Fraunhofer
IGCV

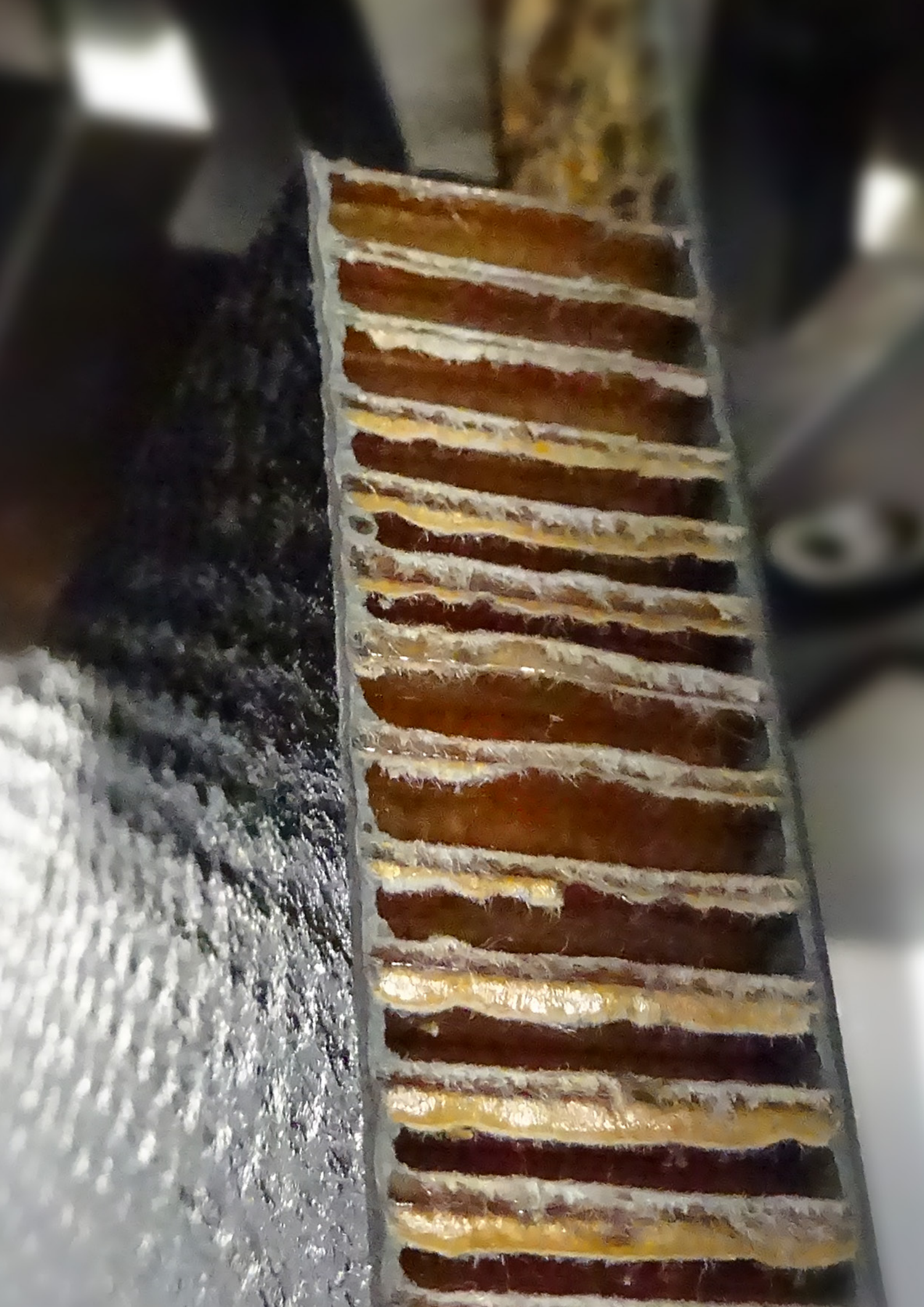
Fraunhofer Institute for Casting,
Composite and Processing
Technology IGCV

Testing Technology Portfolio

Standardized and individual material and component analysis

https://s.fhg.de/testing-technology

Contents



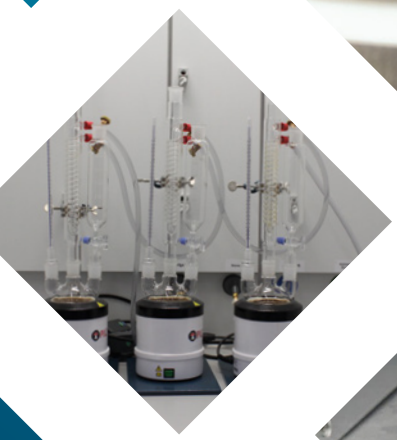
Our portfolio

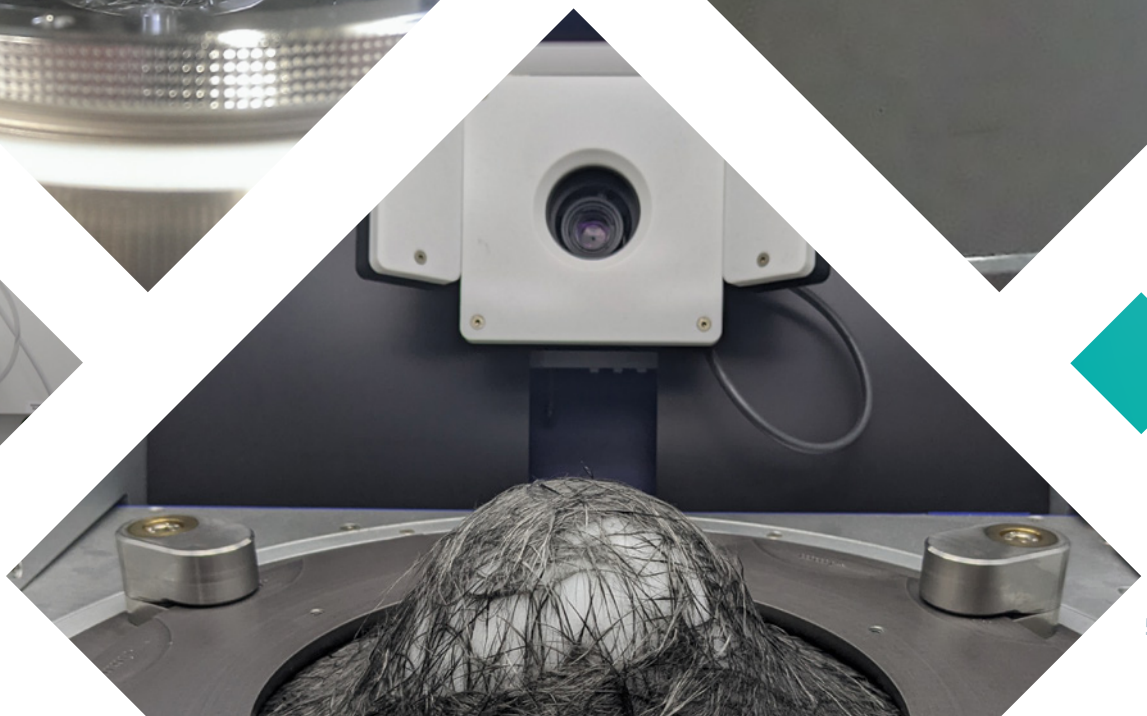
What we offer

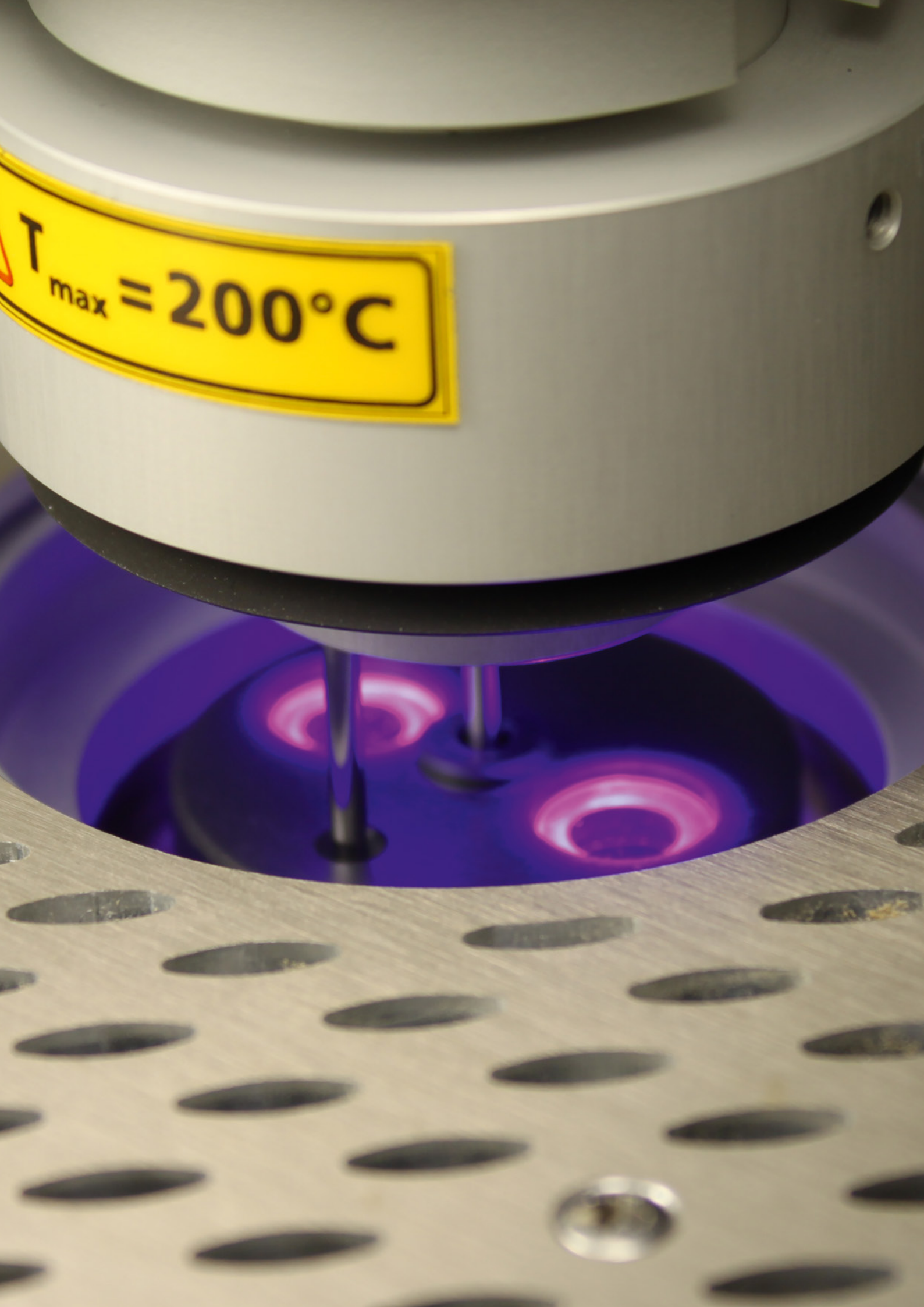
The main focus of testing technology at the IGCV is on identifying, characterizing and scientifically analyzing semi-finished products and components from various manufacturing processes as well as the materials used in these processes. The facilities and expertise have been, and continue to be, extended to other areas, such as technical cleanliness or the investigation of multi-material systems, metal alloys and core materials for sand and gravity die casting or materials used in additive manufacturing. The institute has numerous testing devices and methods to examine the materials and the resultant components. The material data obtained can be used

- for basic assessment of the suitability of the materials,
- for evaluation and optimization of processes and process parameters, as well as
- to develop new processes,
- to evaluate the finished component and
- as an input value for numerical simulations.

This brochure provides an overview of the testing technology equipment at the Fraunhofer IGCV with reference to the individual systems and specifications as well as their possible uses.






T max = 200°C

Thermal analysis

During the production, processing and application of the various materials, they are often subjected to temperature-related structural changes. These changes are characterized using different processes. Depending on the method, thermal transformations (DSC, DMA), changes in mechanical performance (DMA) or chemical reactions and decompositions (TG, DSC, DEA, FTIR) and changes in viscosity (rheometer, DEA) can be measured in relation to temperature, heating and cooling rate, deformation and atmosphere.

Dielectric analysis DEA (Netzsch DEA 288 Epsilon)

- Temperature range from –140 to 400 °C
- Frequency range: 1 mHz to 1 MHz
- Simultaneous measurement of eight sensors possible
- Nitrogen or air atmosphere

DEA is used to determine the dielectric properties of a material, such as permittivity, dissipation factor and ion viscosity. In the field of polymer materials, the curing process of thermosets or phase transitions in thermoplastics and elastomers can be observed down to the highly sensitive range of diffusion-controlled processes for material characterization. Using a variety of different sensors, investigations can be carried out on a laboratory scale or in the field of online process monitoring over a very wide frequency and temperature range. The combination of appropriate sensor technology with a high data recording rate also makes it possible to characterize fast-curing UV systems and carbon fiber composites in the laboratory and process,

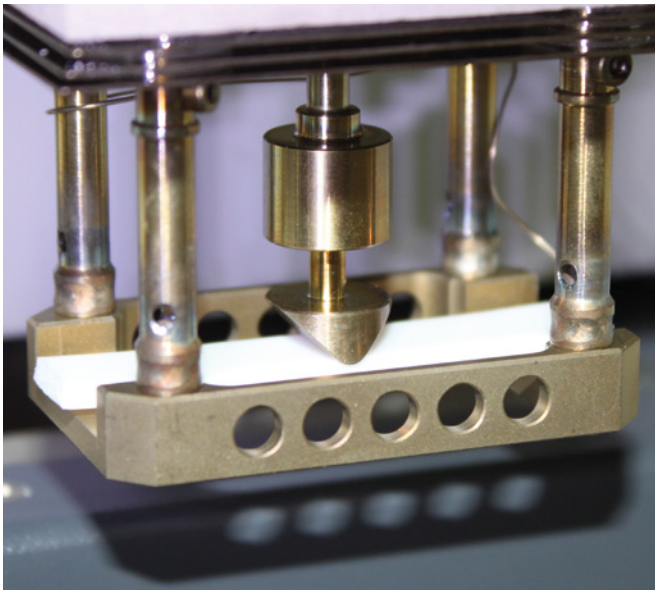
Differential scanning calorimetry DSC (Netzsch DSC 204 F1 Phoenix and DSC 214 Polyma)

- Heat flux principle
- Temperature range from –180 to 600 °C with up to 500 K/min
- Autosampler for up to 64 samples
- Nitrogen or air atmosphere
- Temperature-modulated measurements

DSC can be used to determine thermophysical and chemical characterization parameters such as transition temperatures and the enthalpy of melting, crystallization and reactions. It can also be used to determine the degree of crystallization and curing and to clarify the thermal history of materials. DSC can also be temperature-modulated (TMDSC) to differentiate between reversible and non-reversible effects, particularly with respect to thermal history. A unique feature is a second DSC system that can be operated at heating and cooling rates of up to 500 K/min. This makes it possible to simulate realistic working conditions, such as injection molding processes. Using a UV extension, it is possible to examine both thermally and photonically induced curing reactions. To do this, a high-pressure mercury lamp with a wavelength range of between 320 and 500 nm can be used, allowing up to 10 W/cm² to be transferred to the samples. This testing method presents an important means of investigating the UV-based curing of reactive resins.

Kinetic modeling can also be used to optimize the curing process of resin systems, for instance.

Left image: Differential scanning calorimetry (DSC)



Dynamic mechanical analysis (DMA)

Thermogravimetric analysis TGA (Netzsch TG 209 F1 Libra)

- Temperature range from RT to 1,100 °C
- Autosampler for up to 64 samples
- Nitrogen or air atmosphere (switchover possible during measurement process)

Thermogravimetry is primarily used to examine the decomposition behavior of material systems. The mass loss can be determined as a function of temperature and time. The temperature control allows for both dynamic and isothermal segments, which can be used to map processes and draw conclusions about the thermal resistance of the samples. TGA can also be used to determine the fiber volume content of fiber-reinforced plastics.

Dynamic mechanical analysis DMA (Netzsch DMA 242E Artemis)

- Temperature range from –170 to 600 °C
- Frequency range: 10 mHz to 100 Hz
- Maximum force 24 N

DMA is used to measure viscoelastic material properties such as storage and loss modulus as well as the dissipation factor tan (δ). This is carried out as a function of frequency and temperature under various stress modes. The measured variables can be used to characterize transition temperatures, which characterize the viscoelastic behavior, the damping of a system and the curing behavior of resins.

Rheometer (Anton Paar MCR 302)

- Temperature range from –10 to 450 °C
- Frequency range: 10^{-8} to 100 Hz
- Min. torque: Oscillation 0.5 nNm, rotation 1 nNm
- Max torque: 200 mNm

The rheometer can also be used to identify viscoelastic material properties, but in contrast to the DMA, the primary focus in this case is on pure resin samples and stress in the shear direction. This means that the shear viscosity can also be measured as a function of temperature and frequency. When combined with DEA, further observations can be made on the curing behavior of matrix systems. By combining with FTIR, it is also possible to obtain information about chemical bonding changes, e.g., during resin curing, and their effect on the viscoelastic properties of the material.

Thermomechanical analysis TMA (Netzsch TMA 402 F1 Hyperion)

- Temperature range from –150 to 1,000 °C
- Digital force resolution < 0.01 mN
- Measurements in vacuum or highly purified atmosphere
- Modulation of the force signal possible

Thermomechanical analysis is used to determine changes in the expansion of solids, liquids or pasty substances as a function of time and temperature. It can also be used to determine the creep behavior of materials. Frequent applications of this method include measuring the coefficient of thermal expansion, CTE and calculating the temperature-dependent density. TMA is suitable for all material classes.

Laser flash analysis LFA (Netzsch LFA 457)

- Temperature range from –125 to 1,100 °C
- Measurement range: 0.01 to 1,000 mm²/s
- Laser pulse energy up to 18 J/pulse

To measure thermal diffusivity, laser flash analysis uses a laser pulse to transfer energy into a sample. Using an infrared detector, the resulting temperature rise on the shadow side is measured and the thermal diffusivity is determined. If the specific heat capacity, expansion behavior and density are known, the thermal conductivity can be calculated. All the above data can be obtained on site.

Simultaneous thermal analysis (Netzsch STA 449 F3 Jupiter)

- Temperature range from RT to 1,500 °C
- Heating/cooling rates from 0.001 to 50 K/min
- Atmospheres: Vacuum, inert, oxidizing
- Temperature resolution 0.001 K
- Mass resolution: 0.1 µg
- DSC enthalpy accuracy: ±2%

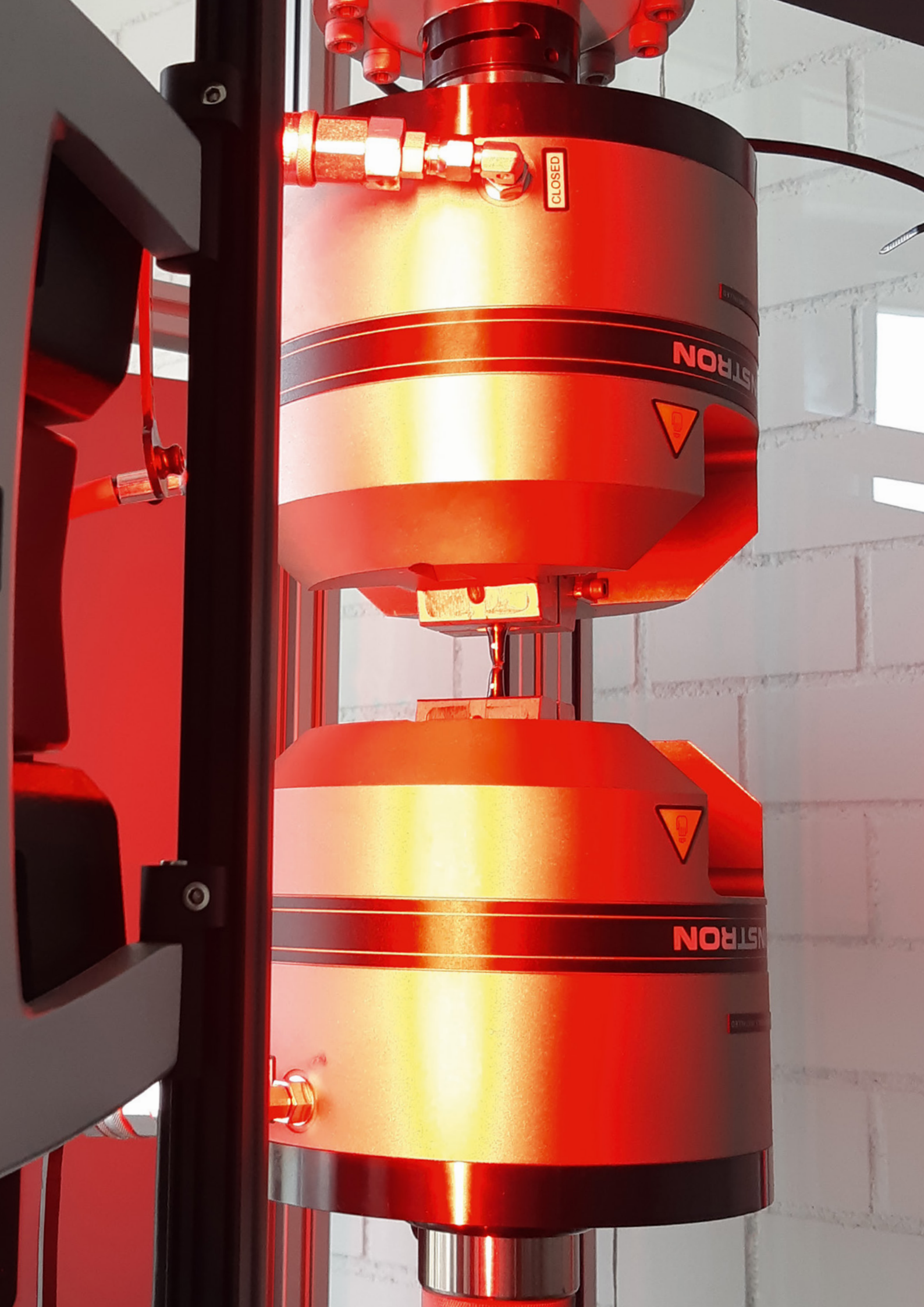
STA enables the parallel measurement of thermogravimetry and differential scanning calorimetry. Due to the larger temperature range of up to 1,500 °C compared to standard DSC, further thermal effects can be observed. Mass changes during the reactions can also be attributed to the DSC curve via the parallel TG analysis.

Thermoanalysis/density index (mk — ALSP highline-2G)

- Preparation of density index samples (approx. 80 g) from molten aluminum under a defined vacuum (80 mbar)
- Density index measurement according to the Archimedean principle
- Preheating the crucible to 200 °C

The mobile device can be used to record cooling curves of molten metals and determine specific characteristic values in order to assess the melt quality of aluminum-silicon (Al-Si) alloys. In order to ascertain the density index, one sample is solidified in air and the other under vacuum. The subsequent difference in density between the two samples provides a measure of the purity of the melt. In addition, thermal analysis can be used to record grain refinement, H_2 content and modification as well as the temperature profile during the solidification process.

Simultaneous thermal analysis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Mechanical tests

Whether for determining the suitability of a particular material, defining process parameters or generating material data to be used in simulations, destructive testing of materials remains essential in all cases. Mechanical material testing comprises various test processes that are used to determine the behavior and material characteristics of standardized material samples (material analysis) or finished components (component testing) under mechanical (and thermal) stress. Fraunhofer IGCV offers a wide range of mechanical tests on molding compounds, semi-finished products and products made of plastic, fiber composites and metal as well as various material combinations. A number of different systems are used for quasi-static and dynamic testing. In addition to standardized tests, the test engineering team also designs and implements devices for specific tests. This means that application-oriented conditions can be taken into account directly when studying the behavior of the material.

Universal testing machine 250 kN (Hegewald and Peschke)

- Load cells: 10 kN, 250 kN
- Testing speeds: 0.002 to 450 mm/min
- Testing temperature: –40 to 200 °C
- Tensile test
- Compression test (CLC, OHC, CAI, HCCF)
- 3-point and 4-point flexure test
- Shear test in accordance with DIN EN ISO 20337

A 250 kN universal testing machine is used to establish mechanical parameters at a standard climate and at different temperatures in the high force range. Strain can be measured using strain gages as well as optical processes such as video extensometers or digital image correlation. This also allows testers to determine the transversal contraction during mechanical strain.

Universal testing machine 100 kN (Zwick/Roell)

- Load cells: 100 kN, 10 kN, 5 kN, 100 N
- Hydraulic grips for short clamping lengths (max. 70 kN)
- Testing speeds: 0.0005 to 1,000 mm/min
- Tensile test
- Shear test
- 3-point and 4-point flexure test
- Compression test
- ILSS (interlaminar shear strength)
- Peel tests

With this universal testing machine, various quasi-static tests can be carried out at room temperature (RT) to determine mechanical parameters. The elongation is recorded using optical measuring systems.

Universal testing machine 50 kN (Zwick/Roell)

- Load cells: 50 kN, 10 kN, 1 kN, 100 N
- Testing speeds: 0.0005 to 600 mm/min
- Testing temperature: –40 to 250 °C
- Tensile test
- 3-point and 4-point flexure test
- Shear test (Iosipescu)
- ILSS (interlaminar shear strength)
- GIC and GIIC

A higher measuring accuracy at low force ranges can be achieved using the 50 kN universal testing machine. Mechanical tests with a temperature range of –80 to 250 °C can also be carried out here using a temperature chamber. In addition, strain gages and optical measurement systems for strain recording can be implemented, as well as the use of physical extensometers.

Left image: High cycle fatigue test

Universal testing machine 20 kN RetroLine (Zwick/Roell)

- Load cell: 20 kN
- Testing speeds: 0.001 to 750 mm/min
- Tensile test
- 3-point bend
- Compression test

The 20 kN RetroLine universal testing machine can be used to determine the mechanical properties of molded materials. The focus here is on flexure and compression testing. Flexural strengths of molded materials are often recorded using 3-point testing on bending bars while compression strengths are recorded using a uniaxial pressure test on cylindrical specimens. The adaptation of optical measurement systems for strain recording and the implementation of physical extensometers is possible after retrofitting.

Servohydraulic testing machine (Instron)

- Force: 100 kN or 10 kN
- Temperature range: –70 to 300 °C
- Piston stroke: ±125 mm
- Mechanical and hydraulic wedge action grips

In cyclic (dynamic) tests, the load is altered at certain time intervals. In this way, the influence that the load has on material fatigue is simulated. A servohydraulic testing machine assists the testing laboratory in determining the high cycle fatigue of components or creating so-called S-N curves. Cyclic loads can be applied to the specimen in the tensile and compression directions as well as flexural pulsating loads. Strain measurement can be carried out using a video extensometer, mechanical strain extensometers or strain gages. All tests are also possible at temperatures from –70 to 300 °C.

Hardness tester (Zwick Roell ZHU 2.5)

- Hardness testing by calculating the depth of indenter penetration
- Calculation of hardness by optical measurement of the indentation diameter
- Vickers and Brinell hardness tests
- Ball indentation hardness test (plastics)
- Martens hardness test (DIN EN ISO 14577-1)

A penetration test is carried out to determine the hardness of the material. As well as classic hardness testing methods such as Brinell/Vickers and ball indentation, a hardness test to Martens can also be carried out. It is possible to determine, for example, the case hardness depth or the nitriding hardness depth using low load hardness testing. Cyclic tests with variable parameters can also be implemented.

Hardness tester (NEXUS 8103)

- Hardness testing by calculating the depth of indenter penetration
- Calculation of hardness through optical measurement of the indentation diameter
- Hardness tests to Rockwell, Vickers and Brinell
- Load range 5 to 3,000 kg

A penetration test is carried out to determine the hardness of metallic materials in accordance with standards. The hardness is determined using the Rockwell, Vickers or Brinell methods. The load range of this hardness testing machine is from 5 to 3,000 kg.

Single fiber tensile tester (Textechno Favimat+)

- Force: 220 cN
- Resolution: 0.0001 cN
- Fiber length: min. 3 mm
- Automated calibration

Textechno Favimat is used to calculate the tensile strength and strain at break as well as the fracture stress of single fibers. The modulus of elasticity of single fibers can also be determined. By measuring the resonance frequency of the fibers, their diameter can be calculated. The device can also be used to determine the coefficient of friction of the fiber.

Single-fiber pull-out tester (Textechno Fimabond)

- Thermoplastic and thermoset systems possible
- Alignment of the fiber in the matrix via a camera
- Embedding crucible can be heated to up to 400 °C
- N_2 or air atmosphere during embedding

One of the most important properties for a fiber composite material is the fiber matrix adhesion. One way of classifying this is to carry out a pull-out test. Using a semi-automated embedding system, a fiber is embedded in the corresponding matrix material at an adjustable depth. After curing and optional tempering, the fiber is extracted from the matrix and the force required for this is continuously measured and recorded.

Hardness testing

Impact test bench (Instron CEAST 9350)

- Drop weight with max. 30 kg mass
- Drop speed up to 24 m/s
- Energy range: 1.47 to 1,347 J
- Temperature range: –70 to +150 °C
- Standardized CAI pre-damaging

The drop tower is used to examine the energy absorption behavior of materials, construction methods, components and structures. The basic function of the drop tower is to transport a specified weight to a height level where it is released or accelerated in a controlled manner and dropped along a linear guide onto a test specimen. The resultant short-term impact makes it possible to assess how energy is absorbed by the specimen in the event of a crash, for example, and which crash signals are generated. The system is suited for impact tests on plastics, composites and other materials. The test bench can also be used for pre-damaging for compression-after-impact measurements. A Charpy device and a grooved table can be used for further impact tests.

Drape test bench (Textechno Drapetest)

- Round specimens with a diameter of max = 330 mm
- Piston stroke max. 100 mm
- Various forming geometries

A drape test bench is used to test the forming behavior of dry semi-finished textile products. For this purpose, a pressure bulkhead is moved from underneath against a fixed textile in order to observe the involved forming phenomena. This makes it possible to simulate the formation and thickness of folds, creases and crease lines, thin and thick areas and shearing. The test provides information about the required forming forces during the draping process and helps to optimize the orientation of the individual layers.

GOM ATOS line scanner (for measuring components)

Optical measuring system for component digitization (GOM ATOS)

- Resolution: 2 × 5 MP
- Measuring range: approx. 300 × 230 mm, can be extended by overlapping images
- Self-monitoring in terms of calibration errors and references
- Measurement of components

A GOM ATOS measuring system is used for 3D digitizing and inspection of small to medium-sized components. This enables both a comparison with the CAD model and verification of the dimensional accuracy of specimens. The high-precision optical coordinate measuring device achieves a spatial resolution in the µm range for measurements with a simple measuring field.

Digital image correlation (GOM ARAMIS)

- Camera system with 2 × 12 MP
- Frame rate 58 Hz (full screen) to 464 Hz (reduced resolution)
- Various interfaces for connecting to external devices

An optical measuring system (GOM ARAMIS) is available to record displacements, strains and shears in three dimensions. This can be used to monitor individual pixels or a stochastic pattern on the specimen surface during deformation. Optical observation can be used in place of strain gages and mechanical extensometers for many mechanical tests.

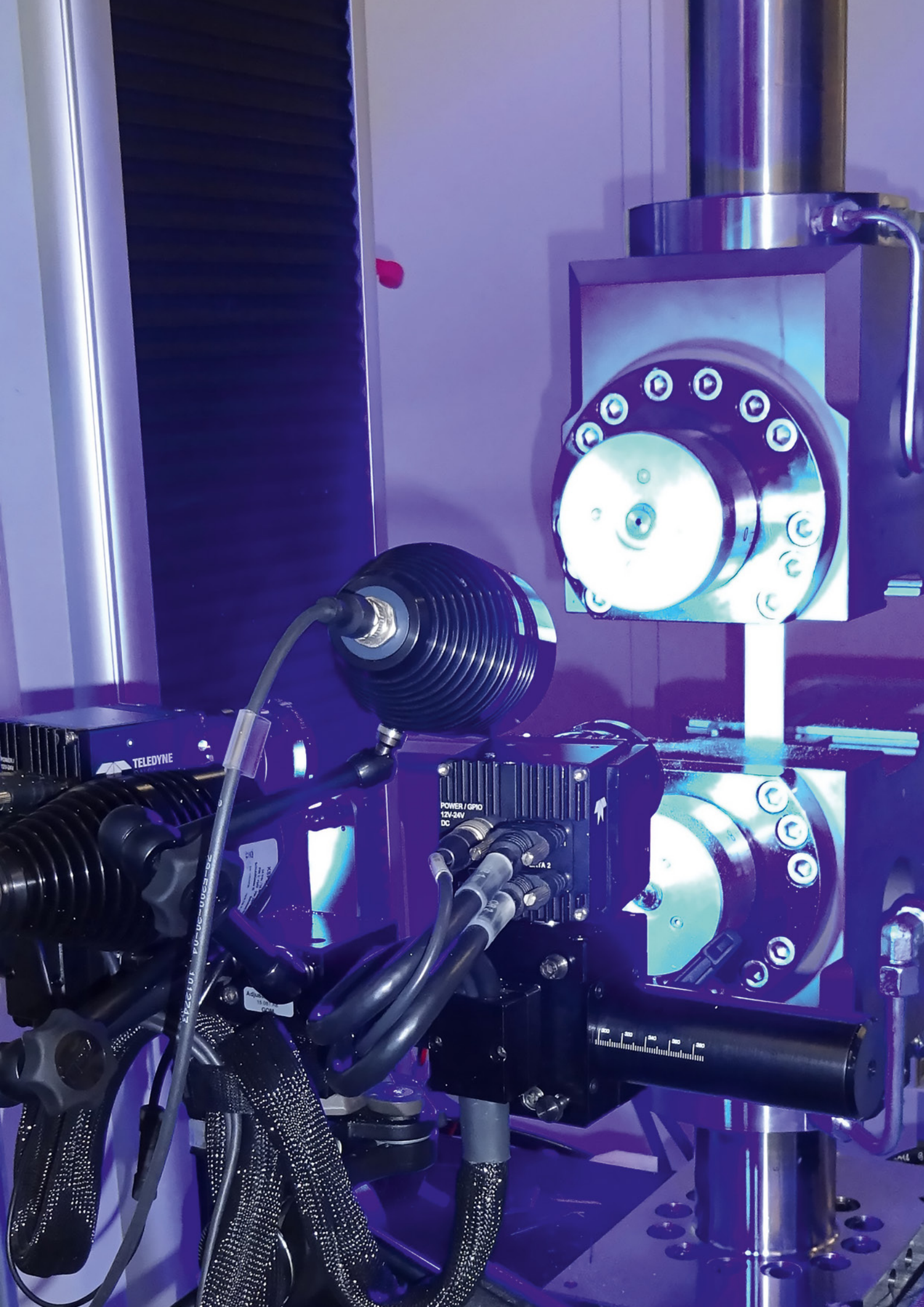
High-speed camera (Photron SA-Z)

- Max. resolution 1,024 × 1,024 pixels
- Frame rate from 20,000 (full resolution) to 2,000,000 FPS (reduced resolution)
- 128 GB internal memory
- Measurement videos as .avi or single images

The high-speed camera, which can also be used as a high-speed extensometer together with the ARAMIS system, provides additional insights into fracture behavior. Thanks to the mobility of the camera, it can be used on all test benches to investigate highly dynamic processes, such as the vibration behavior of test specimens shortly before fracturing.

High-speed camera

Right image: Strain measurement during tensile tests using the digital image correlation system GOM ARAMIS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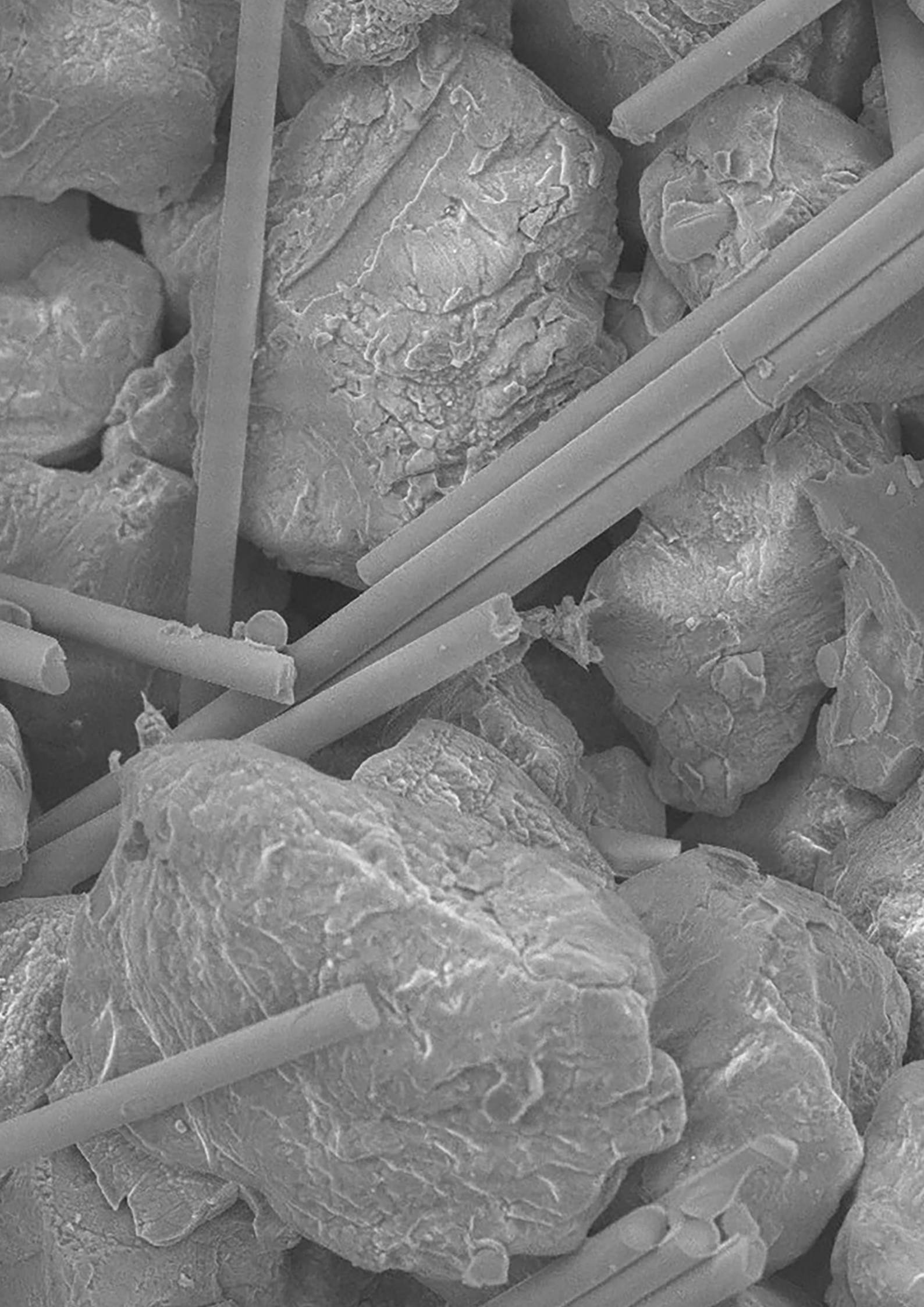
POWER / GPIO
12V-24V
DC



Optical analysis

A wide range of test methods are available for microscopic and macroscopic examinations. From pure component photography using stereo, transmitted and reflected light microscopy to laser scanning and atomic force microscopy, magnifications down to the nanometer scale are possible.

Scanning Electron Microscope (SEM) (Hitachi TM3030Plus) with Energy Dispersive X-Ray Spectroscopy (EDX) (Bruker Scan Generator, Bruker XFlash MIN SVE)

- Magnification: 15× to 60,000×
- View: 5 kV / 15 kV / EDX
- Secondary electrons (surface morphology) and backscattered electrons (phase differentiation)
- Examination of components and powder materials

The scanning electron microscope (SEM) is used to examine the surface morphology or phases of specimens using electron beams. This results in high depths of field of up to 35 µm, so that spatial structures can be identified. This is essential for imaging powder particles, fracture surfaces or microstructures, for example. When examining the surface of the specimen, secondary electrons, i.e., the electrons emitted from the exposed specimen, are primarily used, as the probability of them being emitted depends on the morphology of the specimen. The backscattered electrons (reflected primary beam electrons), on the other hand, allow different phases to be distinguished by their different brightness levels, which increase as the atomic number increases.

The device also includes an apparatus for energy dispersive X-ray spectroscopy (EDX). Based on the intensity of X-rays measured by EDX, conclusions can be drawn about the proportions and distribution of chemical elements in the examined point by checking the corresponding wavelengths. This means that it is possible to examine sections, powder particles or component surfaces, for example, to determine their chemical composition.

Atomic force microscope/AFM (Bruker Dimension Icon)

- Atomic resolution in contact mode
- Resolution in tapping mode up to 30 nm
- Analysis of various samples using a large selection of cantilevers and modes
- Quick and easy sample preparation and analysis

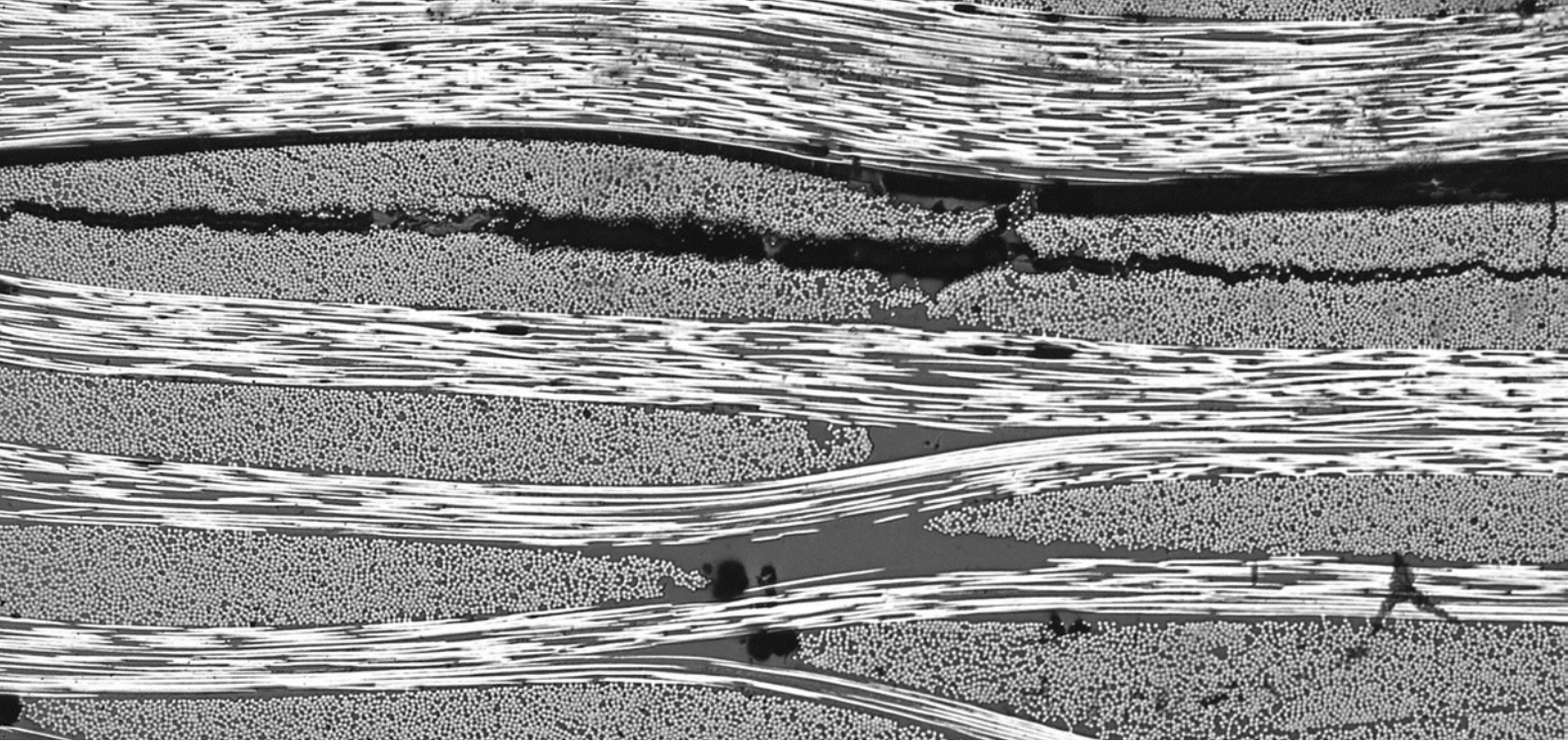
An atomic force microscope is used for microscopic examination down to nanometer level. This allows for a much more detailed surface topography than with regular microscopes. It is also possible to determine local stiffness and hardness using force-strain curves. The sensitivity of the AFM also makes it possible to carry out phase detection and calculate adhesion coefficients.

Particle microscope (Jomesa HFD4)

- Zoom stereomicroscopy
- 18× optical magnification
- Resolution range from 8 µm/pxl to less than 1 µm/pxl
- LED ring light illumination with polarization unit
- Motorized X-Y table
- Evaluation in accordance with ISO 16232 and VDA Volume 19

The microscope has been developed specifically to meet the requirements of cleanliness testing and enables quick and precise particle analyses. In addition, metallic and non-metallic particles on filter membranes can be detected and automatically assessed according to different standards. It is also possible to analyze transparent filter membranes, which means that white particles (e.g., ceramics) can also be detected.

Left image: SEM images of sand with glass fibers



Transverse sections through a sample made of CFRP

Laser scanner for fluorescence analysis (Fraunhofer IPM)

- Imaging measurement of the fluorescence of filmic contamination
- Laser spot/resolution approx. 300 µm
- Measurement surface 50 × 50 cm
- Measurement of layer thicknesses
- Localization of contamination
- Layer thickness measurement to approx. 1 µm

Organic contamination such as oil or grease on the surface of components fluoresce when exposed to UV light. This enables the laser scanner to measure such contaminants on the surface of components. The UV laser scans the entire surface of components and detects the emitted fluorescence in real time, identifying the layer thickness and position of contaminants.

Active thermography (Edevis GmbH)

- Detection of irregularities or defects close to the surface
- Detection of particulate and filmic contamination
- Nondestructive component testing
- Various excitation sources (e.g., flash, halogen lamps, ultrasound, laser) for pulse or lock-in thermography
- Maximum resolution 10 µm (depending on the test setup)

Nondestructive testing of components for irregularities or defects near the surface. Depending on the type of excitation, different component defects can be detected. Examples of applications include the detection of impact damage or delamination on CFRP components or particle detection on battery electrodes.

Light microscopy (Leica M80 and Leica DM 4000M)

- Reflected/transmitted light microscope: up to 1,000× magnification, with camera attachment, motorized focus, LED illumination
- Stereo microscope: up to 60× magnification, camera attachment, eight zoom levels

Transmitted, reflected and stereo microscopes are available. Both are used to examine microsections in which the material structure, element distribution and spherulite sizes can be determined. It is also possible to obtain information on pore content, layer structures and layer thicknesses.

Digital microscope (Keyence VHX-6000)

- Particle analysis in accordance with VDA 19 or ISO 16232
- Lateral view of complex geometries using a swivel lens
- 3D view of particle sizes and morphology
- Resolution up to 1 µm
- Reflected/transmitted light microscope: up to 1,000× magnification, motorized focus
- Motorized X, Y and Z axes for composite 3D imaging
- Bright/dark field illumination, polarization filtration, grazing light
- Detachable lens for analyzing large components

In addition to the vertical view, the microscope also offers the option of examining objects from the side using a swivel lens, a particular advantage when examining complex components. It can also be used to automatically classify particles according to their type, size and distribution across analysis membranes.

Motorized light microscope (Olympus BX53M)

- Bright field, dark field, DICpol, transmitted, polarization
- Magnifications available: 25×, 50×, 100×, 200×, 1,000×
- 200× with greater working distance for use with heating chamber
- Composite images in x-y direction
- Images with depth of field and height profile
- Combined images in x-y direction with depth of field and height profile
- "Count and measure" module
- Automatic analysis modules for layer thicknesses, grain sizes and phases

The motorized light microscope is mainly used for metallographic and material science examinations. Magnifications of up to 1,000× are possible, allowing even fine precipitates and structures to be resolved and examined in the plane. Motorization in all axial directions means that composite images can be created in the x-y direction with a certain degree of depth of field and qualitative height profile. As well as the standard operating elements, the software contains additional evaluation modules. The integrated "count and measure" module opens up a wide range of evaluation options (e.g., particle size distribution, quantity, shape). Modules used to efficiently analyze layer thicknesses, particle sizes and phase distribution are also implemented.

Confocal laser scanning microscopy/LSM (Olympus LEXT OLS 4100)

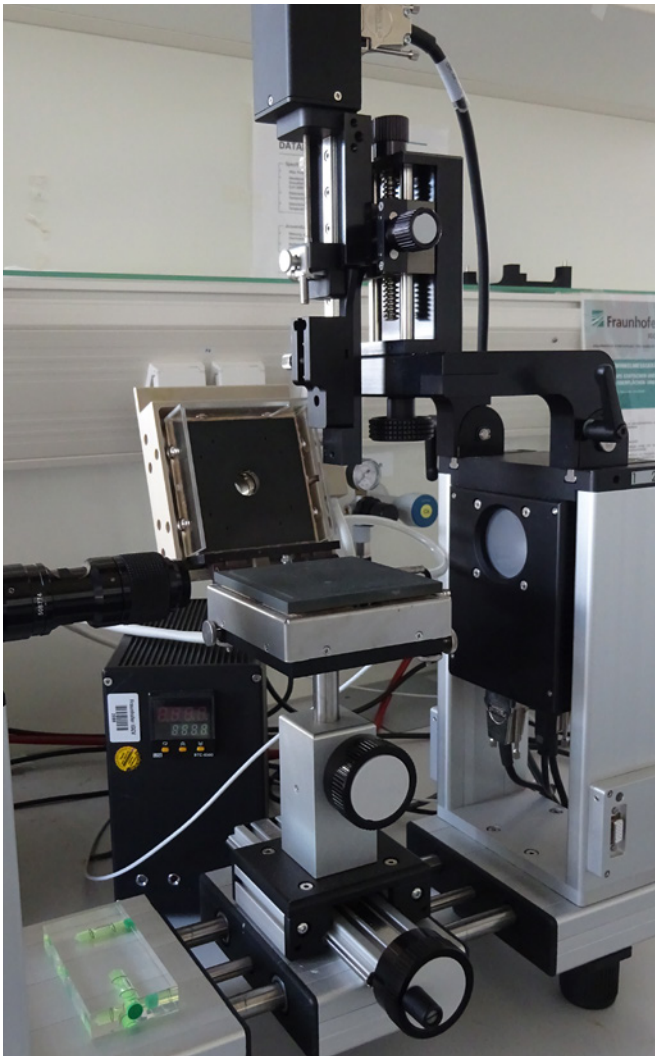
- Height resolution 10 nm
- Edge steepness can be measured artefact-free up to 85°
- Automated nosepiece

Surfaces can be resolved down to 10 nm using the laser scanning microscope. As well as imaging the surface topography, these microprofile measurements can be used to accurately determine levels of roughness thanks to the 4 µm focal point of the laser beam. Particle and surface measurements can also be carried out.

3D laser scanning microscope (Keyence VK-X3000)

- Field of view: 11 to 7,398 µm
- Total magnification: 42× to 28,800×

This laser microscope can be used to carry out surface and line roughness measurements in accordance with different standards by means of automatic roughness analyses. The device also provides the option of high-precision imaging of the surface topologies of a wide range of materials.



Contact angle analyzer

Microscope heating chamber (Linkam TS-1500)

- Use with Olympus BX53M light microscope
- Water-cooled heating chamber up to 1,500 °C
- Internal dimensions of the furnace: D = 7 mm, h = 6 mm
- Supply of (inert) gas possible

The heating chamber along with the associated accessories can be used as an extension to the Olympus BX53M light microscope. It enables microscopic observation of small samples at temperatures of up to 1,500 °C using a special lens and a light filter in the light microscope at high temperatures. This enables, for example, analysis of metallic samples during small-scale heat treatment or analysis of binder samples under high temperatures. The heating chamber can also be operated in an inert gas atmosphere.

Contact angle analyzer (Dataphysics)

- Temperature range from RT to 400 °C
- High-speed camera with 200 FPS and a resolution of 780 × 120 pixels
- Measuring range for surface/interfacial tension: 0.001 to 2,000 mN/m

A contact angle analzer is used for the nondestructive assessment of the wettability of fibers and their semi-finished products with different matrix systems. This involves measuring the contact angle of horizontal droplets and contour analysis of hanging droplets. This enables calculation of surface and interfacial tensions as well as spreading coefficients, which play a large role in infiltration processes, for instance. The roughness of the surface and the relaxation behavior at phase boundaries can also be analyzed. In order to be able to identify these properties near-process conditions, it is possible to heat the test materials up to 400 °C in a temperature chamber.

Mobile contact angle analyzer (Krüss Mobile Surface Analyzer)

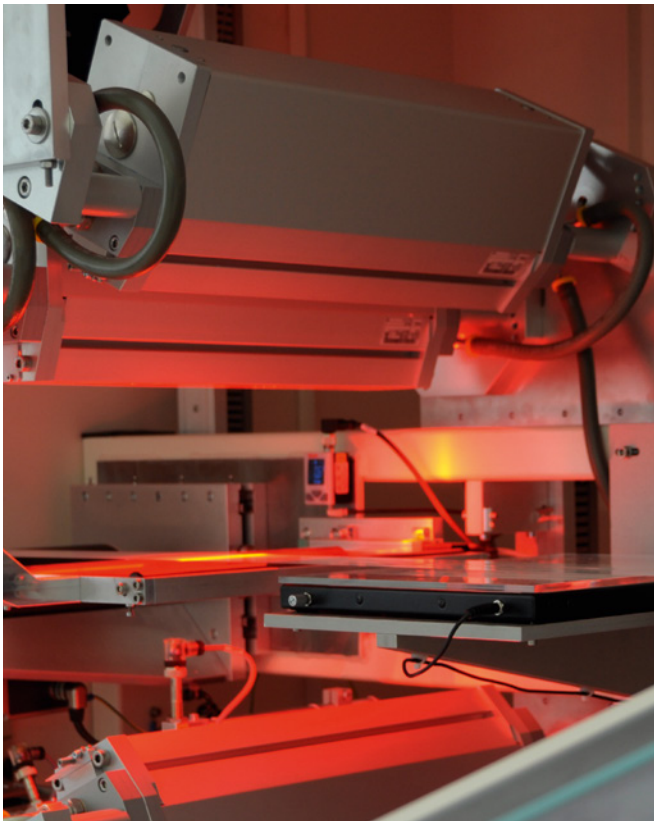
- Analysis of component wettability
- Faster detection of surface cleanliness
- Mobile and fast deployment for the customer
- Calculation of available surface energy
- Calculation of surface polarity

The Mobile Surface Analyzer (MSA) is suited to carrying out nondestructive quality control directly on the production line thanks to its light weight and easy operation via a mobile notebook. Measurements can even take place from above and are therefore also suitable for large components that cannot be moved.

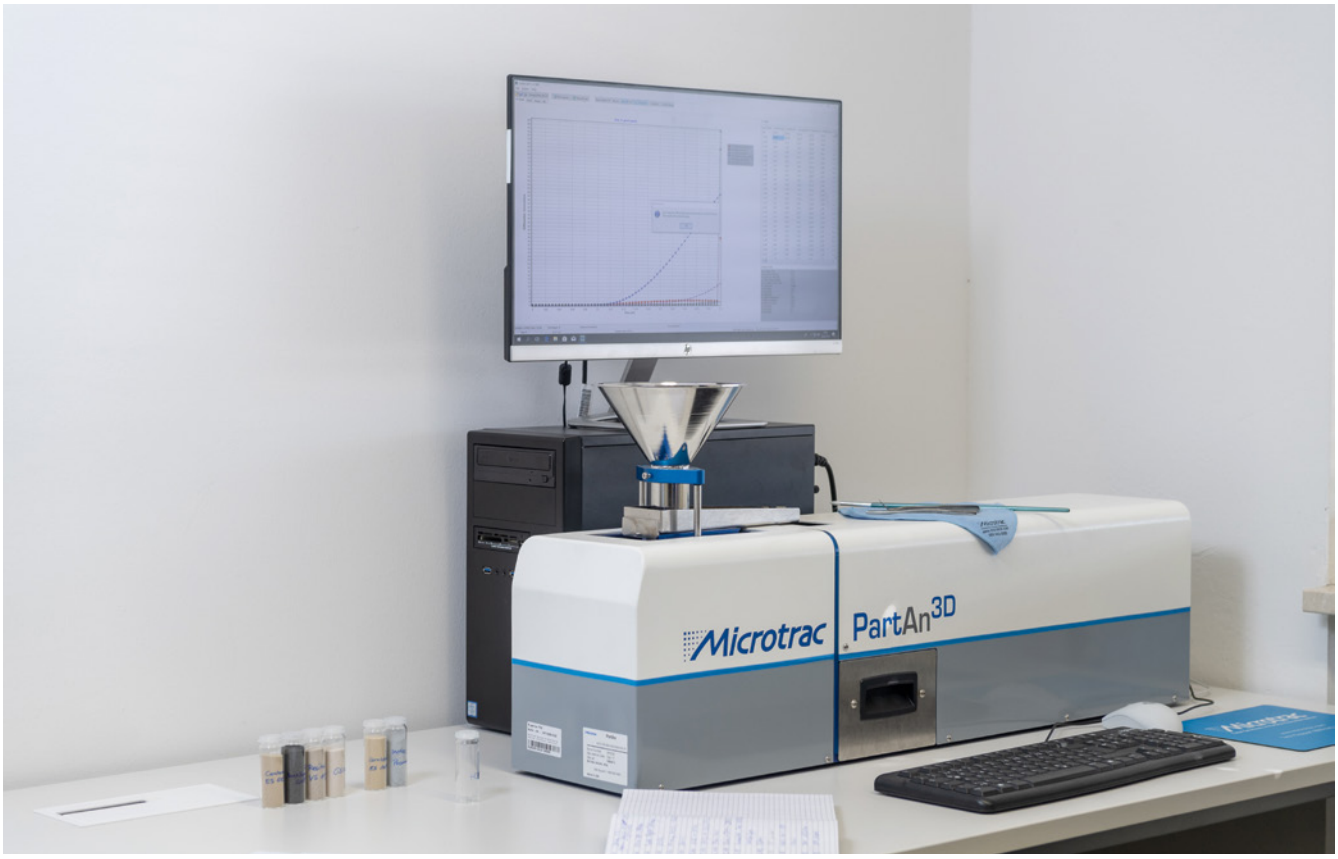
Separator testing (Dr. Schenk)

- Separator testing using a high-resolution line scan camera
- Roll-to-roll process for integrated control of input quality
- Simultaneous recording of four lighting configurations for an optimal data base
- Quality assessment/benchmark of battery separators as purchased parts

With this test bench, battery separators can be tested for production defects through indirect visual inspection using line scan cameras. Four lighting configurations provide the optimal data base for evaluating the defects found using online classification based on machine learning processes.



Separator testing



Particle analyzer

Laser diffraction particle size analyzer (Malvern Panalytical Mastersizer 3000E)

- Particle sizes: 0.1 to 1,000 µm
- Measuring accuracy higher than 0.6%
- Wet measurements possible in various mediums

Particle size distribution (PSD) has a major effect on the powder properties and therefore the ability to process powder materials in powder bed-based additive manufacturing processes: PSD impacts various characteristics, including flow properties, powder bed density, agglomeration and the tendency to form aerosols. For this reason, particle size distribution is examined before introducing a new powder material, for example. Laser light scattering is used as the measurement principle: In this process, after a laser beam has hit a particle, the resulting angle-dependent scattered light intensity is measured. The particle size distribution can be calculated from the angle-dependent scattered light data. This makes it possible, for example, to compare different powder batches or check the PSD of special atomizations. In the field of technical cleanliness, particulate contaminants can be analysed and characterized in this way.

Particle analyzer (Microtrac PartAn 3D)

- High-speed camera with 100 FPS
- Particle sizes from 30 µm to 35 mm
- Measurement of more than 30 morphological parameters

A large number of morphological parameters can be analyzed using non-contact measurement of dry parameters. This includes a 3D depiction of these parameters. A high-resolution, high-speed camera can be used to measure size, shape, surface roughness parameters, surface tension and transparency as part of a single analysis. This enables a quick and reliable assessment of the product quality. The device is best suited for free-flowing granulates/powders > 50 µm.

Chemical analysis

It is particularly important to analyze the emissions and decomposition residues of materials in order to investigate their ecological impact. Thermogravimetry is used primarily for thermal decomposition, whereby the gases produced are analyzed using infrared spectroscopy. It is also possible to determine the environmental influences of processes and process parameters and to analyze contaminants.

Infrared spectroscopy FTIR (Bruker Vertex 70)

- Wave number range: 8,000 to 600 cm^{-1}
- Up to 15 spectra per second
- Temperature range: RT up to 300 °C

Fourier transform infrared spectroscopy is used for qualitative element analysis. The samples can be either liquids or solids. The analysis of gaseous samples is also possible in conjunction with thermogravimetric analysis. This allows studies to be carried out on chemical bonding states and their changes under reactive chemically or thermally induced effects. It is also possible to observe processes that occur during physical changes of state in the areas of rheology, thermophysical analysis or mechanical testing.

ON/H performance oxygen, nitrogen and hydrogen analyzer (Bruker G8 Galileo ON/H High Performance Oxygen, Nitrogen and Hydrogen Analyzer)

- Determination of oxygen, nitrogen and hydrogen
- Can be heated up to 3,000 °C
- Helium or nitrogen atmosphere
- Highly stable detection system with NDIR and thermal conductivity detectors

The proportions of oxygen, nitrogen and hydrogen in alloys often have an influence on component properties, e.g., in aluminum, copper or titanium alloys. The Bruker G8 Galileo ON/H analyzer is used in our powder laboratory to determine oxygen, nitrogen and hydrogen in powders by melting the sample through carrier gas melt extraction and automatically checking the resulting measuring gases. In this way, conclusions can be drawn about the influence of storage, multiple use and corrosion of various powder materials, for example.

Zeta potential analysis (Anton Paar SurPASS 3)

- Streaming potential: ±2,000 mV
- Streaming current: ±2 mA
- Temperature range: 20 to 40 °C
- pH range: 1 to 14
- Sample size: 35 × 15 mm; thickness 40 mm for plates and film
- Particle size: > 25 µm for powder

The device can be used for routine surface analysis with fully automatic zeta potential measurements on macroscopic solids under realistic conditions. The zeta potential is related to the surface charge at the solid-liquid interface and is a key parameter for understanding surface properties and developing new specialized materials. The development of the zeta potential curve over a pH range and the isoelectric point provide information about the electrical charges on the surface of solids, which can be used, for example, to assess the stability of dispersions.

Optical emission spectrometer OES (Hitachi Foundry Master Pro2)

- Chemical spectral analysis of metallic samples
- Wavelength range 130 to 780 nm
- Resolution
  - up to approx. 10^{-4}% by weight, depending on the element and proportion in the alloy
  - Measuring range for each element depending on the selected measuring program
- Matrices:
  - Iron incl. 6 sub-programs each (iron and various steel groups, cast iron)
  - Aluminum incl. 6 sub-programs each (aluminum, various casting alloy groups)
  - Additions possible
- Measurements under argon atmosphere

The chemical analysis of metals using optical emission spectrometers (OES) is a standard method in practically every foundry. Using OES, it is possible to instantly and accurately analyze the chemical composition of metallic (cast) materials, facilitating the adjustment of the melt composition and subsequent quality control. It is also suitable for incoming metal inspection. When molten metal is removed from the melting furnace, it is poured into a special casting mold (die) where it quickly solidifies. The solidified samples, as well as metal samples taken elsewhere, must only have a flat surface that is free of contaminants such as oil, grease or solvents. They are usually ground or milled for this purpose. During the measurement process, a small area of the sample is melted and vaporized by the electric arc in the spark chamber. The light emitted is then analyzed, and the chemical composition is determined by comparing it with calibrated measurement curves. Currently, two material groups (aluminum, iron) can be analyzed with the device. It is possible to add copper, nickel and other metal bases.

Spectrometer (Aryelle 200 and Ocean Flame)

- Detection of the specific emission spectra of solid, liquid and gaseous samples
- UV/VIS spectrometer: 200 to 700 nm (Aryelle 200) or 200 to 850 nm (Ocean Flame)
- High spectral resolution
- Element assignment of spectral lines via NIST database

Detection of specific emission spectra of solid, liquid and gaseous samples. The recorded specific spectral lines can then be assigned to elements via a database comparison enabling statements on the material composition.

Melting analysis with an emission spectrometer

Physical-technological tests

In addition to the individual test methods in the separate subject areas, the Fraunhofer IGCV test laboratories also offer and carry out various comprehensive tests specifically for fiber composites.

Wet chemical analysis of fiber volume content

- Test in accordance with DIN EN 2564
- Sample size approx. 1 × 1 cm
- Determination of fiber volume ratio and pore content possible

To determine the fiber volume ratio, the polymer matrices of the specimens are decomposed in concentrated, boiling sulfuric acid by adding hydrogen peroxide. After filtration, cleaning and drying, the mass of the remaining glass or carbon fibers is determined. The fiber volume ratio is calculated using this value and the density of the test specimens.

Infrared moisture analyzer (Sartorius MA 100)

- Heating source: Halogen lamp
- Readability: 0.1 mg, 0.001%
- Weighing capacity max: 100 g
- Accuracy of the weighing system: 0.1 mg
- Temperature range and setting: 30 to 180 °C in 1 degree increments

Powder materials can be stored throughout the year at varying temperatures and different levels of relative humidity. The condensation that occurs as a result can affect the flow properties or chemical composition of powders. An infrared moisture meter is used to measure the moisture present, e.g., during quality control in the incoming goods department. The MA 100 IR moisture analyzer available in the powder laboratory has the highest possible measuring accuracy of any of the existing thermogravimetric moisture analyzers and can determine the moisture content of powders.

The device has a wide range of functions and is highly versatile so that it can be adapted to frequently changing sample materials or changing measurement requirements.

Gas pycnometer (Quantachrome Ultrapyc 1200)

- Temperature range: 10 to 50 °C
- Measurement cells: 10, 50, 135 cm^3
- Accuracy: 0.0001 g/cm^3
- Operating gases: N_2, He

On porous components, powders and fibers, measurements using a gas pycnometer are preferable to the standard method for determining density according to Archimedean principle as they ensure greater accuracy . This method is based on the fact that the solid to be measured displaces its volume of a test gas in a sample chamber. This difference in the volume of the test gas compared to the empty sample chamber or a reference chamber is measured. Helium is usually used as the test gas, as it interacts very little with solids. Helium also penetrates porous materials easily. Measurements can also be carried out with nitrogen.

Powder rheometer (Freeman Technology FT4 Powder Rheometer)

- Force ±50 N maximum (0.0001 N resolution)
- Torque: ±900 mNm maximum (0.002 mNm resolution)
- Vertical traverse: 185 mm
- Rotor speed: 120 rpm maximum
- Axial velocity: 30 mm/s maximum

Different particle size distributions, storage conditions and frequent re-use can have a significant impact on the flow properties of powders. The powder rheometer in the powder laboratory can be used to determine the flow properties of powders, which play a central role in powder bed-based manufacturing processes: For example, the powder's resistance against flow and the shear forces of the powder against the wall of the equipment (ASTM standard D7891) are measured to determine their influence in the manufacturing process.

Eddy current meter (Suragus EddyCus CF lab 4040)

- Nondestructive testing of rCF or CF nonwoven fabrics or CFRP sheets
- Quick and easy measurement of carbon fiber orientation
- Estimation of homogeneity
- Sample size: approx. 10 × 10 cm up to 50 × 50 cm

The orientation or preferred direction of the carbon fibers in a nonwoven fabric has a large impact on its mechanical properties. The EddyCus CF lab 4040 eddy current meter, which is equipped with a special eddy current sensor, can be used to determine this orientation as quickly and easily as possible during the production or development of a new nonwoven fabric made of carbon fibers.

The device can be used to test 100% carbon fiber nonwoven fabrics as well as hybrid nonwoven fabrics with additional thermoplastic fibers. Measurements can also be made on a consolidated CFRP sheet. As well as the orientation of the fibers, it is also possible to examine whether the carbon fibers are homogeneously distributed in the nonwoven fabric.

Surface roughness tester (MarSurf M 300 and M 400)

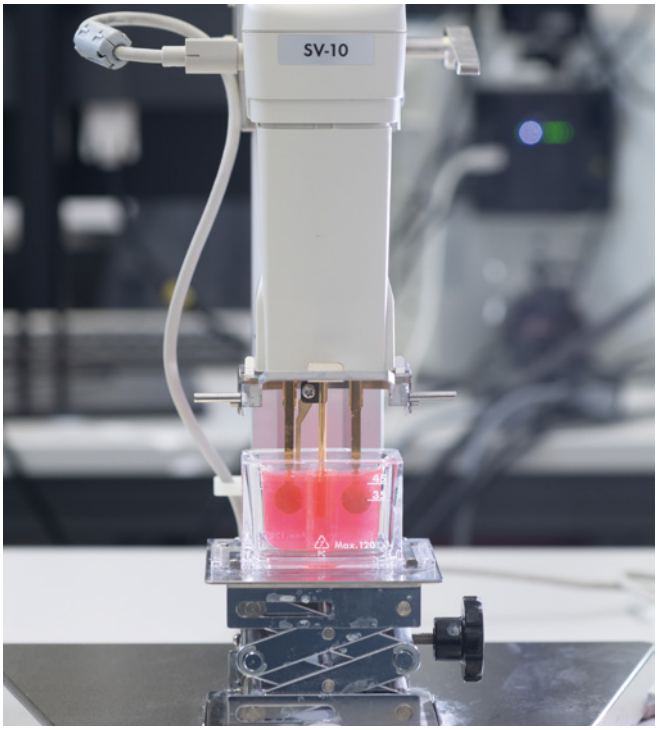
Specification M 300:

- Measurement range: –200 to +150 µm
- Stylus length: 17.5 mm
- Measuring force: 0.75 mN

Specification M 400:

- Measurement range: ±250 µm
- Stylus length: 26 mm
- Measuring force: 0.75 mN

Both MarSurf M 300 and M 400 devices are mobile devices for physical measurement of surface roughness. The stylus of the measuring device is moved at a constant speed across the surface over a specified distance and records the height profile of the surface. The measured values can then be evaluated according to various criteria and printed out or exported as a file. The M 400 also has an X-Y table as well as an additional, longer stylus and a measuring stand.



Viscosy meter

Viscometer (A & D SV-10)

- Measurement range: 0.3 to 10,000 mPa.s
- Accuracy: ±3% (1 to 1,000 mPa.s)
- Working temperature: 10 to 40 °C
- Minimum sample volume: 35 ml
- Temperature shown: 0 to 160 °C / 0.1 °C

This process involves immersing sensor plates in the liquid medium being measured and causing them to vibrate. The medium counteracts this vibration with resistance. The electrical input voltage, which is required to keep the amplitude constant, is a measure of the viscosity of the sample and is converted into the viscosity value.

Sieve analysis (Retsch — AS 300 control)

- Measurement range: 20 µm to 40 mm
- Batch size max. 6 kg
- Sieve diameter: 305 mm
- Sieve stack up to 510 mm

The vibrating sieve shaker can separate and fraction bulk materials and powders as well as determine the particle sizes of the sample material in a single step. Both wet and dry sieving are possible.

Sample production and sample preparation

The specimens for the tests can be produced both in accordance with standards and adapted to the specific application. This starts with the production of sheets and components made of FRP using vacuum infusion (for thermosets), tape laying processes and compression processes (for thermoplastic tapes) as well as various additive manufacturing processes for metallic and foundry technology materials. In addition, materials for specimens can be produced using additive manufacturing, pultrusion or a wetlaid system. Machines and devices for all materials used are available for the further processing of components and the production and post-processing of various specimens. Customized testing equipment can also be produced on request. The Fraunhofer IGCV is also equipped with an extraction system for sample preparation in the field of technical cleanliness.

Sawing and cut-off machines (Gröber Kestrel saw, ATM Brillant 265 and 220)

- Trimming length: max. 1,500 mm
- Max. specimen dimensions: approx. 150 × 300 mm
- Min. specimen dimensions: up to approx. 2 mm edge length
- Cutting disks for plastics and hybrid materials

The preparation of specimens for various mechanical tests is carried out using cut-off machines with diamond or corundum cutting disks with accuracies of up to 0.01 mm. There is a saw available for rough cuts.

CNC milling machine (4 Cam EasY 440 mini)

- Vacuum clamping system
- Max. traverse path: approx. 350 × 380 mm
- CAD/CAM system for importing CAD files

Specimens for push frames and special fixtures can be manufactured to an accuracy of 0.1 mm using a CNC milling machine.

Climate chamber (Vötsch VTL 4010)

- Temperature range: 0 to 100 °C during dry operation
- Humidity level from 0 to 100% depending on the set temperature
- Temperature/humidity programs can be set individually

Specimen conditioning or drying in the climate chamber, as specified in DIN EN ISO 1110, for example, is also carried out according to requirements.

Extraction system (Gläser ACM 18)

- Ultrasonic application and rinsing of components with solvent
- Manual or automatic internal and external flushing
- Cascade filtration
- Max. component weight approx. 15 kg
- Analysis membranes: 47 mm

To analyze technical cleanliness, various guidelines (e.g., VDA Volume 19) require the use of extraction systems to repeatedly flush components in order to remove particulate contaminants and fibers and collect them on analysis membranes. The ACM 18 can be used to analyze only the relevant component areas, the entire component or just the interior. Automated processes guarantee the repeatability of the test procedure.

Cryogenic grinder (Retsch Cryomill)

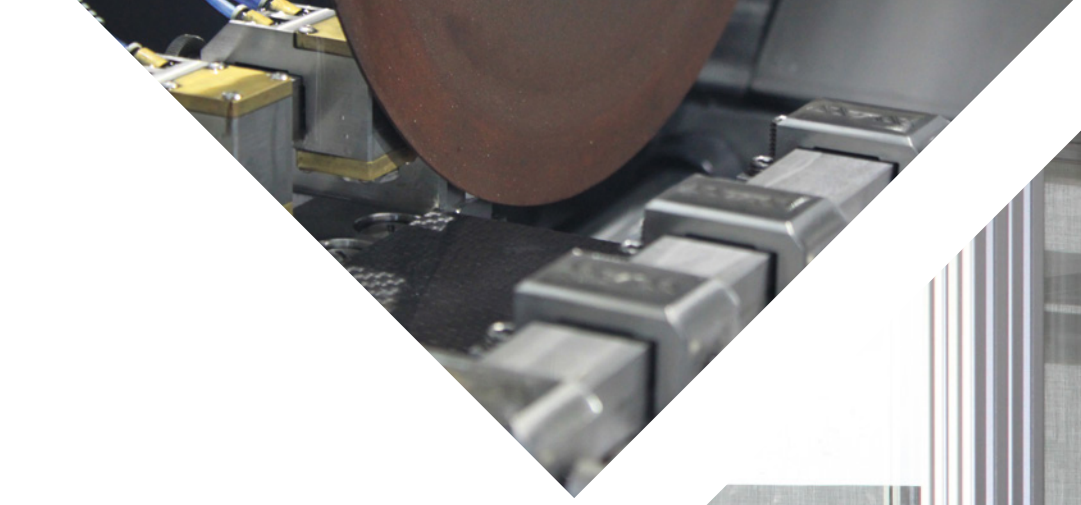
- Grinding frequency 5 to 30 Hz
- Pre-cooling and intermediate cooling at 5 Hz
- Grinding jar made of PTFE
- Volume 5 ml

The sample material is filled into screw-on jars together with one or more grinding balls, cooled with liquid nitrogen and caused to vibrate. The movement of the balls inside the jars grinds the sample. The device can also be operated without cooling.

Grinder and polisher (ATM Saphir 550)

- Disk diameter: 300 mm
- Continuous speed adjustment
- Central and single pressing force
- Automatic removal measurement

A semi-automatic grinder and polisher is used to prepare sections for microscopy.



Service overview

Machine/device	Data	Testing option
DEA	Temperature range: –140 to 400 °C; nitrogen and air purging system; UV attachment; simultaneous measurement with up to 4 sensors; frequency range: 1 mHz to 1 MHz	Characterization of the curing behavior of thermoset materials
DSC	Temperature range: –180 to 600 °C; heating and cooling rates up to 500 K/min; nitrogen and air purging system; UV attachment; autosampler for up to 64 samples	Transition temperatures; enthalpies; degree of crystallization and curing; thermal history; heat capacity; creation of kinetic models
TGA	Temperature range: RT up to 1,100 °C; nitrogen and air purging system; measurements under vacuum	Material-specific mass changes; determination of fiber volume ratio; chemical composition of end products by combining with FTIR
DMA	Temperature range: –170 bis 600 °C; nitrogen and air purging system; maximum force 24 N; frequency range: 10 mHz to 100 Hz	Viscoelastic properties (storage/loss modulus, dissipation factor); transition temperatures
Rheometer	Temperature range: –130 to 450 °C; max. torque: 200 mNm; min. torque: 1 nNm (rotation); frequency range: 1E–8 to 100 Hz	Viscosity; viscoelastic properties; rotational DMA
TMA	Temperature range: –150 to 1,000 °C; digital force resolution: < 0.01 mN; nitrogen, air and helium purging system; measurement under vacuum; modulation of the measurement signal possible	Temperature-dependent changes in volume (isotropic samples) and length; temperature-dependent density; measurement via changes in state also possible (e.g., metal melts)
LFA	Temperature range: –125 to 1,100 °C; measurement range: 0,01 to 1,000 mm²/s; laser pulse energy up to 18 J/pulse	Thermal diffusivity of films, liquids and solids; thermal conductivity (in combination with DSC and TMA); heat capacity determination
STA	Temperature range: RT up to 1,500 °C; atmospheres: vacuum, inert and oxidizing; measurement accuracy: 0.1 µg (mass), ±2% (DSC enthalpy); heating/cooling rates up to 50 K/min	Simultaneous determination of the DSC signal and the change in mass; simple correlation of reactions; metals can also be analyzed up to the point of melting due to the high temperature range
Thermoanalysis/density index	Suitable for molten aluminum; vacuum 80 mbar; crucible preheating 200 °C	Measurement of the density index according to Archimedean principle; grain refinement and H_2 content
Universal testing machine 250 kN	Temperature range: –40 to 200 °C; load cells: 10 kN, 250 kN; testing speeds: 0.002 to 450 mm/min;	Tensile, compression, flexure tests; interlaminar shear strength (ILSS); combined load compression; open hole compression; Celanese; compression after impact (CAI); HCCF; Iosipescu
Universal testing machine 100 kN	Temperature range: RT; testing speeds: 0.0005 to 100 mm/min	Tensile, compression, flexure tests; interlaminar shear strength
Universal testing machine 50 kN	Temperature range: –40 to 250 °C; testing speeds: 0.0002 to 600 mm/min	See universal testing machine 250 kN
Universal testing machine 20 kN	Testing speeds: 0.001 to 750 mm/min	Tensile, compression and 3-point flexure testing
Servohydraulic testing machine	Temperature range: –70 to 300 °C; piston stroke: ±125 mm; force: 10 kN, 100 kN; up to 100 Hz	High cycle fatigue; pulsating load

Machine/device	Data	Testing option
Hardness tester (Zwick Roell ZHU 2.5)	Vickers, Brinell, ball indentation and Martens hardness tests; load range of up to 2.5 kN	Hardness testing on different materials, small load hardness test (e.g., HV1)
Hardness tester (Nexus 8103)	Rockwell, Vickers and Brinell hardness tests, load range of 5 to 3,000 kgf	Hardness testing on metallic materials
Single fiber tensile tester	Max. force: 220 cN; resolution: 0.0001 cN; fiber length: min. 3 mm	Tensile strength and strain of single fibers; modulus of elasticity; fiber diameter; coefficient of friction
Single fiber pull-out tester	Embedding crucible up to 400 °C; N_2 or O_2 atmosphere during embedding; thermoplastic or thermoset matrix	Fiber matrix adhesion
Impact test bench	Temperature range: –50 to 150 °C; drop weight: max. 30 kg; drop speed: max. 24 m/s; max. energy: 1,347 J	Standardized CAI pre-damaging; Charpy device
Drape test bench	Round specimens with a diameter of max. 330 mm; piston stroke: max. 100 mm	Drape behavior of textiles; formation and thickness of folds; creases; crease lines; thin and thick areas; shearing
Digital image correlation	Camera system 2 × 12 MP; frame rate 58 Hz (full resolution) to 464 Hz (reduced resolution)	Recording of displacements, strains and shears in three dimensions
Optical measuring system for component digitization	Resolution: 2×5 MP; measurement range: 300×230 mm (can be extended by overlapping)	3D digitization; comparison with CAD model; dimensional accuracy of specimens
High-speed camera	Max. resolution: 1,024 × 1,024 pixels; Frame rate from 20,000 (full resolution) to 2,000,000 FPS (reduced resolution)	Recording of fracture behavior; high-speed extensometer; vibration behavior before fracture
Scanning electron microscope (SEM) with energy dispersive X-ray spectroscopy (EDX)	Magnification: 15 to 60,000× (digital zoom: 2×, 4×), view: 5 kV / 15 kV / EDX)	Examination of surface morphology and composition distribution, e.g., for powder particles, grindings, fracture surfaces, etc., proportion and mapping of existing elements
AFM	Resolution (tapping mode): 30 nm; atomic resolution in contact mode	Topography of fiber surfaces; microscopic examination at nanometer level
Particle microscope	Zoom stereomicroscopy; analysis of technical cleanliness in accordance with ISO 16232 or VDA 19	Differentiation between metallic and non-metallic particles and fibers; analysis of white and transparent filters (for white particles)
Laser scanner for fluorescence analysis	UV laser scanning with 405 nm; detection of emitted fluorescence of up to 520 nm; resolution approx. 300 µm	Detection of oils, greases, etc.; quantification and measurement of layer thicknesses; surface component measurement 500 × 500 mm²
Active thermography	Measurement principle: Heat flow induction into the specimen by means of external heat sources (e.g., flash or halogen lamps, laser, inductor, etc.). Maximum resolution depending on the application and testing arrangement: 10 µm.	Detection of surface or near-surface defects such as delamination, cracks, pores, impact damage, etc. as well as filmic contamination
Light microscopy	Reflected/transmitted light microscope: Magnification: 1,000x; camera attachment; motorized focus, LED illumination stereo microscope: Magnification: 60x; camera attachment	Examination of microsections; discontinuities; spherulite sizes; pore content; layer structures; layer thicknesses; surface topographies; sample dimensions; particle analysis
Digital microscope	Resolution 1 µm; swivel lens	Automatic detection of particle distribution and size
Motorized light microscope	Up to 1,000× magnification; 3D profile imaging for e.g., roughness measurement; mosaic imaging of entire components; side view of samples; bright/dark field, polarization, transmitted light, multi-lightning, etc.	3D inspection of components with various lighting configurations; cleanliness inspection, particle analysis or surface examination

Machine/device	Data	Testing option
Contact angle analyzer	Temperature range: RT up to 400 °C; high-speed camera with 200 FPS and 780 × 120 pixels; measuring range for surface/interfacial tension: 0.001 to 2,000 mN/m	Wettability of fibers and semi-finished products; surface and interfacial tension; spreading coefficients; surface roughness; relaxation behavior at phase boundaries
Mobile contact angle analyzer	Measurement with diiodomethane and water for a better calculation of the contact angle or surface free energy. Testing also possible on large and upside-down objects	Testing on large components on site, without taking samples for the laboratory; measuring the cleanliness of components
Separator testing	Measurement principle: Use of line scan cameras in three lighting configurations (dark field, bright field and transmission reflection)	Holes > 10 µm, inclusions 150 to 500 µm, degenerated pores 200 µm to 1 mm, pressure marks < 200 µm, scratches 100 to 400 µm, inhomogeneities 400 µm to 3 mm, thin areas 400 µm to 3 mm, fibers 150 µm to 3 mm, metal particles 50 to 200 µm, particles 50 to 200 µm
Laser diffraction particle size analyzer	Particle sizes: 0.1 to 1,000 µm; principle: laser light scattering; analysis: Mie and Fraunhofer scattering; measurement accuracy: better than 0.6%	Measuring the particle size distribution of powders
LSM	Height resolution: 10 nm; edge steepness of up to 85%; automated nosepiece; focal point: 0.4 µm	Microprofile measurements of the surface; determination of roughness coefficients
3D laser microscope	Field of view: 11 to 7,398 µm; total magnification: 42 to 28,800x	Microprofile measurements of the surface, determination of roughness coefficients
FTIR	Temperature range: RT up to 300 °C; wave number range: 8,000 to 600 cm^{-1}; up to 15 spectra/s	Qualitative element analysis; liquids, solids and gases (coupled via TGA); chemical bonding states; changes due to chemical/thermal influences
ON/H performance oxygen, nitrogen and hydrogen analyzer	Measurement principle: Carrier gas melt extraction, sample is melted in graphite crucible at high temperatures (up to 3,000 °C), NDIR detector and thermal conductivity detector to detect the elements	Determination of oxygen, nitrogen and hydrogen in solids in order to record their influence on component properties, for example.
Zeta potential	Streaming potential: ±2,000 mV; streaming current: ±2 mA; temperature range: 20 to 40 °C	Fully automatic zeta potential measurements on macroscopic solids
Emission spectrometer	Wave lines range: 130 to 780 nm; resolution up to approx. 10E–4% by weight	Chemical spectral analysis of metallic samples
Determination of fiber volume ratio	Wet chemical analysis; DIN EN 2564	Determination of fiber volume ratio and pore content
Infrared moisture analyzer	Measurement of the moisture content from 0.005% to 100% readability: 0.1 mg, 0.001%, weighing capacity: max. 100 mg, temperature range and setting: 30 to 180 °C, 1 degree increments	Determination of the moisture content in the sample by thermogravimetric moisture analysis
Pycnometer	Temperature range: 10 to 50 °C; measurement cells: 10, 50, 135 cm^3; accuracy: 0.0001 g/cm^3	Density determination; volume measurement
Eddy current meter	Sample size: 10 × 10 cm to 50 × 50 cm	Measurement of carbon fiber orientation on nonwoven fabrics and sheets; estimation of homogeneity
Surface roughness testers	Mobile; measurement range: maximum ±250 µm; stylus length: 17.5 or 26 mm	Determination of roughness values

Machine/device	Data	Testing option
Viscometer	Measurement range: 0.3 to 10,000 mPa.s Accuracy: ±3% (1 to 1,000 mPa.s) Working temperature: 10 to 40 °C	Determining the viscosity of liquids
Sieve analysis	Measurement range: 20 µm to 40 mm batch size max. 6 kg	Separating powders and bulk materials; determining grain size
Powder rheometer	Force: ±50 N maximum (0.0001 N resolution), torque: ±900 mNm maximum (0.002 mNm resolution); rotor speed: 120 rpm maximum; axial velocity: 30 mm/s maximum	Characterization of the flow properties of powders: e.g., resistance of the powder to flow and the shear forces of the powder against the wall of the equipment (ASTM standard D7891)
Wet cut-off machines	Positioning accuracy of all axes: ± 0.1 mm; cutting force-dependent feed control; variable rotor speed; two different sized machines	Sample preparation for mechanical testing; wet chemical testing; thermal analysis; etc.
Milling machine	Traverse path (X, Y, Z): 425 × 415 × 180 mm; absolute accuracy: 0.1 mm; programming via CAD/CAM interface	Preparation of complex sample geometries
Climate chamber	Temperature range: –40 to 180 °C; humidity range: 10 up to 95% RH.; dew point range: 5.5 to 93.6 °C	Drying and conditioning of samples
Extraction system	Extraction of particles from component surfaces in accordance with VDA 19.1 using cold cleaning agents; cascade filtration for better evaluation of different size classes; internal and external flushing, ultrasonic and syringe extraction	Standardized cleanliness testing to ensure the comparability of cleaning results or to set cleaning parameters
Grinder/polisher	Semi-automatic grinding and polishing system; disk diameter: 300 mm; continuous speed adjustment; central and single pressing force; automatic removal measurement	Preparation of polished sections
Cryogenic grinder	LN_2 cooled mixer mill; up to 5 µm final fineness	Uniform size reduction of samples, e.g., for TGA

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