TECHNISCHE UNIVERSITÄT DRESDEN

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Isotropic/anisotropic materials and manufacturing technologies

Lecture "Function-Integrative System Lightweight Engineering in Multi-Material Design"

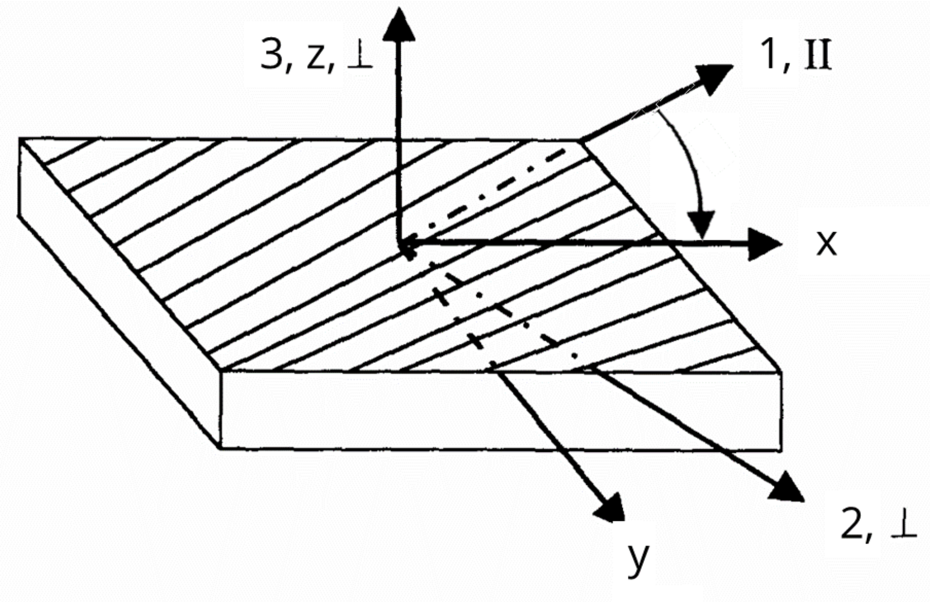
Warszawa, 26th June 2023

Institut für Leichtbau und Kunststofftechnik

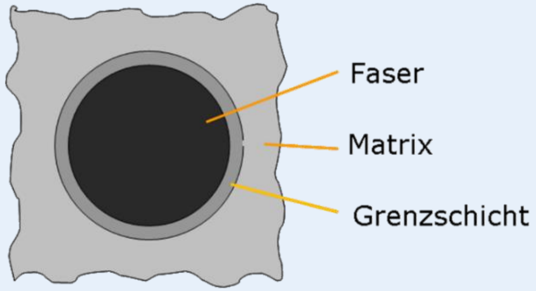
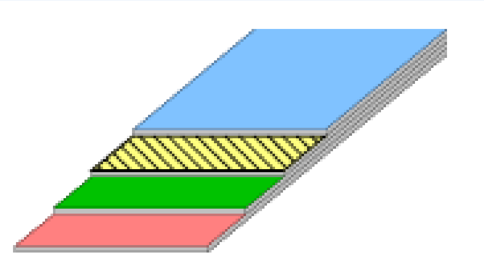
DIRECTIONAL PROPERTIES

Orthotropic fibre-reinforced single layer (e. g. UD layer)

- Fibre- adapted coordinate system 1, 2, 3 or II, ⊥
- Structure-adapted coordinate system x, y, z
- z-direction: through the thickness (TTT) direction



DEFINITIONS FOR FKV

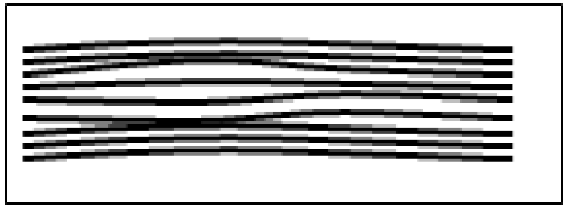
Fibre, matrix, interface	Single layer (UD layer)	Multilayer composite
Micro scale	Meso scale	
		
Fibre • homogeneous • Linear elastic • isotrop/transverse isotropic Matrix • homogeneous • linear elastic Interface • Not considered Fibre composite • inhomogeneous, anisotropic	• the fibre-matrix composite is considered as a continuum • macroscopically homogeneous • macroscopically orthotropic/ transversely isotropic	• a multilayer composite (laminate) consists of several perfectly bonded individual layers • a multilayer composite behaves macroscopically like a homogeneous board, but with specific stiffness properties
Micromecanical model	Material model	Laminate model

GENERAL REQUIREMENTS FOR POLYMER MATRIX MATERIALS

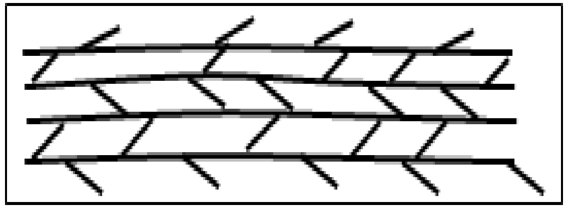
- High mechanical strength
- High thermal resistance
- Low water absorption
- Low viscosity (uncured resin systems)
- Good wetting capacity to the reinforcing fibre
- Good adhesion to glass, carbon and armaid fibres
- Low density
- Elongation at break greater than that of the reinforcing fibre
- Low price
- Low shrinkage

Thermosets are mainly used for the manufacture of products from reinforced high polymers. However, reinforced thermoplastics are currently gaining in importance and their share of reinforced plastics is steadily increasing.

STRUCTURAL DIAGRAM OF VARIOUS PLASTIC GROUPS



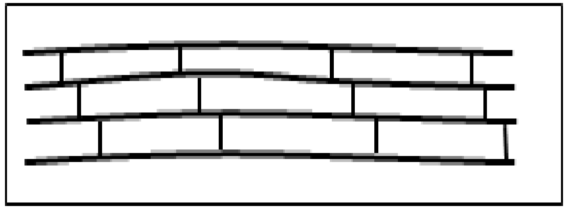
linear chain molecules



branched chain molecules

Thermoplastics

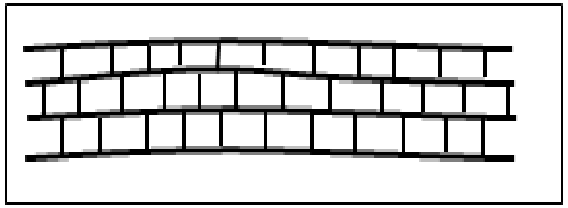
- Slipping of the chains under load
- Meltable as often as required
- Soluble
- Swellable
- Low tensile strength and stiffness
- Medium to high elongation at break
- Creep



Weakly cross-linked chain molecules

Elastomers

- No slipping of the chains (cross-linking
- Non-meltable, non-soluble
- Source bar
- Low tensile strength and stiffness
- Medium to high elongation at break



Strongly cross-linked chain molecules

Thermosets

- No slipping of the chains (cross-linking)
- Non-meltable, non-soluble
- Low to medium tensile strength and stiffness
- low to medium elongation at break

ADVANTAGES AND DISADVANTAGES OF THERMOSETS AS MATRIX FOR COMPOSITE

Advantages

- Cold curing resins facilitate the production. ("Hobbyplast")
- Low-pressure curing means cost-effective process (simple counter mould, vacuum)
- No problems even with large-scale production in the moulding troughs (e.g. wind turbines)
- Good adjustable temperature and fire resistance
- Modification for chemical resistance (vinyl ester resins)

Disadvantages

- The user must observe the chemical reactions and regulate the curing process
- Liquid resins have a limited shelf life
- Health problems when processing the liquid resins
- No suitable recycling possible so far
- The high brittleness gives the resins low toughness
- With polycondensates, the occurrence of water is disadvantageous

ADVANTAGES AND DISADVANTAGES OF THERMOPLASTICS AS MATRIX FOR FVW

Advantages

- Fast cycle times possible during production
- Little knowledge of the chemism necessary
- Available as granules, safe to handle and long shelf life
- Elongation capacity and thus toughness very high
- Recycling is possible
- High resistance to environmental influences
- Semi-finished products can be continuously produced and processed as sheets

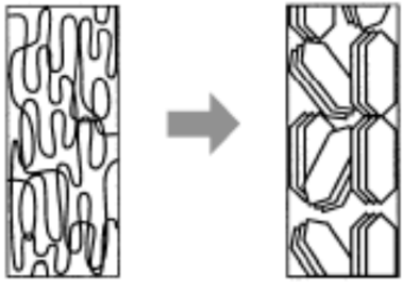
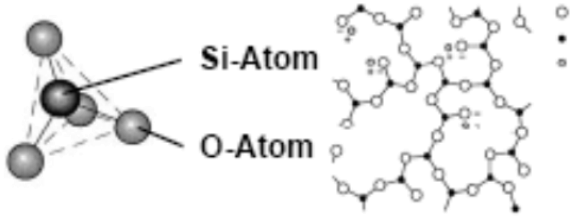
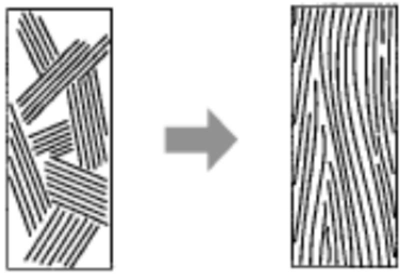
Disadvantages

- Moulding at high temperatures and high pressures requires expensive tools and precise cycle control
- Expensive tools are only worthwhile for larger quantities
- At high temperatures, the thermoplastics soften and can burn
- Resistance to temperature and the chemical resistance vary over larger ranges

POLYMERIC MATRIX MATERIALS - PROPERTIES

	Material \ Eigenschaft	Dichte in g/cm³	Bruchdehnung in %	Kriechneigung	Verarbeitungstemperatur in °C	Dauergebrauchstemperatur in °C	Wärmeformbeständigkeit nach ISO/R75 in °C
Duroplaste	Ungesättigte Polyester - UP	1,17-1,26	< 3	sehr gering	Raumtemp. bis 180	80-160	55-90
	Epoxidharz - EP	1,17-1,25	6-8		Raumtemp. bis 170	80-130	60-110
	Phenolplaste - PF	1,25-1,30	< 3		150-190	100-150	150
	Vinylesterharz – VE	1,17-1,25	3,5-7		Raumtemp. bis 175	100-150	55-85
	Polyimid - PI	1,27-1,42	6-10		um 350	260 in Luft kurzzeitig bis 500	250
Thermoplaste	Polypropylen – PP	0,90-0,91	> 600	Kriechen möglich, insb. quer zur Faserrichtung und bei kurzen Fasern	170-300	110	48-65
	Polyamid – PA	1,01-1,19	200-250		210-290	80-120	50-110
	Polyether-etherketon PEEK	1,32	50		380-400	250	140
	Polyethersu				340-380		

CHARACTERISTICS OF REINFORCING FIBRES

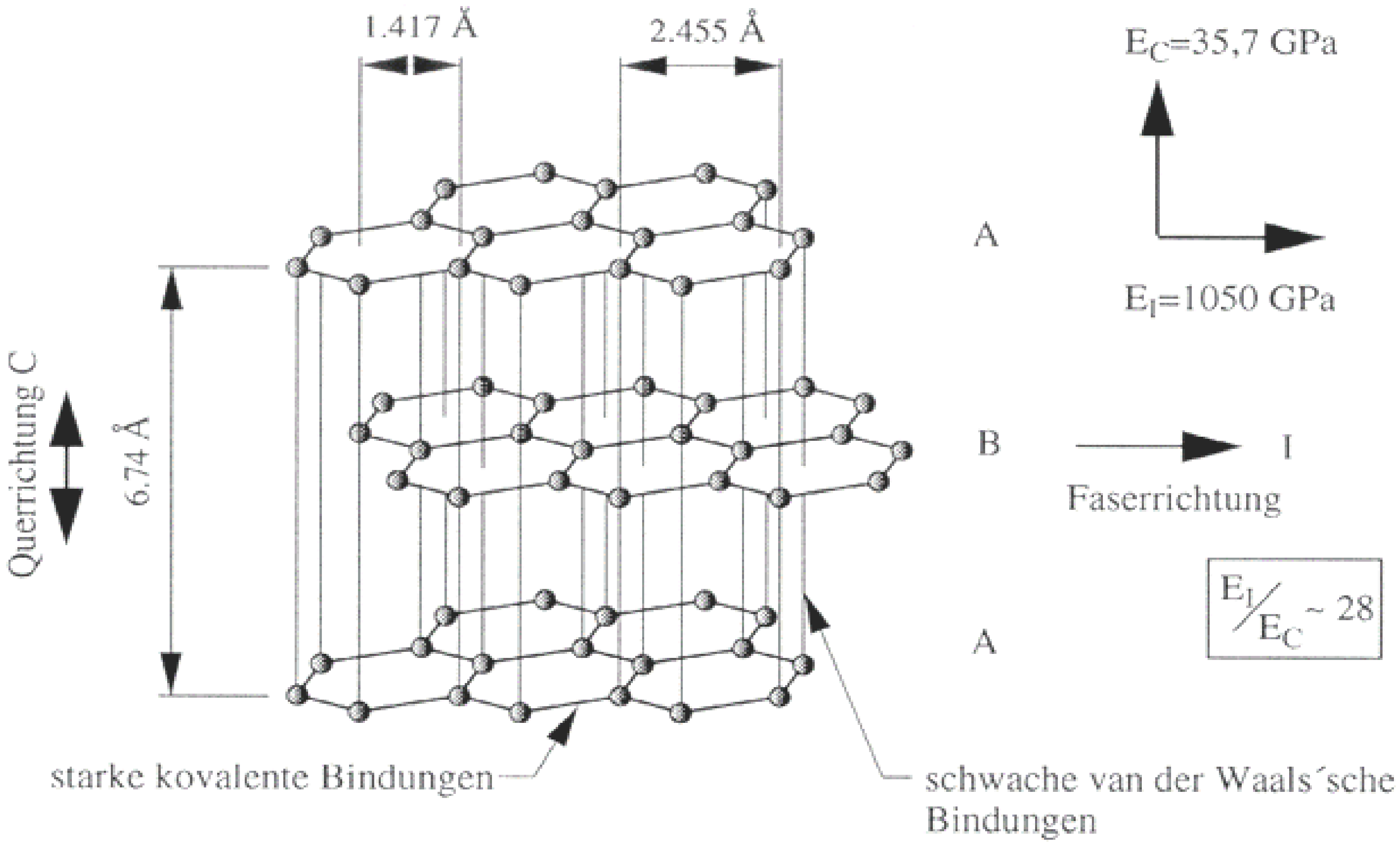
Faser	Struktur	Merkmale
Kohlenstoffaser		2D kovalente Bindungen Parakristallin (100%) Hohe Orientierung
Glasfaser		3D Vernetzung führt zu isotropen Eigenschaften Kovalente Bindungen zwischen Silizium und Sauerstoff
Synthesefasern (z.B. Aramid)		1D kovalente Bindungen Wasserstoffbrücken- und Van der Waalsbindungen Parakristallin (100%) Sehr hohe Orientierung

Source: Flemming el al.

SEMI-FINISHED FIBRE PRODUCTS – CARBON FIBRES

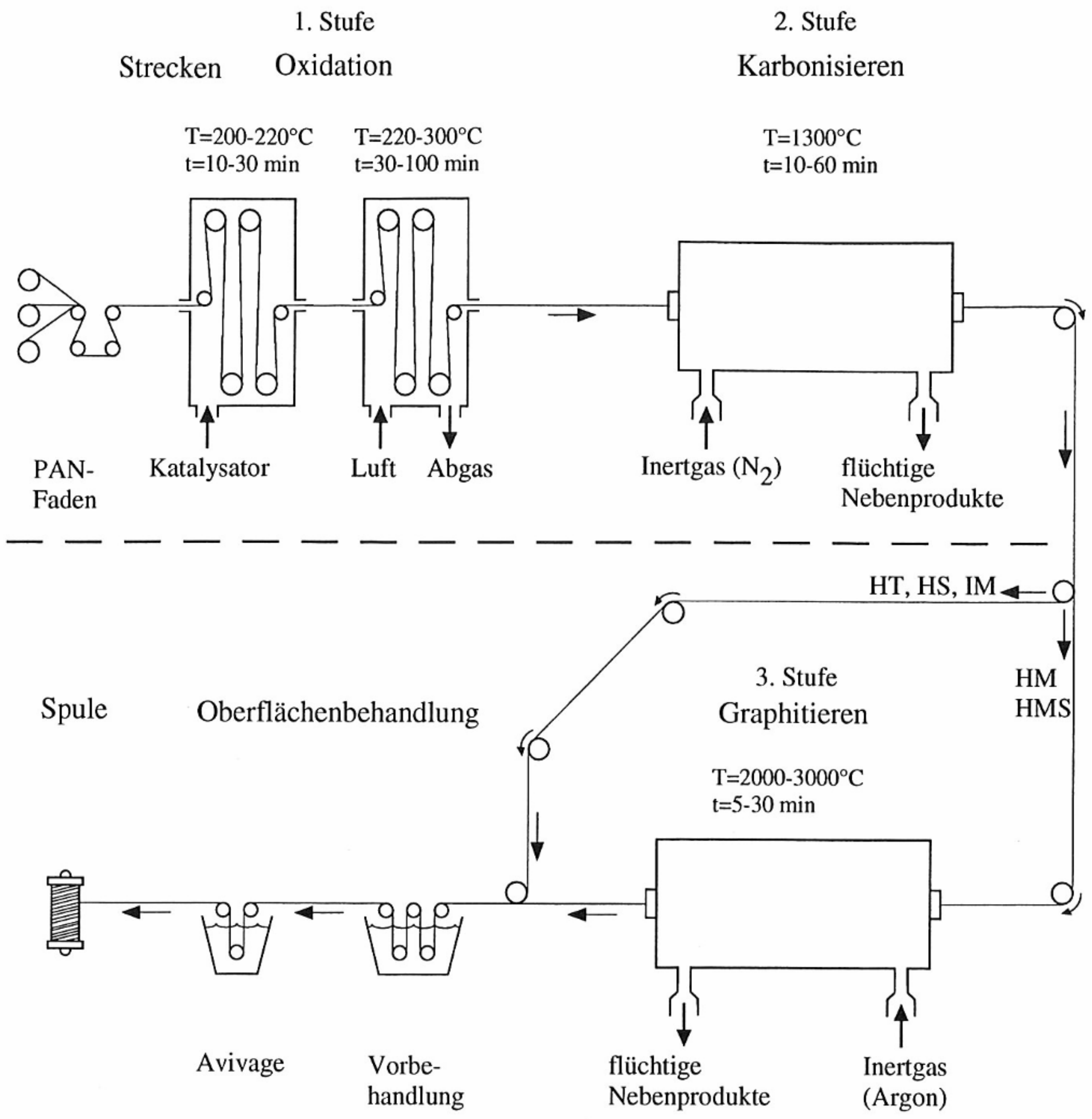
- **Very stiff fibre (HT fibres: ~230 MPa)**
- **Low density**
  - Density CF: ~1.8 g/cm³
  - GF: ~2.5 g/cm³
- **Strength like glass fibre approx. 5 GPa**
- **Negative thermal expansion in fibre direction (dimensional stability)**
- **Anisotropic fibre**
- **High price**
- **Applications:**
  - Aerospace,
  - Racing,
  - Sports,
  - Optics

A GRAPHITE MODIFICATION OF CARBON

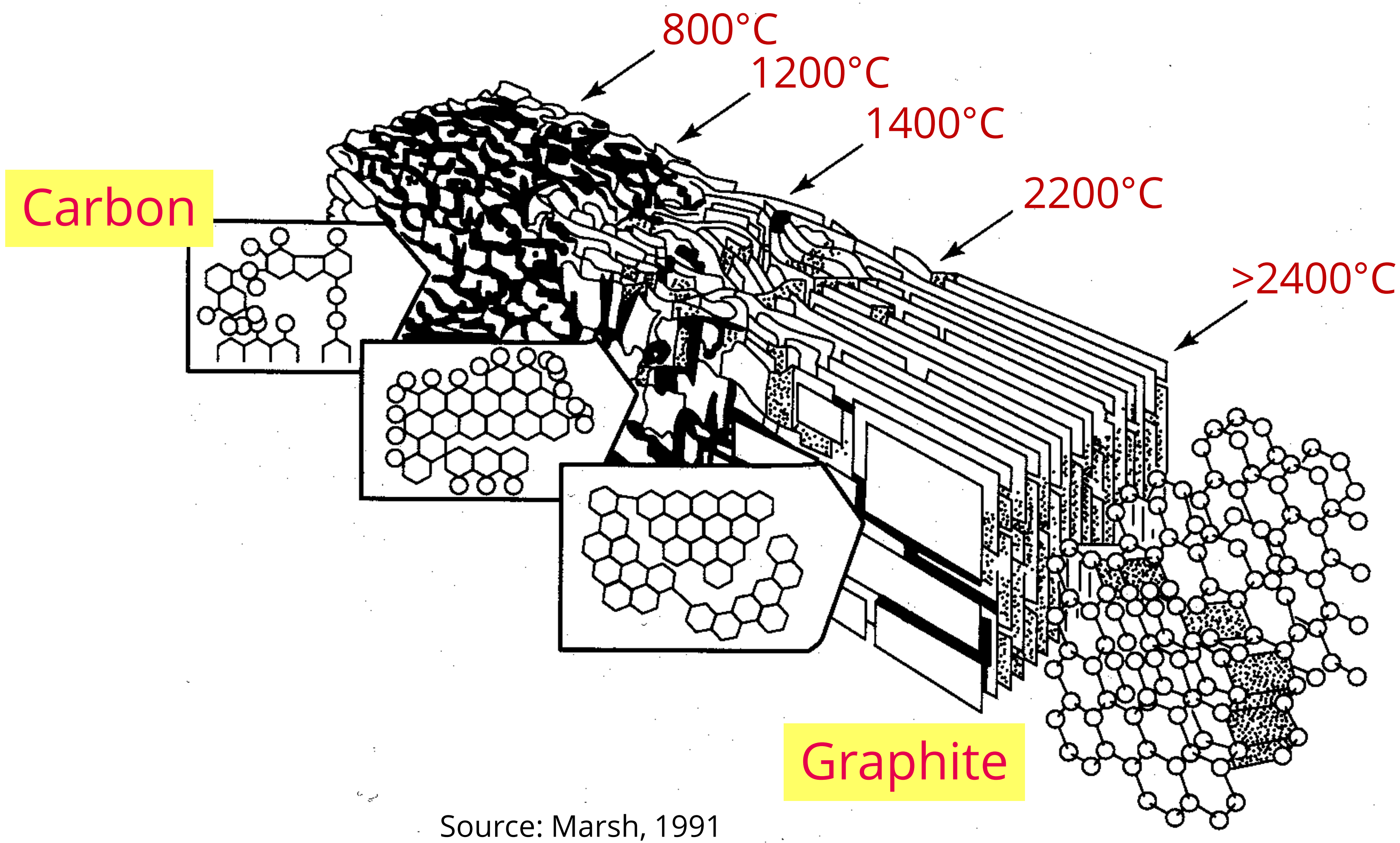


Source: Flemming

SCHEMATIC PROCESS OF CF PRODUCTION FROM PAN



SCHEMATIC SEQUENCE OF CARBONISATION



Source: Marsh, 1991

PROPERTIES OF DIFFERENT CARBON FIBRE TYPES

Physikalische Eigenschaft	Formel-zeichen	Einheit	HT (hoch-fest)	IM (inter-mediate)	HM (hoch-modul)	HMS (hochmodul /hochsteif)
Dichte	ρ	g/cm^3	1,74	1,80	1,83	1,85
Zugfestigkeit	σ_B	MPa	3600	5600	2300	3600
Zugmodul	E_Z	GPa	240	290	400	550
Druckfestigkeit	σ_B	GPa	2,50	4,20	1,50	1,80
Bruchdehnung	ε_B	%	1,7–1,9	1,6–2,0	1,0–1,4	0,7–1,5
Faserdurchmesser	d	µm	7	5	6,5	5

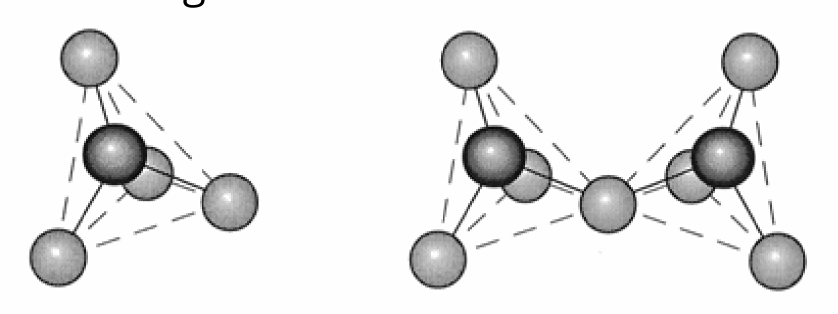
SEMI-FINISHED FIBRE PRODUCTS – GLASS FIBRE

- **Lower stiffness than carbon fibre**
  - GF: 70 GPa,
  - CF (HT): 230 GPa
- **Similar strength to carbon fibre 5 GPa**
- **Lower price**
- **Isotropic fibres**
- **Mass applications:**
  - Boat building,
  - Vehicle construction,
  - Wind power,
  - Modelling

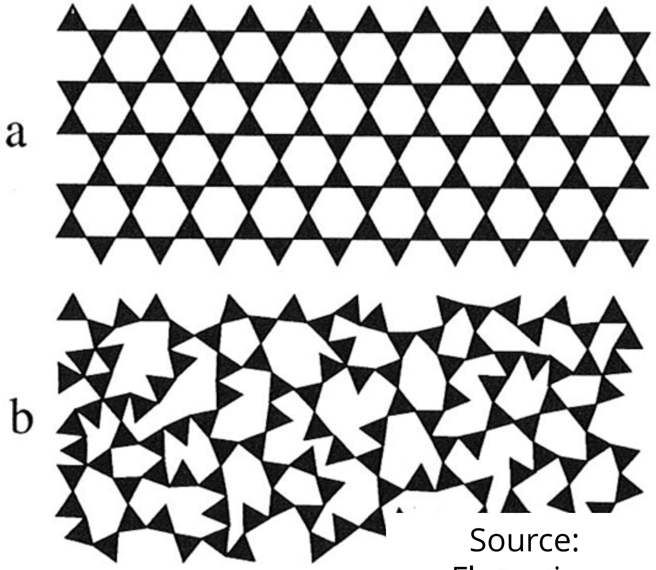
Quelle shop1.r-g.de

SCHEMATIC STRUCTURE OF GLASS

Basic building block silicon oxide

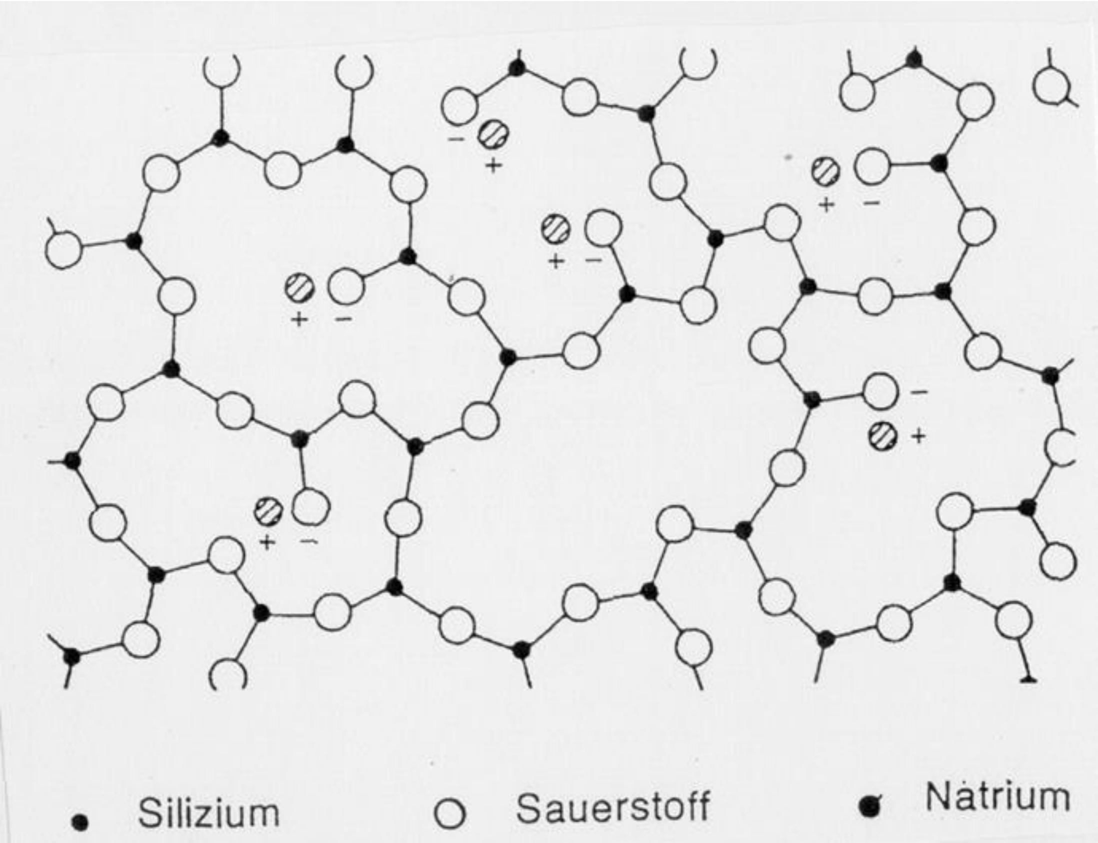


a Quartz glass
b amorphous glass



Source: Flemming

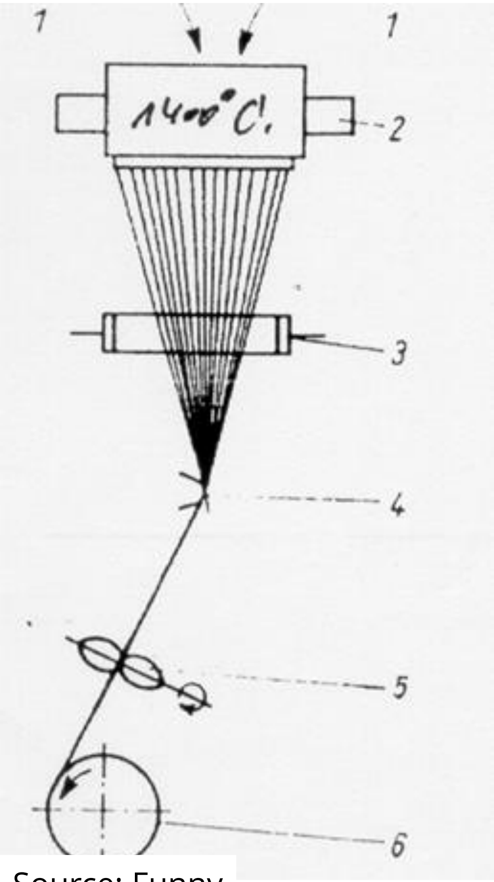
Amorphous glass structure



Source: Funny

SCHEMATIC REPRESENTATION OF THE NOZZLE DRAWING PROCESS

- **Use of glass melting furnaces with homogenisation (UNIMELTER) usual**
- **Glass balls as an intermediate product in the melting tank**



Source: Funny

1. Metering device for glass, previously as balls, in the modern direct spinning process as molten glass
2. Electrically heated platinum tank (400 to 4000 hole nozzles, diameter: 1 to 2 mm → filament diameter 3 to 13 µm)
3. Roller for coating application
4. Combining the elementary threads to form the spinning thread
5. Thread thrower
6. Bobbin head

- Glass fibre melt 1200° - 1400°C
- Filament-forming forces: gravity and filament force
- Take-off speed: approx. 3000 m/min
- Surfaces on roller 3 wetted with coating
- High quality fibre

PROPERTIES OF GLASS FIBRES

		E	R/S	M	C
Zugfestigkeit	GPa	3,5	4,7	7,0	3,1
E-Modul	GPa	73	88	125	71
Bruchdehnung	%	~ 4,5	5,0	~ 5,5	3,5
spez. Zugfestigkeit	GPa x cm^3/g	1,38	1,8	2,8	1,3
spez. E-Modul	GPa x cm^3/g	28,8	34	50,3	29
Faserdurchmesser	µm	3 - 13	10	10	
Dichte	g/cm^3	2,55	2,49		2,45
therm. Ausdehnungskoeffizient	$10^{-6}/K$	5 - 6	4		7,2
Schmelzpunkt	°C	840	1000		

SEMI-FINISHED FIBRE PRODUCTS – ARAMID FIBRE

- **Cut resistant (special cutting tools)**
- **UV-resistant (lacquering or special resin)**
- **Negative thermal expansion in fibre direction (dimensional stability)**
- **Strength lower than CF/GF**
- **Stiffness comparable to glass**
- **Application:**
  - Cut protection (safety waistcoats, forestry trousers, protective gloves),
  - Impact layer for exterior components

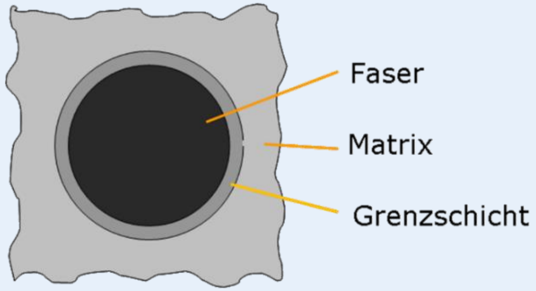
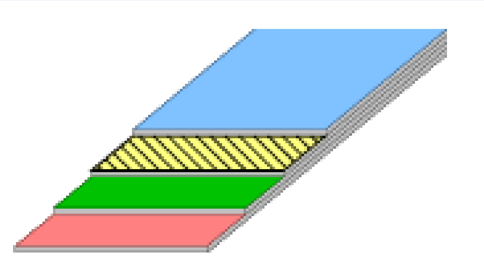
Quelle cyccomposites.net

PRICES OF HIGH PERFORMANCE FIBRES

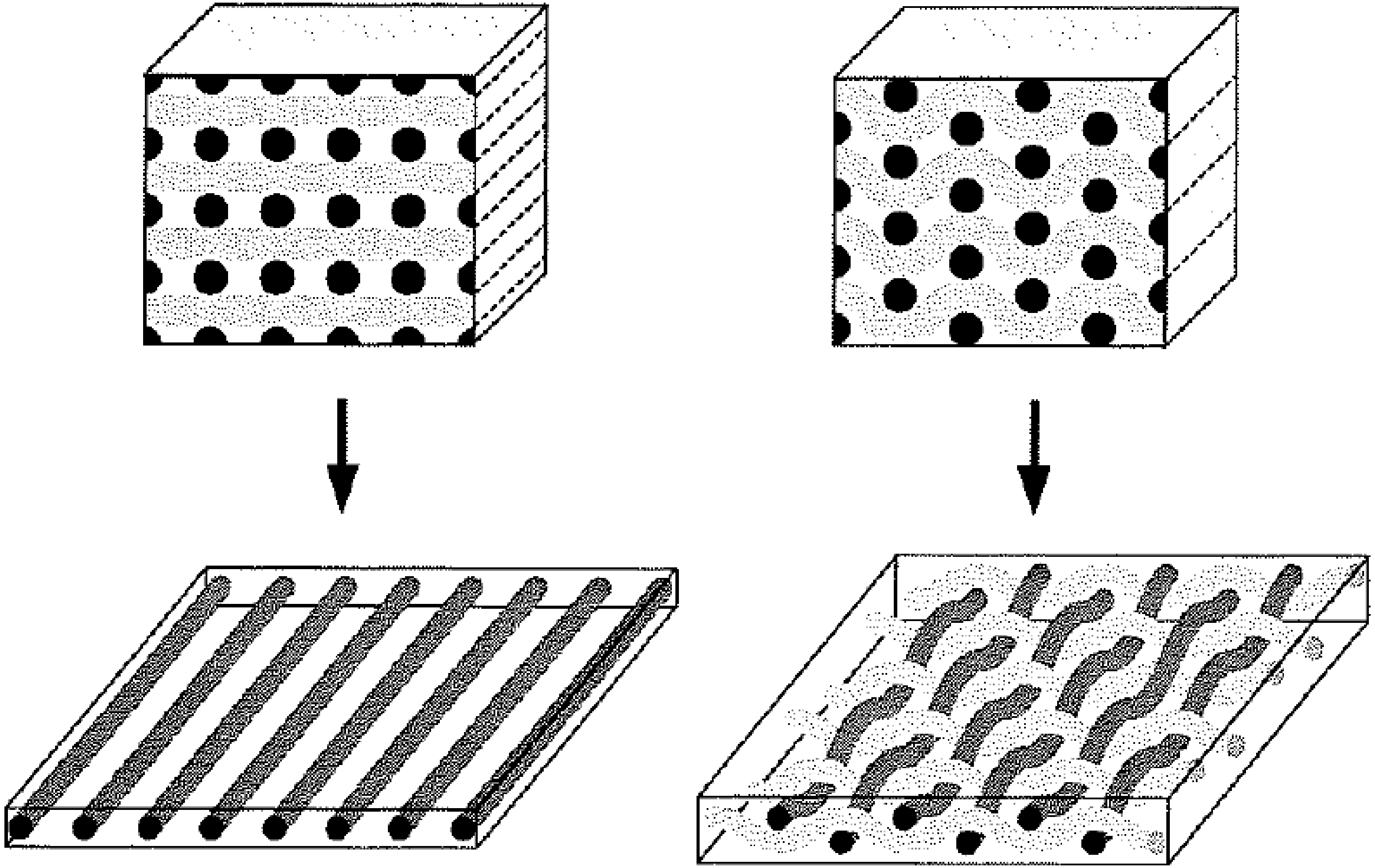
Fibre type		€/kg
Glass		2-3
Basalt		15-60
Aramid		20-30
Carbon	HT	20-80
	HM	80-500
	UHM	500-1000
Al_2O_3		260-900
SiC		1100-7000

Source: Hunter

DEFINITIONS FOR FKV

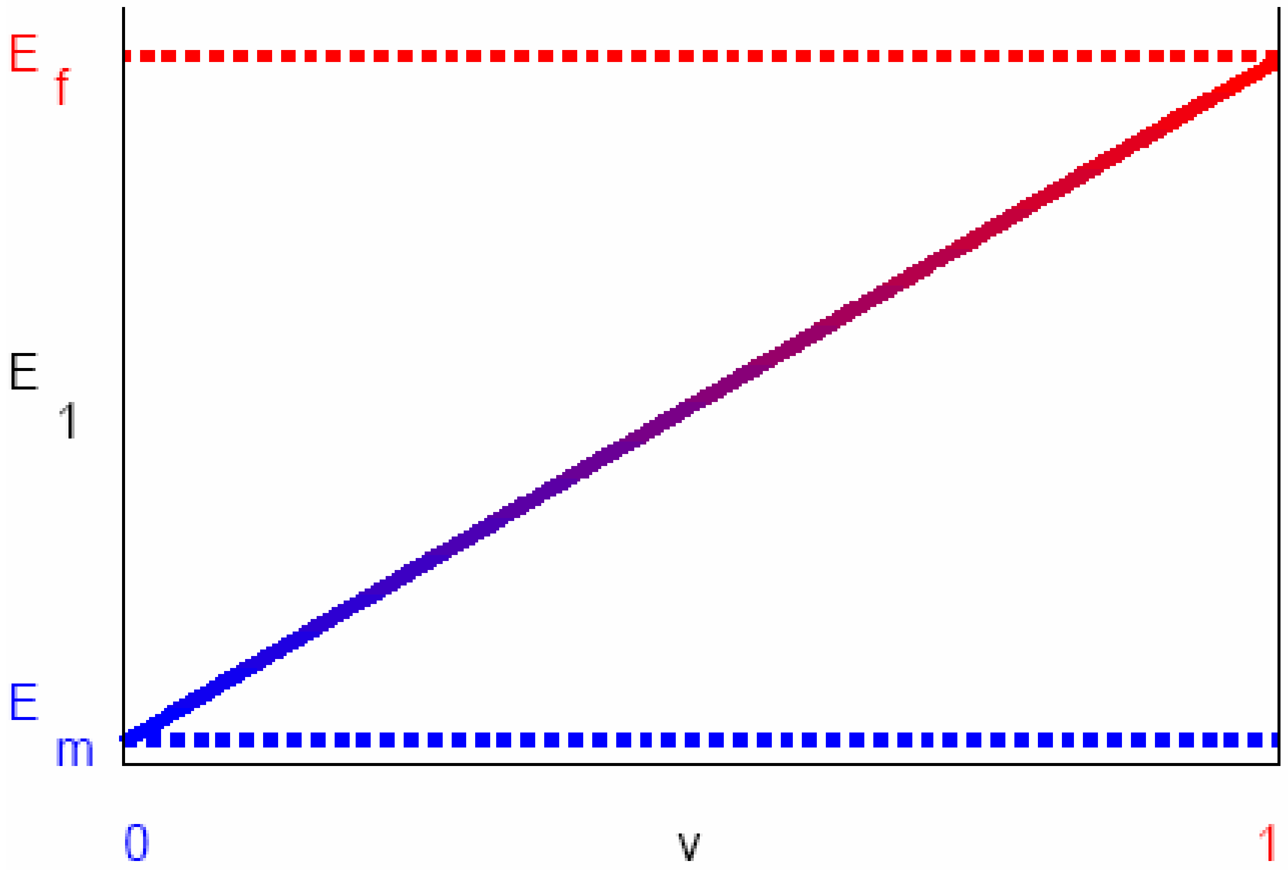
Fibre, matrix, interface	Single layer (UD layer)	Multilayer composite
Micro scale	Meso scale	
		
Fibre • homogeneous • Linear elastic • isotrop/transverse isotropic Matrix • homogeneous • linear elastic Interface • Not considered Fibre composite • inhomogeneous, anisotropic	• the fibre-matrix composite is considered as a continuum • macroscopically homogeneous • macroscopically orthotropic/ transversely isotropic	• a multilayer composite (laminate) consists of several perfectly bonded individual layers • a multilayer composite behaves macroscopically like a homogeneous board, but with specific stiffness properties
Micromecanical model	Material model	Laminate model

UNIDIRECTIONAL AND INTERWOVEN BALANCED SINGLE LAYER



RULE OF MIXTURES: E-MODULUS IN FIBRE DIRECTION

Spring model: Parallel connection of fibre and matrix stiffness



$$\varepsilon_m = \varepsilon_f = \varepsilon_1$$

$$\sigma_f = E_f \varepsilon_1$$

$$\sigma_m = E_m \varepsilon_1$$

$$P = A\sigma_1 = A_f \sigma_f + A_m \sigma_m$$

$$E_1 = \frac{\sigma_1}{\varepsilon_1} = E_f \frac{A_f}{A} + E_m \frac{A_m}{A}$$

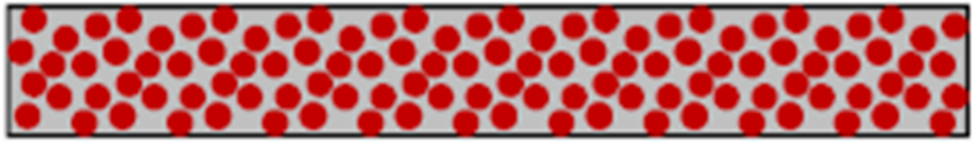
$$E_1 = E_f v_f + E_m v_m$$

Quelle: Ermanni

RULE OF MIXTURES: E-MODULUS TRANSVERSE TO THE FIBRE DIRECTION

Spring model: Serial connection of fibre and matrix stiffness

Anordnung der Fasern im Verbund



Idealisierte Reihenanordnung

Idealisierter Rechteckquerschnitt der Faser

Hintereinandergeschaltete Federn

$$\sigma_{2f} = \sigma_{2m} = \sigma_2$$

$$\varepsilon_f = \frac{\sigma_2}{E_f}$$

$$\varepsilon_m = \frac{\sigma_2}{E_m}$$

$$\varepsilon_2 = v_f \varepsilon_f + v_m \varepsilon_m$$

$$E_2 = \frac{E_f E_m}{v_f E_m + v_m E_f}$$

Quelle: Ermanni

PROTOCOL TASK:
INFLUENCE OF REINFORCEMENT TYPES ON MECHANICAL PROPERTIES

Calculate the Young's modulus of following unidirectional fibre reinforced composite materials in (0°) and perpendicular (90°) to the fibre direction for fibre volume fracture (FVF) of 40, 50, 60 % using rule of mixture.

- Glass epoxy
- Standard carbon epoxy
- High strength carbon epoxy
- High stiffness carbon epoxy
- Intermediate carbon epoxy

Compare the results in two diagrams for different FVF, also with selected steel, aluminum and titan alloys

PROTOCOL TASK:
INFLUENCE OF REINFORCEMENT TYPES ON MECHANICAL PROPERTIES

		ρ [g/cm3]	$E_{\parallel}$ [GPa]	$E_{\perp}$ [GPa]	$\nu_{\parallel\perp}$	$\varepsilon_{F\parallel}$	$R_{F\parallel}$ [MPa]
EP	Standard	1,23	3,5		0,35	4	65
Glass	E	2,52	73		0,25	3,5	2200
Carbon	Standard	1,70	230	15	0,27	1,5	3600
	High strength	1,80	300	10	0,28	1,9	5600
	High stiffness	1,80	400	5,8	0,36	0,6	2700
	Intermediate	1,82	240	16	0,23	2.1	3200

MATERIAL LAW FOR THE SINGLE LAYER IN PSEUDOVECTORIAL REPRESENTATION

$$\begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & 0 & 0 & 0 \\ S_{12} & S_{22} & S_{23} & 0 & 0 & 0 \\ S_{13} & S_{23} & S_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & S_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & S_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & S_{66} \end{pmatrix} \begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{pmatrix} + \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ 0 \\ 0 \\ 0 \end{pmatrix} \Delta T$$

S_{ij} – Coefficient of compliance

$$\begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{pmatrix} = \begin{pmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{13} & C_{23} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{pmatrix} \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{pmatrix} - \begin{pmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ 0 \\ 0 \\ 0 \end{pmatrix} \Delta T$$

C_{ij} - Stiffness coefficients

MATERIAL LAW FOR THE SINGLE LAYER FOR THE PLANE STRESS STATE

$$\begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & 0 \\ S_{12} & S_{22} & 0 \\ 0 & 0 & S_{66} \end{pmatrix} \begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{pmatrix} + \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ 0 \end{pmatrix} \Delta T,$$

$$S_{11} = \frac{1}{E_1}, \quad S_{12} = -\frac{\nu_{12}}{E_1} = S_{21} = -\frac{\nu_{21}}{E_2}, \quad S_{22} = \frac{1}{E_2}, \quad S_{66} = \frac{1}{G_{12}}$$

S_{ij} – Compliance coefficients calculated from four independent engineering constants

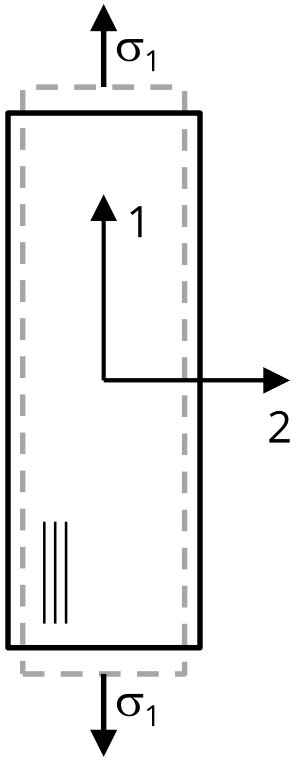
$$\begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{pmatrix} = \begin{pmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{pmatrix} \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{pmatrix} - \begin{pmatrix} \beta_1 \\ \beta_2 \\ 0 \end{pmatrix} \Delta T$$

$$Q_{11} = \frac{E_1}{1 - \nu_{12}\,\nu_{21}}, \quad Q_{12} = \frac{\nu_{12}\,E_1}{1 - \nu_{12}\,\nu_{21}}, \quad Q_{22} = \frac{E_2}{1 - \nu_{12}\,\nu_{21}}, \quad Q_{66} = G_{12}$$

Q_{ij} – reduced stiffness coefficients

DETERMINATION OF THE ENGINEERING CONSTANTS E, ν, G

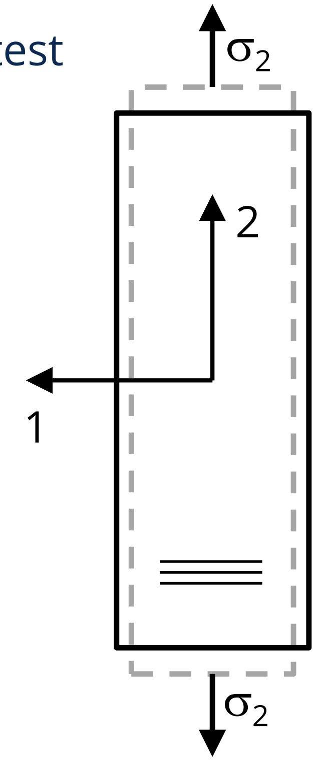
Tensile test



$$E_1 = \frac{\sigma_1}{\varepsilon_1}$$

$$\nu_{12} = -\frac{\varepsilon_2}{\varepsilon_1} = -\varepsilon_2 \frac{E_1}{\sigma_1}$$

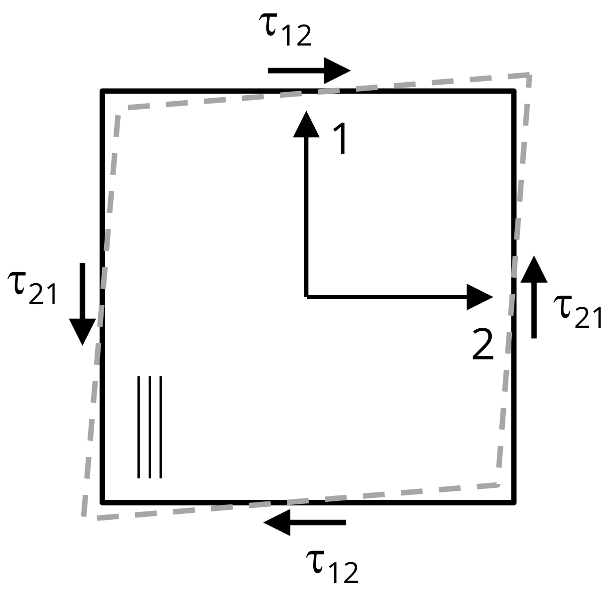
Tensile test



$$E_2 = \frac{\sigma_2}{\varepsilon_1}$$

$$\nu_{21} = -\frac{\varepsilon_1}{\varepsilon_2} = -\varepsilon_1 \frac{E_2}{\sigma_2}$$

Shear test



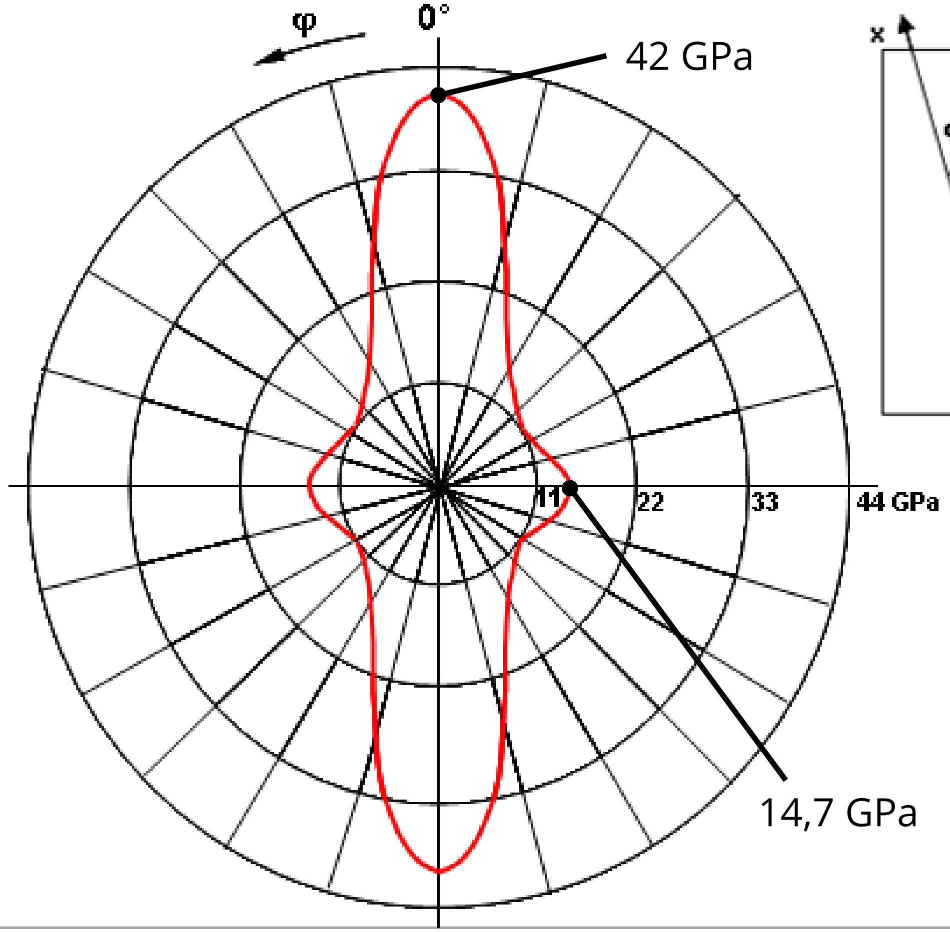
$$G_{12} = \frac{\tau_{12}}{\gamma_{12}}$$

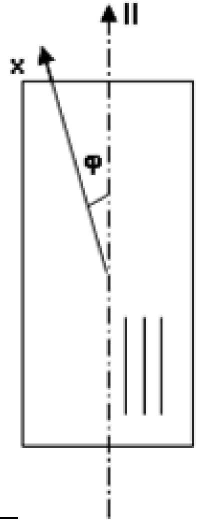
The engineering constants for other material directions can be calculated using transformation rules

POLAR DIAGRAM: DIRECTIONAL MODULUS OF ELASTICITY

Glass fibre reinforced epoxy with UD fabric

Young's modulus [GPa]





Reinforcement :	E glas (DU gewebe)
Harz:	Epoxy
Faservolumengehalt:	56 %
Lagenzahl:	30

Basic characteristic values of the UD single layer:

$E_{II} = E_1 = 42$ GPa

$E_{\perp} = E_2 = 14{,}7$ GPa

$G_{\#} = G_{12} = 3{,}6$ GPa

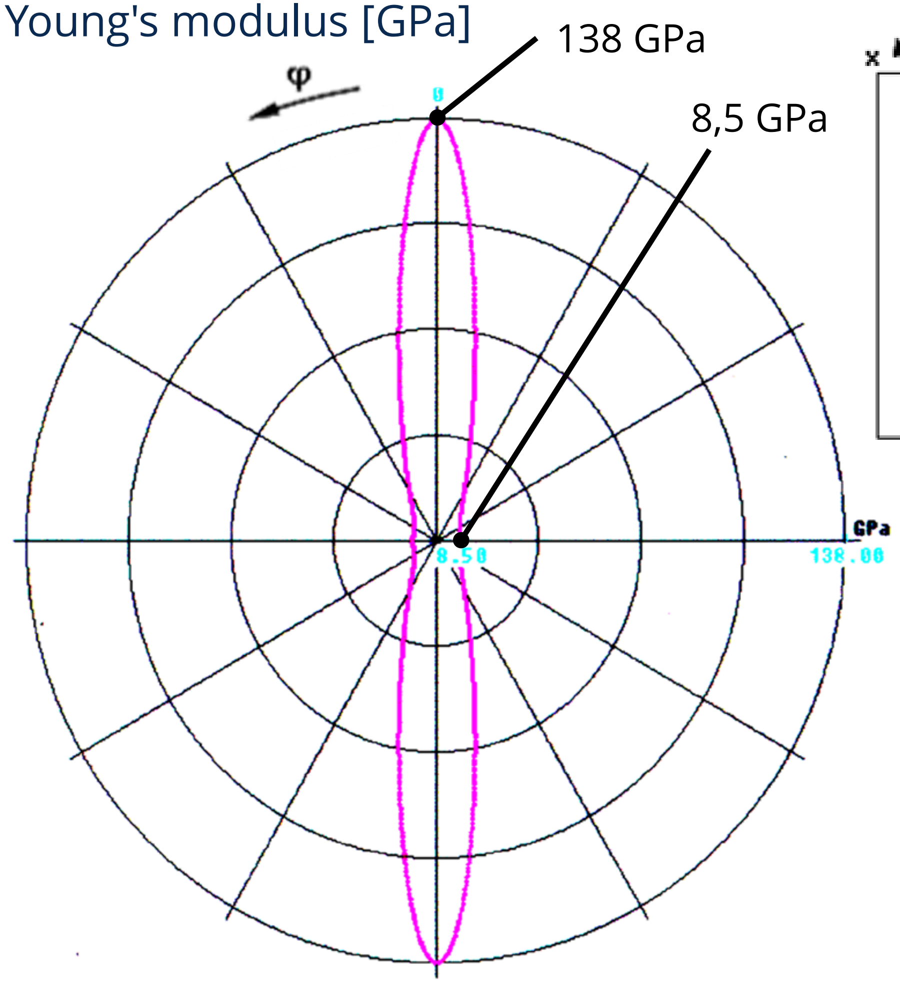
$\nu_{II\perp} = \nu_{12} = 0{,}24$

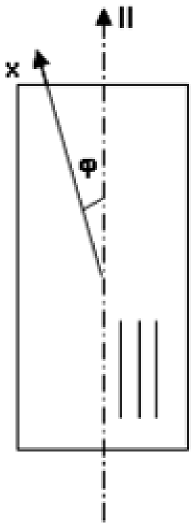
$\nu_{\perp II} = \nu_{21} = 0{,}09$

Polar diagram: Directional modulus of elasticity

UD carbon fibre reinforced epoxy

Young's modulus [GPa]





Reinforcement:	Teijin HTA 40 (pur UD)
Resing:	Epoxy
Fibre volume fracture:	60 %

Basic characteristic values of the UD single layer: :

$E_{II} = E_1 = 138$ GPa

$E_{\perp} = E_2 = 8{,}5$ GPa

$G_{\#} = G_{12} = 4{,}5$ GPa

$\nu_{II\perp} = \nu_{12} = 0{,}29$

$\nu_{\perp II} = \nu_{21} = 0{,}02$

FRACTURE AND DAMAGE MODES

- **Basic terms**

  Fracture: crack initiation

  Damage: Increase and propagation of fractures (cracks)

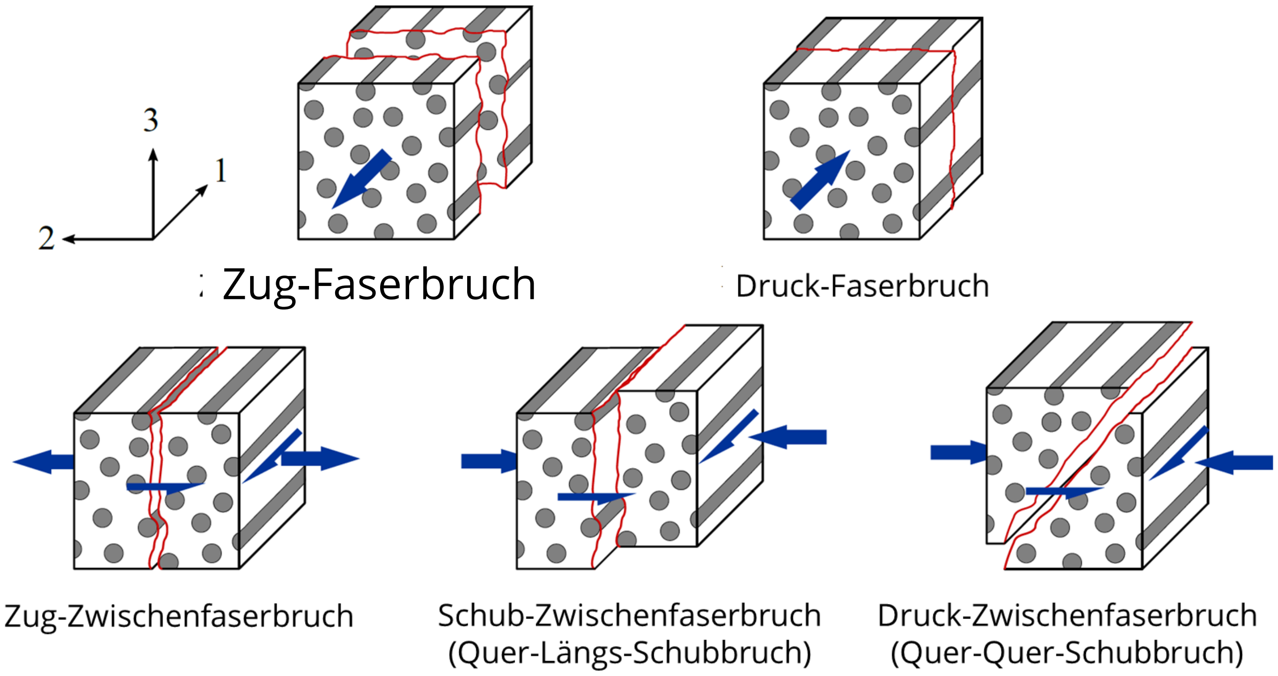
  Failure: Structural failure
- **Intralaminar fractures**

  Fibre failure

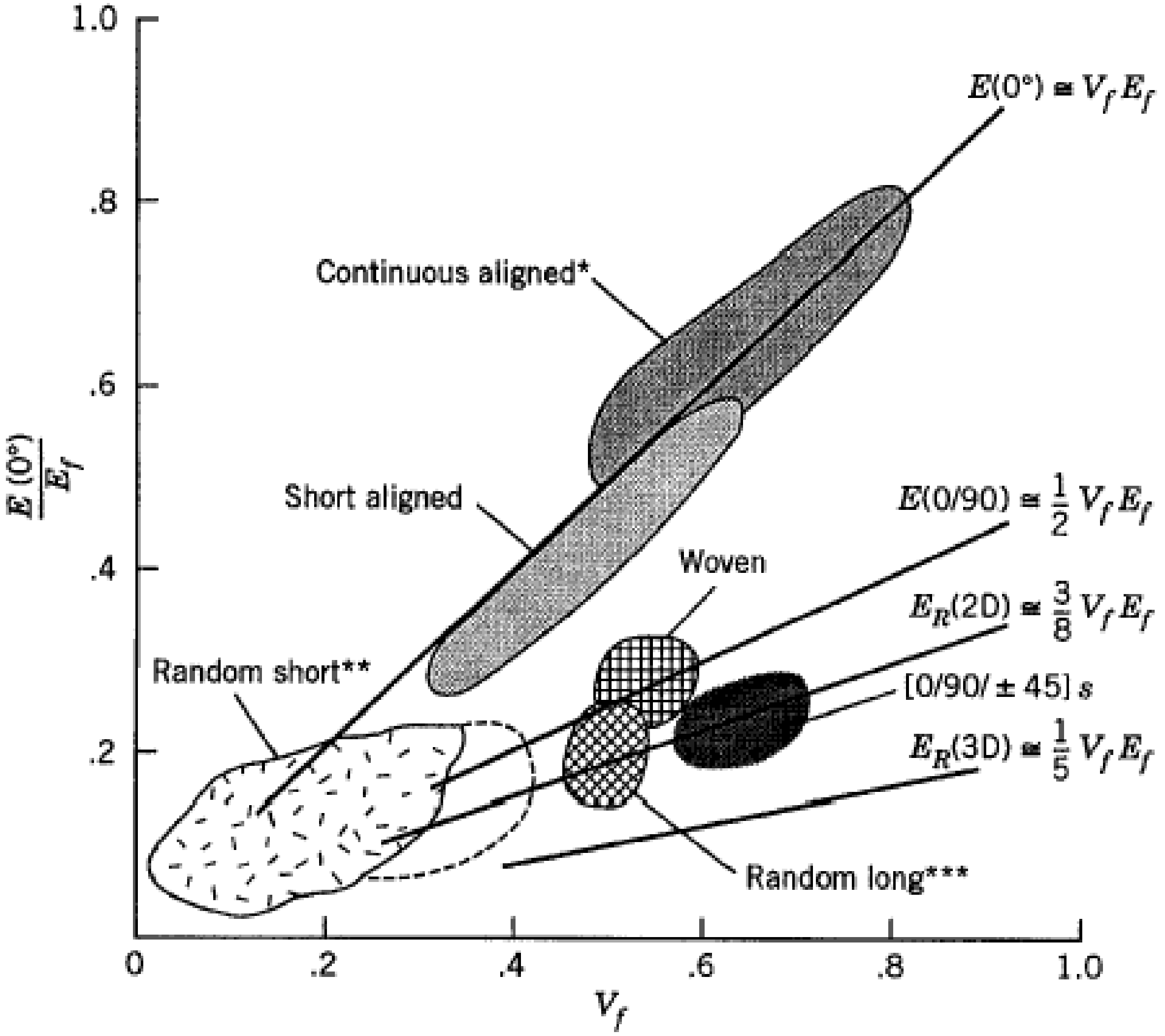
  Inter fibre failure
- **Interlaminar fractures**

  Delamniation

Fibre and intermediate fibre fracture modes according to Puck [Kuhtz]

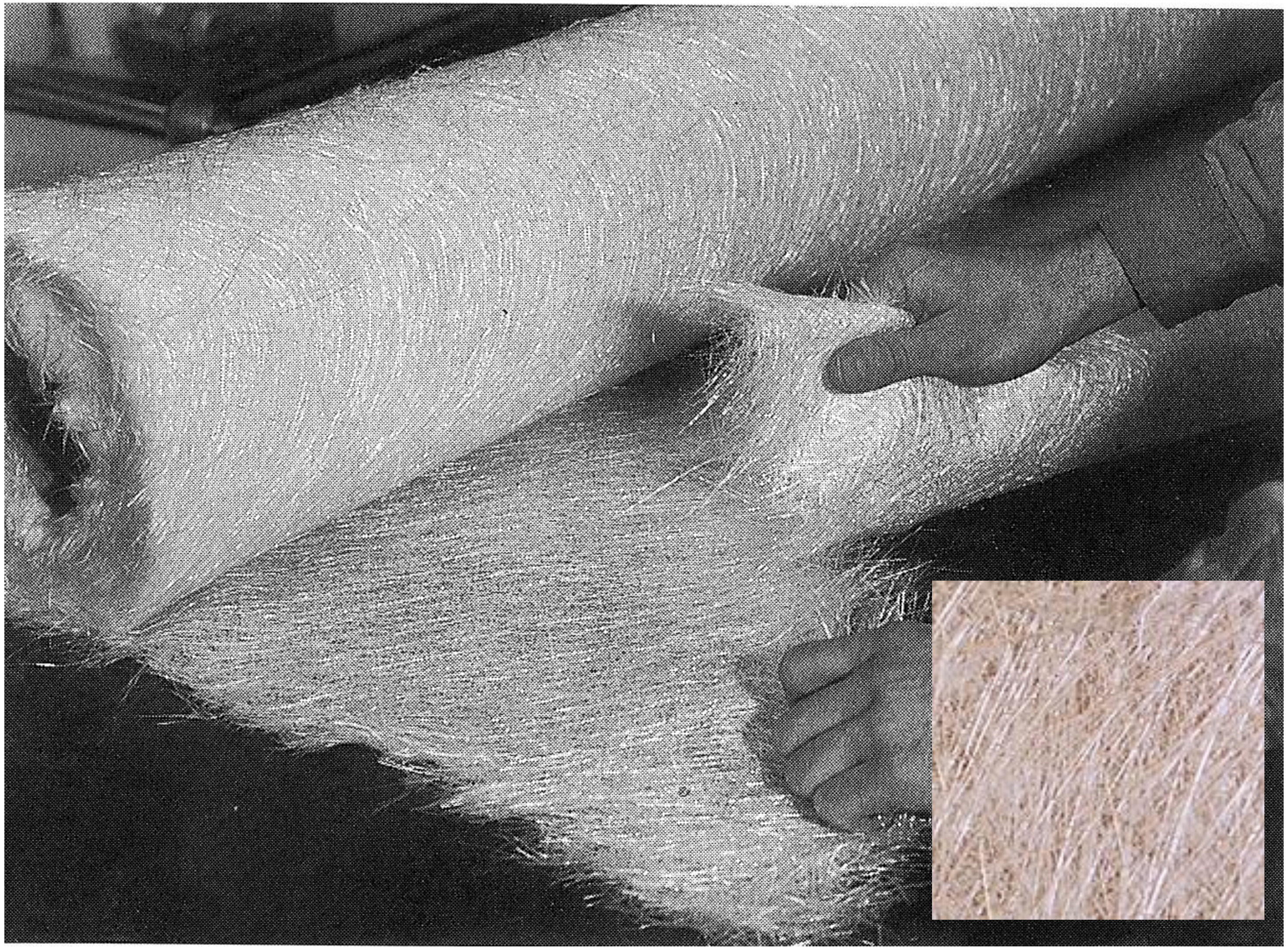


INFLUENCE OF REINFORCEMENT TYPES ON MECHANICAL PROPERTIES



Source: Gutowski

CHOPPED STRAND MAT



Quelle:
Flemming

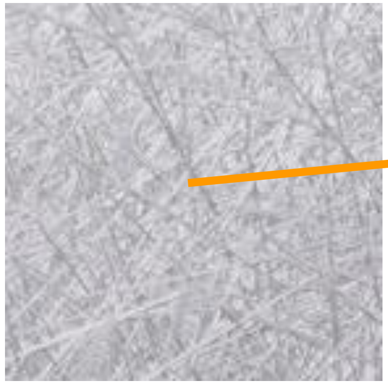
CHOPPED STRAND MAT

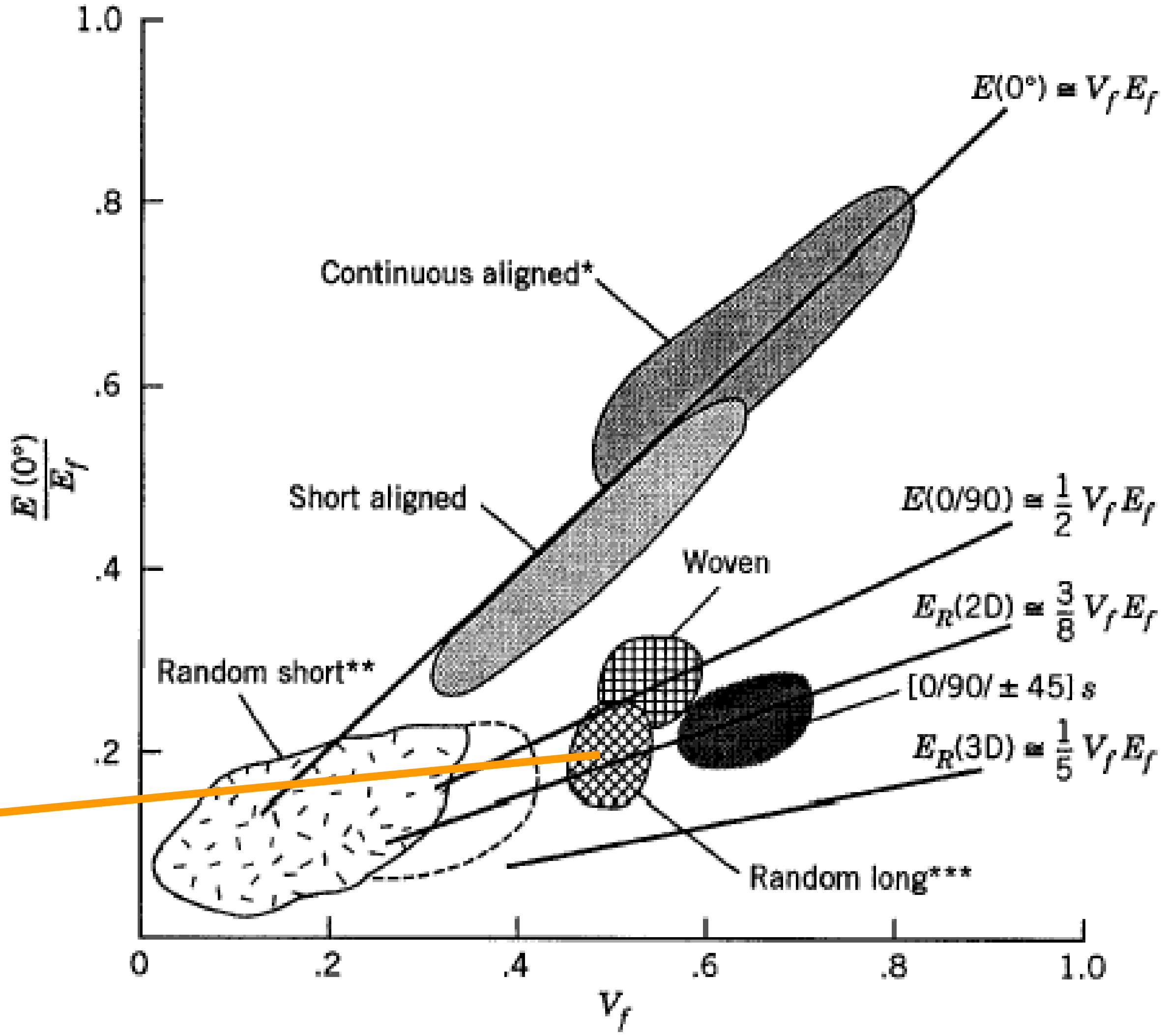
www.r-g.de/en/art/190165

Standort (PEZ, KAZ)	KAZ ...	Lagerort	Paternoster ...
Bereich (ILK,LZS), ILKid	I ... 154011	Gefahrenstoff	○ ja ◉ nein
Bezeichnung	GF-Matte Textilglasmatte 225 g/m²		
Datenblatt	nicht vorhanden		
Lieferschein	Bestellung 900/4700040712		
Chargennummer			
angenommen von	Mikolajczyk ...		
angenommen am	14.03.2022	Verfallsdatum	31.12.2099
Faser	Glas ...	Faserart	Glasfaser ...
Materialtyp	Matte ...	Bindung	...
Gewicht	225	Orientierung	0 ...
Rollenbreite	1.27	Einheit	m ...
Rollenlänge	213	Einheit	m ...
Bemerkungen:	Lieferant: Lange+Ritter Bestellung 900/4700040712 Reserviert für die Laminierübungen Preis: 1,21 EUR/m² Entnahme:		

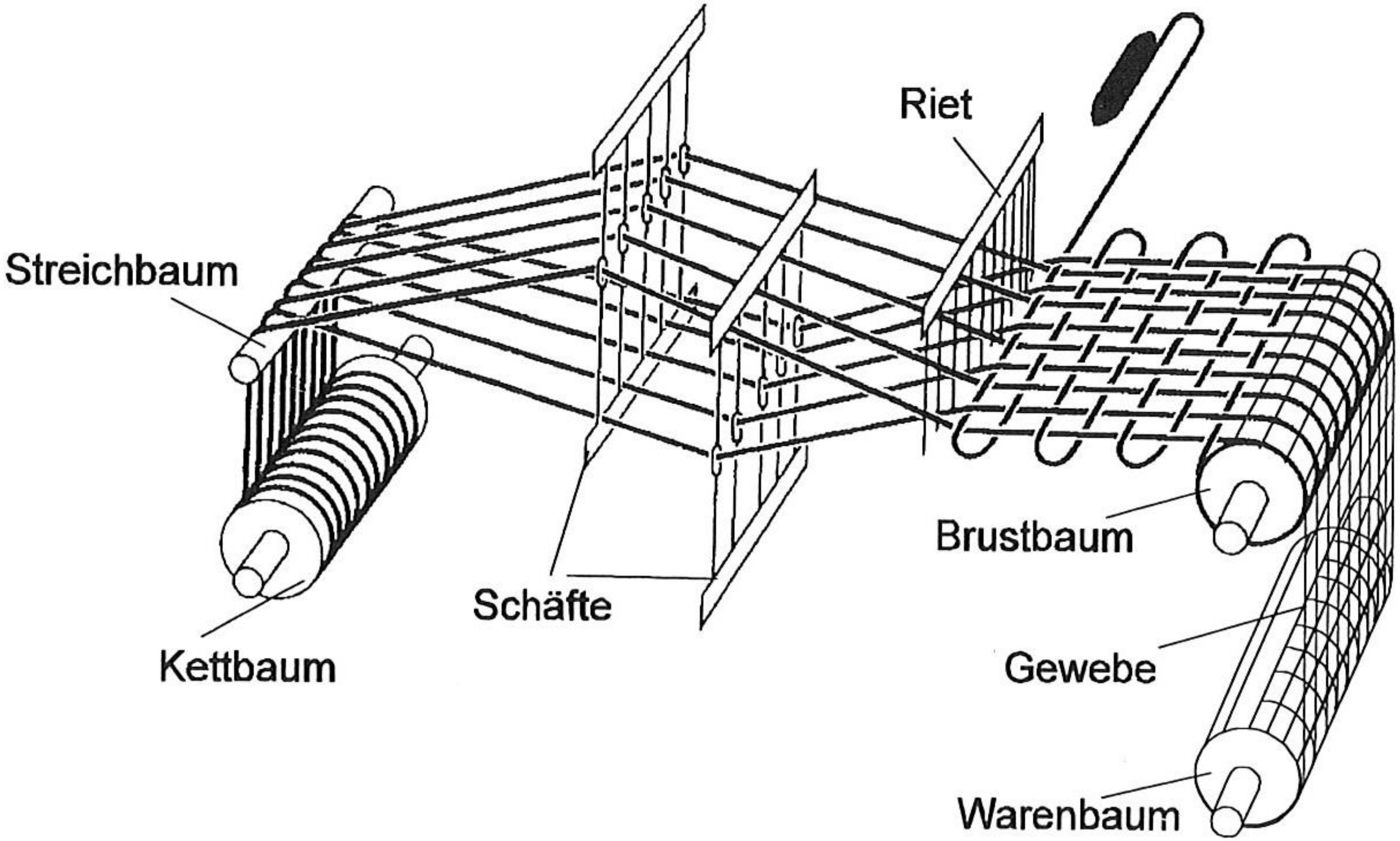
INFLUENCE OF REINFORCEMENT TYPES ON MECHANICAL PROPERTIES

Glass chopped strand mat





WEAVING - PRINCIPLE OF THE LOOM

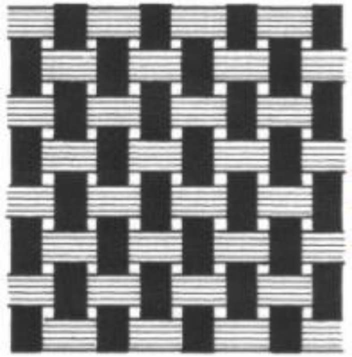


Source: Wulfhorst

WOVEN REINFOCEMENTS

Plain:

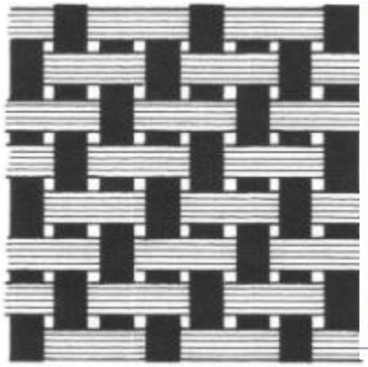
- High ondulation:
- Reduction of inplane properties,
- very good manageability
- Poor drapeability




Quelle: phd-24.de

Twill:

- medium ondulation:
- Lower reduction of inplane properties.
- good manageability
- medium drapability




Quelle: phd-24.de

Satin:

- Low ondulation:
- Hardly any reduction of the inplane properties
- difficult handling
- good drapeability

Quelle: Compositeshop.de

GLASS FIBRE PLAIN WEAVE - PRODUCT SPECIFICATION

www.r-g.de/en/art/190139

GLASS FILAMENT FABRICS for PLASTICS REINFORCEMENT

PRODUCT SPECIFICATION

interglas porcherindustries

porcherindustries Germany GmbH

				Specification
Style Number		92115		MIL-Y-1140H
US Style				AMS / MIL-C-9084
WLB No.				DIN 65066
British Standard				BS 3396
Finish/Designation		FK144		
	Unit		**Tolerance**	**Specification**
Weave pattern		Plain		DIN ISO 9354
Area weight	g / m²	280,0	± 5%	DIN EN 12127
Yarn	tex			DIN EN 12654
warp yarn		EC9-68x3t0		
weft yarn		EC9-204		
Fibre count	1 / cm			DIN EN 1049
warp ends		7,0	± 5%	
weft picks		6,5	± 5%	

Temperature resistance 1)				
Continuous load	°C	260		
Short time resistance	°C	600		
Moisture content	%	< 0,2		DIN EN 3616
Finish content	%	0,08 - 0,28		DIN ISO 1887
				DIN EN 60
Thickness (approx. dry)	mm	0,30	± 5%	DIN ISO 4603/E
in laminate (43% Vol.)	mm	0,25	± 5%	

Fibre content in warp direction:
7 * (68 tex x 3) yarns/cm → 1,428 tex/cm

Fibre content in weft direction:
6.5 * 205 tex yarns/cm → 1,332.5 tex/cm

Ratio warb/weft = 1,07 : 1

(1 tex = 1 g/1000 m)

CARBON FIBRE TWILL WEAVE - PRODUCT SPECIFICATION

www.r-g.de/en/art/190235-SV-100

TECHNISCHES DATENBLATT

ECC FABRICS FOR COMPOSITES

Artikel: Style 462
Einstellung [Fd./cm]: 6,1/6,1
Bindung: Köper 2/2
Ausrüstung: einseitig schiebeverfestigt

Konstruktion:	Kette	Schuss
Material:	Carbon	Carbon
Feinheit:	200 tex	200 tex

Technische Daten	Norm		Einheit	Sollwert	+/-	Toleranz
Dichte 1) 3)		**Kette** **Schuss**	g/cm³ g/cm³	n.G. n.G.	+/- +/-	n.G. n.G.
Feinheit 1)		**Kette** **Schuss**	tex tex	200 200	+/- +/-	10 10
Drehung 1)		**Kette** **Schuss**	T/m T/m		+/- +/-	
Einstellung	DIN EN 1049 T2 4)	**Kette** **Schuss**	Fd./cm Fd./cm	6,1 6,1	+/- +/-	0,1 0,1
Flächengewicht	DIN ISO 12127 4)		g/m²	258	+/-	13

Technische Daten	Norm		Einheit	Sollwert	+/-	Toleranz
Einstellung	DIN EN 1049 T2 4)	**Kette** **Schuss**	Fd./cm Fd./cm	6,1 6,1	+/- +/-	0,1 0,1
Flächengewicht	DIN ISO 12127 4)		g/m²	258	+/-	13
Trockengewicht	DIN EN ISO 3344 4)		g/m²		+/-	
Feuchtegehalt	DIN EN ISO 3344 4)		%			
Dicke 2)	DIN ISO 5084 4)		mm		+/-	
Breite	DIN EN 1773 4)		cm	nach Bestel-lung	+/-	1

1) oder n.G.: nach Bestellung und jeweiliger Garnspezifikation
2) Richtwert, nicht freigaberelevant
3) wird nicht geprüft, Angabe des Garnherstellers
4) in Anlehnung an DIN...

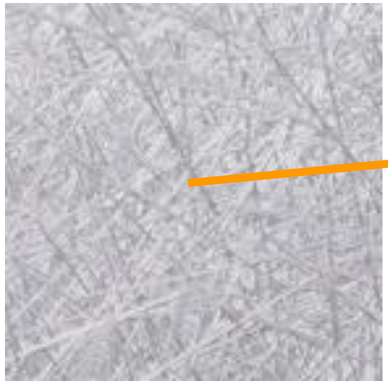
mit EP-Binder Auftrag 10-15 g/m²

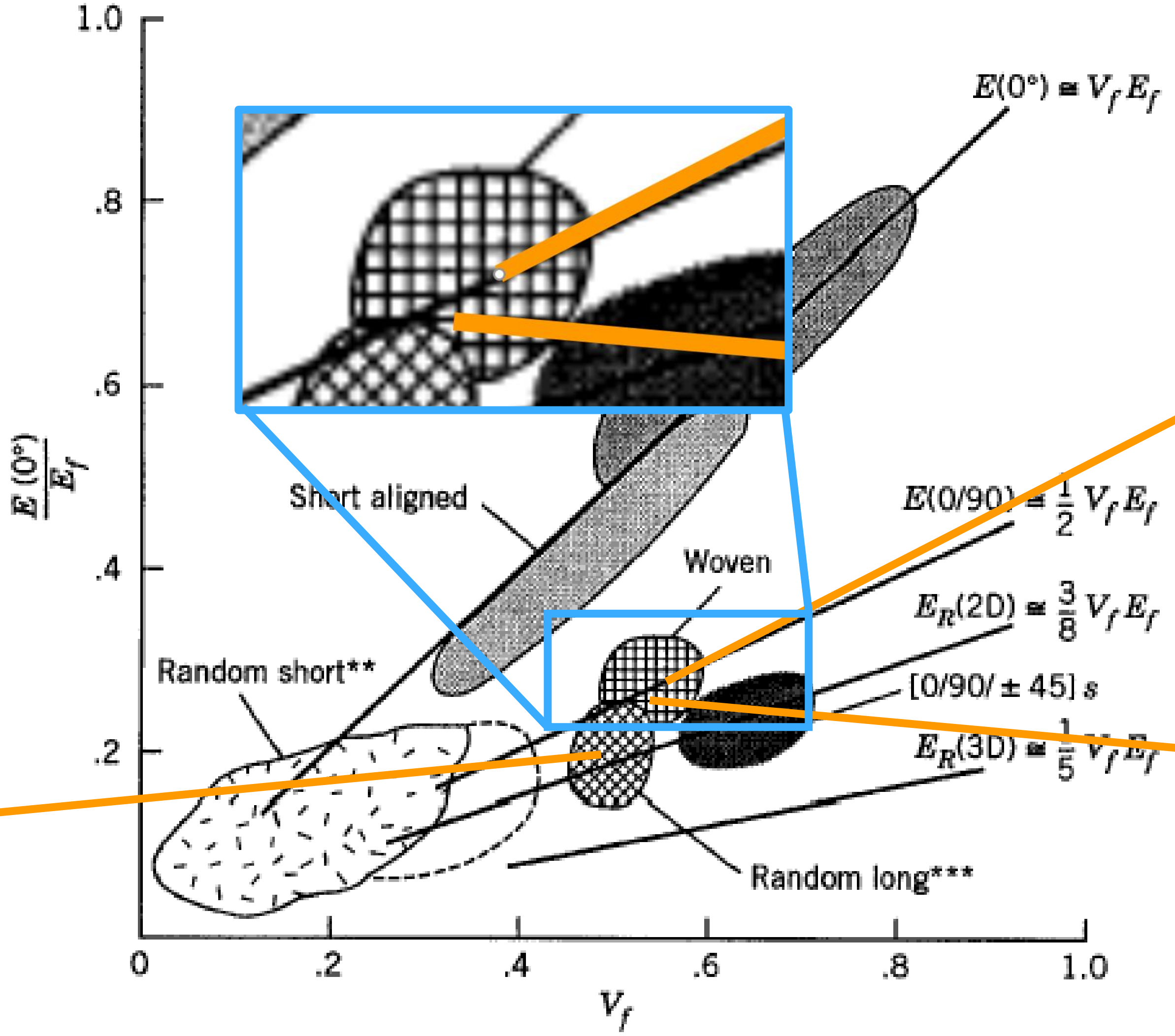
Carbon fibre:

Grade	Filament count	Yield	Tensile Strength	Tensile Modulus	Elongation	Density
		tex	MPa	GPa	%	g/cm³
Standard Modulus						
HTA40	1 000	67	4100	240	1.7	1.77
	3 000	200				
	6 000	400				
	12 000	800				

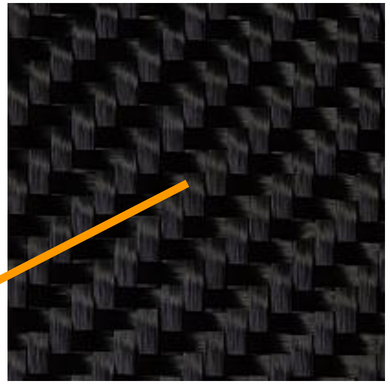
INFLUENCE OF REINFORCEMENT TYPES ON MECHANICAL PROPERTIES

Glass chopped
strand mat

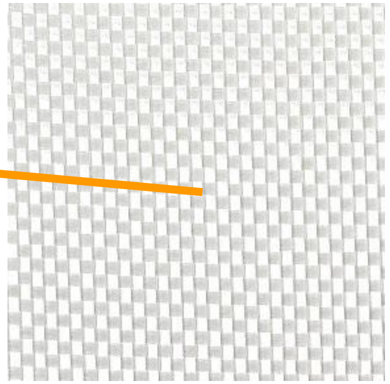




Carbon BD
weave

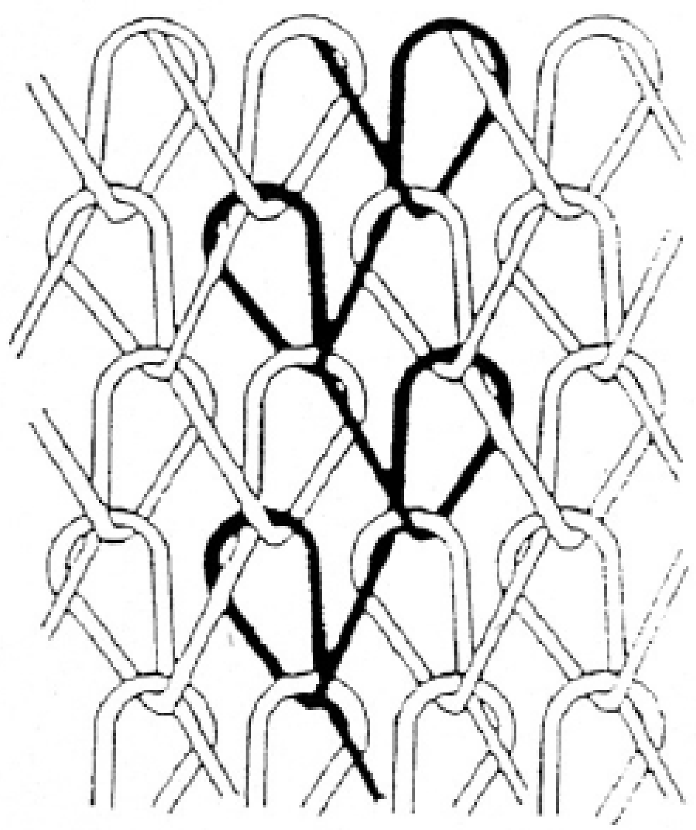


Glass BD
weave

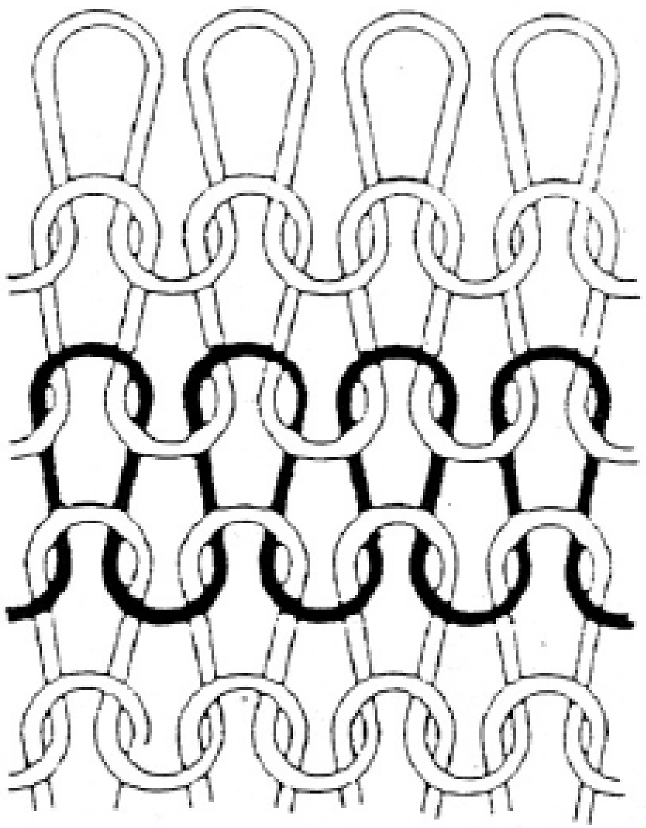


Source: Gutowski

KNITWEAR



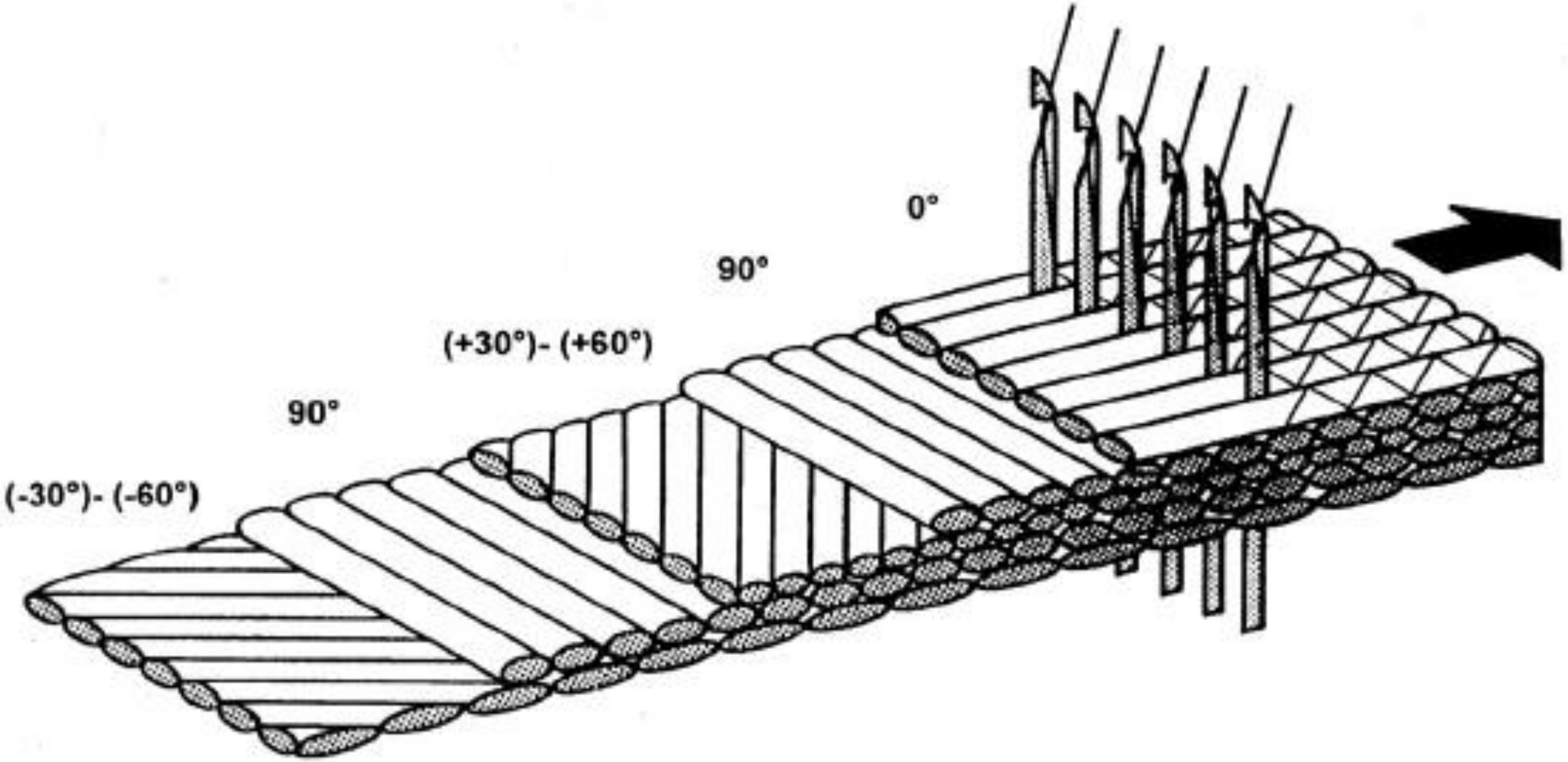
Kettfaden - Maschenwaren
"warp knitting"



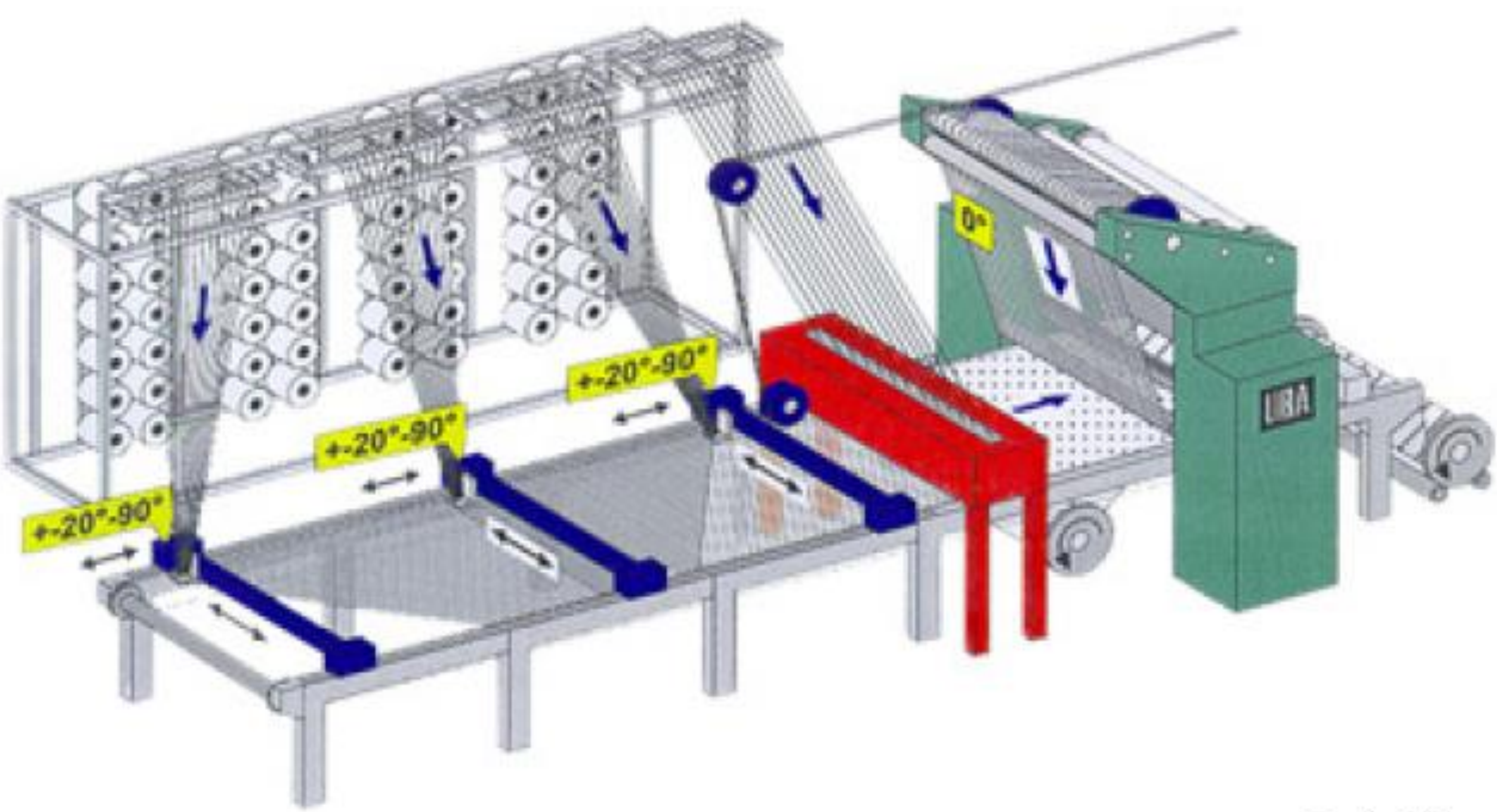
Einfaden - Maschenwaren
"weft knitting"

Source: Wulfhorst

MULTIAXIAL NON-CRIMP FABRIC (LIMA TECHNIQUE)

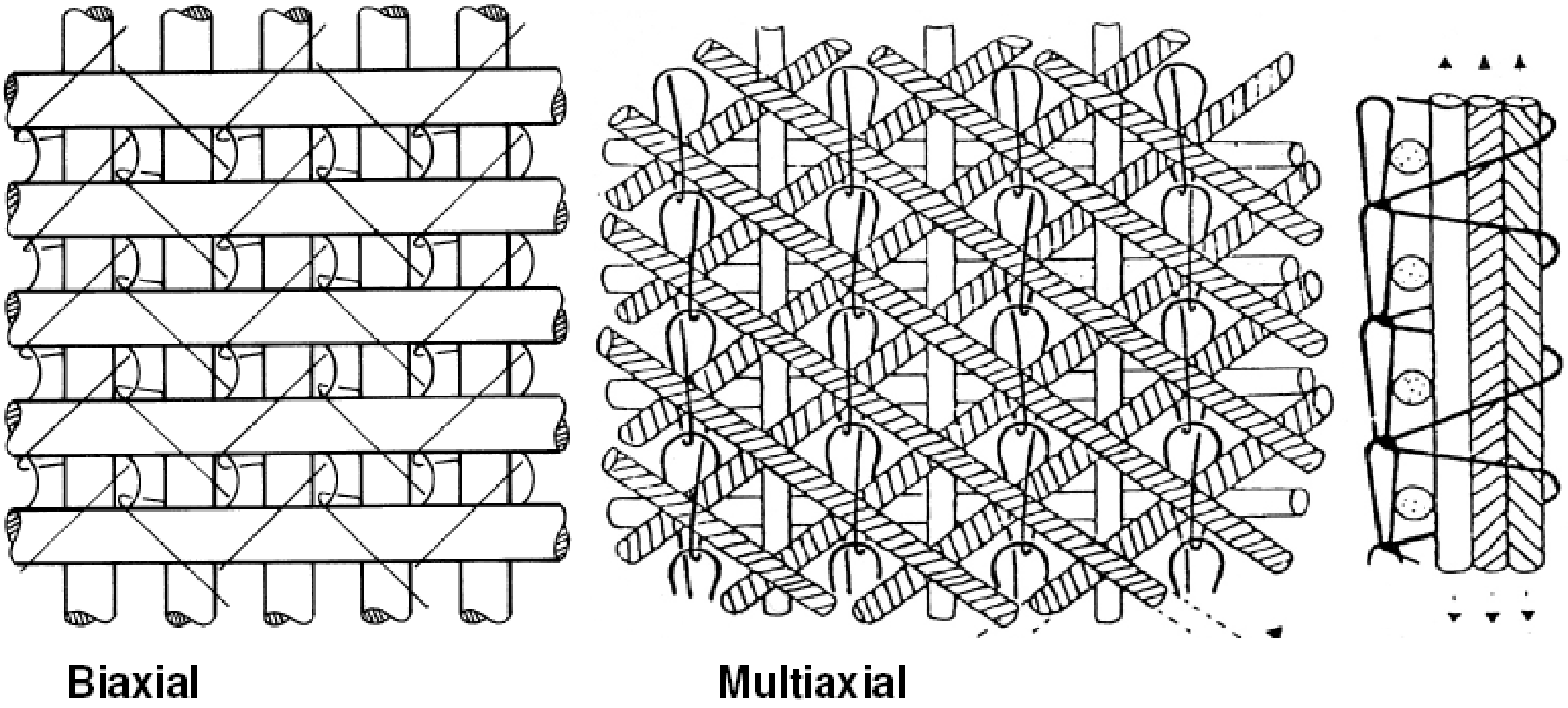


WARP KNITTING MACHINE WITH 4 MULTIAXIAL WEFT INSERTION SYSTEMS



Quelle: Liba

BI- AND MULTIAXIAL NON-CRIMP FABRIC



The mesh thread system is only used to fix the stretched layers of scrim

Source: Wulfhorst

BIAXIAL NON-CRIMP FABRIC

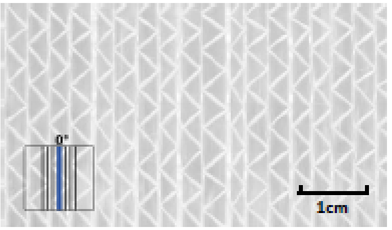
https://shop.hp-textiles.com/shop/en/650g-m-Unidirectional-glass-fabric-HP-U600E.html

Technisches Datenblatt
technical data sheet
HP-U600E

HP-Textiles ...light up your future!!!

Produktkennung* / *product identification

Artikelnummer article number	HP-U600E
Bezeichnung name	Unidirektional Glas Gelege unidirectional glass fabric
Faserausrichtung fibre orientation	0°



Technische Spezifikation* / *technical specification

Konstruktion construction	Flächengewicht areal weight	Toleranz tolerance	Material material	
	[g/m²]	[± %]		
0°	608	5	E-Glas e-glass	
-45°		5		
90°	40	5	E-Glas e-glass	
+45°		5		
Nähfaden / stitching	15	5	PES	

Gesamtflächengewicht total areal weight	663	5	g/m²	
Nähbindung stitch type	Trikot tricot			
Nähfeinheit stitch gauge	10			

Gesamtflächengewicht total areal weight	663	5	g/m²	
Nähbindung stitch type	Trikot tricot			
Nähfeinheit stitch gauge	10			

Aufmachung* / *dimensions

Länge / length	40	lfm / lm	± 2%	
Breite / width	127	cm	± 2%	

*Abweichende Breiten auf Anfrage möglich / customized widths on request are available

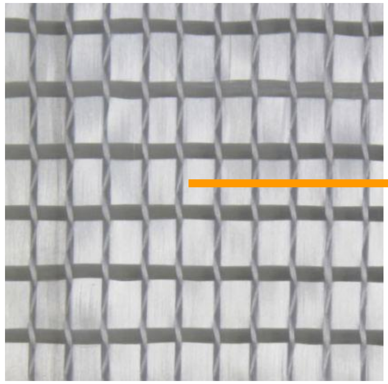
Verpackung* / *packaging

Hülsendurchmesser tube diameter	76 / 152	mm	innen inside	
Folie / foil	LDPE	transparent		

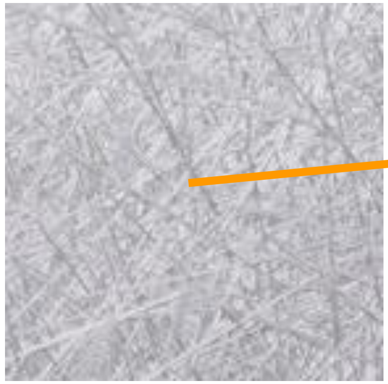
Ratio warb (0°)/weft (90°) = 15,2 : 1

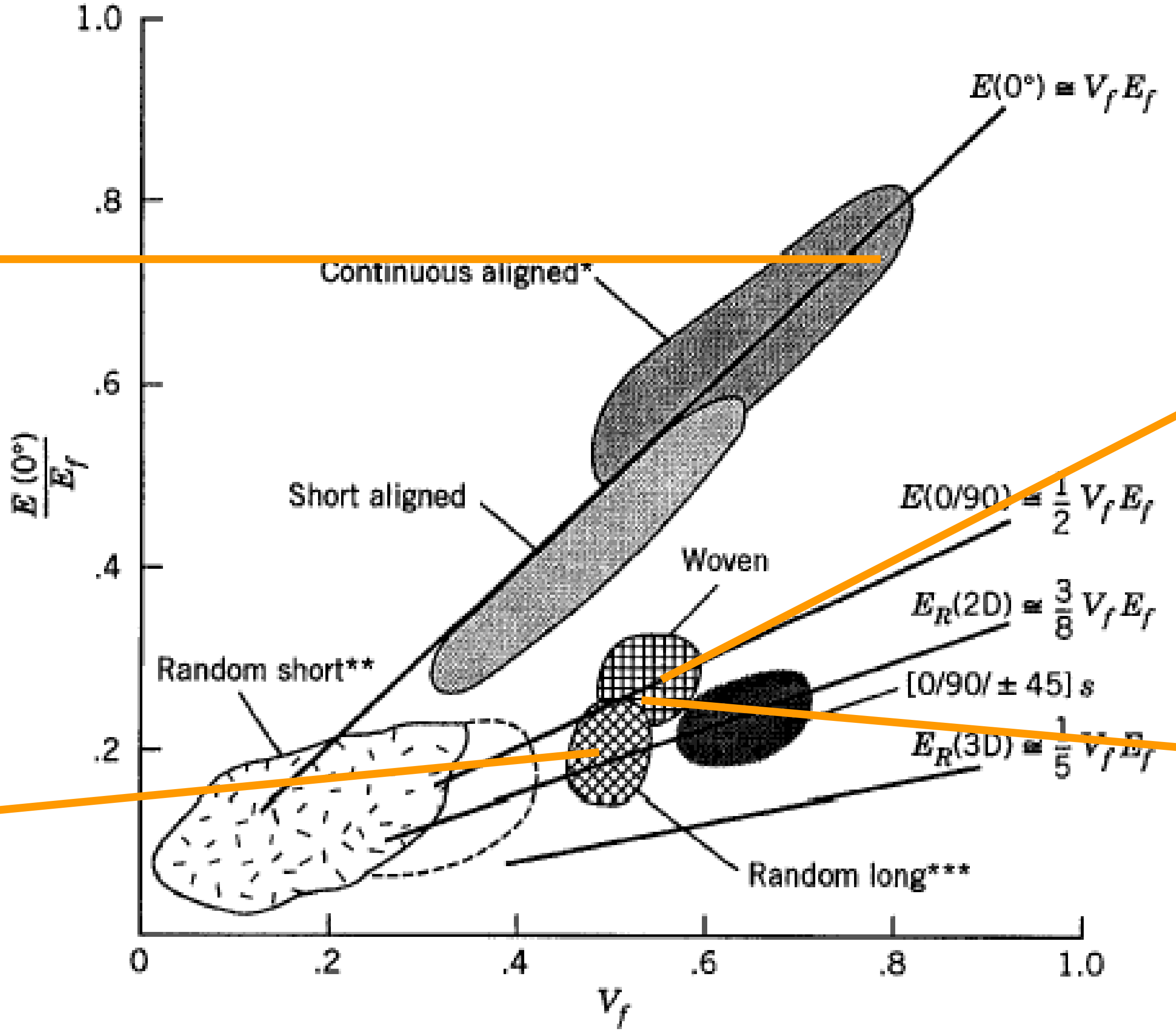
INFLUENCE OF REINFORCEMENT TYPES ON MECHANICAL PROPERTIES

bIaxial non-crimp fabric

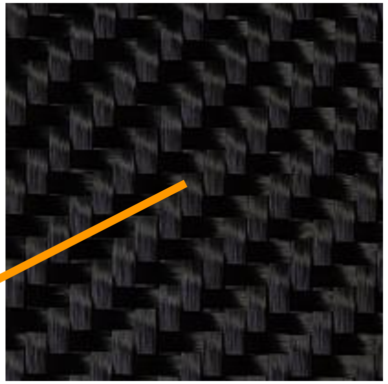


Glass chopped strand mat

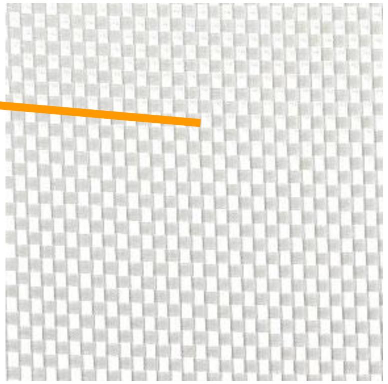




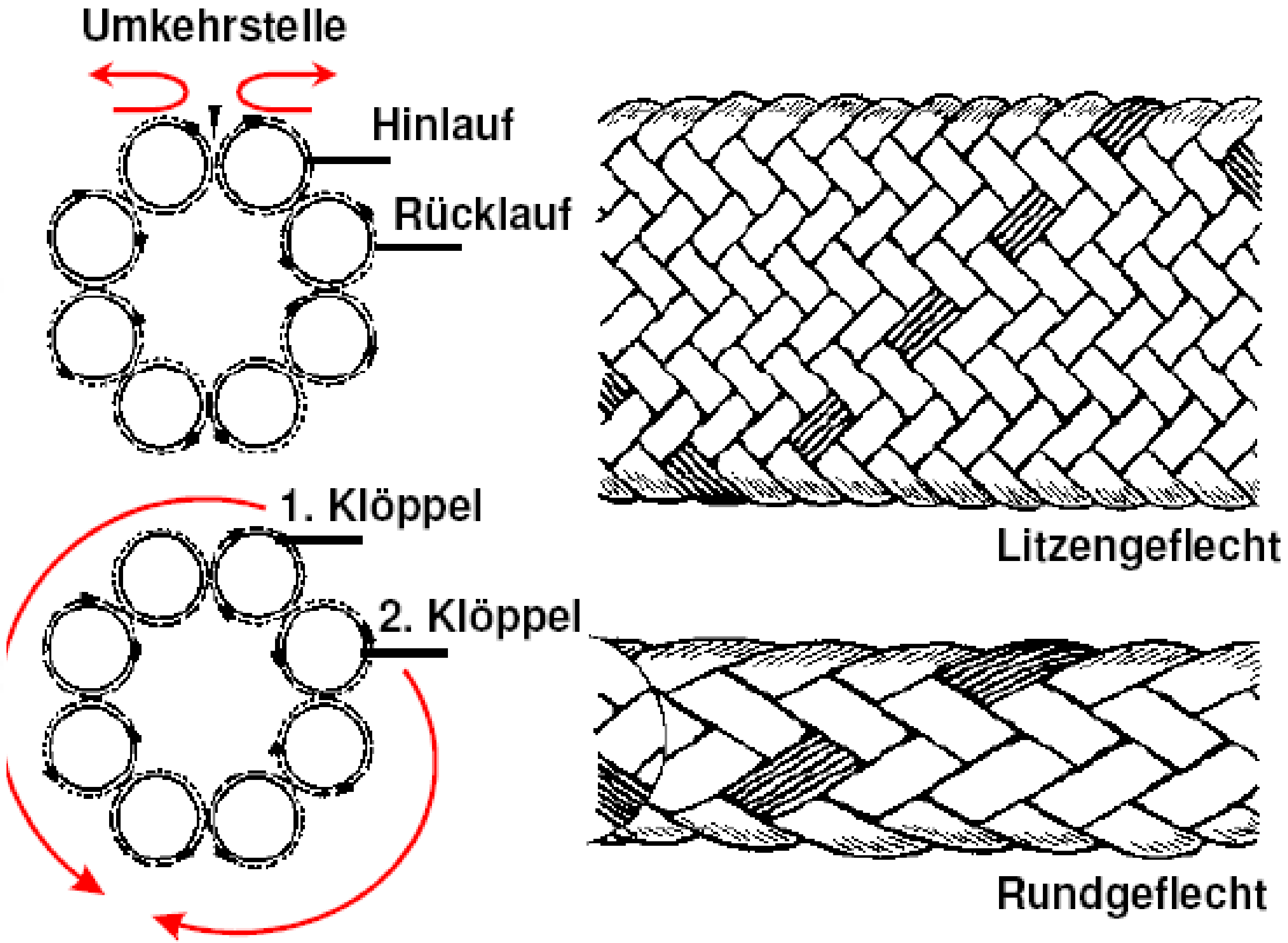
Carbon BD weave



Glass BD weave



BRAIDING - PRINCIPLE ILLUSTRATION

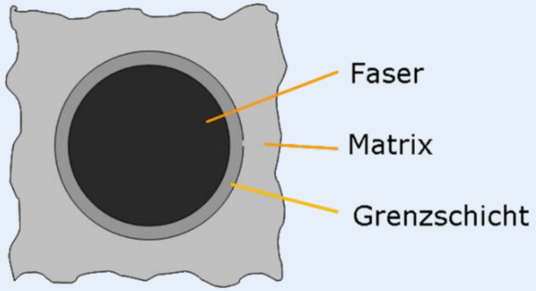
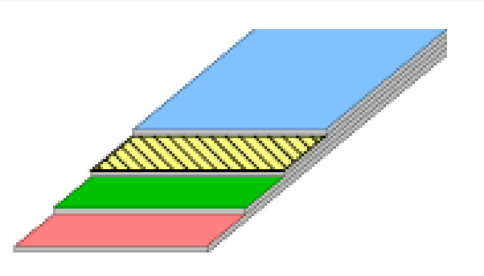


Source: Wulfhorst

ROUND BRAIDING MACHINE WITH ROBOT SUPPORT

Source: ITA

DEFINITIONS FOR FKV

Fibre, matrix, interface	Single layer (UD layer)	Multilayer composite
Micro scale	Meso scale	
		
Fibre • homogeneous • Linear elastic • isotrop/transverse isotropic Matrix • homogeneous • linear elastic Interface • Not considered Fibre composite • inhomogeneous, anisotropic	• the fibre-matrix composite is considered as a continuum • macroscopically homogeneous • macroscopically orthotropic/ transversely isotropic	• a multilayer composite (laminate) consists of several perfectly bonded individual layers • a multilayer composite behaves macroscopically like a homogeneous board, but with specific stiffness properties
Micromecanical model	Material model	Laminate model

CLASSICAL LAMINATE THEORY

$$\begin{pmatrix} N_x\\ N_y\\ N_{xy}\\ M_x\\ M_y\\ M_{xy}\end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16}\\ & A_{22} & A_{16} & B_{12} & B_{22} & B_{26}\\ & & A_{66} & B_{16} & B_{26} & B_{66}\\ & & & D_{11} & D_{12} & D_{16}\\ & sym. & & & D_{22} & D_{26}\\ & & & & & D_{66}\end{pmatrix} \begin{pmatrix}\varepsilon_x^0\\ \varepsilon_y^0\\ \gamma_{xy}^0\\ \kappa_x\\ \kappa_y\\ \kappa_{xy}\end{pmatrix}$$

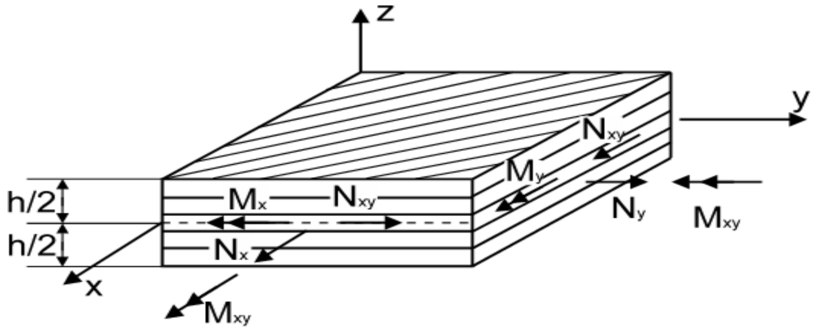
Strain, coupling and bending stiffnesses

$$A_{ij} = \sum_{k=1}^{N} \overline{Q}_{ij}^{(k)} \int_{z_{k-1}}^{z_k} dz = \sum_{k=1}^{N} \overline{Q}_{ij}^{(k)} (z_k - z_{k-1}) = \sum_{k=1}^{N} \overline{Q}_{ij}^{(k)} h_k$$

$$B_{ij} = \sum_{k=1}^{N} \overline{Q}_{ij}^{(k)} \int_{z_{k-1}}^{z_k} z\,dz = \frac{1}{2} \sum_{k=1}^{N} \overline{Q}_{ij}^{(k)} (z_k^2 - z_{k-1}^2) = \sum_{k=1}^{N} \overline{Q}_{ij}^{(k)} \bar{z}_k h_k$$

$$D_{ij} = \sum_{k=1}^{N} \overline{Q}_{ij}^{(k)} \int_{z_{k-1}}^{z_k} z^2\,dz = \frac{1}{3} \sum_{k=1}^{N} \overline{Q}_{ij}^{(k)} (z_k^3 - z_{k-1}^3) = \overline{Q}_{ij}^{(k)} \left(\bar{z}_k^2 + \frac{h_k^3}{12}\right)$$

Cutting forces and moments



$$N_x = \int_{-h/2}^{h/2} \sigma_x\,dz \qquad M_x = \int_{-h/2}^{h/2} \sigma_x\,z\,dz$$

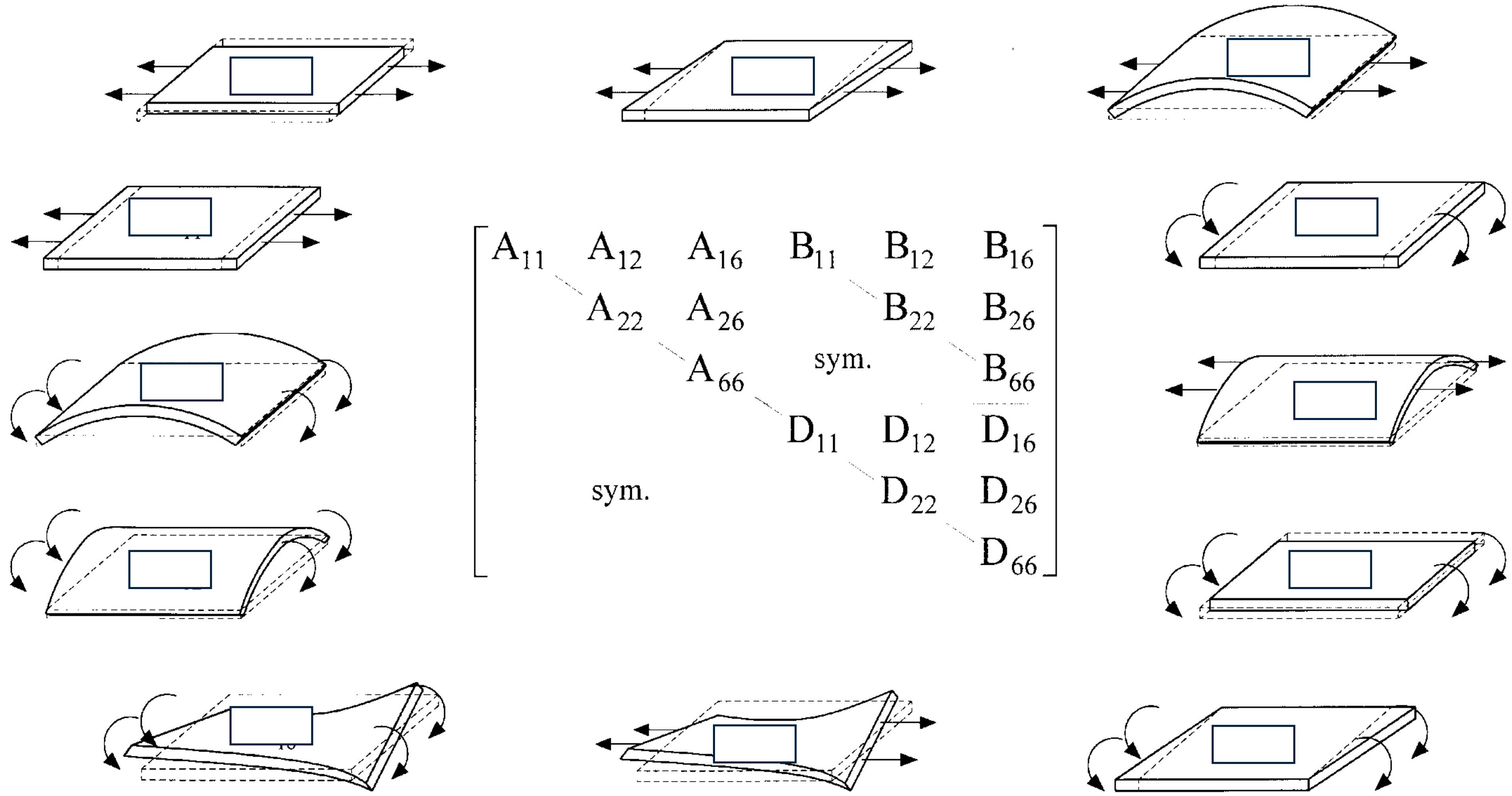
$$N_y = \int_{-h/2}^{h/2} \sigma_y\,dz \qquad M_y = \int_{-h/2}^{h/2} \sigma_y\,z\,dz$$

$$N_{xy} = \int_{-h/2}^{h/2} \tau_{xy}\,dz \qquad M_{xy} = \int_{-h/2}^{h/2} \tau_{xy}\,z\,dz$$

$$\boldsymbol{N} = \begin{bmatrix} N_x\\ N_y\\ N_{xy}\end{bmatrix} = \sum_k \boldsymbol{N}^{(k)} \qquad \boldsymbol{M} = \begin{bmatrix} M_x\\ M_y\\ M_{xy}\end{bmatrix} = \sum_k \boldsymbol{M}^{(k)}$$

$$N^{(k)} = \begin{bmatrix} N_x\\ N_y\\ N_{xy}\end{bmatrix}^{(k)} \qquad \boldsymbol{M}^{(k)} = \begin{bmatrix} M_x\\ M_y\\ M_{xy}\end{bmatrix}^{(k)}$$

COUPLING PHENOMENA IN MULTILAYER COMPOSITES



$$
\begin{bmatrix}
A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\
 & A_{22} & A_{26} & & B_{22} & B_{26} \\
 & & A_{66} & \text{sym.} & & B_{66} \\
 & & & D_{11} & D_{12} & D_{16} \\
 & \text{sym.} & & & D_{22} & D_{26} \\
 & & & & & D_{66}
\end{bmatrix}
$$

Basic manufacturing processes and associated manufacturing operations

Faserverbund-Rohteil, gekennzeichnet durch