Fraunhofer
ICT

FRAUNHOFER INSTITUTE FOR CHEMICAL TECHNOLOGY ICT

POLYMER ENGINEERING

COMPETENCE IN POLYMER TECHNOLOGY AND COMPOSITE MATERIALS

STIMULATING MATERIAL AND PROCESS INNOVATION

Material and process innovations provide the impetus for the development of advanced products. Long-standing experience in material and process development makes our institute a competent partner for application-oriented research and development in polymer and composite material technology - from the initial idea and the concept development through to the manufacture of prototypes.
Our researchers work in the following thematically focused working groups:

- Material Development and Compounding Technologies
- Foam Technologies
- Injection and Compression Molding
- Structural Composites
- Microwave and Plasma Technology
- Material Characterization and Failure Analysis

We develop materials, processes and methods for our customers in the automotive, aerospace, construction, packaging, toy and leisure industries. In addition to individual topics from and along the value chain, we also provide solutions for long-term social challenges, in particular sustainable mobility, the circular economy, hybrid lightweight construction and the digitalization of process chains.

Networking

We strengthen our research expertise through participation in Fraunhofer-wide thematic alliances and innovation clusters, and through our close scientific collaboration with the Karlsruhe Institute of Technology KIT.
With our two Fraunhofer Project Centers in Canada and South Korea, we offer our customers an international research and development environment. Excellent contacts on national and international level help solve complex, interdisciplinary problems and address different markets and their requirements.

Possibilities for cooperation

Pre-competitive development tasks are mainly carried out together with our cooperation partners in national or international collaborative projects. Individual solutions are mostly developed in direct bilateral cooperation with our customers on a contractual basis.

COVER PHOTOGRAPH

Fully-automated production cell for the manufacture of hybrid thermoplastic structural components (MoPaHyb project).

PHOTO LEFT

Colored PET bottles shredded, depolymerized and cleaned to form white PET precursors, polymerised and converted back into PET-preforms.

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STRATEGIC TOPICS

SUSTAINABILITY

Efficient recycling and optimized material cycles have become a key topic for global economic and social development. Closing material cycles is essential for the development of new processing chains. For example, we are developing improved material formulations based on secondary raw materials, bio-based and recyclable material systems, energy-efficient processing methods and biobased, self-reinforced composite materials.

FLEXIBLE MANUFACTURING TECHNOLOGIES

Industrial manufacturing requires increasing flexibility in view of product individualization. Economical implementation can only be achieved through shorter development and production times, greater production agility and the efficient use of resources. We are meeting these challenges in the development of modular and adaptable manufacturing technologies and process chains and the further development of additive manufacturing.

ARTIFICIAL INTELLIGENCE

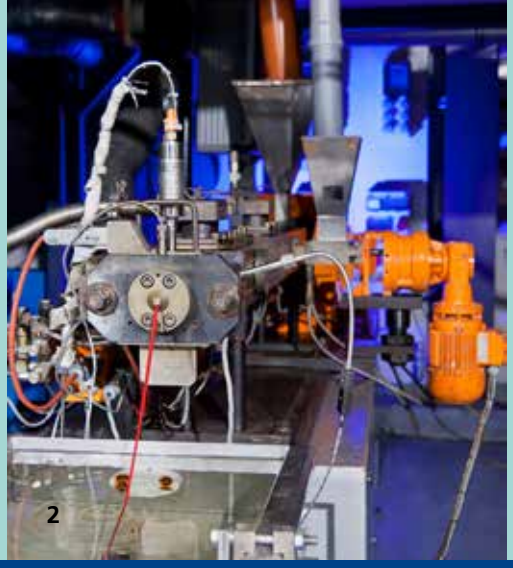
Using artificial intelligence to optimize products, processes and materials is one goal of digitalization. Against the background of our core competences in polymer and composite materials technology, we are using methods of machine learning and simulation to enable new processes and optimize existing ones. The development of digital twins of plastic processing processes and materials, and connection to a virtual production are a current research priority.

LIGHTWEIGHT CONSTRUCTION

Lightweight construction conserves resources, energy and the climate. The sector-specific design and construction of lightweight solutions determines the selection process for suitable materials as well as the manufacturing process. At Fraunhofer ICT, polymer-based fiber composites and their hybrids are at the center of the developments. Key research topics are long- and continuous-fiber-reinforced polymers with a thermoset and thermoplastic matrix, and their hybridization. In close collaboration with the KIT, method, process, and material development is advanced.

MATERIAL INNOVATION

Modern materials need to meet both structural and functional requirements. For this a profound understanding of material behavior is required as well as extensive know-how in material formulation. Current research focuses on functional materials which, in addition to their structural properties, have functionalities such as electrical or thermal conductivity, improved acoustic properties, scratch resistance or antibacterial properties. Programmable materials show a targeted reaction to changing environmental conditions or stresses. Sustainability along the value chain is becoming increasingly important. Our research therefore focuses on biobased material systems, material formulations on the basis of recycled components and novel recycling concepts.



MATERIAL DEVELOPMENT AND COMPOUNDING TECHNOLOGIES

The group for material development and compounding technologies is concerned with the development of formulations for thermoplastic polymer compounds and the development of innovative compounding processes.

Material development – tailored formulations

Based on many years of experience and the latest scientific findings, we develop material formulations together with our partners. Depending on the desired property profile, the incorporation of powders and nanomaterials in granules and fibers and the dosing of highly-viscous liquids.
or gases, also in supercritical state, can be carried out. The addition of functional fillers and additives enables the targeted adjustment of the properties of plastic compounds. Stabilizers, for example, often make it possible to produce and process compounds in the extrusion process without degrading the material. Reinforcing fibers provide the requisite mechanical properties of the component.

Process development - continuous mixing processes

Process development includes all tasks from the optimization of a screw configuration through to the development of material-specific extruder configurations including the necessary dosing and pelletizing strategies. In addition to optimized conventional compounding processes, we are also developing completely new process variants for twin-screw extruders. Examples include extractive compounding or reactive extrusion processes.

Our expertise in material and process development

- General compounding tasks
- Biopolymers and natural-fiber-reinforced polymers
- Reprocessing/re-formulation of recyclates
- Purification/odor reduction/emission reduction
- Functional compounds
- New materials for additive manufacturing methods
- Polymerization and polymer modification through reactive extrusion
- Online process control
- Safe handling of reactive materials and nanomaterials in extrusion

Fraunhofer ICT has a fully-equipped and flexible pilot plants. Extruders with various diameters and processing section lengths enable the demonstration of different processing approaches. Alternative energies such as microwave heating and incorporation of ultrasound or the use of supercritical fluids in compounding technology significantly expand the achievable process window.
A comprehensive portfolio of a variety of dosing and pelletizing technologies enables the visualization of complex processes.

1 *Polylactide pellet: starting material for the manufacturing of mono-material systems.*

2 *Compounding line for the manufacturing of functional polymer compounds.*

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FOAM TECHNOLOGIES

Foamed materials are increasingly used for transport packaging, heat insulation of buildings and also in the automotive sector. The goal of the development of new foamed materials is to optimize mechanical properties, temperature stability and recyclability.

Material development for thermoplastic foams

Foams with tailored properties have attracted increasing attention in the field of material development. Emphasis is placed on the development of foamable polymer compounds in the extrusion process, based on renewable resources and on the targeted use of functional additives, for example to improve the mechanical and thermal properties or to achieve environmentally-friendly fire protection. Additional trends include the development of high-performance foams from technical polymers, and the hybridization of foams, for example in sandwich processes.

Process development for extrusion foams

For the development of extrusion-foamed semi-finished products, sheets and foils, Fraunhofer ICT has a cutting-edge Schaumtandex laboratory unit, which consists of a twin-screw and a single-screw extruder. The plant makes it possible to test and further develop new material and blowing agent formulations without excessive use of resources. We contribute our extensive material and process know-how in the field of foam extrusion to the development work.

Process development for particle foams

Fraunhofer ICT offers the following development services and competences in the field of particle foam technology:

- Material development and optimization of the foam structure in the extrusion and autoclave process
- Development of foamed granules, or granules containing a blowing agent, by extrusion and subsequent underwater pelletizing
- Investigation into the foaming of granules to generate foamed particles in the laboratory pre-foamer
- Investigations into processing in the molding machine (based on steam and radio frequency)
- Verification of the insulation properties or mechanical indices of the foams in the in-house testing lab.

This complete process chain forms the basis for successful cooperation with our partners. New material mixtures can be quickly characterized in terms of their processability and component properties, for example insulation properties.

1 *Particle foam line for the continuous production of particle foams.*

2 *Material development for innovative particle foam components.*

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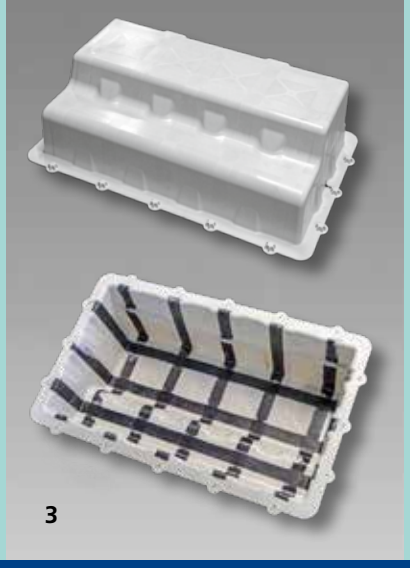

INJECTION AND COMPRESSION MOLDING

The injection and compression molding group specializes in the development of large-series processing technologies for flowable material systems. In addition to standard injection and compression molding processes, work is focused on single-stage, resource- and energy-efficient direct processes, tailored local continuous-fiber reinforcement, and spraying processes.

Injection molding

Thermoplastic and thermoset material systems are processed using state-of-the-art plant technology. Emphasis is placed on thermoplastic foam injection molding, the processing of high-performance polymers and hybridization technologies. Foam injection molding: Blowing agents are incorporated into the polymer melt and generate a foam structure during injection. Together with our partners we develop material compositions and processes for foamed components using both chemical and physical (Mucell®) blowing agents.

In comparison to standard and engineering thermoplastics, thermosetting polymers and high-performance thermoplastics have advantages in terms of media and temperature stability which make them attractive for demanding applications. This enables, for example, the substitution of aluminum diecast material.

Sheet molding compound (SMC)

The thermosetting composite sheet molding compound (SMC) permits lightweight construction solutions in application areas that are characterized by stringent requirements regarding mechanical, chemical and thermal stress. Activities at Fraunhofer ICT include formulation development, the use of novel resin systems and reinforcing fibers, and the development of an optimized process control.

Long-fiber-reinforcement in direct processes: in-line compounding in injection and compression molding

When compounding technology and molding are combined into a single process, plastic processors gain new, innovative options to improve the mechanical properties of components while saving energy and material costs. By incorporating fibers directly during material processing, longer fiber lengths can be achieved than with conventional semi-finished product-based processes. This technology offers particular flexibility in terms of the possible combinations of the matrix materials and reinforcing fibers such as standard, natural and recycled fibers.

Selective use of unidirectional fiber-reinforcements

We achieve maximum lightweight construction potential for components through the selective and resource-efficient use of continuous fiber reinforcements in areas exposed to high loads. By introducing unidirectional fiber reinforcements in the matrix, the specific properties of fiber composites can be further improved to enable structural application. 3D skeleton winding technology and the use of local UD prepregs offer large-scale solutions for components in injection and compression molding.

1 *Prototype of a seat structure made of PLA composite.*
2 *Injection press, modular long fiber injection molding unit.*
3 *SMC battery box with local continuous-fiber reinforcement.*

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STRUCTURAL COMPOSITES

The structural composites group is concerned with the development and optimization of materials and processes for the manufacture of high-performance lightweight structures. The highest strengths in components can be achieved through the targeted use of continuous fibers.

Material development

Many raw materials and semi-finished products can be used for the manufacture of fiber composite structures. We support our customers in the development or selection of the right matrix and fiber semi-finished products to achieve the best material properties and at the same time enable efficient manufacturing. We work with both thermoplastic and thermoset matrix systems using the available fiber types and production processes suitable for series production. Hybrid materials and their processing also play an important role.

Process development

Our large portfolio of manufacturing processes allows us to efficiently manufacture fiber composite structures on an industrial scale. Our expertise lies in the consideration of the entire process chain and the optimization or further development of individual processes to meet the required quality and production rate. One of our core competences is the validation of the manufacturing processes and the plant technology in an industrial environment, using our own facilities.

Benefit from our expertise

- Production of samples for material characterization
- Operating and manufacturing with customer molds with the RTM/HD RTM/wet molding process
- Instrumented test stands to characterize the deformation behavior of dry and wet textile semi-finished products
- Preforming: automation and optimization of the subprocess steps cutting, handling, draping, and trimming
- RTM/HD RTM: reactive thermoset and thermoplastic processing with injection pressures of up to 200 bar
- Industrialization of processes for epoxy resin systems, polyurethanes and caprolactam (in-situ polymerization)
- Wet and prepeg compression: Characterization and further development of the molding processes and their derivatives
- Tape laying on industrial scale, energy-efficient consolidation of fiber-reinforced semi-finished products
- Automated reshaping or compression molding of thermoplastic and thermoset semi-finished products
- Manufacture of profiles by pultrusion (classic and with injection chambers; with thermoset and thermoplastic material systems)
- Process data acquisition and evaluation for documentation and simulative validation

1 *Integrated composite floor module manufactured using the pressure-controlled RTM process (front) and local advanced tailored LFT (rear).*

2 *Draping tool for a composite floor module for automated preform manufacture.*

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MICROWAVE AND PLASMA TECHNOLOGY

In the field of microwave and plasma processing technology, our team of experts focuses on the development of production and measurement technologies for thermal and coating processes. The numerical simulation of microwave and plasma processes developed specifically for this purpose often enables the rapid generation of new process solutions.

Microwaves

The thermal processing of non-metallic materials such as plastics, glass or natural materials is usually carried out via hot air contact heating or infrared radiators. These heat up the surfaces of the material, causing the heat to diffuse into the material until the desired temperature of heating is achieved. The low thermal conductivity of these materials make this process time-consuming. Microwaves are non ionizing electromagnetic waves that are absorbed by polar and magnetic materials, and by materials that are poor electric conductors. With their long wavelength, microwaves have a high penetration depth into many non-metals. The quick, contact-free volumetric deposition of heat deep inside the material can therefore be achieved independently of the thermal conductivity. Our work focuses on the development of processes, testing units and material formulations for the industrial use of microwave technology. Current development areas include microwave-assisted chemistry, pultrusion and the RTM process.

Plasmas

Plasma coating methods such as PECVD (plasma enhanced chemcial vapour deposition) can equip the surfaces of various materials with thin functional layers that significantly improve the properties or application suitability of the components.

The coated surfaces have properties that often cannot be achieved using conventional coating methods. Plasmas generated with microwaves protect the surface and are characterized by high coating rates.
Together with our partners, we develop new coating methods and transfer them to industrial processes. Developments include a highly efficient new method of coating polycarbonates with a scratch-resistant coating and an extremely effective corrosion protection for metals such as high-strength steels or aluminum alloys. A new nanoporous adhesive layer significantly improves the adhesion of polymers or adhesives in hybrid components, for example metal polymer hybrids.

Simulation

Simulation technologies already facilitate and accelerate the design and the construction of technical systems in many areas. Using commercial software and models developed in-house, we calculate electromagnetic fields in microwave plants and the related heat or plasma generation, and use this information to support the development of the microwave and plasma plant and process development.

1 *Corrosion-resistant layer on Damascus knife, as an application case study for a corrosion-resistant layer on metals.*
2 *Microwave plasma unit, large-scale.*

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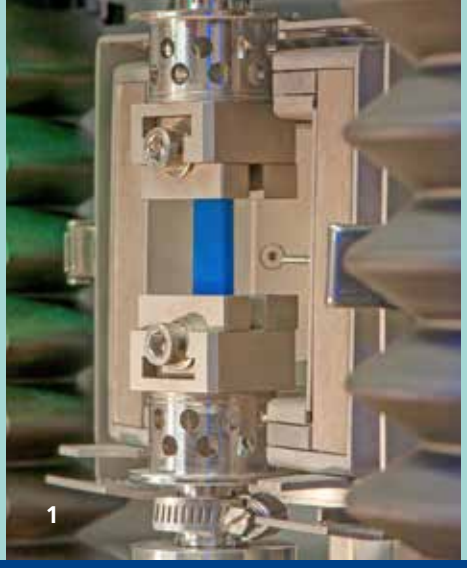

MATERIAL CHARACTERIZATION AND FAILURE ANALYSIS

In our testing laboratory, we carry out comprehensive examinations of polymer materials along the entire processing chain, from the raw material through to the component. We generate material data for structure and process simulation and, in the event of failure, we offer a systematic analysis of its cause.

Sample manufacture

Test results can only be used to compare different materials when the sample production and the preparation of the materials are identical. In this field Fraunhofer ICT can offer the following production methods for samples:

- Injection molding for thermoplastics and free-flowing thermosets
- Production of sheet material for the manufacture of test samples by compression molding (such as RTM)
- Mechanical separation processes and hot wire cutting
- Conditioning of samples in climate chambers

Mechanical testing in the material testing laboratory

- Tensile test with determination of lateral contraction behavior
- 3- and 4-point bending test
- Interlaminar shear strength test (e.g. ILSS, tensile shear test, cutting shear test, etc.)
- Compression test, e.g. for fiber composites or foams
- Impact strength/notched impact strength (Charpy) and puncture test
- Bond strength test (e.g. lap-shear test)
- Heat distortion temperature and Vicat softening temperature
- Dynamic mechanical analysis (DMA)
- Characterization of the deformation behavior of semi-finished products

Rheological and supplementary testing procedures for plastics

- Shear viscosity of plastic melts (high-pressure capillary viscometer)
- Extensional viscosity of plastic melts (Rheotens)
- Melt index test (MFR/MVR)
- Measurement of fiber content and length
- Measurement of moisture content
- Shore-hardness (Shore A and Shore D)
- Density measurement (immersion method)
- Colorimetry
- Measurement of wetting angle/measurement of interfacial energy
- Thermal analysis (DSC, TGA, TG-MS etc.)
- Spectroscopy (FTIR, UV-VIS)

Microscopy and preparation methods

We have comprehensive know-how in the preparation and microscopy of plastic samples, including:

- Crystallinity of polymers
- Visualization of cavities / pores, fiber impregnation
- Fiber and particle distribution in polymers
- Morphology of polymer blends
- Measurement of layer thickness of surface coatings

1 *Dynamic mechanical analysis (DMA) under tensile stress.*

2 *Series extraction e.g. to measure residual monomers.*

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FACILITIES AND EQUIPMENT

Fraunhofer ICT has cutting-edge facilities and equipment to meet the requirements of application-oriented research and development.

MATERIALS AND COMPOUNDING TECHNOLOGIES

- Various twin-screw extruders
  - Screw diameter: 16 – 40 mm
  - Processing section length: 36 – 60 D
- Various gravimetric feeders for the dosing of pellets, powders and flakes in the range of a few grams to more than 250 kilograms per hour
- Dosing technology for special processes
  - Dosing feeders for milled/cut fibers
  - Gas dosing station for nitrogen, hydrocarbon and carbon dioxide
  - Dosing systems for liquid and highly viscous media
  - Liquid dosing for suspensions of nanoparticles
- Safety facilities and extraction systems for working with nanomaterials and hazardous substances in the extruder
- Strand pelletizing, underwater pelletizing (also for the production of microgranules) and hot die pelletizing, variable use in all extruders
- Melt filter
- Various dryers for pellets
- Various vacuum pumps based on water rings or rotary vane technology for up to 1 mbar
- Mold technology for inline conductivity measurements
- Ultrasonic application in extrusion and injection molding
- Laboratory press for the production of test samples
- Analytical methods for dispersion conditions
- Measuring station for electrical surface and bulk conductivity
- Various additive production processes for the manufacture of thermoplastic prototypes and small series (AKF, FFF)
- Various testing units for filament production

FOAM TECHNOLOGIES

- Particle foaming technology
  - Two particle foam lines with twin-screw extruders and underwater pelletizing
  - Compounding technology for gas-loaded granules
  - Production technology for directly foamed particles
  - Prefoamers and pressure loading
  - Laboratory steam chest molding machine
  - Steam chest molding machine on an industrial scale with freely-programmable control
  - Radio-frequency-based laboratory-scale steam chest molding machine
  - Various mold geometries for components
- Foam extrusion
  - Tandem foam extruder for foamed semi-finished products, sheets, and foils
  - Two slot dies, one hole die, one annular gap die
  - Several gas dosing stations (two membrane pumps and a compressor station for liquid and gaseous blowing agents, HPLC pumps, etc.)
- Autoclave technology
  - 13 l autoclave
  - Dosing of various blowing agents


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INJECTION AND COMPRESSION MOLDING

- Compression molding technology
  - Parallel-operating, hydraulic compression molding machines for the processing of thermoplastic and thermoset fiber composites with clamping forces of 6,300 kN and 36,000 kN
  - LFT-D unit for material development, with a 6,300 kN press
  - Various production and sample molds for the manufacture of monolithic and hybrid structures
- Injection molding technology
  - Clamping force: 600 – 36,000 kN
  - Equipment suited to high processing temperatures
  - Specialized technologies: LFT-D-IM, FDC, TSG, MuCell®,
  - LFT-D foam, expansion foaming, multi-component injection molding, mono sandwich, counter-cycle injection molding, cascade injection molding, injection embossing
  - 7,000 kN injection-molding compounder with a 40 mm twin-screw extruder (48 D)
  - 5,500 kN injection molding unit with a fully-automated manufacturing cell for the processing of thermoplastic and thermoset polymers
  - 36,000 kN injection press with bolt-on injection molding units:
    - 80 mm FDC injection molding unit
    - 90 mm standard injection molding unit
  - Various production and sample molds with integrated sensor systems for process monitoring
- Hybrid technologies
  - 3D skeleton winding technology for the manufacture of complex reinforcing structures
  - Metal-plastics hybrids
  - Back-injection of laminates
- Heating technology: IR-heating panels, contact heating table, and various heating cabinets
- SMC technology
  - SMC production line with glass and carbon fiber wide cutting unit for a width of up to 1,600 mm
  - Vacuum unit for evacuating molds
  - Mixing laboratory with various dissolvers, twin-screw extruder
  - Measurement technology (Brookfield viscosimeter, plate-plate rheometer)
  - Testing technology (DSC, TGA, plastometer, qualisurf, mechanical testing, etc.)
  - Extrusion compression molding rheometer with in-mold pressure sensors
  - Various molds for testing and prototype production
- Polyurethane processing
  - PU-RIM technology
  - PU-fiber-spray technology

STRUCTURAL COMPOSITES

- Thermoplastic RIM/RTM processing
  - Melt preparation and dosing unit, 2-3 components
  - Pivoting mold carrier with a clamping force of 600 kN
  - Various test molds
- Thermoset RIM/RTM technology
  - High-pressure injection RTM process (HP-IRTM)
  - High-pressure compression RTM process (HP-CRTM)
  - Automated preform production technology
- Preform center
  - Fully-automated
  - Up to 3 different textiles for preparation on the cutting table
  - Integrated bindering
- Thermoplastic prepreg processes
  - Automated thermoplastic tape-laying process
  - Consolidation of laminates
  - Radiation-induced vacuum consolidation of laminates
  - Fully-automated production cell for the shaping of planar semi-finished products with a 3,600 t press
- Pultrusion
  - Pull-off force caterpillar haul-off 8t with up to 4 m/min
  - Max. profile width 300 mm

- 2K dosing unit for polyurethane systems
- Various tools for spar caps, rebars, U-shape, flat sections, etc.
- Adaptable impregnation and injection chambers
- Bobbin shelf for carbon fibers with 2 x 108 bobbins, bobbin shelf for glass fibers with up to 250 bobbins

MICROWAVE AND PLASMA TECHNOLOGY

- Microwave plants
  - Generators with an output of 1.2 to 50 kW at 915 MHz, 2.45 GHz, and up to 5.8 GHz
  - Directional coupler for impedance measurement, leakage radiation meters
  - Lab facilities for measurement of dielectric properties
  - Production technology for large-area and local resin curing
  - Pyrolysis unit for the recovery of carbon fibers from composites
  - Microwave-based sensors for process monitoring
- Plasma technology
  - Low-pressure area plasma, 500 x 1.000 mm application area 8 x 2 kW power
  - Low-pressure plasma system, 8 gas channels, ECR-plasma
  - 1,000 mm plasma length
- Simulation
  - FEM software for the solution of multiphysical tasks
  - Hardware with 512 GB RAM and 64 processor cores

MATERIAL CHARACTERIZATION AND FAILURE ANALYSIS

- Mechanical testing
  - Universal testing machines (50 kN and 5 kN) with fixtures for bending, tensile and compression testing, and optical and mechanical extensometry
  - Impact pendulum and drop weight impact test
  - HDT/Vicat device
  - Dynamic-mechanical analysis (DMA)
- Rheological characterization
  - High-pressure capillary viscometer
  - Rheotens® device for the measurement of extensional viscosity
  - Melt index testing device
  - Plate-plate viscosimeter
- Interface characterization
  - Contact angle measurement device
- Thermal analysis
  - Differential scanning calorimetry (DSC)
  - Thermogravimetry TG-MS, pyrolysis-GC-MS
  - Macro-TGA and microwave ashing to determine the fiber content
- Microscopy
  - Light microscopy (incident light and transmitted light), polarization
  - (Cryo-)microtome, grinding and polishing machines
  - White light interferometer
  - Scanning electron microscope with element analysis (SEM-EDX)
  - Fiber length measurement (FASEP®)
- Spectroscopy
  - FTIR with ATR attachment, IR microscope
  - UV-VIS and NIR
- Test stand for process-oriented determination of the compressive strength of polymer foams (e.g. RTM sandwich foams)
- Flame tests
- Thermal conductivity measurement

1 *Schaumtandex extrusion line.*

2 *High Pressure RTM process setup based on compression press and high pressure injection equipment for manufacturing high performance composites.*

3 *Fully automated injection molding machine to process free flowing thermoset materials and thermoplastic injection molding granules.*

4 *Fiberforge, fully automated machine for the placement of unidirectional fiber reinforced thermoplast tapes (UD-Tapes).*

POLYMER ENGINEERING
COMPETENCE IN POLYMER TECHNOLOGY

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