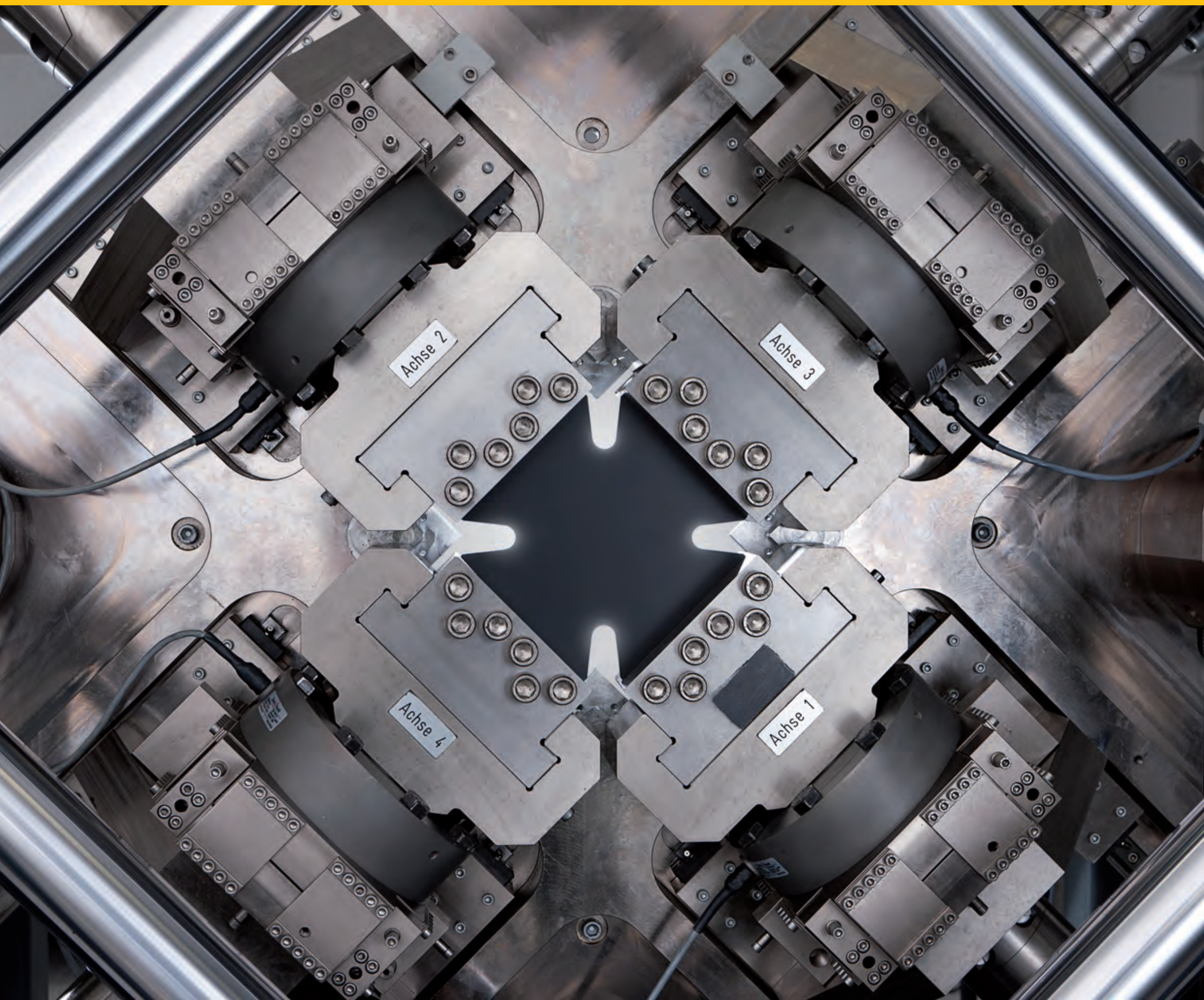
Fraunhofer IWU

FRAUNHOFER INSTITUTE FOR MACHINE TOOLS AND FORMING TECHNOLOGY IWU

# MATERIAL TESTING AND CHARACTERIZATION



# MECHANICAL AND THERMAL MATERIAL PROPERTY TESTING

It is essential to determine the relevant properties resulting from deformation, forming-temperature, forming-speed or the degree of deformation that accurately describes the material behavior under actual process conditions.

In order to achieve, with the FE-simulation, a reproduction of the forming operations that is as faithful to reality as possible, it is necessary, in addition to the variables depicting the forming capability of the sheet metal material, to ensure that other characteristics which are also relevant to the process, such as the friction coefficients, the heat transfer ratios, heat conductivity, specific heat capacity and, under certain circumstances, the thermal expansion coefficient are determined. Only a meticulous determination of all parameters delineating the forming process will guarantee a precise reproduction using FE-simulation.

A concept that takes a holistic approach to determining forming relevant parameters, considering the requirements of FE-simulation in particular, was developed at the Fraunhofer Institute for Machine Tools and Forming Technology IWU. Within this concept established testing methods are combined with new and innovative characterising concepts used to describe phenomena like spring back, anisotropy and the Bauschinger effect. The interaction between the work piece material, the tool material and the lubricant can, with the help of this information, be described more precisely in an FE-simulation.

Both modern standardized as well as specially developed equipment are available for material testing. The wide range of equipment in combination with many years of experience allows us to be flexible and react to customer requests with customized solutions, which includes tests with complex loading conditions.

Some of the standard testing methods available at the institute are presented below. Our competent personnel would gladly support you in selecting, modifying or developing a customized solution for your special needs or unique applications.

At the Fraunhofer IWU modern computer-controlled testing equipment is employed to experimentally establish the mechanical and physical material properties. Using tensile and upsetting tests on flat and rod samples, the following forming parameters and characteristics can be determined:

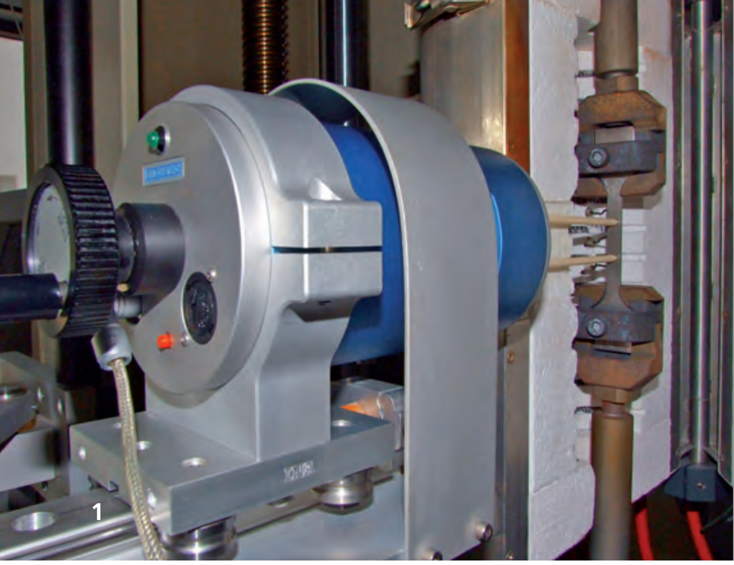
- Elastic characteristics (E-modulus, Poisson's ratio)
- Plastic characteristics (uniform elongation, hardening exponent, fracture strain)
- Strength characteristics (yield strength, tensile strength)
- Stress-strain diagrams
- Anisotropy parameters (r-values)
- Cold yield curves
- Warm yield curves (ambient to 1100 °C)

The EN ISO 6892-1 and EN ISO 6892-2 standards are used as guidelines for conducting the tensile tests at room and elevated temperatures respectively. During the tests the strain rates are controlled with an optical strain rate measurement device, capable of measuring local strain rates. The exact yield point the temperature change (Joule-Thompson-effect) in the specimen is measured with a thermal camera.

Determining mechanical material properties at high strain rates through tensile and upsetting tests is also possible with customized equipment.

Different static hardness tests for tool and work piece materials can be conducted and depending on which material any of Brinell, Vickers or Rockwell in micro and small load ranges hardness values can be carried out. Furthermore the measurement of hardness profiles is possible (eg. hardness depth of heat treated parts), as well as conversion between different hardness values.

**1** *Hot tensile test with high temperature extensometer*
**2** *Experimental procedure with a dilatometer*



Fraunhofer IWU has a wide range of equipment available to establish thermal-physical properties serve the determination of thermal conductivity according to. Information required for a thermo-mechanical FE-simulation can be obtained independently with the equipment listed below.

**Dilatometer**

This piece of equipment is used to determine the thermal expansion coefficient while indicating phase transformation and relaxation behavior. The phase change temperature can be measured as well as the influence alloying elements have on the material properties. It forms the basis for the time-temperature transformation diagram. By measuring the expansion in relation to the sample temperature with an inductive displacement sensor, both differential and absolute dilatometry are available.

Technical specification:
– Temperature range: Rt … 1,600 °C
– Heating rates: 0.1 … 50 K/min
– Contact pressure: 15 … 45 cN
– Measuring range: ± 2.5 mm
– Closed, thermally insulated vacuum chamber

Sample geometry:
– Cylindrical sample (dimensions: max. 25 mm length; 6 mm diameter)

**Laser flash apparatus**

A laser flash apparatus is used to determine the thermal diffusivity of normal and multi-layer materials. This is done by evenly heating the front side of a disc shaped sample with a high energy laser pulse while using an infrared sensor to measure the temperature change on the back side against the lapsed time. The thermal diffusivity can be calculated by using the time-temperature change and sample geometry.

Technical specification:
– Thermal diffusivity measurement range: 0.01 to 1,000 $mm^2/s$
– Temperature range: Rt … 1,500 °C
– Heating and cooling rates of up to 100 K/min
– Nd-YAG SW 40 laser (Output: max. 20 Joule/Puls; Puls duration: 0.3 to 1.2 ms; Wave length: 1,064 nm)
– InSb IR-sensor with liquid nitrogen cooling
– Measurement in inert atmosphere

Sample geometer:
– Disc shape sample (dimensions: 12.7 mm diameter; 2 mm thickness)

**Differential scanning calorimeter**

To analyze the energetic effect that takes place in a solid or fluid medium under a controlled temperature program a differential scanning calorimeter is needed. During the running of the program the actual temperature and temperature difference of both the sample and reference are measured, from this data the heat flow difference is deduced. This method is used to asses the melting behavior at glass transition as well as to accurtely measure the specific heat capacity.

Technical specification:
– Temperature range: Rt … 1,650 °C
– Heating rates: 0.1 … 50 K/min
– Closed, thermally insulated, vacuum chamber

Sample geometry:
– Disc shape sample (dimensions: 5.6 mm diameter; 4 mm thickness)

# TECHNOLOGICAL MATERIAL PARAMETERS

**Maxi-Bulge-test**

The Maxi-Bulge-test is used to quantify the yield behavior at strain rates beyond the uniform elongation. To eliminate the problems of conventional bulge tests, Fraunhofer IWU developed a Maxi-Bulge-test with a 500 mm diameter die.

The deformation of the bulge sample is measured at its pole with the help of an optical system, consisting of four cameras. The blank holder force can be adjusted up to a maximum of 50,000 kN to ensure no material flow out of the clamped area. The complete test is managed by a central computer that simultaneously captures the strain and curvature at the pole as well as the pressure and blank holder force.

Both the automatic measurement system and pressure sensors return highly accurate data, which are required to calculate the yield curves. The curvature radius, strain and material thickness at the pole are measured within an accuracy of one percent and the pressure measurement accurate to 0.15 bar.

By achieving a very small sheet metal thickness/die ratio (< 0.003), an important validity criterion for the membrane theory is completely fulfilled thus ensuring that the cold yield curves calculations, based thereupon, would be sufficiently accurate.

**Tribology and friction behavior**

A strip draw test is used for determination of friction data and wear behavior between the sheet metal, lubricant and tool material to describe the property and character changes of the sheet and tool surface during the forming process.

This allows for wear and friction experiments, returning precise friction coefficients usable in numeric simulations for deep drawing and stretch forming operations, in addition to these varying tribological systems (tool material/tool surface finish, lubricant and sheet metal material/surface finish) can also be tested.

Equipment features:

| | |
|---|---|
| – Tensile force | = 100 kN |
| – Counter force | = 100 kN |
| – Blank holder force | = 50 kN |
| – Stroke length | = 500 mm |
| – Sheet metal temperature | = 1000 °C |
| – Tool temperature | = 800 °C |
| – Speed | = 300 mm/s |
| – Strip width | = 100 mm |
| – Draw edge radius | = 3 mm |

The temperature of the top and bottom tools can be set individually and the equipment allows the counter force (representing the blank holder force) and speed to be constant or gradually controlled.

**Strain analysis**

The results from a strain analysis are needed for FE-simulations, which in turn help to optimize the forming process and blank geometry. Advanced optical measuring systems (ViALUX, GOM, Dantec) are available to visualize the strain distribution, including the forming limit near the necking area or cracks in sheet metal samples. This enables an in-process measurement or an assessment thereafter of the strain conditions. The strain and thickness distribution of the sheet metal can be determined and shown, thereby helping to locate critical areas in complex components.

The measured strain limit values are transferred onto a component specific picture as demonstrator, simplifying the forming process analysis.

Depending on the chosen evaluation technique, the appropriate surface grid, albeit square or round, large or small can be applied to a multitude of materials, using the most modern techniques available. These grids can also be applied to pipes for the purpose of bursting or internal high pressure forming tests.

**Forming limit analysis**

Using the forming limit curves derived from stretch forming sheet metal over a hemispherical punch with different die and punch geometries, material specific forming limits can be derived, thus improving the, previously mentioned, FE-simulation accuracy.

In doing so a sheet metal specimen is formed up to the point where a crack develops, all while the deformation is measured against time with an AutoGrid®-system to establish the maximum tolerable strain. The maximum strain is then represented in a forming limit diagram, indicating the strain limit the particular material can endure.

**Forming limit analysis up to a temperature of 950 °C**

A special testing tool with a maximum punch diameter of 200 mm and a maximum usable temperature of 950 °C was developed at Fraunhofer IWU to test the strain rates of high strength sheet metal (UTS up to 1,800 MPa) with thicknesses ranging between 0.2 mm and 8 mm at different tool and work piece temperatures. Marciniak tests can also be conducted in addition to the forming limit analysis.

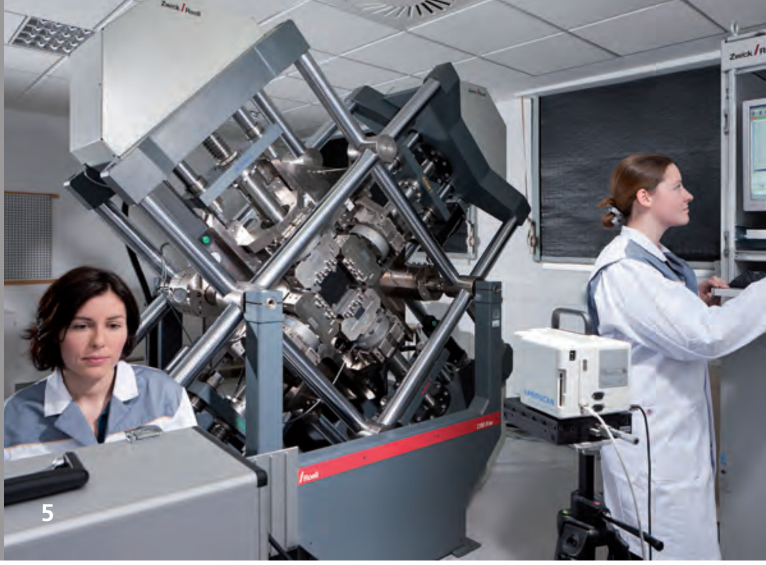
**Cupping and Erichsen tests**

The following special tests and testing procedures are available to investigate load-dependent parameters:
– Cupping tests (round and square punch)
– Erichsen cupping test
– LDH-Test
– Hydraulic cupping test (classic bulge test; circular and elliptical)
– Tube expansion tests

These determine the following forming characteristics:
– Drawing limit ratio
– Cupping index
– Forming limit curve
– Maximum cup height
– Cold yield curve
– Diameter expansion (tube)

The formability of coated, textured as well as sandwich materials can also be determined by inducing different strain rates.

**3** *Tool for Maxi-Bulge-test with specimen*
**4** *Tool for in-process determination of FLC*



# CHARACTERIZATION OF MATERIAL BEHAVIOR

**Tension-compression-testing of sheet metal**

Cyclic tension-compression tests are used to determine the isotropic-kinematic and mixed isotropic-kinematic yield behavior of sheet metal. A major challenge is to prevent the sheet metal specimen from buckling during the tension-compression test. Load cells are used to measure the forces needed to deform the sheet metal parts and the local longitudinal and lateral deformation are quantified with a laser-speckle-interferometer, giving an overview of the stress and strain situation in the measured area. The yield point is measured optically by detecting the Joule-Thomson-Effect (strain dependent temperature change) with a thermo camera. The analysis of the results of the tension-compression-test is done with parameter identification, and the measured stress and strain values are entered into the object of a non-linear optimization function.

Yield curve information for cyclical loading, including the Bauschinger-effect, can be measured with tension-compressive testing.

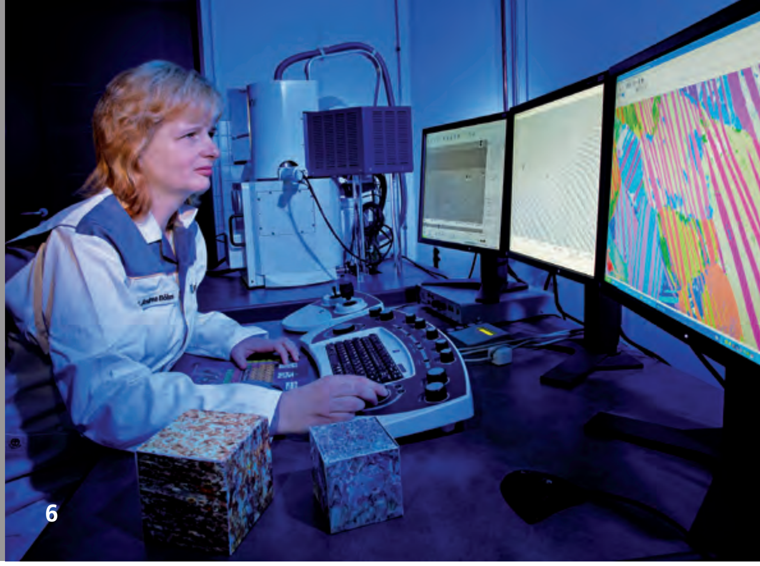
**Biaxial tensile tests**

Initial and subsequent yield locus curves for sheet metal in the tensile-tensile region can be measured in different directions with a biaxial tensile test to characterize the actual multi-axle strain behavior. In order to do this, the sample is strained in two directions arranged squarely to each other by four individually controlled spindles. Similar to the tension-compression test load cells are used to measure the force needed to deform the samples, a laser-speckle-interferometer is used to measure the displacement in the measured region and an infrared camera is used to determine the yield point.

The challenge in determining the stress at the yield locus lies therein that the effective cross-sectional area depends on the actual position of the yield locus, thus influencing the degree of temperature change during forming and therefore require more precise temperature measurement to determine the yield point. Various load directions are applied to the sample to determine its forming behavior.

Both the tension-compression and biaxial tensile tests fulfill the prerequisites for the realistic numerical simulations needed to optimize the sheet metal forming process.

**5** *Implementation of a biaxial tensile test*
**6** *Metallographical determination with a raster electron microscope*



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# FURTHER TESTING POSSIBILITIES, METALLOGRAPHY AND EQUIPMENT

**Further testing possibilities**

- Dye penetration tests (red-white tests) for surface defect recognition (cracks, porosity)
- Magnetic particle inspection for the detection of surface and shallow defects in ferromagnetic materials
- Notch impact tests to determine notch impact strength
- Roughness measurements

**Metallography**

Fraunhofer IWU can also prepare polished metallography specimens, suitable for assessing macro and micro crystal structures, conducting hardness measurements as well as the measurement of the cross-section's parameters. Our metallographic repertoire includes the analysis of material microstructures more specifically the micro-structural components, micro-structural transformations and micro-structural flaws. In addition, specific macro structural examinations at ruptured or etched surfaces can be carried out, e.g. the examination of damaged components or the portrayal of grain orientation in formed components. When preparing polished samples, the correct cold mounting material is matched with the mounted materials, taking into account the purpose of the final sample. Modern stereo-microscopes are used to inspect the polished samples, and Olympus Stream Motion is used to evaluate the micrographs.

**Equipment**

- Erichsen sheet metal and strip testing machine [600 kN Punch force, 200 kN blank holder force]
- Tension-compression testing machine WPM 300 [Fmax = 300 kN]
- Tensile testing machine Zwick 1475 [Fmax = 100 kN] with high temperature capability supplied by Maytec [1,100 °C]
- Tensile testing machine Zwick FR 020TN [Fmax = 20 kN]
- Tensile testing machine UTS 20 [Fmax = 20 kN] with vacuum/inert gas oven [1,600 °C]
- Pendulum impact tester [300 J]
- Heated strip draw tester with 90 °C bending angle
- Biaxial tensile testing machine Zwick [combined force 250 kN]
- CNC hardness tester EMCOTEST M1C 010-DR
- Nikon Epiphot Reflected light microscope and Olympus SZX10 stereo-microscope
- Cutting, mounting, grinding and polishing equipment
- GOM 3D contour, displacement and strain measurement equipment
- ViALUX [compact mobile and vario system] AutoGrid® deformation analysis equipment
- ESPI Dantec Q-300 laser strain measurement system
- Optimized equipment to apply electro-chemical or screen printed grids in diverse applications
- InfraTec VarioScan 3021 ST thermo camera with IRBIS® professional software

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