billion Euro p.a. turnover; 2.6 million workforce and 200,000 companies in the enlarged EU (95% are SME's - highly fragmented industry).
- WTO predict that by 2007 China will control up to 50% of world textile and apparel market - creating a major European challenge.
- "In apparel, innovation is absolutely necessary to keep the European industry competitive" - Lutz Walter (*Euratex*).
- Require added-value performance attributes - provides an opportunity for nonwoven materials.

Source: *Euratex*, 2006

Nonwoven Outerwear: Evolution

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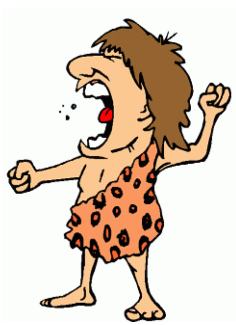

Disposable to Durable

BC	AD	1966	1967	1970
Pressed wool/hair felts (DFE mechanism)	Japanese lacquer coated paper materials for clothing & footwear	Yarn-reinforced paper apparel (the ultimate "fad")	Flash-Spun PE (Tyvek) garments	Mechanically bonded microfibre bicomponent **Alcantara®**

Nonwoven outerwear : the evolution continues

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1999-2000
Spunlaid + spunlaced splittable Bico fabrics (**Evolon®**)

Spunlaced fabrics made on imaged support surfaces: (**Miratec®**)

2002
Drylaid & mechanically bonded Australian wool (**Canesis**)

2005-2007
Designer apparel products based on existing nonwoven fabrics

Evolution of dyeable elastic nonwovens

Development of flash-spun PE and elastomeric fabrics (**Inova®** & **Neotis®**)

Nonwoven fabric shear rigidity vs. tensile strength map (comparative)

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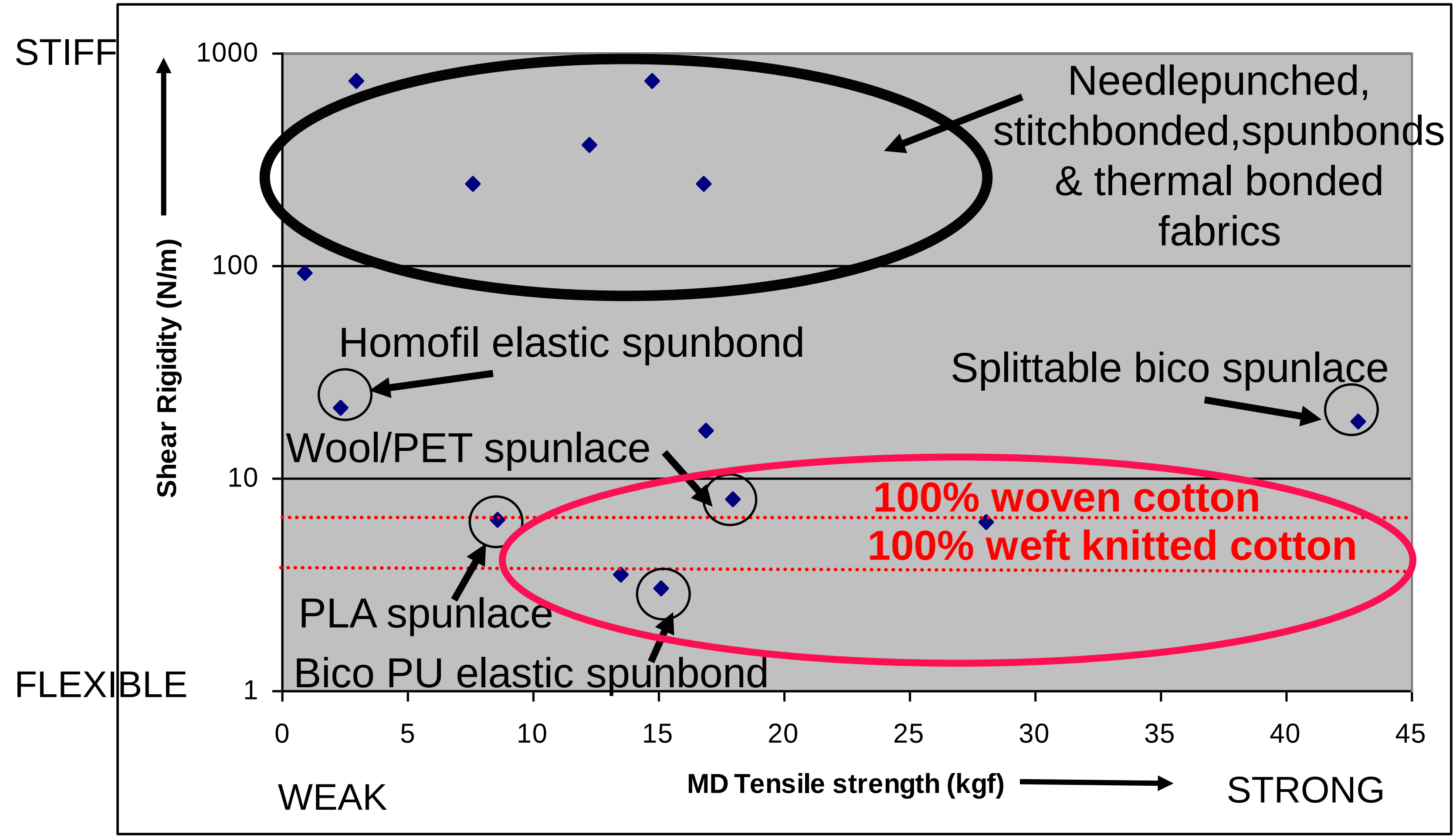

Nonwoven fabric property map: Low stress mechanical and geometric properties (bonding method)

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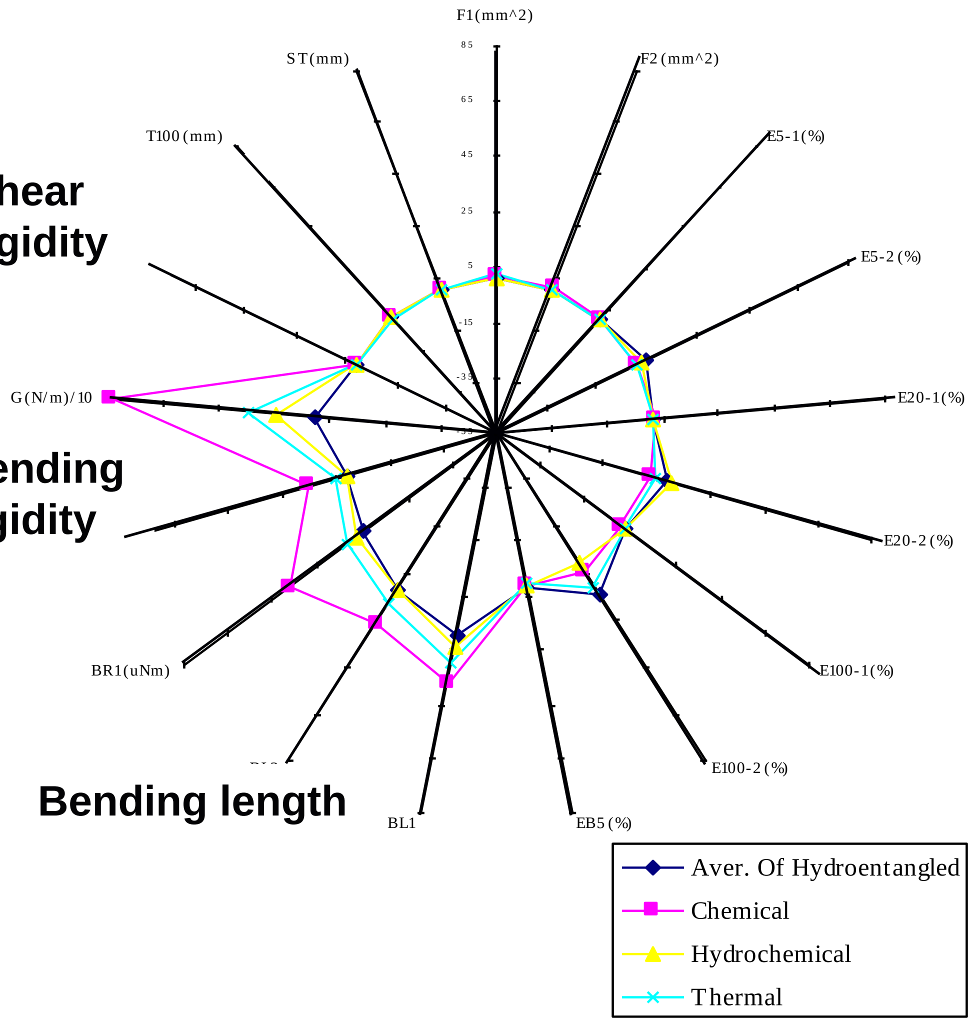
Shear rigidity

Bending rigidity

Bending length



hydroentangled

chemical bonded

twin step:
(hydro + chemical bonded)

thermal point bonded

Hydroentangled fabric property map: (compared to woven shirting)

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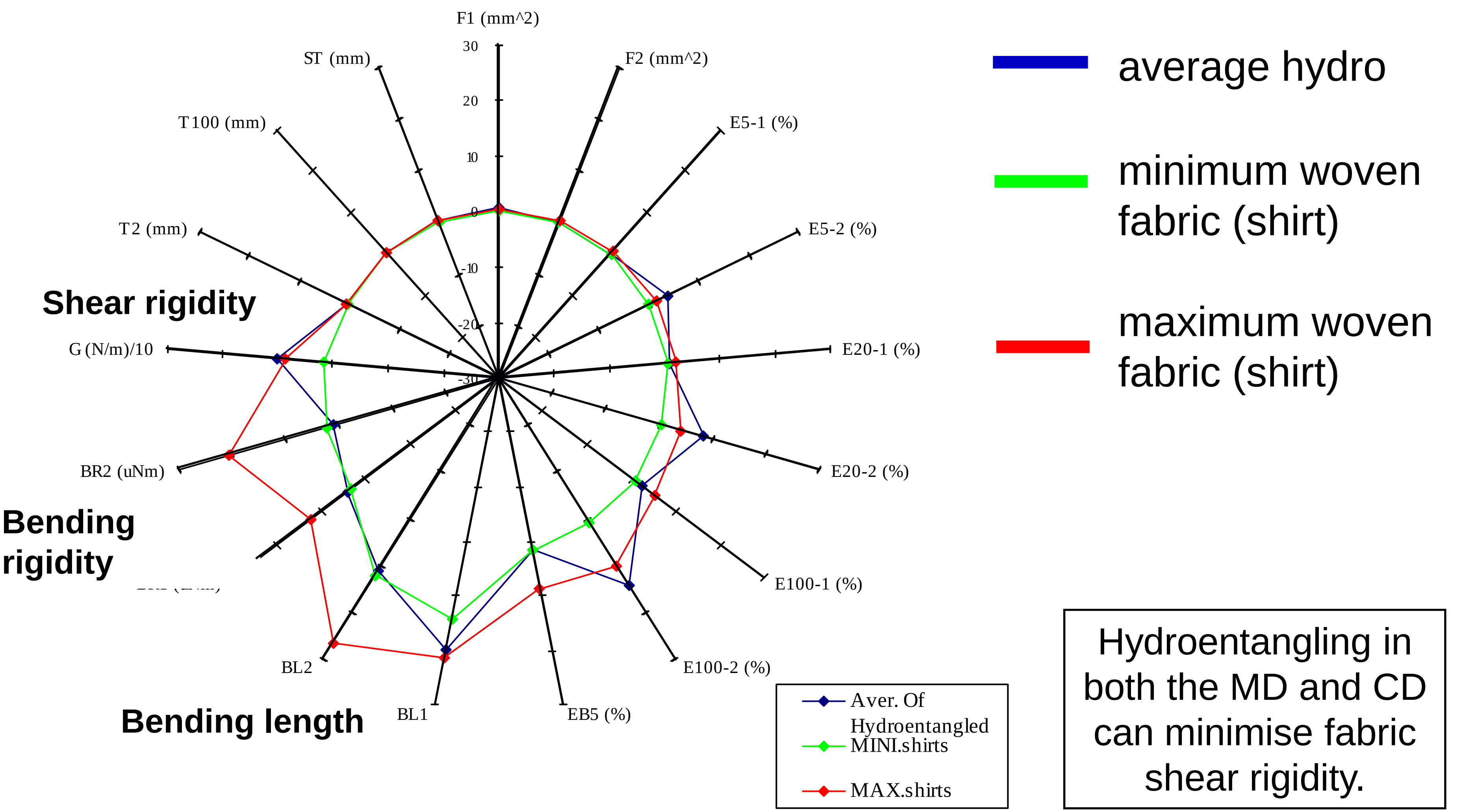

Hydroentangling in both the MD and CD can minimise fabric shear rigidity.

Hydroentangled protective linings
(e.g. thermal & fire, penetration-impact)

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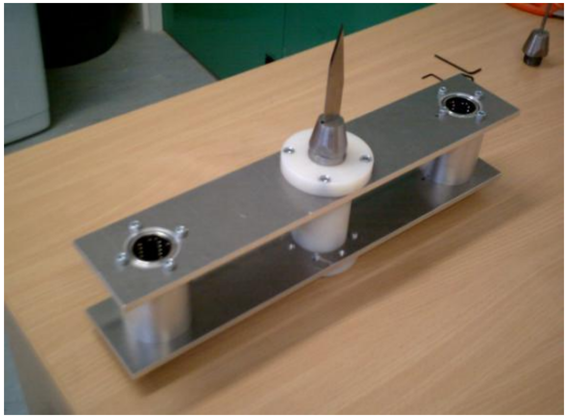

Experimental: Hydroentangled Impact Protection Fabrics for Protective Clothing

- Formation and properties of hydroentangled HMPE impact-puncture resistant fabrics for light-weight armour linings (carded & cross-lapped).

- Influence of water jet pressure, fabric structure and layering on impact & puncture resistance (low and high velocity).

- Installation as protective linings within protective clothing systems.

Selected polymers utilised in impact resistant fabrics

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Polymer	Tensile strength (g/d)	Extension at break (%)	Young's Modulus (g/d) (MPa)	Specific gravity (g cm^{-3})
PA	5.9-9.8	15-28	21-58 (2.1-5.8)	1.14
Para-Aramid	23-28	2.5-3.5	500-900 (63.5-114.3)	1.44
HMPE	30-40	2.5-3.6	1400-2400 (119.8-205.3)	0.97
PBO	40.3	2.5-3.5	1254-1875 (170.3-254.7)	1.54

Hydroentangled HMPE fabric formation

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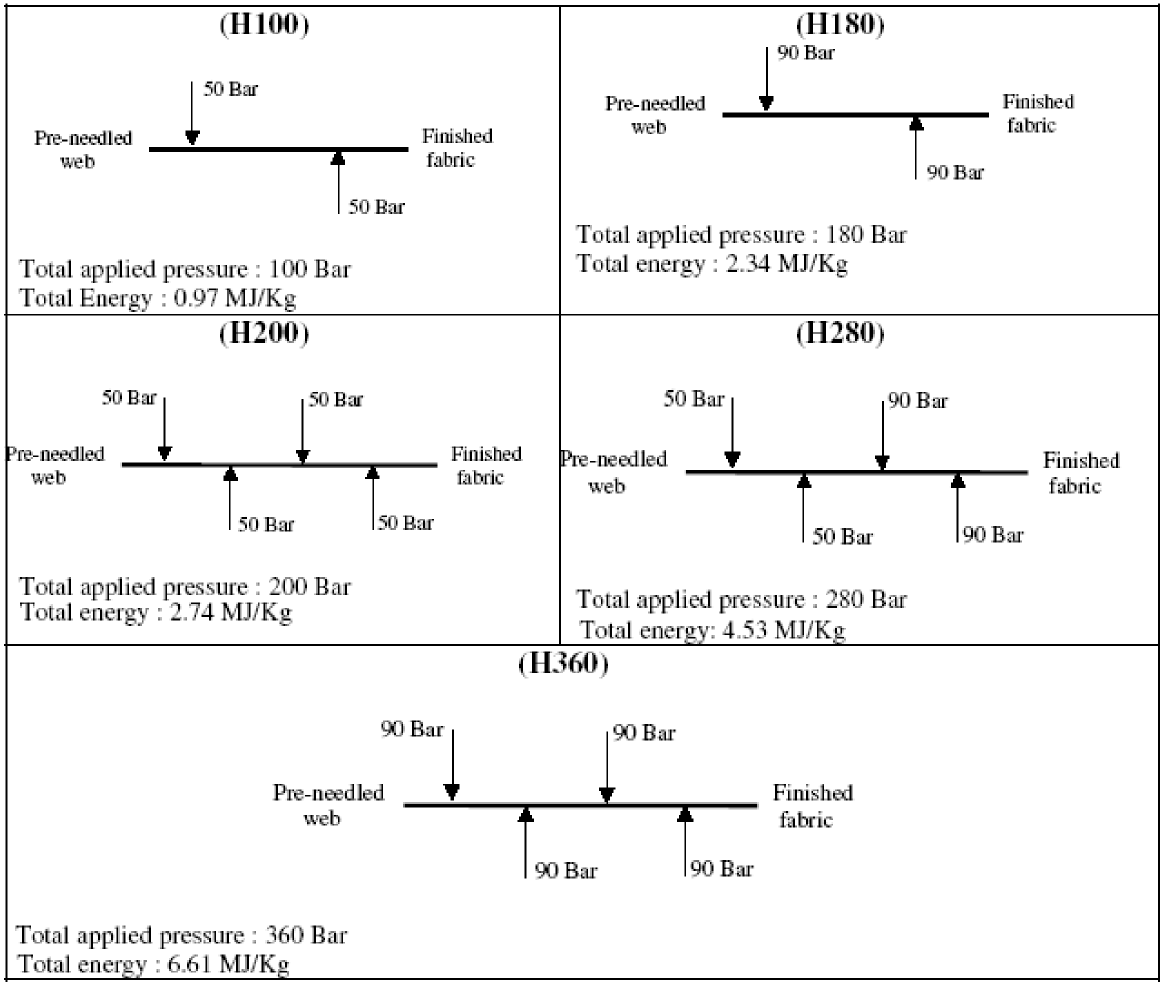

Parameters	Specifications
Water pressure	Profiled (alternating)
Conveyor speed	8 m min^{-1}
Belt specifications	4/1 step twill (weft-faced)
Jet orifice diameter	130µm (0.7 mm pitch)
Jet frequency	1250 holes/m
CD	0.66

Pilot Hydroentanglement

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Flat bed + 2 cylinder sections.

7 injectors

200 bar pressure

0.5 m wide

Hydroentangled HMPE fabric dimensions

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Samples	Weight (g/m²)		Thickness (mm)		Density (g/cm³)
	Mean	SD	Mean	SD	
NP (Commercial Sample)	204	9.71	2.5	0.188	0.082
H100	113	6.04	1.7	0.092	0.066
H180	114	5.63	1.4	0.083	0.081
H200	120	7.43	1.4	0.078	0.086
H280	124	6.92	1.3	0.073	0.095
H360	124	6.23	1.2	0.069	0.103
NP	212	11.05	1.9	0.127	0.112

H = hydroentangled

NP = needlepunched

Hydroentangled HMPE fabric mechanical properties

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Samples	Load at break (N)		Extension at break (%)		Energy (MJ)		Fabric tenacity (g/d)	Specific energy absorption (N/mm²/kg)
	Mean	SD	Mean	SD	Mean	SD		
NP (MD)	84.4	20.6	168.9	14.0	5.43	0.80	0.19	1.09
NP (CD)	807.4	43.2	50.8	1.4	23.93	0.90	1.89	4.79
H360 (MD)	353.2	48.1	68.4	4.1	15.31	2.14	1.38	6.12
H360 (CD)	586.6	38.8	87.5	2.8	17.18	2.55	2.29	6.87

Needepunched, t = 2.5 mm

Hydroentangled, t = 1.2 mm

Hydroentangled HMPE fabric: puncture resistance (single layer)

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Sample type	Weight (g/m²)	Thickness (mm)	Applied specific energy during hydroentangling (MJ/kg)	Specific puncture load (kNm²/kg)	
				Mean	SD
Needle-punched commercial sample	204	2.5	Needled	5.1	0.73
H100	113	1.7	0.97	3.9	0.24
H180	114	1.4	2.34	7.2	0.91
H200	120	1.4	2.74	4.6	1.53
H280	124	1.3	4.53	7.5	1.11
H360	124	1.2	6.61	8.3	0.57

Specific puncture force for HE > NP.

Density of NP is similar to H180.

Influence of dual layer hydroentangled HMPE fabric constructions on puncture resistance

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Sample type	Weight (g/m²)	Thickness (mm)	Applied specific energy during hydroentangling (MJ/kg)	Specific puncture load (kN m²/kg)	
				Mean	SD
H200 MD / H200 MD	241	2.7	2.742	5.8	0.78
H200 CD / H200 MD	241	2.7	2.742	6.3	0.8
Carded cross-lapped / Carded cross-lapped	212	1.9	3.800	7.3	0.85
H360 MD / H360 MD	248	2.4	6.612	9.2	0.95

Influence of isotropicity

Influence of fabric structure on HMPE fabric puncture resistance

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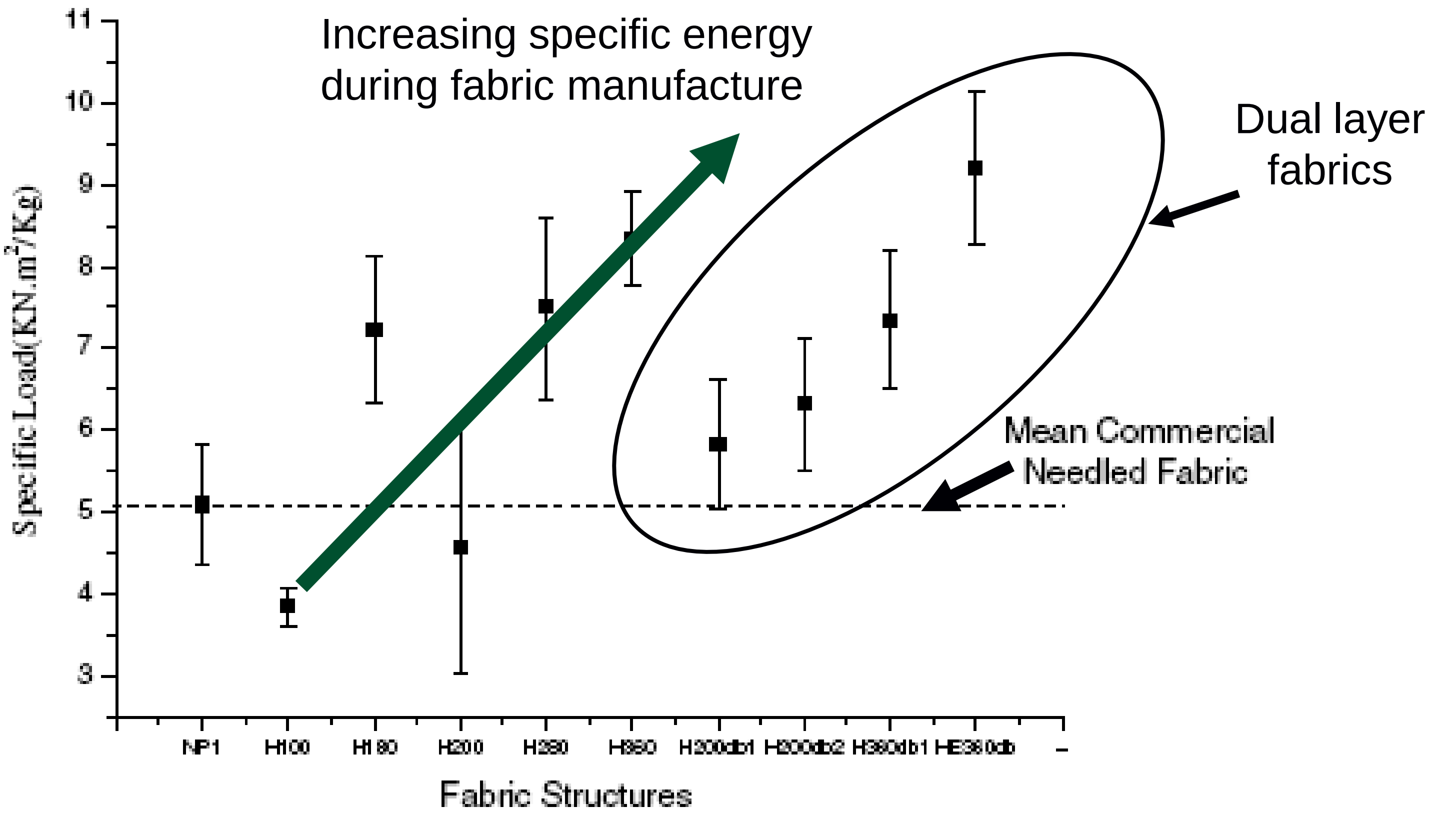

Ballistic Performance

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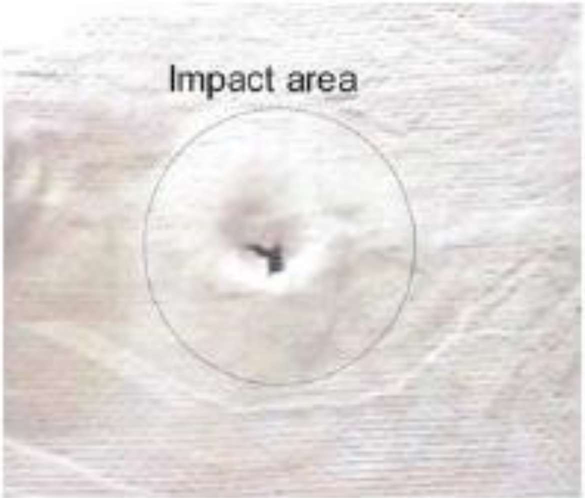
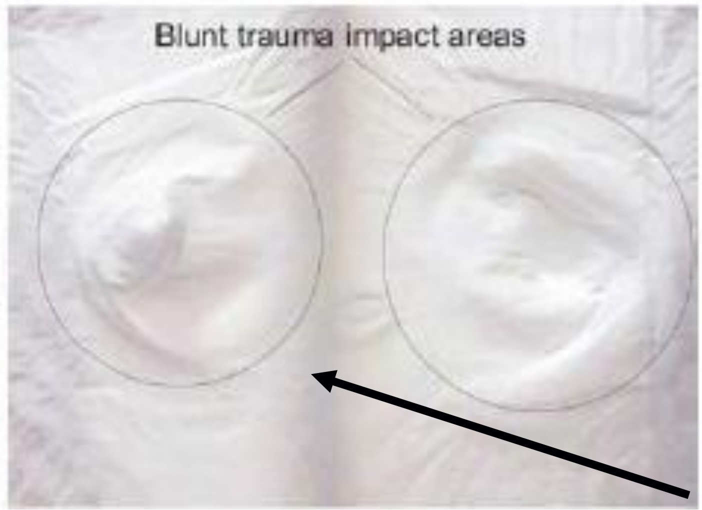


Projectile penetration
(top layer 1)



Blunt impact trauma
(inner layer 3)

NIJ Handgun Test (0101.03: Type I)

38 mm round nose lead bullet (10.2g)

Velocity: 259 m/s

Handgun: 0.38 calibre.

Layered weight: 3.3 kg/m².

Test firings: 3

Blunt trauma: 24 mm
(limit: 44 mm)

FSP Material	Weight (kg/m²)	V_{50} (ms)	Specific energy absorbed (J m²/kg)
Hydroentangled HMPE (H360)	**1.24**	**428**	**81**
Commercial needle-punched HMPE	**1.20**	**>490**	**110**

NATO Stanag 2920 V_{50} , chisel point metal cylinder (1.1g, diameter = 5.6mm)
10 layers in 90º offset (MD + CD orientation).

Summary

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- Hydroentangled, 100% HMPE impact protective fabrics (compared to existing needle-punched):

  - Improved low velocity impact resistance but not ballistic performance (in respect of specific energy absorption). Blunt impact trauma: 24mm.
  - Higher specific tensile strength and specific energy absorption with up to 50% decrease in fabric thickness.
  - HMPE fabric density increases with jet pressure.
  - Fabric isotropicity (as determined by the direction of lay-up and MD:CD) influences the specific puncture force.
  - Dual hydroentangled HMPE layers increase the specific puncture force.

Integration of multiple webs by hydroentanglement is preferable to plying fully bonded fabrics.

Concurrent research: thermo-physical wearer comfort in hydroentangled armour

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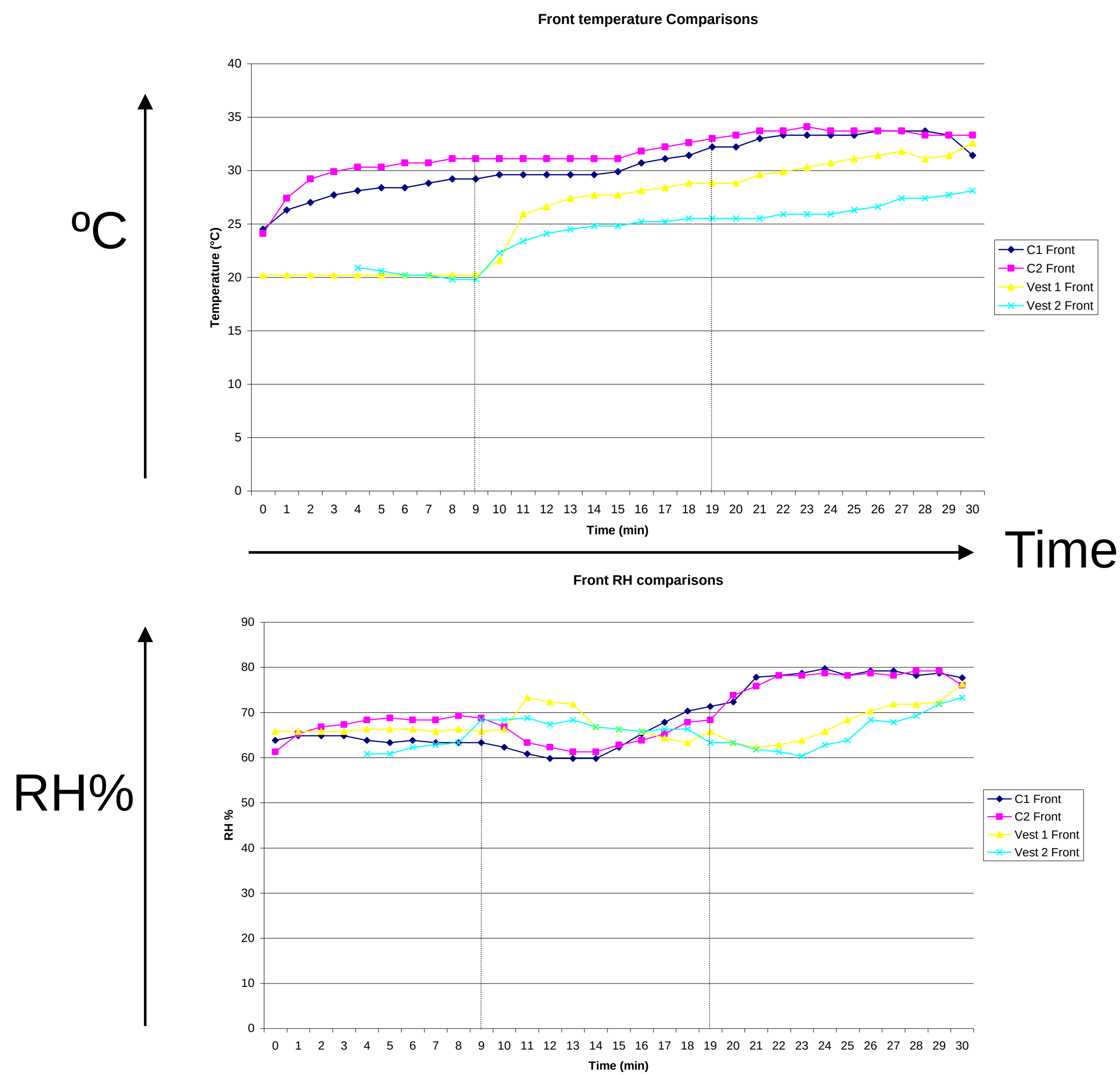
- Discrete mechanically integrated bi-laminar constructions with hydrophilic layer.
- Microclimate monitoring (T and RH%).
- Modelling fabric heat transfer and permeability and development of structure-property relationships.



Thank you

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