Definition

Investigations into fatigue life are becoming more and more important for the design of safety relevant components that are simultaneously subjected to thermal and mechanical load. To investigate the thermo-mechanical behaviour of metallic materials, uniaxial tests are conducted on samples in a laboratory under idealised conditions. Temperature and strain are varied on the basis of time within the strain measuring section of the test piece until failure. This testing procedure is called “thermo mechanical fatigue” or “TMF”.

Test procedure

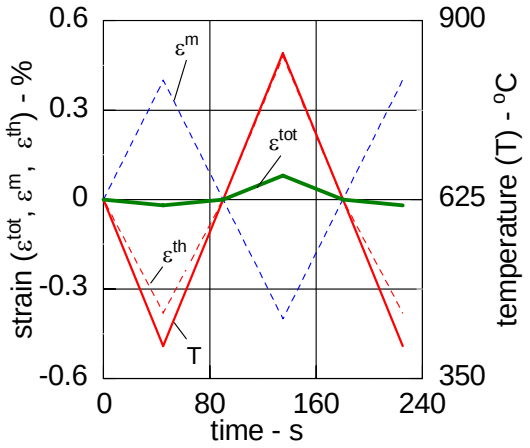
Before running a TMF test four different pre tests are conducted to obtain material properties that are necessary for the further test procedure and to check the test setup:

- *Determination of the Young’s Modulus in the temperature range between RT and T_{max},E = f(T)*
  Furthermore the test is used for the plausibility check of the measurements force, strain, and temperature.
- *Optimisation of the temperature path*
  A test to minimize the temperature time error.
- *Determination of the thermal strain $\varepsilon^{th} = f(T)$*
  Mandatory test to balance the thermal strain for a strain controlled testing procedure.
- *σ-zero-test*
  Test to verify the thermal strain balance.

After successful completion of all pre tests the TMF test can be started. In most cases test pieces are loaded with defined constant mechanical strain amplitude and with a temperature cycle. During the temperature cycle the test piece length changes during unimpeded expansion. The thermal expansion must not influence the mechanical load of the test piece. Thus strain controlled TMF-tests are controlled according to the total strain (ε^{tot}) that consists of the mechanical (ε^{m}) and the thermal strain (ε^{th}):

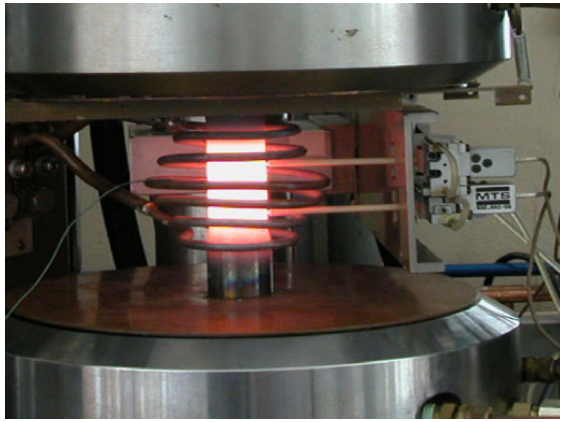
$$\varepsilon^{tot} = \varepsilon^{m} + \varepsilon^{th}$$

The calculation of ε^{tot} is performed for “time based tests” before the test starts from the time curves ($\varepsilon^{m}_{(t)} + \varepsilon^{th}_{(t)}$), or for “temperature-based-tests” by actual temperature measurement taken during the test. The calculation of the thermal strain is based on the measured temperature with the subsequent addition of the mechanical strain ($\varepsilon^{m}_{(t)} + \varepsilon^{th}_{(T)}$). The phase φ between temperature and mechanical strain can be chosen between 0° and 360°. There is a special case ($\varphi = 0°$) where the maximum and minimum of temperature and strain are reached at the same time. This is called the “in-phase” (IP).



Example of TMF set point sequence ($\varepsilon^{tot} = \varepsilon^{m} + \varepsilon^{th}$)

Phase position temperature / strain φ =180°, mechanical strain amplitude ε^{m} = ±0,4%, T= 400-850°C, ($\varepsilon^{th}_{400°C}$ = -0,38%, $\varepsilon^{th}_{850°C}$ = 0,48%), temperature rate 5 K/s (180 s per cycle).



TMF test setup

Objectives

Characterisation of the material properties under thermo-mechanical loading:

- cyclic stress strain behaviour
- cyclic hardening and softening
- fatigue life
- determination of the TMF material properties

Standards

At present a valid TMF standard does not yet exist, only incomplete drafts for the uniaxial strain controlled TMF test are available (ASTM, ISO). These drafts are the basis for the testing procedure. The working group is involved in the further development of the TMF testing procedure in the frame of a European research project.
Additionally, force controlled and axial-torsional TMF tests as well as uniaxial TMF tests under vacuum can be performed.

Test equipment

All TMF tests are conducted on test systems with inductive heating devices. To increase the temperature rates tubular test pieces are preferred. Furthermore the cooling rate of the test piece can be increased by blowing it with compressed air.

Activities of the working group

„Mechanical Behaviour of Metals“

The following working scope is covered mainly in national or international cooperation with partner in industry, universities or other research institutes:

- High temperature materials for gas turbines
- Fibre reinforced light metals for aero engines
- Grey cast iron for break disks
- Development of new testing procedures in mechanical testing
- Collaboration in development of technical standards
- Customized mechanical testing
- Optimization of testing techniques by loading simulation
- Analysis of damage caused by loading
- Education of materials testing personnel
- Supervision of engineering student projects
- Failure analysis

BAM, division V.2 is approved by DAP Deutsches Akkreditierungssystem Prüfwesen GmbH according to DIN EN ISO/IEC 17025:2000 as an accredited testing laboratory.

Deutscher Akkreditierungs Rat

DAP-PL-2614.16

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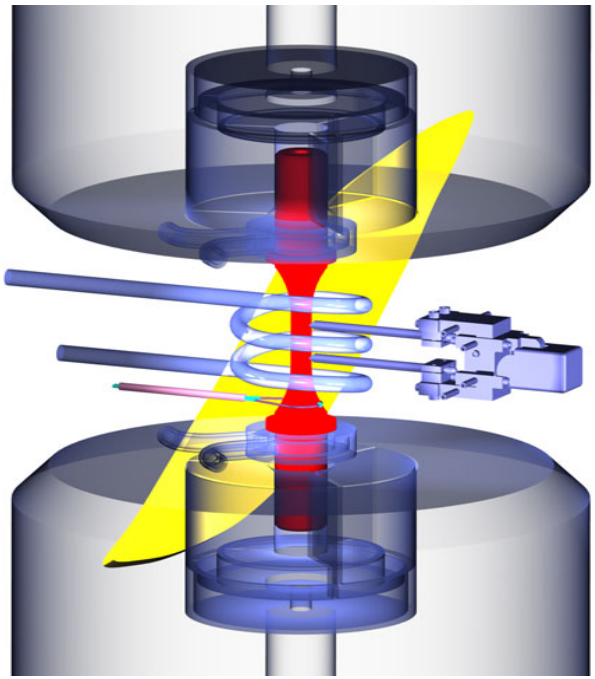
Thermo-mechanical Fatigue (TMF)



Working Group
„Mechanical Behaviour of Metals“