VESTAPE

Uni-directional tapes for structural lightweight design

Evonik. Power to create.

Evonik, the creative industrial group from Germany, is one of the world leaders in specialty chemicals, operating in the Nutrition & Care, Resource Efficiency and Performance Materials segments.

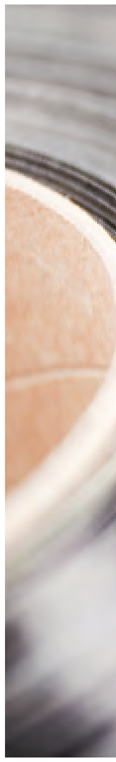
The Resource Efficiency segment is led by Evonik Resource Efficiency GmbH and brings together Evonik's activities in specialty chemicals for industrial applications. The Resource Efficiency segment supplies high performance materials for environmentally friendly as well as energy-efficient systems.

For the composite industry, the Resource Efficiency segment already delivers different thermoplastic matrix materials, matrix-related products, such as additives, and specialty foams for sandwich constructions.

This brochure describes a new product for the lightweight design industry: uni-directional tapes (UD tapes) made from endless glass or carbon fibers and specialty polyamides as a thermoplastic matrix.

Evonik. Power to Create.

Content



Uni-directional tapes

Endless fiber-reinforced plastics offer a promising and innovative solution with high potential for lightweight construction.

Our composites of endless fiber-reinforced plastics consist of carbon or glass fibers and a matrix made of high-performance polymers. In a UD tape, the properties of both materials combine ideally to create innovative construction materials for new paths in component design. Several layers of UD tapes in a laminate form “organosheets,” which significantly outperform the mechanical properties of metal sheets of the same thickness.

Organosheets can be thermoformed and, therefore, adopt a variety of component geometries. They also offer the opportunity of integrating additional functions or components, as the parts can be overmolded with a fiber-reinforced compound. Naturally, using the same polymer class as for the matrix in the UD tape ensures a good connection between the two components, which is essential for dynamic load conditions.

The matrix is made from specially developed high-performance polymers with a high glass transition temperature and therefore features good heat resistance. It is customized to high-strength endless fibers and allows production of parts that can be used even in areas exposed to extreme temperatures.

Evonik is one of the leading suppliers of high performance thermoplastic resins such as specialty polyamides for use under adverse environmental conditions and polyetheretherketones (PEEK).

Matrix systems

The polymer of a composite system serves to protect the load-bearing fibers against all environmental influences and to transfer loads evenly over the fibers. For this reason, the polymer – the "matrix", as it is called – plays a pivotal role in composites. In general, the matrix in a fiber-reinforced composite serves to:

- Keep the fibers in place
- Transfer stresses evenly over the fibers
- Provide a barrier under adverse conditions such as chemicals and moisture
- Protect the surface of the fibers from mechanical degradation, for example, as a result of abrasion

The matrix you select has a major impact on the compressive, interlaminar and in-plane shear strengths of the composite material. Polymer matrix systems fall into two broad categories: thermosets and thermoplastics.

A thermoset matrix has a three-dimensional network structure, where the molecular chains are permanently crosslinked. The transformation is irreversible, and the original properties of the material cannot be restored. The advantage of thermoset resins is that they are easy to formulate and use.

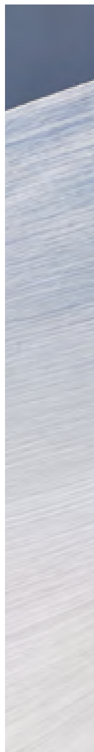
A thermoplastic matrix has a linear structure that must be heated to be formed, and cooled to be set. That is, the chains lock into place. You can reverse the operation, thereby regenerating the material, and repeat the cycle. The advantage of thermoplastic matrix systems is that they exhibit significantly higher impact strength, allow faster production rates, are storable at ambient temperatures without any special protection, and are reprocessable.

When selecting a matrix, a manufacturer considers primarily its basic mechanical properties under the expected environmental conditions (maximum service temperature, water uptake and exposure to harmful chemicals). For high performance composites, the most desirable mechanical properties of a matrix are:

- High tensile modulus, which influences the compressive strength of the composite
- High tensile strength, which controls the interply cracking in a composite laminate
- High fracture toughness, which controls ply delamination and crack growth
- Good dimensional stability at elevated temperatures (glass transition temperature higher than maximum service temperature)
- Resistance to moisture and solvents, for example, fuels and gasoline, motor oil, deicing fluids and antifreeze, and paint strippers (polymer should not swell, crack or degrade)

All Evonik thermoplastics are excellent in these aspects.

Properties



Comparison of main properties of the matrix polymers

Physical properties		Unit	PA 6	PA 66	PA10T/X	HT-PA12
Density		g/cm^3	1.14	1.17	1.11	1.02
Glass transition temperature		°C	50	60	130	140
Melting temperature		°C	220	265	240-270	250
Moisture absorption (23°C, 50% rF)		%	3	2.1	1.1	1.5
Mechanical properties						
-30°C (700 h, 23°C, 50% rh)	Stress at yield	MPa	* 100	* 95	80	80
	Strain at yield	%	* 4	* 3	7	10
	Tensile modulus	MPa	3200	3800	2100	1500
23°C (700 h, 23°C, 50% rh)	Stress at yield	MPa	55	* 65	60	55
	Strain at yield	%	22	* 3	6	8
	Tensile modulus	MPa	2000	3000	2000	1400
80°C (700 h, 23°C, 50% rh)	Stress at yield	MPa		45	40	38
	Strain at yield	%		25	3.5	4.5
	Tensile modulus	MPa	440	950	1600	1150

* Material exhibits brittle fracture behavior.

Matrix

The following chapter provides an overview of the polyamide matrix systems Evonik supplies for its structural VESTAPE UD tapes:

These are semi-aromatic polyphthalamide PPA (PA10T/X) grades and specialty transparent, high-temperature polyamide 12 grades (HT-PA12).

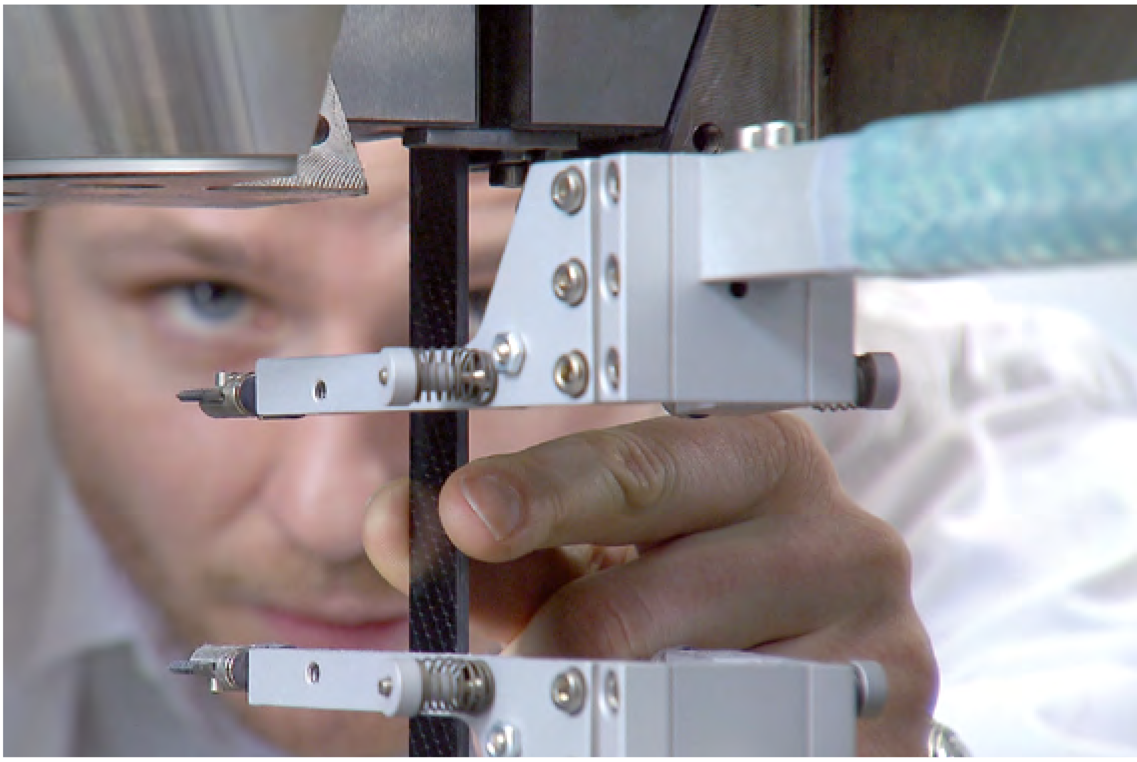
Although HT-PA12 has a crystalline structure its crystallites are so small that they do not scatter visible light, and the material appears transparent to the human eye. These materials combine the chemical resistance of semi-crystalline polymers with the advantages of amorphous, UV-resistant plastics.

Mechanical properties

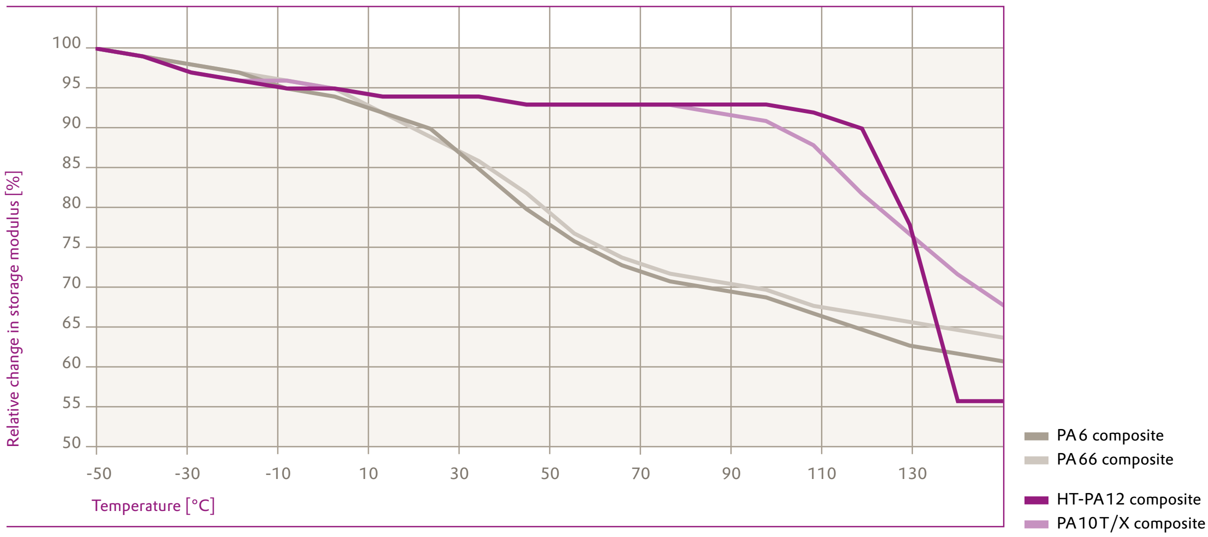
The advantages of UD tapes with a PPA or HT-PA12 matrix are particularly evident in applications where unchanged material performance is required for a broad temperature range.

Compared with composites made from most commonly used materials such as PA6 and PA66, VESTAPE UD tapes have largely stable mechanical properties over a wide temperature range. Polyamide 6 and PA66 composites on the other hand show a strong, almost linear decline in mechanical properties; as a result, com-ponents made from these materials must be significantly overdimensioned in order to satisfy requirements.

In the temperature region between -30°C and 80°C, which is typical for automotive construction, the high-temperature materials display their full potential: They reduce material requirements, thus allowing more econo-mical design of components.

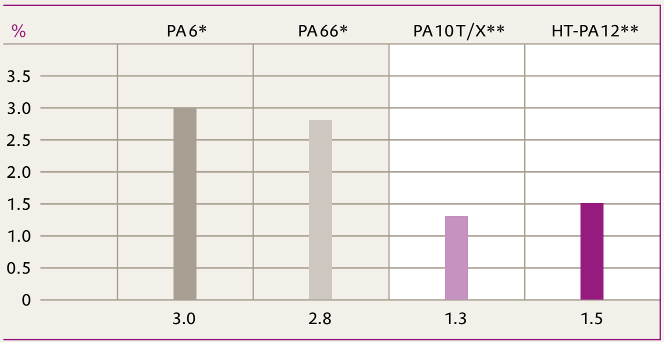


Comparison of temperature influence (DMA) on fiber reinforced PA6, PA66, HT-PA12, and PA10T/X



Measured according to ISO 6721-5

Moisture absorption of PA6, PA66, HT-PA12, and PA10T/X



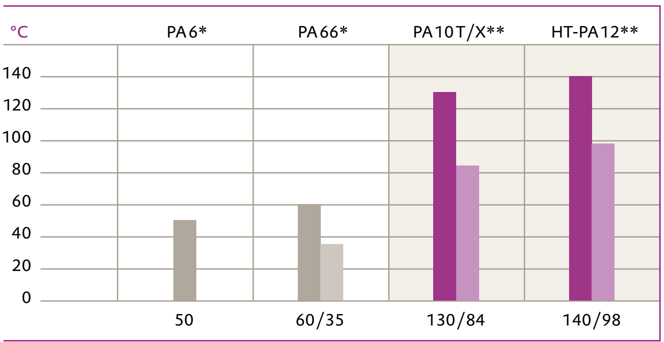
* Source: CAMPUS®
** Measured according to ISO 62 at 23°C, 50% r.h

Moisture absorption behavior

High-temperature polyamides such as PA 10T/X and HT-PA 12 respectively are distinguished by low water absorption as compared with 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—which in any case have high mechanical strength—and makes for greater safety in the design of heavily loaded component groups.

Effect of moisture absorption on glass transition temperature

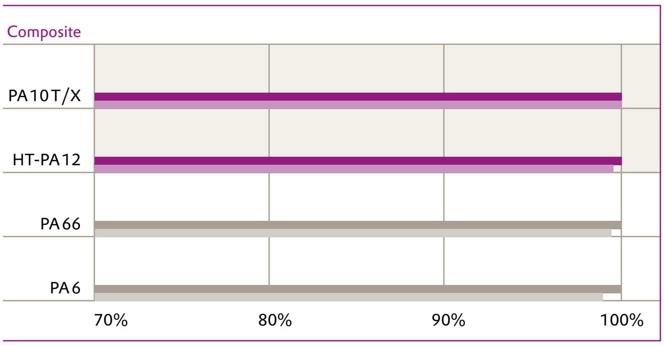


Measured according to ISO 11357-1/-2

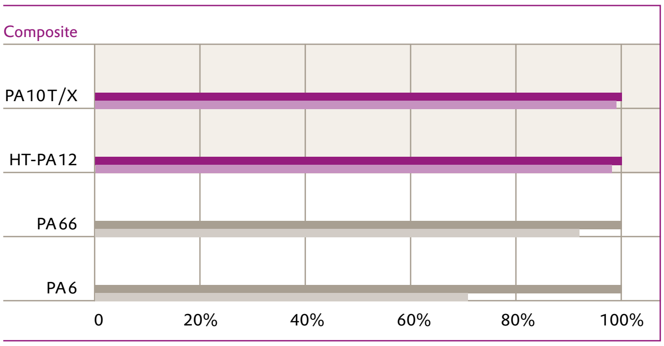
* Source: CAMPUS®
** Source: Evonik data based on DSC analysis (dry) and DMA (cond.) resp.

dry
conditioned at 23°C, 100% r.h.

Effect of moisture absorption on Young's modulus of composite specimen



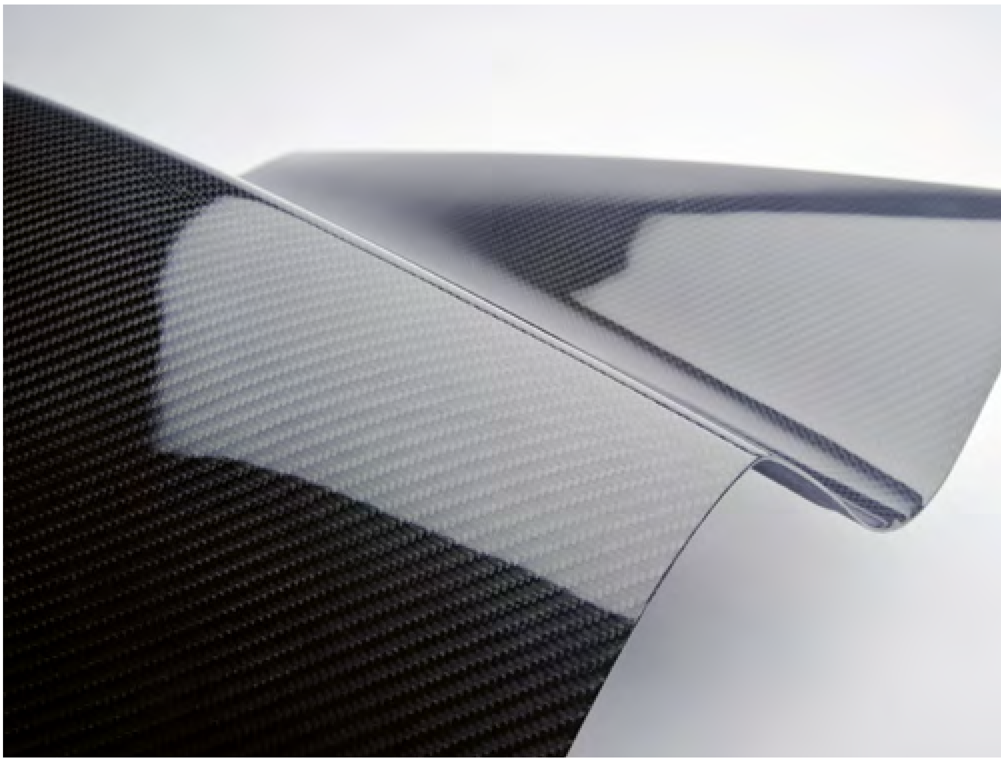
Effect of moisture absorption on tension at break of composite specimen



Measured in 3-pt. bending trial according to ISO 14125, conditioned vs unconditioned

dry

conditioned at 23°C, 50% r.h.



Composite

VESTAPE UD tapes are available in combination with all relevant types of glass and carbon fiber whereas Evonik's proprietary melt impregnation technology assures an excellent wetting of the fiber rovings at competitive costs.

Our high-temperature polyamides are specifically modified for the fiber impregnation process in order to ensure an optimum bonding between matrix and fiber. This results in composite systems that can withstand the highest loading requirements.

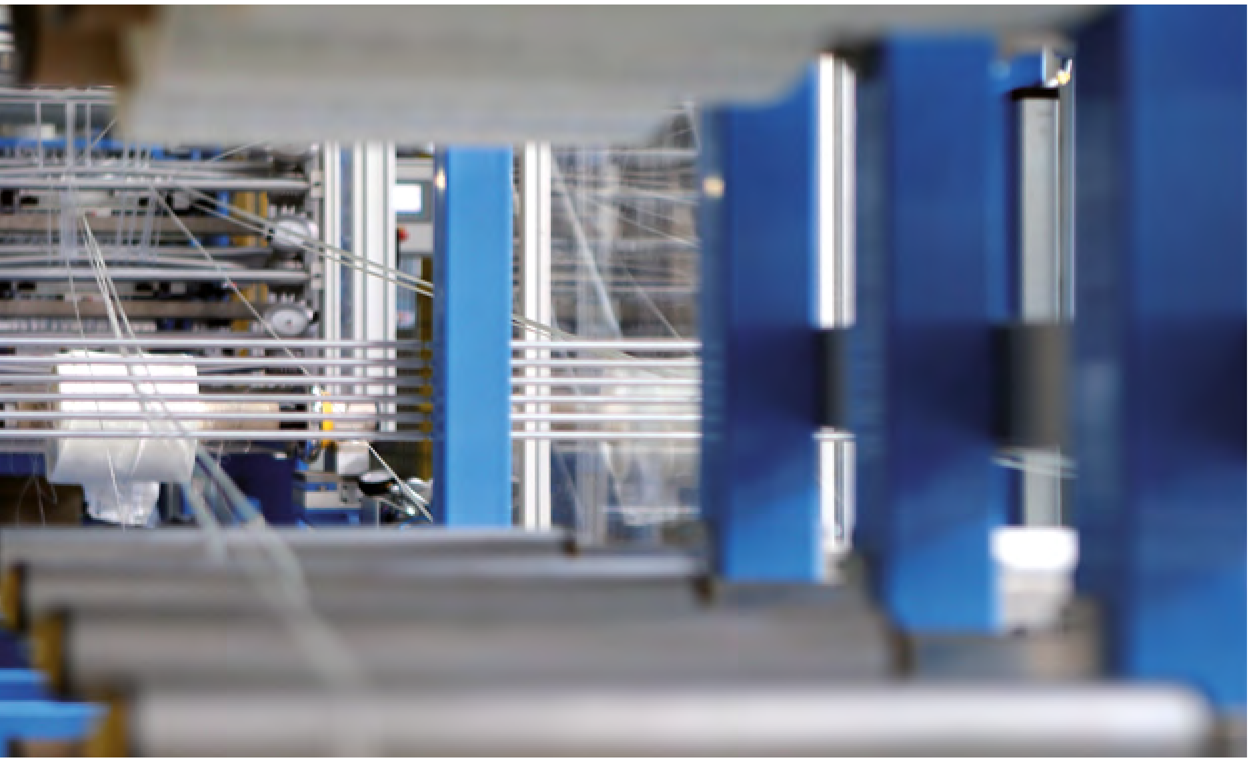
Tape properties

Composition	Unit	Standard	High performance
Polymer		PA 6	VESTAMID® HT-PA12
Fiber type		carbon fiber	carbon fiber
Physical properties			
Density	kg/m³	1.47	1.41
Porosity	%	< 1	< 1
Fiber volume fraction	%	50	50
Fiber weight fraction	%	61	64
Mechanical properties (0° direction)			
Stress at failure	MPa	2000	2100
Strain at failure	%	1.5	1.6
Tensile modulus	GPa	125	117

Typical laminate properties

Physical properties		Unit	Standard	High performance
23°C, as molded	Density polymer	g/cm^3	1.14	1.02
	Density composite	g/cm^3	1.46	1.42
	Fiber mass content	%	61	67
	Fiber volume content	%	50	52
Tape properties				
23°C, as molded	Axial tensile strength	MPa	2,000	2,100
	Axial tensile modulus	MPa	125,000	117,000
	Axial tensile elongation	%	1.5	1.6
Laminate properties				
23°C, as molded	Axial tensile strength	MPa	1,660	1,680
	Axial tensile modulus	MPa	120,000	120,000
	Axial tensile elongation	%	1.3	1.3
	Transverse tensile strength	MPa	40	35
	Transverse tensile modulus	MPa	7,100	6,700
	Transverse tensile elongation	%	0.6	0.5
	Axial flexural strength	MPa	780	960
	Axial flexural modulus	MPa	100,000	103,000
	Axial flexural elongation	%	0.8	0.9
80°C, conditioned	Axial tensile strength	MPa	940	1,400
	Axial tensile modulus	MPa	110,000	110,000
	Axial tensile elongation	%	0.9	1.3
	Transverse tensile strength	MPa	20	23
	Transverse tensile modulus	MPa	2,800	2,900
	Transverse tensile elongation	%	1.0	1.1

Processing



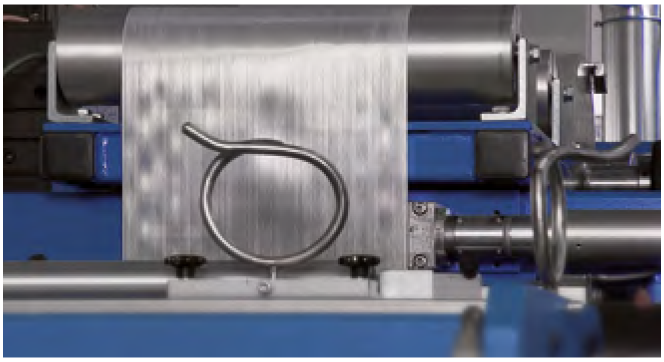
Processing of UD tapes

One big advantage of composites with thermoplastic matrix is the high potential for low-cost and fast processing, along with the broad 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 through the forming of thermoplastic components to the composite structure.

One opportunity is 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 the same type. With materials that adhere compatibly, usually the temperatures of both bonding partners in the contact area are particularly important.
A sufficiently high and continuous contact temperature further promotes bond formation in the right combination for materials.

The temperature level in the joint area is primarily determined by the temperature of the mold and the melt temperature of the overmolded component. Often, increasing the temperature improves the bond strength. The temperature of the thermoplastic composite should also be high enough in the joint area when it comes into contact with the overmolded component. Depending on the overall process it may make sense to preheat the composite part prior to insertion into the injection mold.

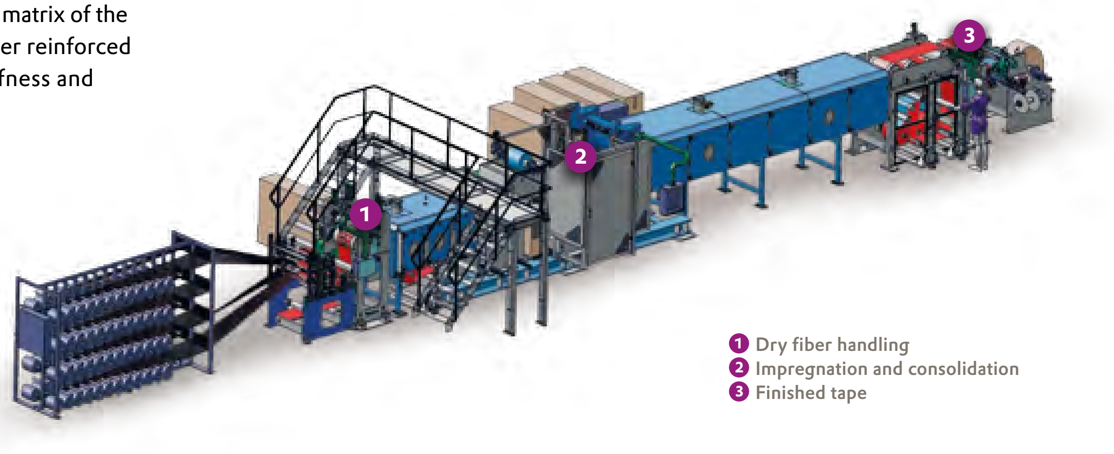


Suitable compounds for overmolding VESTAPE

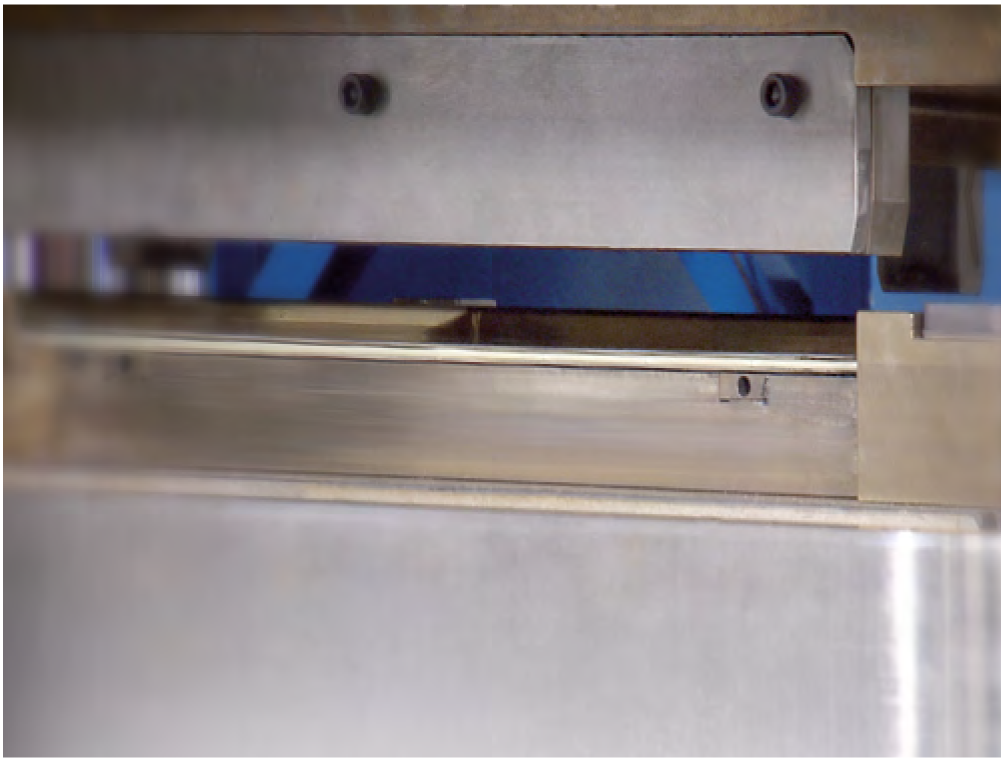
Due to technical demands, injection molding compounds for overmolding composites generally contain fillers and reinforcing materials, especially short or long fibers. These ensure good mechanical properties in combination with reduced thermal expansion and low shrinkage.

VESTAMID® CW1129 is an example of such a compound. The base polymer is compatible with the HT-PA12 matrix of the respective tape. The short fiber reinforced compound features high stiffness and good flowability.

Please contact the indicated persons for more details.



1 Dry fiber handling
2 Impregnation and consolidation
3 Finished tape



Production of UD laminates by pressing

Planar laminates, so-called organosheets, of VESTAPE can be produced by pressing. For high laminate quality, particular care is required in the production and preparation of the UD tape layers. Deviations in fiber orientation or in the stacking dimensions of the individual tapes may negatively impact the quality of the resulting laminate.

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. Such measures may be avoided by heating in a preheating unit without pressure and subsequently transferring to a cooling press.

Preliminary drying of the tape material is usually not necessary due to the low water absorption of our high-temperature polyamides. If preliminary drying is nonetheless desired, this can be performed for two hours at 80°C under vacuum or at 110°C in an oven.

The lamination process and equipment used in the processing facility strongly influence the pressing parameters. The parameters shown here therefore represent only an initial starting point for process optimization.

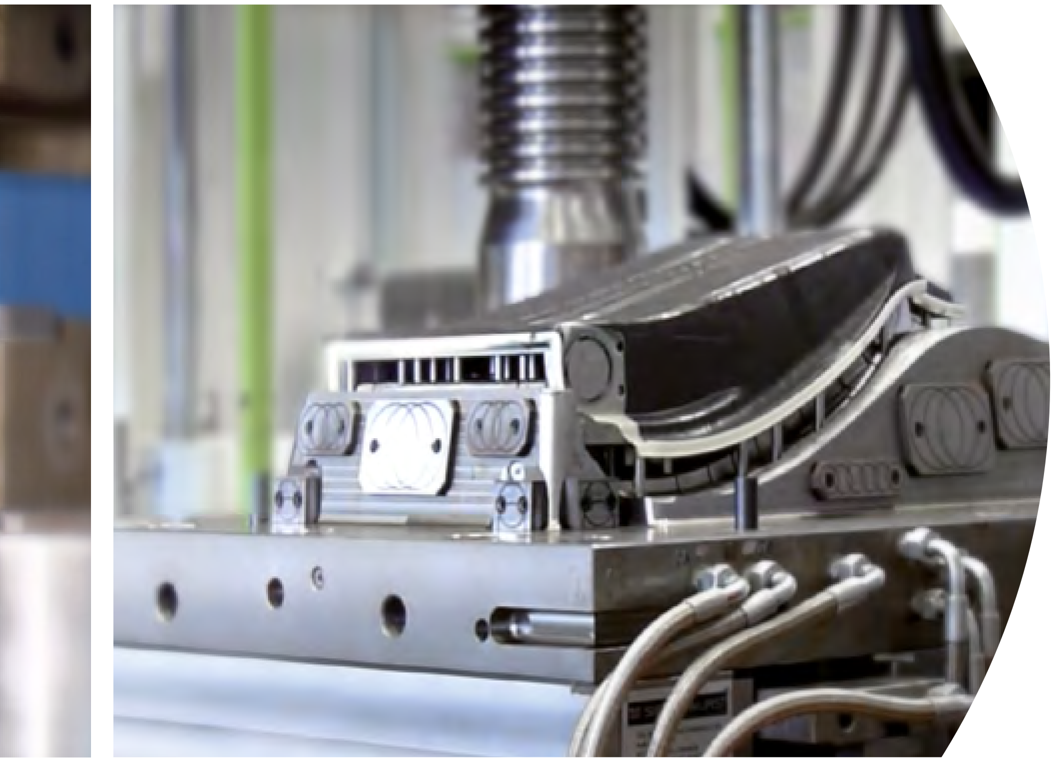
The high glass transition temperature (Tg) of VESTAMID® HT-PA12 reduces processing time by allowing removal temperatures of up to 160°C. It is recommended that the laminate panels be supported, for example by metal sheets, during removal. The subsequent cooling of the panel should occur uniformly on 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.

The consolidation temperature of the laminate must be set so that values of 280 - 300°C are attained in the center; this ensures complete consolidation and optimal bonding of the individual tape layers. Temperatures above 300°C may, however, lead to degradation of the polymer.

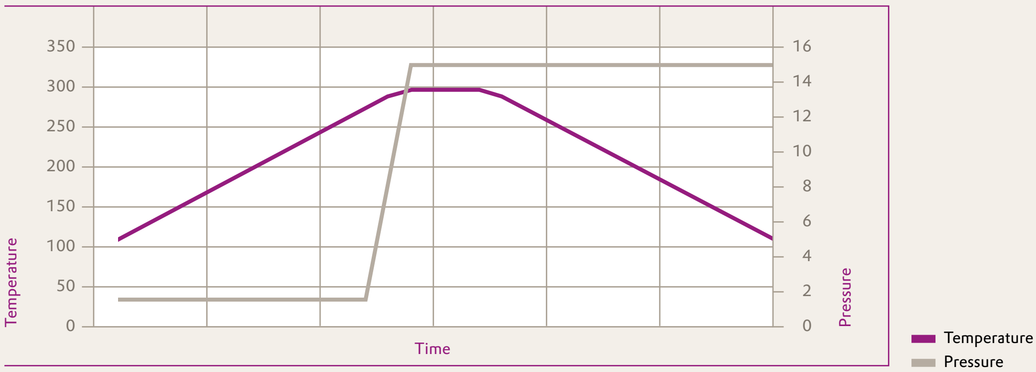
To ensure a homogeneous temperature distribution over the pressing surface during the cooling phase, it may be advisable to limit the heating and cooling rates of the press to 10 -15 K/min.

Once the target temperature has been attained in the center of the laminate, a pressing time of 1-2 minutes shall be applied to achieve good bonding of the layers. If for any reason the temperature inside the laminate cannot be recorded the pressing time shall be extended to 5 -10 minutes; this ensures that the UD structure is adequately heated through.

In the heating phase, pressures of 1 - 2 bar are sufficient to obtain good heat transmission and exclusion of air. In the consolidation phase the pressure should be increased to 15 - 20 bar and maintained at this value until the removal temperature is attained.



Typical press cycle



Material data

Melt temperature: 250°C
Melt temperature range at 20 K/min: 220-260°C
Glass transition temperature: 140°C
Crystallization temperature at 20K/min: 170°C

Process parameters

Pressing temperature: 280-300°C
Removal temperature: <160°C
Consolidation pressure: 15-20 bar
Consolidation time: 1-2 min

Environmental compatibility, handling and safety

Environmental compatibility and safety

VESTAPE UD tapes are articles. They are composed of compounds which are not hazardous based on the criteria of CLP regulation 1272/2008 (classification, labelling and packaging). VESTAPE UD tapes can be disposed of in landfills or by incineration, in accordance with local regulations. During intended processing of VESTAPE UD tapes the national exposure limits for dust have to be followed. Generally sufficient ventilation and exhaust during processing have to be ensured. The EU safety data sheets for the relevant products provide further guidance.

Delivery and storage

VESTAPE UD tapes are supplied on spools in cardboard boxes. It is our experience that, under normal storage conditions, storage time is practically unlimited provided that the packaging has not been damaged. Avoid storing at temperatures above 45°C. 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.

Combustibility

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

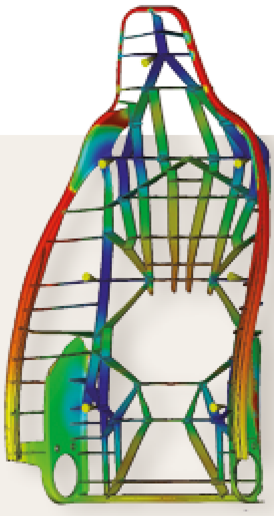
Technical service and CAE support

For an adequate prediction of UD tape processing and component properties powerful material models and modern simulation software tools are needed. Evonik offers strong expertise in both regards. We develop technologically sophisticated system solutions in collaboration with our customers. This includes comprehensive technical support during the design phase of particular components, detailed processing guidelines for our compounds and UD tapes as well as on-site technical support during piloting and manufacturing.

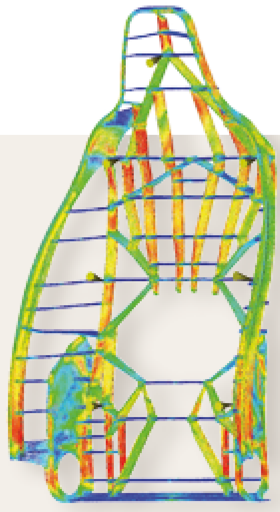
Our CAE support is an essential element of all customer projects. We optimize the part design and describe the behavior of the composite and overmolding materials numerically via integrative simulation to support the successful full-scale market launch at our customers.
In the design phase, we use state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

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

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

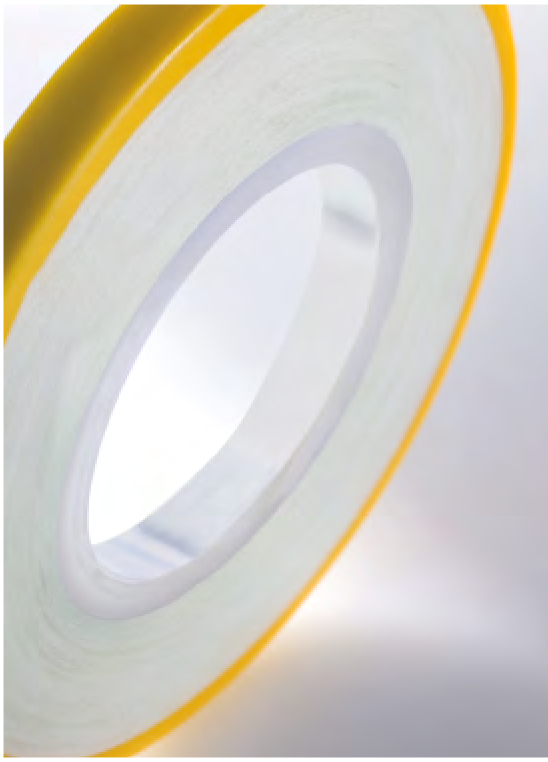


Simulation of the filling process



Fiber orientation

Further thermoplastic matrices for UD tapes



In addition to the polymers shown before, Evonik also offers UD tapes with PEEK and PA12 as matrix materials.

VESTAKEEP® PEEK

VESTAKEEP®, the PEEK from Evonik, is perfectly suitable as a matrix for unidirectional fiber layouts or woven fabrics of glass, carbon or aramid fibers, and thus makes it possible to produce fiber composite materials with this thermoplastic matrix. In general, the thermoplastic fiber composite materials are produced by a powder-coating or dispersion-coating process. Evonik has developed optimized powders suited specifically to fiber impregnation, thus confirming its eligibility for production of composites. Its VESTAKEEP® 2000 powder line with different particle sizes is established as the ideal polymer for this application.

PEEK composites are suitable for applications where extreme mechanical, thermal, and chemical requirements must be satisfied like in the oil and gas industry.

VESTAMID® PA12

VESTAMID® PA12 has been used as a matrix for many years in composites with glass fiber fabrics. So far, it has been used in automotive, sports, and orthopedic applications as well as in the oil and gas industry. Composites with VESTAMID® PA12 as the matrix are processable at a lower temperature. Compared to high temperature-resistant matrices such as PEEK and PPA, this presents an advantage, thus significantly shortening cycle times for mass-production. Recently, Evonik has launched PA12 VESTAPE UD tapes with glass fibers.

Please contact the indicated contact persons for more detailed information on composite solutions with VESTAKEEP® PEEK and VESTAMID® PA12.

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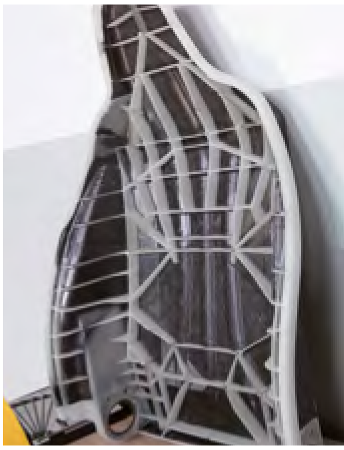

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