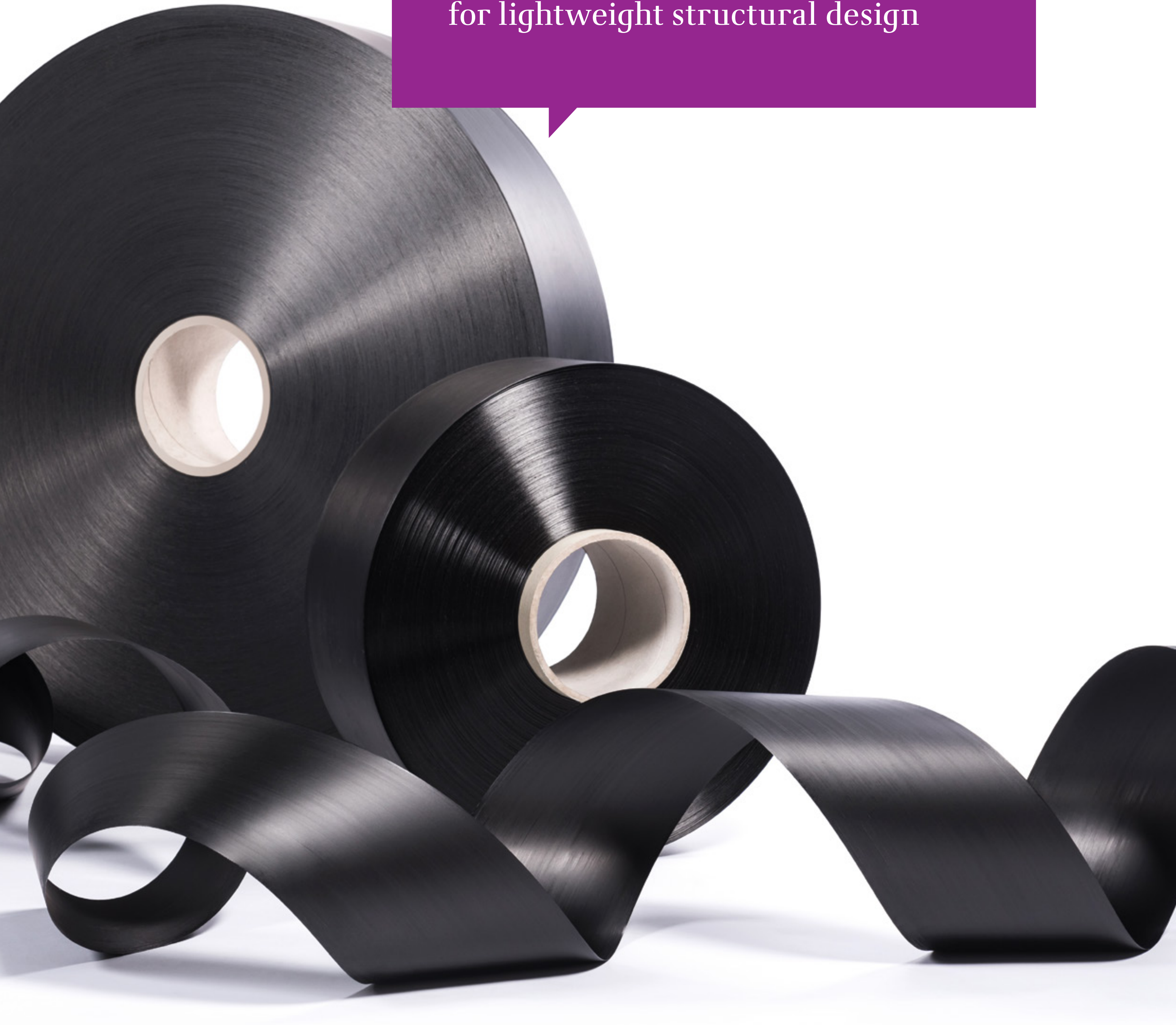
LIGHTWEIGHT AND STRONG

VESTAPE® uni-directional tapes for lightweight structural design



EVONIK
POWER TO CREATE

CONTENT

3 Introduction
4 Matrix systems
6 Tape
8 Processing
14 Applications

LIGHTWEIGHT AND STRONG

A growing number of the challenges presented by renewable energy requirements, efficient resource management, and ecological considerations can be mastered, now and in the future, only by using lightweight construction. Fiber-reinforced composites will play a major role here as one of the key technologies for the 21st century.

Thermoplastic unidirectional tapes (UD tapes) where carbon fibers are impregnated with polyether ether ketone (PEEK) or polyamide 12 (PA12) as a thermoplastic matrix offer a high-performance solution for applications where weakness is simply not acceptable.

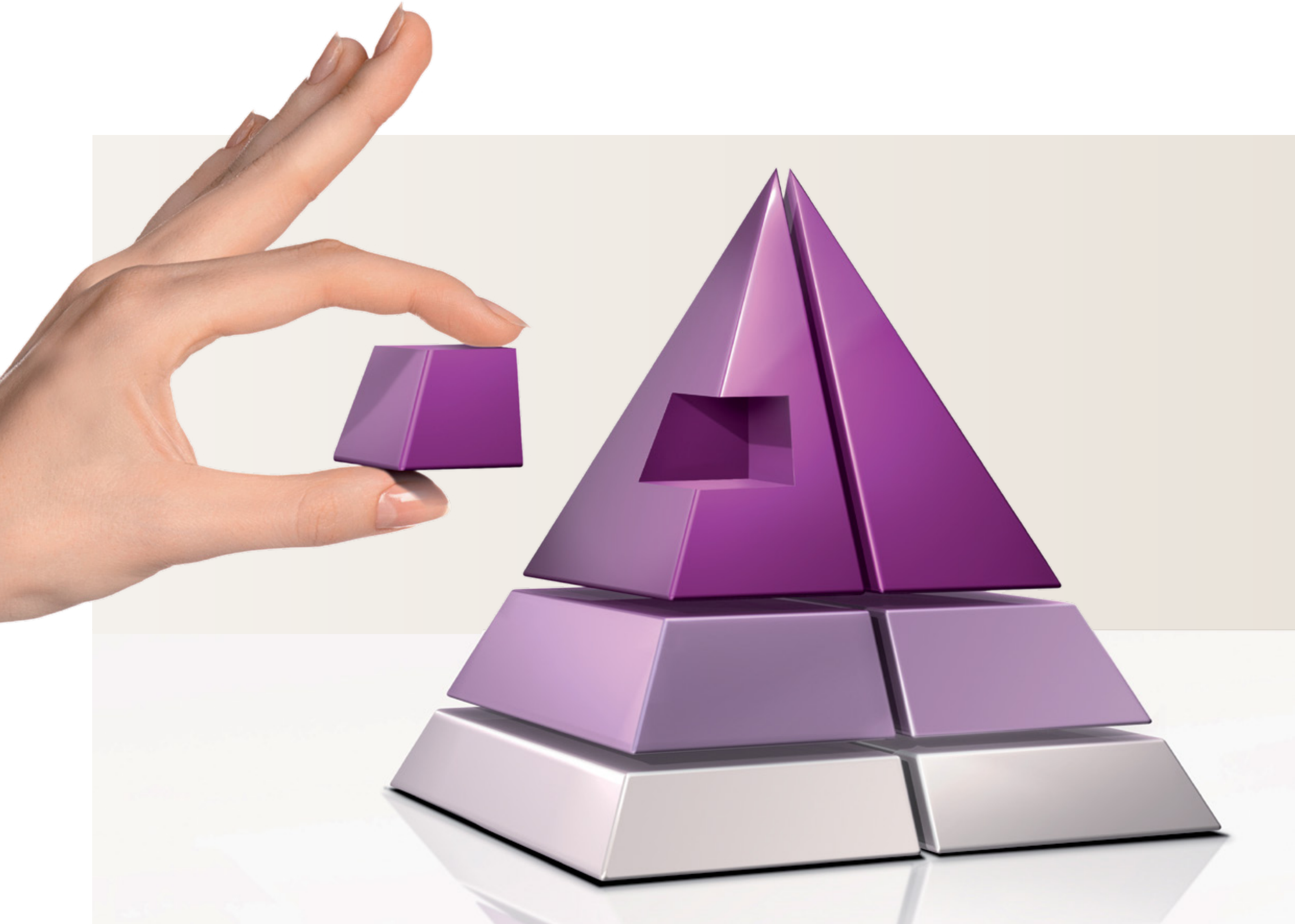
Whether in pipes for the oil and gas industry or structural components, you can depend on VESTAPE® to hold firmly and reliably against all forces with low water absorption and impressive mechanical properties.

Our composites of endless-fiber reinforced plastics consist of carbon fibers and a matrix of high-performance polymers. In a UD tape, the properties of both materials are ideally combined to create innovative materials for new paths in component design. Several layers of UD tapes form a laminate whose mechanical properties significantly outperform those of metal sheets of the same thickness. In particular, the possibility of arranging the reinforcing fibers in load direction offers new options for part design.

Laminates can be thermoformed to give a variety of component geometries. They also offer the opportunity of integrating additional functions or components, as the parts can be overmolded with short- or long-fiber reinforced compounds. Using the same polymer class as for the matrix in the UD tape naturally ensures good bonding between the two components, which is essential for dynamic load conditions.

The matrix is based on specially developed high performance-polymers customized for embedding of high-strength endless fibers, and allows production of parts that can be used even in areas exposed to extreme conditions.

Evonik is one of the leading suppliers of high-performance thermoplastic resins such as specialty polyamides and PEEK for use in adverse environments.



MATRIX SYSTEMS

We have the right materials to take you to the top

When selecting a matrix, a manufacturer first considers its basic mechanical properties under the expected environmental conditions (maximum service temperature, water uptake, and exposure to harmful chemicals).

Main properties of matrix polymers

Physical Properties	Unit	PA12	PEEK
Density	g/cm³	1.02	1.3
Glass transition temperature	°C	40	151
Melting temperature	°C	178	340
Moisture absorption (50% RH, 23°C)	%	0.7	0.5

Mechanical properties*	Unit	PA12	PEEK
Tensile test 23°C			
Stress at yield	MPa	45	100
Strain at yield	%	5	5
Tensile modulus	MPa	1400	3700
Charpy -40°C			
Charpy impact strength	kJ/m²	N	N
Charpy notched impact strength	kJ/m²	5 C	6 C
Charpy 23°C			
Charpy impact strength	kJ/m²	N	N
Charpy notched impact strength	kJ/m²	5 C	6 C

*dry and conditioned

N = no break, C = complete break

For high-performance composites, the most desirable mechanical properties of a matrix are:

- → high tensile modulus
- → high tensile strength
- → high fracture toughness
- → good dimensional stability at elevated temperatures (glass transition temperature higher than maximum service temperature)
- → resistance to moisture and solvents such as fuels and gasoline, motor oil, deicing fluids and anti-freeze, and paint strippers (the polymer should not swell, crack or degrade)

All Evonik thermoplastics are excellent in these respects.

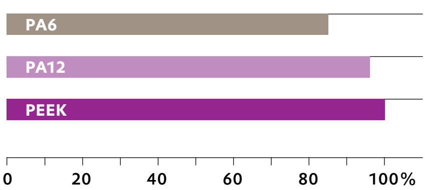
Evonik supplies two matrix systems for its structural VESTAPE® UD tapes:

- → VESTAMID® PA12 has been used as a matrix in composites for many years. A superior grade is now used for manufacturing tapes based on carbon fibers.
- → Where service temperatures are higher, VESTAKEEP® PEEK as a matrix material fulfills the requirements due to its high glass transition temperature and melting temperature ranges.

Moisture absorption behavior

High-performance polyamides such as PA12 are distinguished by low water absorption compared with, e.g., PA6 and PA66. In the conditioned state, therefore, the decrease in tensile strength is only very small. This is an additional benefit for the long-term behavior of VESTAPE® UD tapes.

RESIDUAL YIELD STRENGTH 50% RH



Tape properties

Composition	Unit		
Polymer	-	PA12	PEEK
Fiber type	-	HT carbon fiber	HT carbon fiber
Tape thickness	mm	0.25	0.25
Tape width	mm	160	160
Physical properties			
Density	g/cm^3	1.36	1.51
Fiber volume fraction	%	45	45
Fiber weight fraction	%	59	53
Mechanical properties			
Tensile strength 0°	MPa	1750	1750
Tensile modulus 0°	GPa	100	100
Strain at break 0°	%	1.8	1.8

TAPE

VESTAPE® UD tapes

VESTAPE® UD tapes are available with a selection of relevant types of carbon fiber, at which Evonik's proprietary melt impregnation technology assures excellent wetting of the fiber roving at competitive cost. The PA12 and PEEK matrix compounds are specially modified for the fiber impregnation process to ensure optimum bonding between matrix and fiber. This results in composite systems that can withstand the highest loading requirements.

Composites

The advantages of composites manufactured with PA12 or PEEK matrices are particularly evident in applications where unchanged material performance is required over a wide temperature range. Between -20°C and 80°C these composites demonstrate their full potential, even in harsh environments such as aggressive fluids and gases. The figures show that the effect of saturation with a representative aromatic fluid composition used in the oil and gas industry (according to NORSOK standard M-710) on the physical characteristics of a composite with a PA12 matrix is extremely low, even at arctic and elevated temperatures.

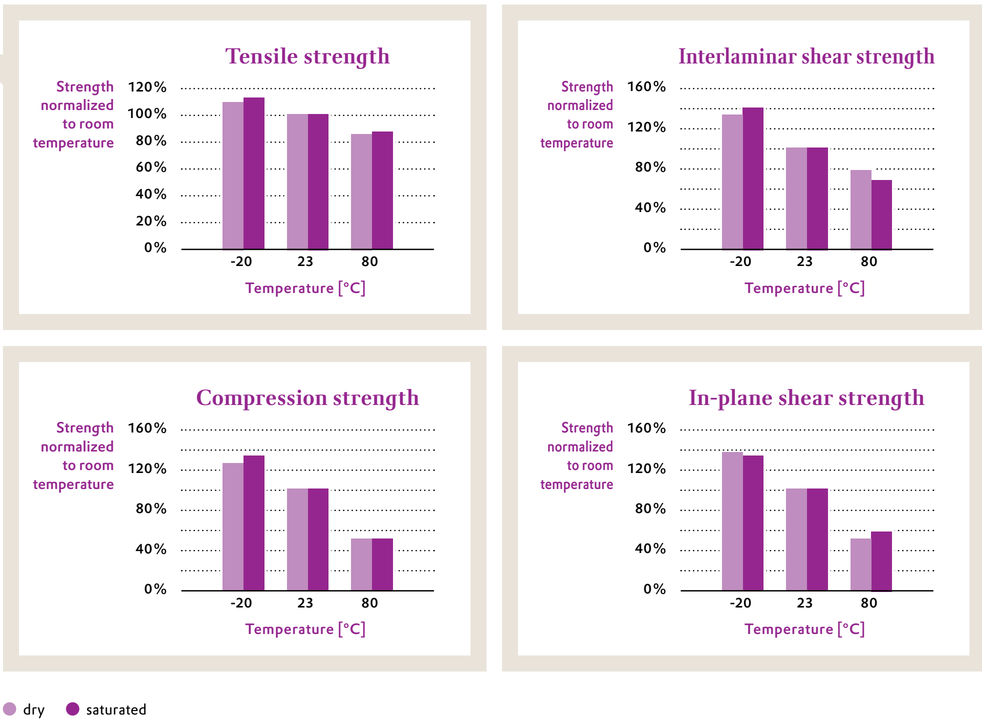
Typical laminat properties

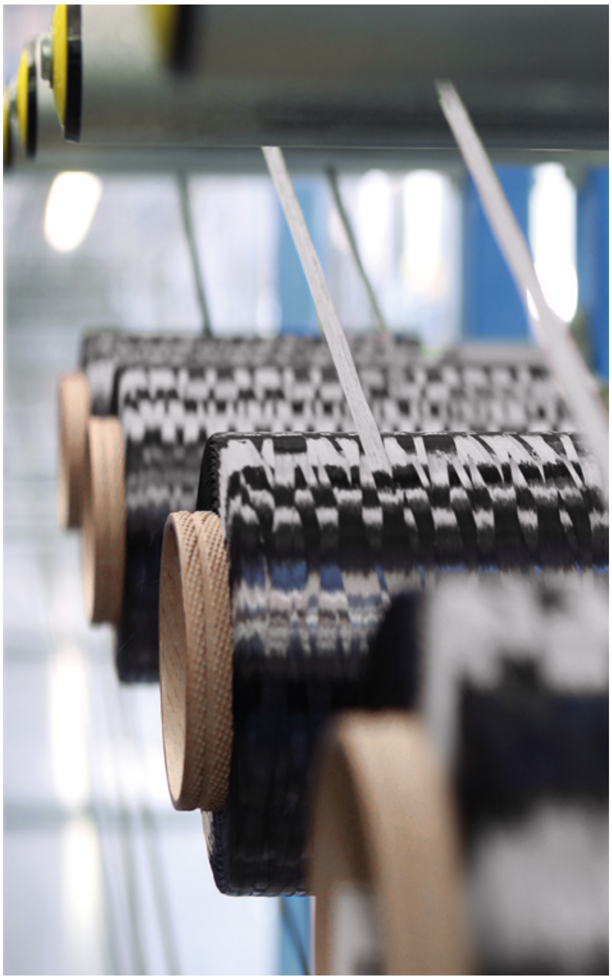
Properties	Condition	Test method	Unit	PA12/CF	PEEK/CF
Tensile strength 0°	RTD	ISO 527	MPa	1750	1750
Tensile modulus 0°	RTD	ISO 527	GPa	100	100
Flexural strength 0°	RTD	ISO 14125	MPa	900	1350
Flexural modulus 0°	RTD	ISO 14125	GPa	95	100
Compressive strength 0°	RTD	ISO 14126	MPa	350	500
Short beam shear, ILSS	RTD	ISO 14130	MPa	45	70
In-plane shear strength*	RTD	ISO 14129	MPa	30	50
In-plane shear modulus	RTD	ISO 14129	GPa	1.4	3
Poisson's ratio	RTD	ISO 572	-	0.32	0.34

*at 5% strain

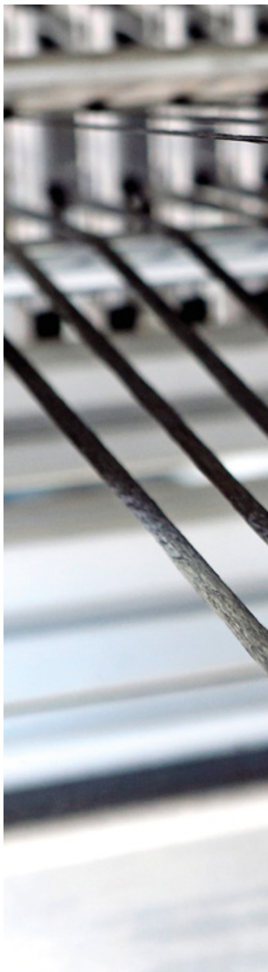
Values of laminates manufactured from tapes with a fiber content of 45 vol% using a heated press.

Relative change of the mechanical properties of VESTAPE® PA12/CF specimens in the dry state and saturated with organic fluids, at different temperatures.





FAST PROCESSING WITH VESTAPE®



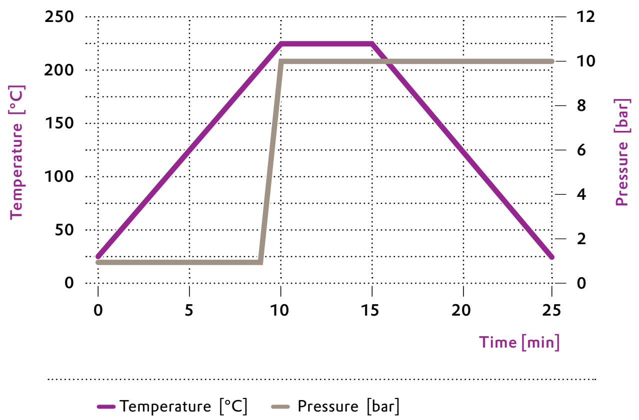
PROCESSING

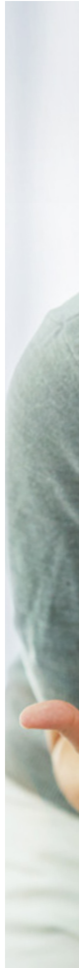
Processing with all state-of-the-art layup methods

One big advantage of composites with thermoplastic matrix materials is their high potential for fast processing, along with the wide range of options they offer for integrating functions through welding, injection-molding and compression molding processes. With the right process settings, material selection and design, they can produce highly durable seamless connections by forming of thermoplastic components to the composite structure.

VESTAPE® can be processed with all state-of-the-art layup methods, such as hand-layup, automated fiber placement, automated tape laying or tape winding. Consolidation of the individual tapes to a part or laminate is then achieved by the application of heat and pressure. All kinds of heat sources can be used, including contact, hot gas, infrared, laser or ultrasonic heating.

Typical consolidation cycle for manufacturing flat laminates in a heated press using VESTAPE® PA12-CF





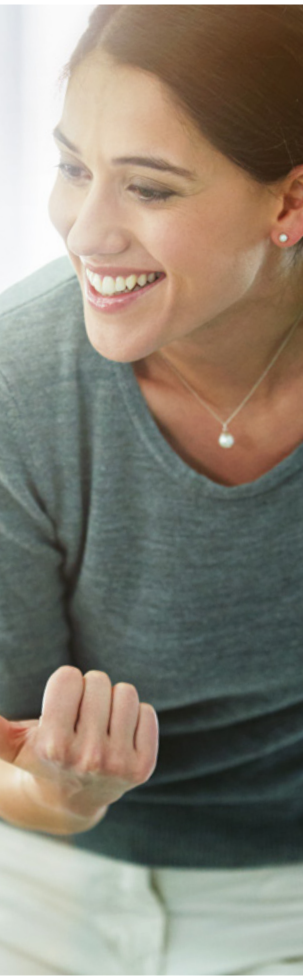
Production of UD laminates by pressing

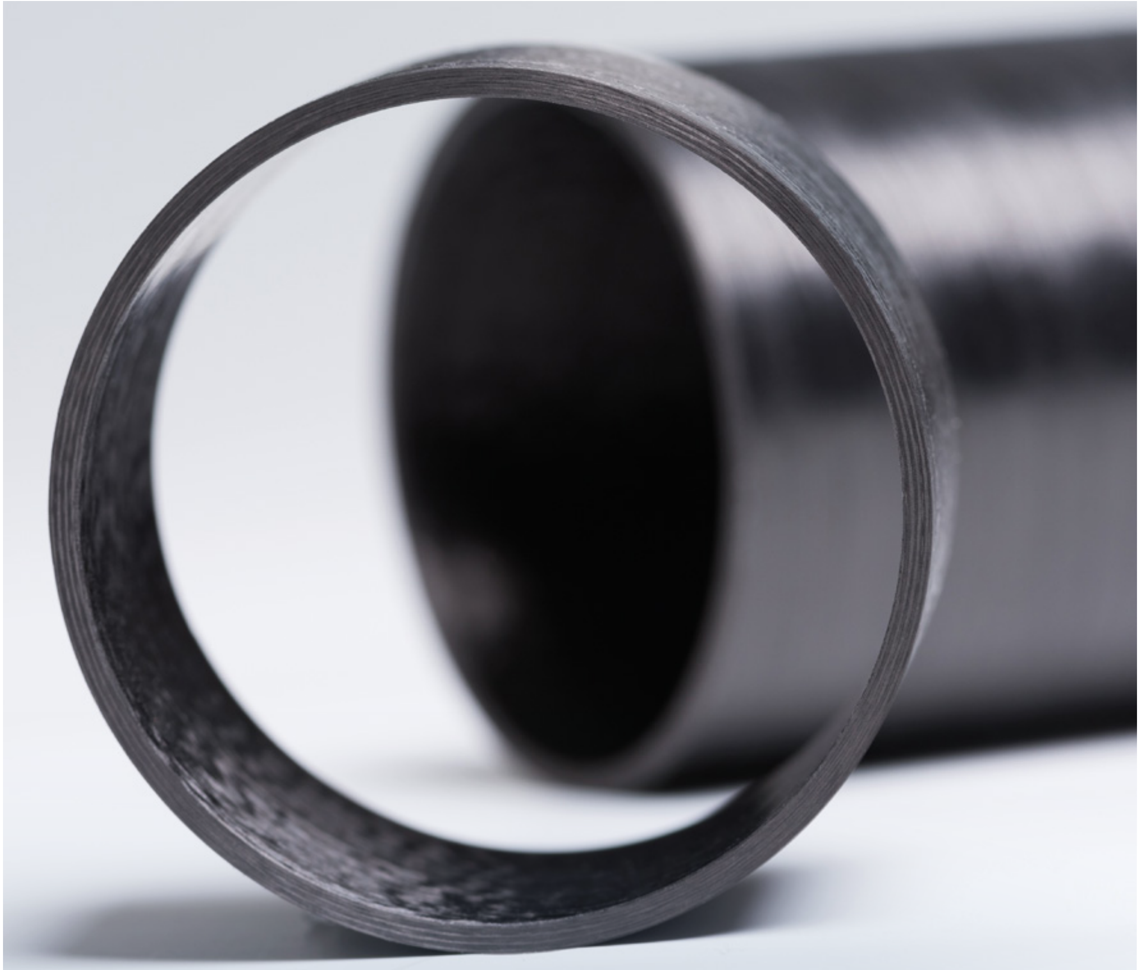
Planar laminates of VESTAPE® can be produced by using a heated press. When heating under pressure it must be ensured that the resin flow of the fusing laminate is controlled appropriately, e.g. by a mold or other accessory. Preliminary drying of the tape material is usually not necessary due to the low water absorption of both our PA12 and PEEK matrix polymers. If preliminary drying is nonetheless desired, this can be performed for 2 to 4 h at 80 to 100 °C for PA12 and for 4 h at 160 °C for PEEK. For additional information on drying, please see the processing information of VESTAMID® and VESTAKEEP® in separate brochures.

A typical consolidation cycle for production of flat laminates in a heated press using VESTAPE® PA12/CF tape is shown in the figure. Note, that those parameters represent only an initial starting point for further process optimization, because the lamination process and equipment used in the processing facility strongly influence the pressing parameters. The stacking of the tapes prior to consolidation can be carried out either manually or automated. The quality of the stacking particularly in regard to the precision of fiber orientation and the gaps and overlaps of the tapes, significantly influences the overall quality of the laminate.

It is recommended that the laminate panels be supported, for example by metal sheets, during removal. The subsequent cooling of the panel should occur uniformly on both sides; uneven cooling may lead to deformation and warping of the laminate. Suitable release agents prevent adherence of the laminate to the mold or the supporting sheets.

	PA12/CF	PEEK/CF
Temperature	220 ± 10 °C	400 ± 10 °C
Pressure	10 ± 5 bar	10 ± 5 bar
Time	≥ 5 min	≥ 10 min
Cooling rate	≤ 20 K/min	≤ 20 K/min





Tape processing using automated tape laying

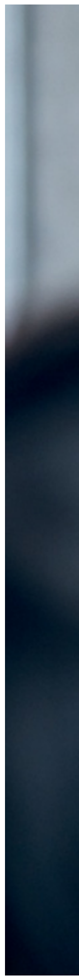
Automated tape laying is a manufacturing method to produce flat, curved or even more complex parts out of thermoplastic tape material by using automated application systems. The parts are generated by applying the tape material onto a surface usually using an industrial robot system. By applying heat and pressure during layup, the tapes are welded onto each other directly in an in-situ consolidation process with no additional autoclave or other consolidation step being required. In that way, the part is built up layer by layer.

Pressure usually is applied by a roller system; heat can be applied in various ways, the use of a diode laser source being the most powerful and flexible method. With a suitable robot system and sufficient laser power, lay-up speeds of more than 1 m/s can be achieved. As the consolidation takes place directly on the part, the tape laying process can also be used to locally reinforce existing components or semi-finished products.

Tape winding for tubular parts

Besides structural parts, tubular parts can also be manufactured directly using tape laying equipment in combination with a rotational axis. With this method, nearly continuous parts such as pipes, tubes or pressure vessels can be manufactured efficiently in a fully automated process. For continuous production of pipes, Evonik offers sufficient tape lengths.

TAKE ADVANTAGE OF OUR SERVICE AND SUPPORT



Delivery and storage

VESTAPE® UD tapes are supplied on spools in cardboard boxes. In our experience storage time is practically unlimited under normal storage conditions, provided that the packaging has not been damaged.

Storage at temperatures above 45°C should be avoided. In our general technical terms of delivery, we guarantee a storage time of two years in undamaged packaging and at a maximum temperature of 30°C.

Environmental compatibility and safety

VESTAPE® UD tapes consist of compounds that are not hazardous by the criteria of the CLP (Classification, Labelling, Packaging) Regulation 1272/2008. VESTAPE® UD tapes can be disposed of in landfills or by incineration, in accordance with local regulations. During the processing of VESTAPE® UD tapes national exposure limits for dust must be complied with. Generally adequate ventilation and exhaust must be ensured during processing. The EU safety data sheets for the relevant products provide further guidance.

Combustibility

Most VESTAPE® UD tapes are flammable. At melt temperatures above 350°C, decomposition generates flammable gases. With sufficient air supply, combustion yields CO, CO_2, H_2O and nitrogen compounds as combustion products. More details on gas composition cannot be given as the spectrum of crack and combustion products depends heavily on combustion conditions. All the necessary guidance is available in the safety data sheet for the relevant product, which is included with delivery and obtainable on request.

Technical service and CAE support

Powerful material models and modern simulation software tools are needed for adequate prediction of UD tape processing and component properties. Evonik offers strong expertise in both areas. In collaboration with our customers we develop technologically sophisticated system solutions including comprehensive technical support during the design phase of particular components, detailed processing guidelines for our compounds and UD tapes, and on-site technical support during piloting and manufacturing.

Our CAE support is an essential element of all customer projects. We optimize part design and numerically describe the behavior of the composite and overmolding materials via integrative simulation to support successful full-scale market launch by our customers. In the design phase, we use state-of-the-art simulation software such as ABAQUS CAE, DIGIMAT, or Autodesk Moldflow for fast and straightforward design. This is ensured by material models considering properties such as anisotropy, non-linearity, and dependence on temperature and tension-compression asymmetry. In this way the strengths of endless-fiber reinforced materials are fully utilized.

Furthermore, our technical services include recommendations for tape laying and draping as well as for the entire overmolding process from the filling phase, through simulation of fiber orientation, to computation of shrinkage and warpage.

In general, this approach can significantly reduce design costs and lead time. Our team, which is highly skilled in application engineering and process development, discusses all objectives and challenges with the customer to develop appropriate solutions.

APPLICATIONS

Aviation

Quality standards are high in the aviation industry, where lightweight solutions are especially relevant.

High-performance thermoplastic VESTAPE® UD tapes are ideal for manufacturing long-lasting components for use as primary structural parts under the toughest conditions, such as in fuselage applications. Tight tolerance parts can be produced by tape laying or winding to withstand high temperature as well as chemical and conductive environments. Thanks to higher ductility and molecular weight, mechanical benefits such as higher impact strength and lower notch sensitivity can be achieved at elevated temperatures and improve both, ease of fabrication and longevity. Inherent flammability properties and robust performance make VESTAPE® UD tapes an ideal choice for aerospace applications. Excellent fatigue, impact, and creep behavior are achievable in continuous use at elevated temperatures around 250°C. Due to its low weight combined with high mechanical strength, VESTAPE® is an adequate alternative to traditional thermosets and metals.

Oil & Gas

In the oil and gas market, tapes are used to form continuous pipes and pipe sections. VESTAPE® forms the reinforcement layers of flexible composite pipes for all kinds of subsea applications such as risers, jumpers, downlines, flowlines and service lines.

Composite tapes offer many advantages including low weight, high strength, low permeation, and resistance to corrosion. Lightweight thermoplastic composite pipes (TCPs) are spoolable and cost-effectively transported; they can be installed with light vessels in fewer vessel days, allow quick termination in the field, and significantly reduce the total installation cost.

VESTAPE® UD TAPES – WHEN UNRIVALED PERFORMANCE IS THE ONLY OPTION!

PA12 as matrix polymer offers numerous advantages such as very good resistance to oil and gas hydrocarbons and corrosive environments, a wide temperature range from arctic conditions to 80°C, well-known and predictable long-term ageing behavior, and a track record in the oil and gas industry. For several years Evonik has been supplying VESTAMID® NRG PA12 extrusion grades for the oil and gas industry. These are API qualified and ideally suited for the PA12 matrix polymer used in VESTAPE®.

VESTAPE® PA12/CF will be qualified for TCP applications in compliance with DNV-GL-ST-F119 by the end of 2019.

Hybrid parts

One advantage here is the possibility of efficient production of functionally integrated, load-optimized composite components by overmolding certain areas of a composite structure in an injection mold with a molding compound that adheres compatibly. For a strong bonding between the partners, sufficient adhesive compatibility between the thermoplastic matrix material of the composite and the thermoplastic used for overmolding is essential. Good adhesion can be achieved when the polymers are of the same type. With materials that adhere compatibly, the temperatures of both bonding partners in the contact area are usually particularly important. A sufficiently high and continuous contact temperature further promotes bond formation with the right combination of materials. The temperature in the joint area is determined primarily by the temperature of the mold and the melt temperature of the overmolded component. Increasing the temperature often improves the bond strength. The temperature of the thermoplastic composite should also be high enough in the joint area where it comes into contact with the overmolded component. Depending on the overall process it may be advantageous to preheat the composite part prior to insertion into the injection mold.

CONTACTS

Global technical contact

Dr. Alexander Brack
PHONE +49 2365 49-4728
alexander.brack@evonik.com

Contact for Americas

Lisa Allen Mueller
PHONE +1 951 852 6615
lisa.mueller@evonik.com

Contact for Asia and Pacific region

Jing Zhu
PHONE +86 159 0064 1267
jing1.zhu@evonik.com

Evonik Operations GmbH
High Performance Polymers
45764 Marl
Germany
PHONE +49 2365 49-9878
evonik-hp@evonik.com

www.evonik.com/composites
www.evonik.com

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