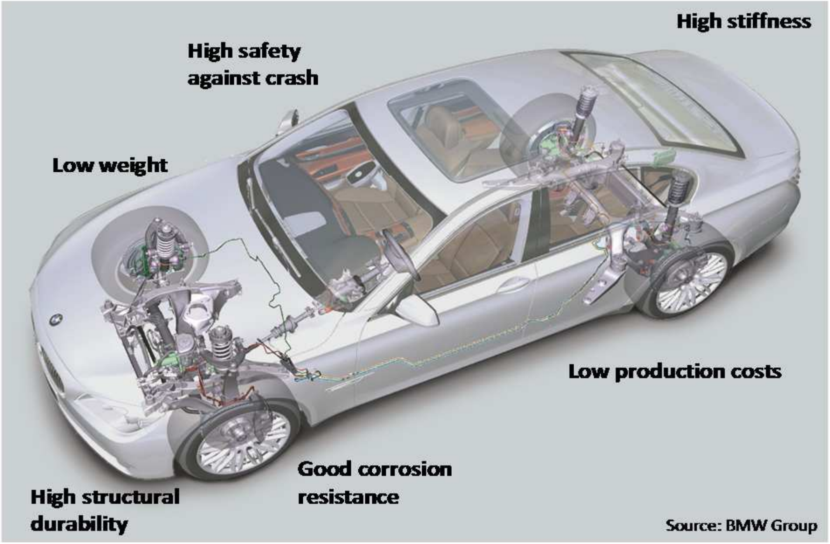
Vorlesung bei der EPFL, Lausanne, 9. September 2015

Multiaxial Fatigue of Welded Joints under the Aspect of Local Assessment Concepts

C. M. Sonsino

Fraunhofer LBF

Chassis of a 7 Series BMW



DIA 8313

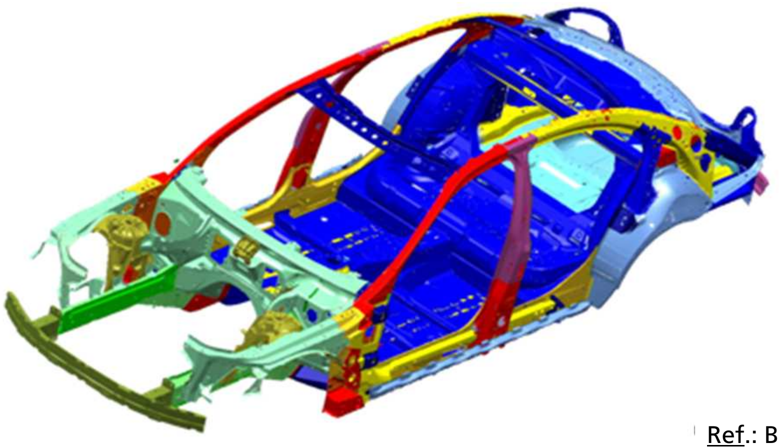
Fraunhofer LBF

Car Structure in White

DIA 6857e

Fraunhofer
LBF

Karosserierohstruktur

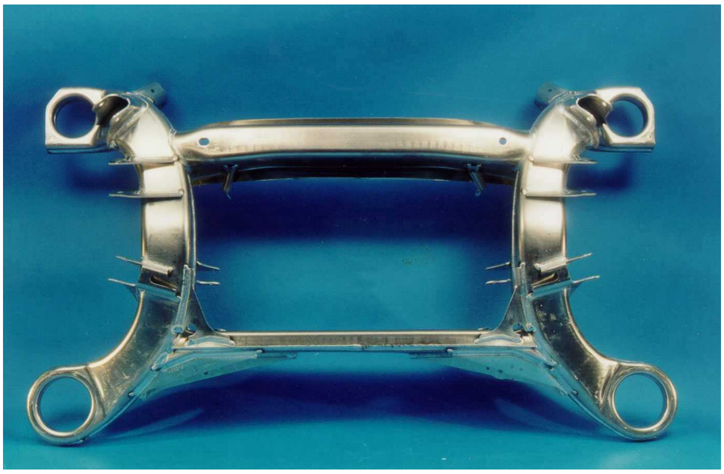


Ref.: BMW AG

DIA 8379e

Fraunhofer
LBF

Welded Aluminium Rearaxle Carrier

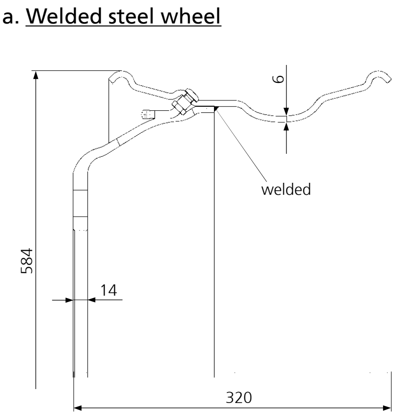


Material: AA 5454 (AlMg3Mn) Ref.: Daimler AG

DIA 6035e

Fraunhofer LBF

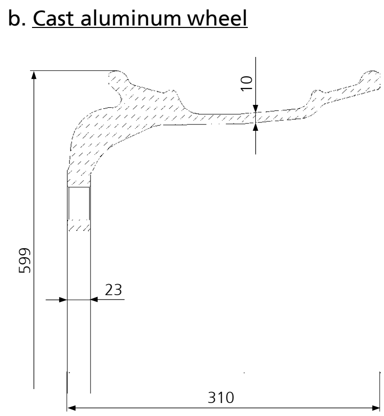
Comparison of Welded Steel and Cast Aluminum Truck Wheels (22.5x9.00)



Material: Disk: St 52, Rim: St 37

Weight: 41 kg

Ref.: Hayes Lemmerz Holding GmbH



Material: G-AlSi7Mg T6 (A 356 T6)

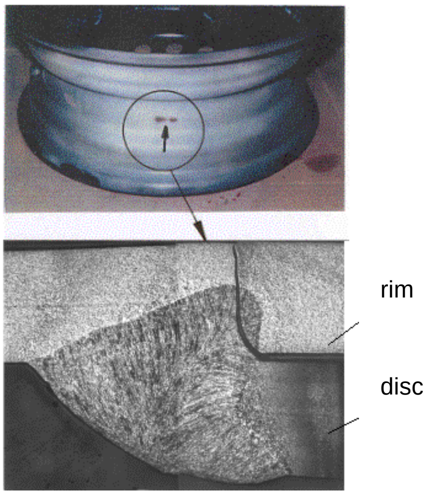
Weight: 27.1 kg

Ref.: Borbet GmbH

DIA 7451e

Fraunhofer LBF

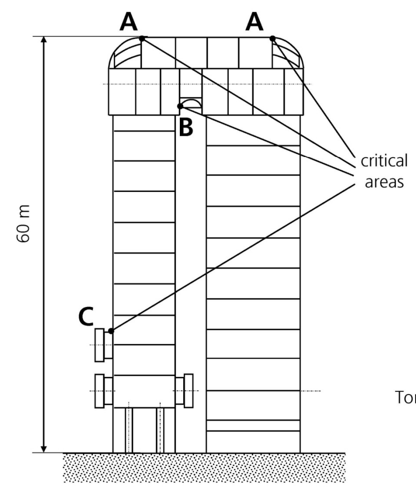
Fatigue Crack on Welding between Disc and Rim

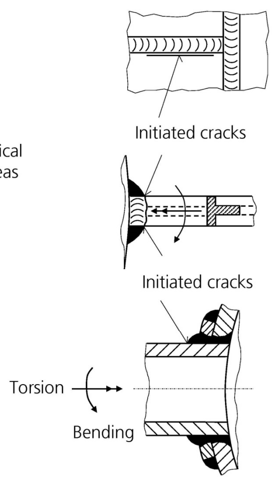


DIA 7302e

Fraunhofer LBF

Hot-Blast Furnace and Critical Areas





A

Constant amplitude biaxial loading with constant principal stress directions

B

Constant amplitude bending and torsion with changing principal stress directions

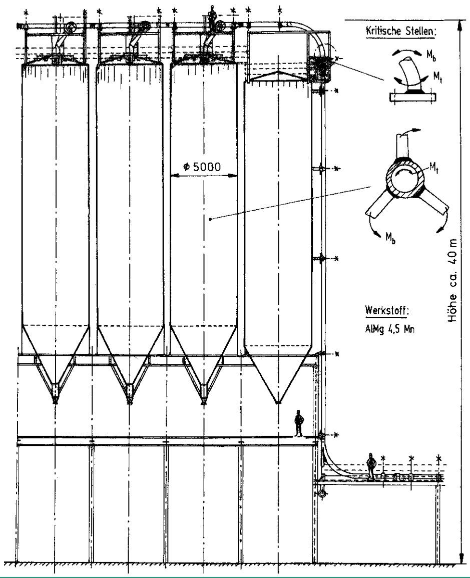
C

Constant amplitude bending and torsion with changing principal stress directions

DIA 5521 d = 6240 e

Fraunhofer LBF

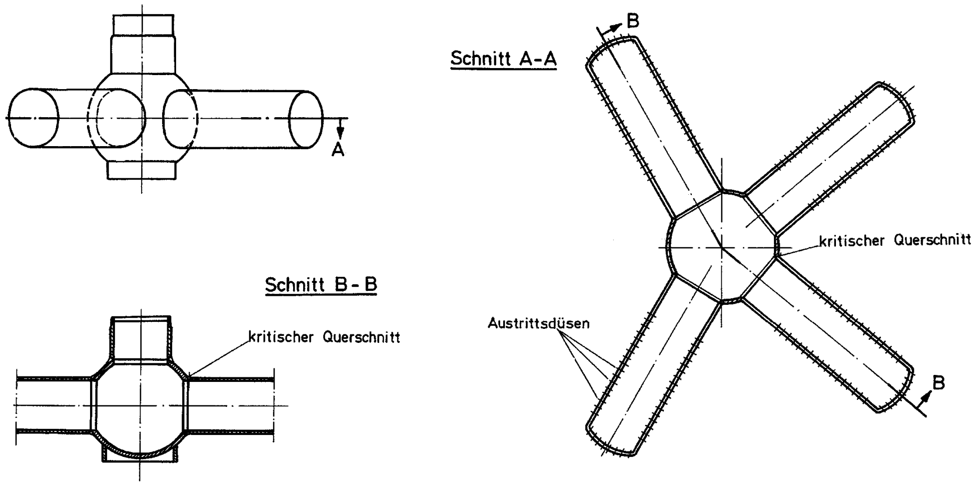
Silos aus Aluminium zur Aufbewahrung von Kunststoffgranulaten



DIA 6037d

Fraunhofer LBF

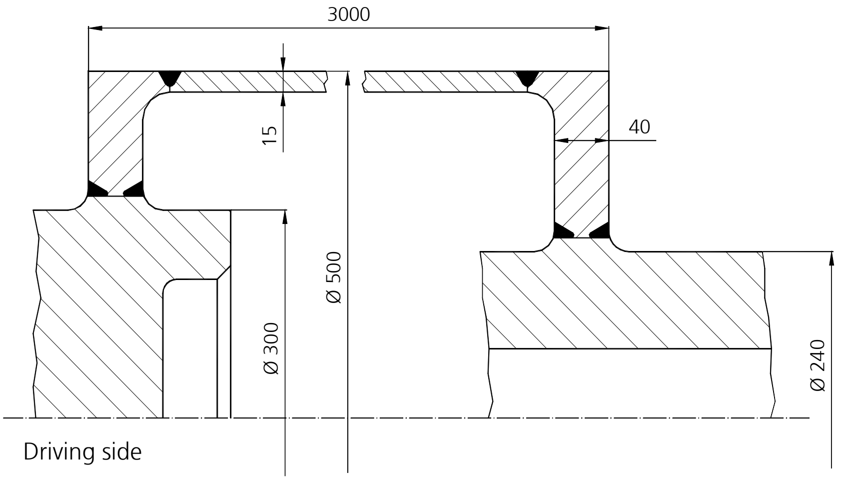
Kritische Bereiche eines Druckentlastungssystems eines Reaktors



DIA 5091 d

Fraunhofer LBF

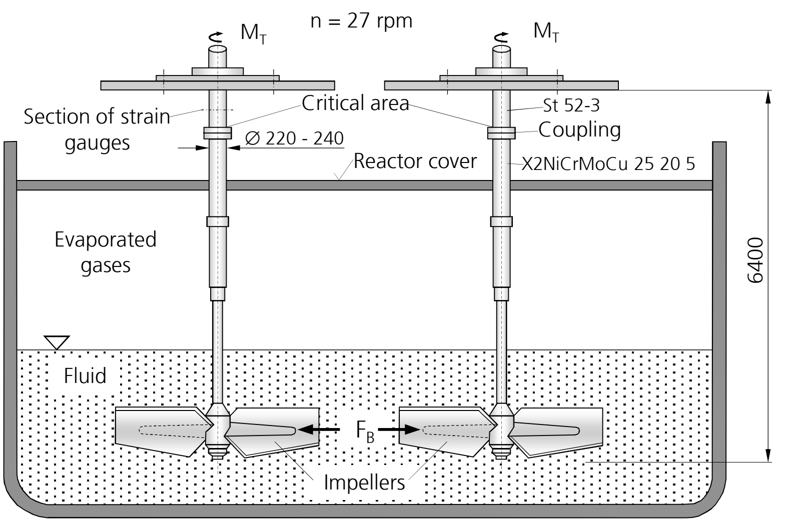
Fatigue Critical Areas of a Welded Stirrer



DIA 6241 e

Fraunhofer LBF

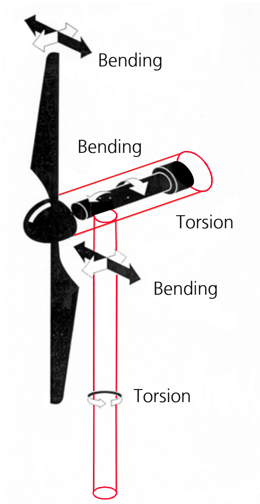
Stirrers of a Fertilizer Plant



DIA 6239e

Fraunhofer LBF

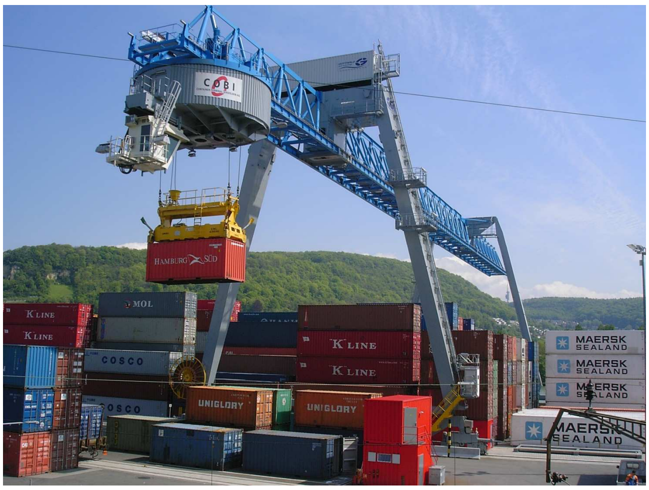
Most Important Loading Components of a Wind Power Plant



DIA 7138e.ppt

Fraunhofer LBF

Geschweißte Krankonstruktion

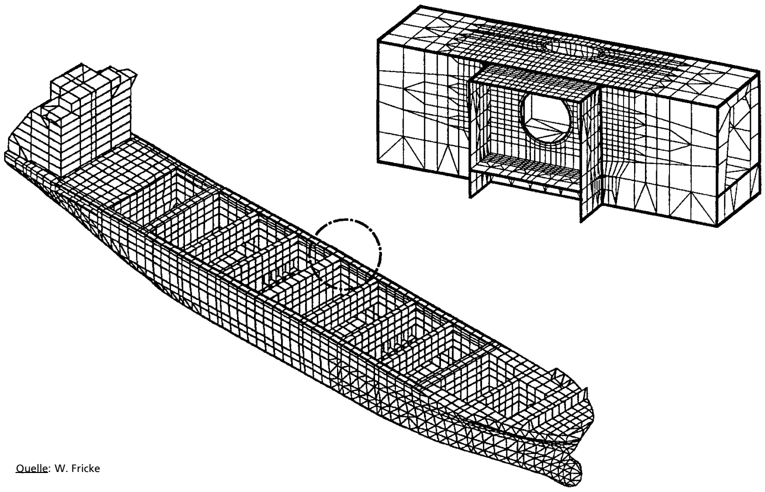


Ref.: Gottwald Port Technology GmbH

DIA 7652d

Fraunhofer LBF

Schiffstruktur mit Schweißverbindungen und Durchbrüchen in hoch beanspruchten Bereichen

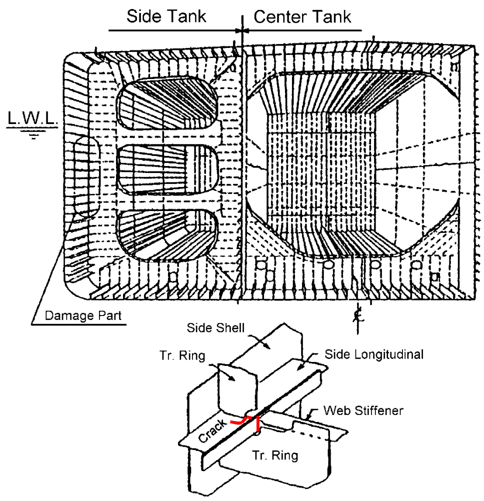


Quelle: W. Fricke

DIA 7640d

Fraunhofer LBF

Fatigue Damages in Tankers



Ref.: W. Fricke (TUHH)

DIA 7205e

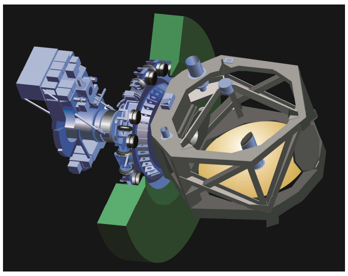
Fraunhofer LBF

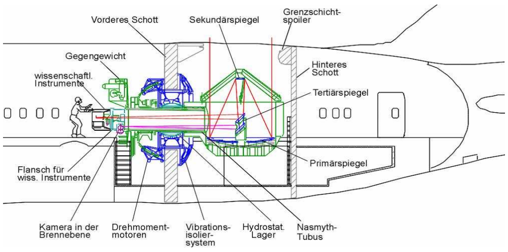
Seto Bridge, Highway and Railway Combinations of Suspension and Cable Stayed Bridges

Ref.: Ch. Miki

Fraunhofer LBF

Stratospheric Observatory for Infrared Astronomy (SOFIA)



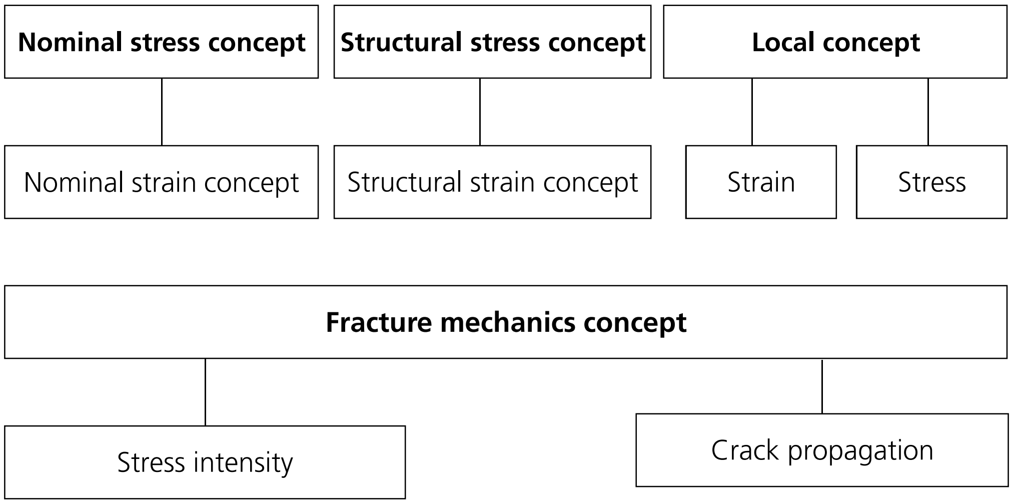


Ref.: NASA, DLR, MAN Technologies

Fraunhofer LBF

DIA 8680 e

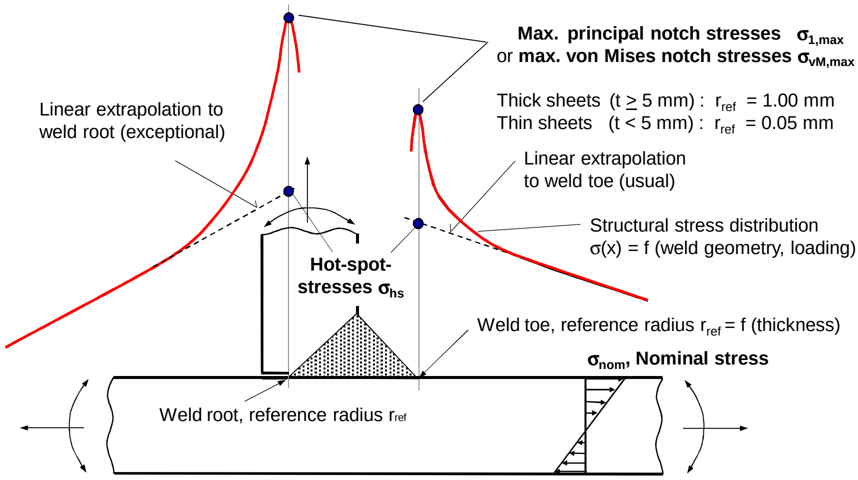
Design Concepts of Structural Durability



DIA 6737e

Fraunhofer LBF

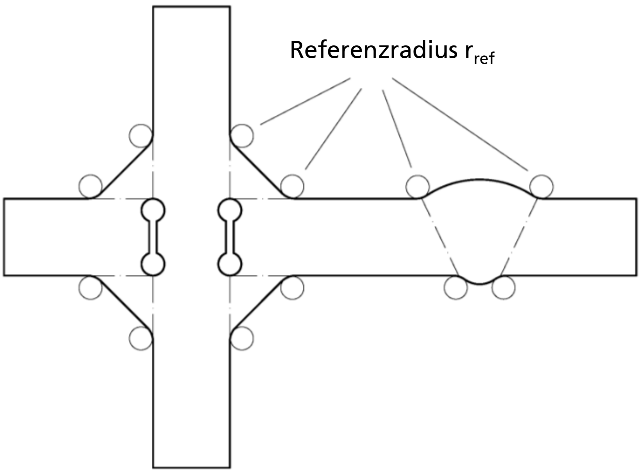
Definition of Stresses According to Different Assessment Concepts



DIA 8423e

Fraunhofer LBF

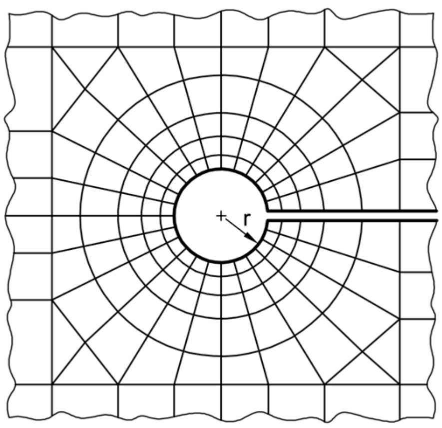
Berechnung von Kerbspannungen mittels des Referenzradius



DIA 7472d

Fraunhofer LBF

Typisches FE-Netz für eine Schlüssellochkerbe aus Elementen mit quadratischem Ansatz

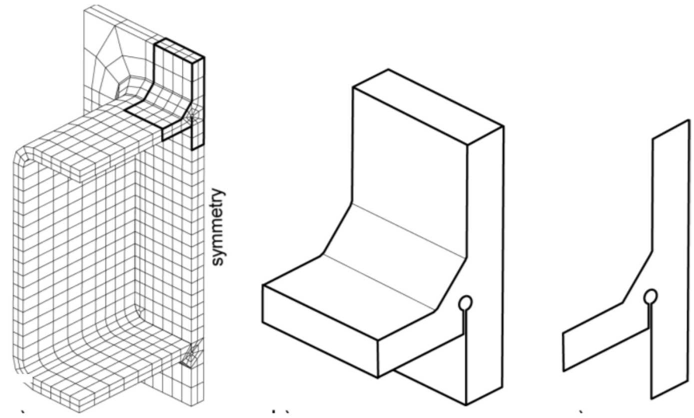


DIA8137d

Fraunhofer LBF

FE-Modelling of a Fillet-Welded End Joint of a Rectangular Hollow Section

a. Overall model — b. 3D-submodel — c. 2D-submodel

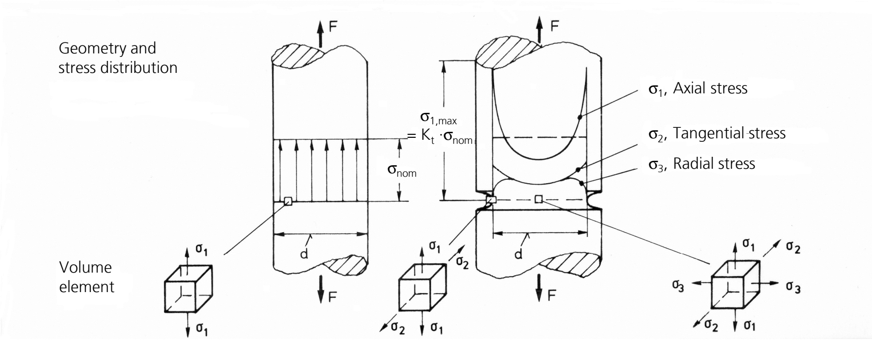


Ref.: W. Fricke

DIA 8203e

Fraunhofer LBF

Uni- and Multiaxial Stress-Strain-States



Stress state	uniaxial σ_1; $\sigma_2 = \sigma_3 = 0$ $\sigma_1 = E\,\varepsilon_1$	biaxial (plane stress) σ_1, σ_2; $\sigma_3 = 0$ $\sigma_1 = \frac{E}{1-\mu^2}(\varepsilon_1 + \mu\,\varepsilon_2)$; $\sigma_2 = \frac{E}{1-\mu^2}(\mu\,\varepsilon_1 + \varepsilon_2)$	triaxial σ_1, σ_2, σ_3
Strain state	triaxial ε_1, $\varepsilon_2 = \varepsilon_3 = -\mu\,\varepsilon_1$	triaxial ε_1, ε_2, $\varepsilon_3 = -\mu(\varepsilon_1 + \varepsilon_2)/(1-\mu)$ sharp notches ($K_t > 2$): $\varepsilon_2 = 0$ (plane strain)	triaxial ε_1, ε_2; $\varepsilon_3 = -\mu(\varepsilon_1 + \varepsilon_2)/(1-\mu)$

DIA 7137e.ppt

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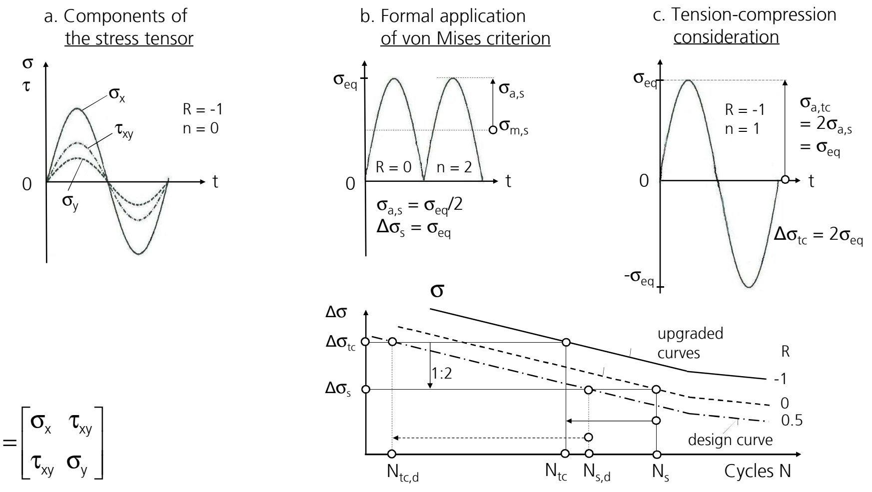
Errors by Formal (Scalar) Application of von Mises Hypothesis



$$\bar{\sigma} = \begin{bmatrix} \sigma_x & \tau_{xy} \\ \tau_{xy} & \sigma_y \end{bmatrix}$$

$$\sigma_{eq} = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3\tau_{xy}^2}$$

DIA 8099e.ppt

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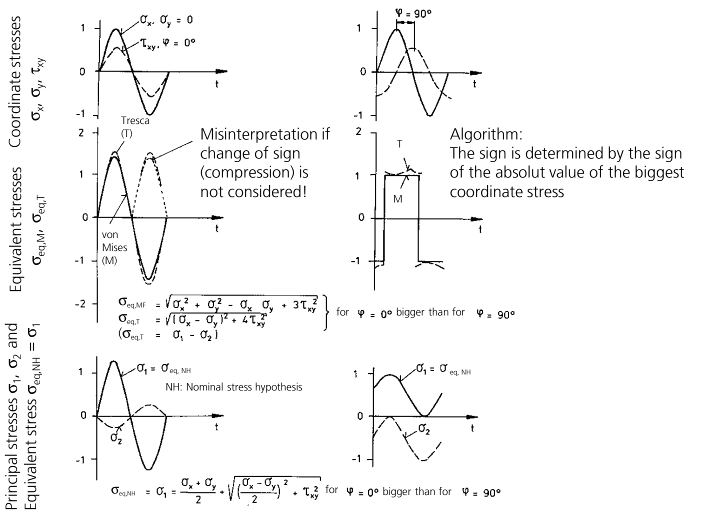
Conventional Strength Hypotheses



Comments for fatigue life assessment:

A higher fatigue life by out-of-phase loading is for ductile materials misrepresented. Therefore, need of an appropriate hypothesis.

By out-of-phase loading a higher fatigue life for brittle materials is indicated. However, for calculating the maxiamum equivalent stress a direction dependent modification is necessary.

DIA 5198e.ppt

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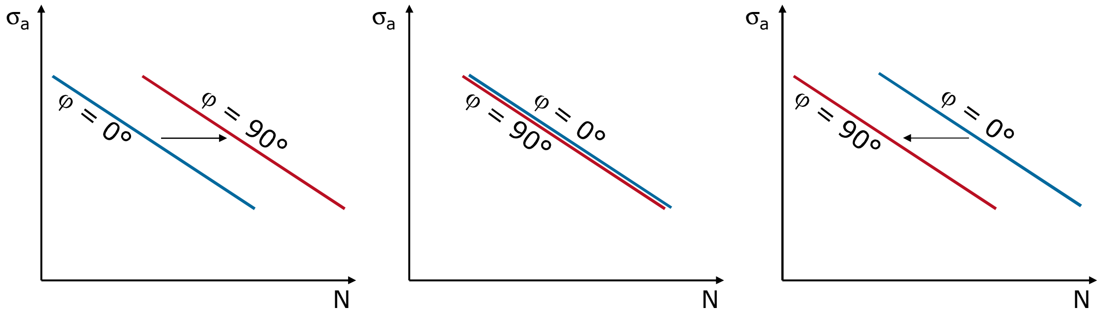
Einfluss von zeitabhängigen Hauptspannungsrichtungen auf die Lebensdauer

Sprödes (wenig duktiles) Materialverhalten

Semi-duktiles Materialverhalten

Duktiles Materialverhalten



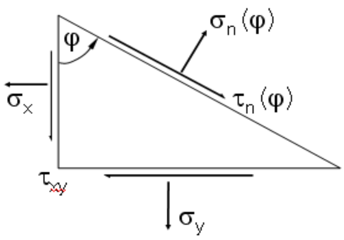
— $\varphi = 0°$, proportional -> konstante Hauptspannungsrichtungen

— $\varphi = 90°$, nichtproportional -> zeitabhängige Hauptspannungsrichtungen

Fraunhofer LBF

Spannungen in der Schnittebene und Schadensmechanismen

a. Schnittebenenspannungen



$$\sigma_n(\varphi) = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2} \cdot \cos 2\varphi + \tau_{xy} \cdot \sin 2\varphi$$

$$\tau_n(\varphi) = \frac{\sigma_x - \sigma_y}{2} \cdot \sin 2\varphi - \tau_{xy} \cdot \cos 2\varphi$$

b. Zähigkeitsabhängiger Schadensmechanismus

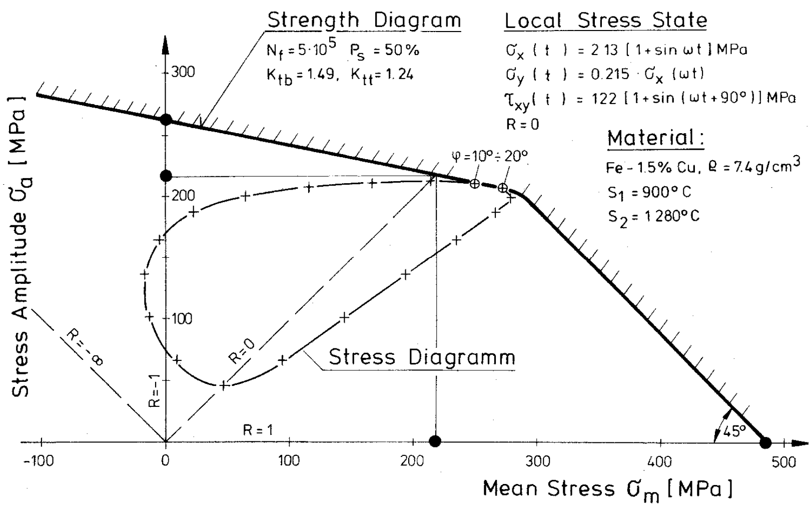
- $\sigma_n(\varphi)$ für **spröde** Werkstoffe (Aluminiumguss, Gusseisen, Sinterstähle)
- Kombination aus $\sigma_n(\varphi)$ und $\tau_n(\varphi)$ für **semi-duktile** Werkstoffe (Aluminiumknetlegierung, Stahlguss)
- $\tau_n(\varphi)$ für **duktile** Werkstoffe (z.B. Baustähle)

c. Rechenalgorithmus

- Maximale Normalspannung in der kritischen Schnittebene
- Spannung als Kombination aus Normal- und Schubspannung in der kritischen Schnittebene
- Integraler Wert aus der Schubspannung über alle Schnittebenen

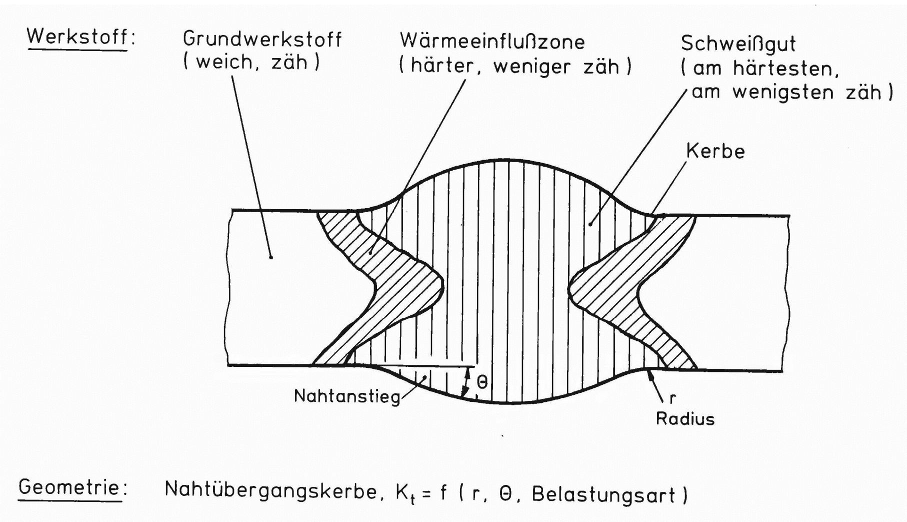
Fraunhofer LBF

Correlation of the Calculated Stresses and Fatigue Strength



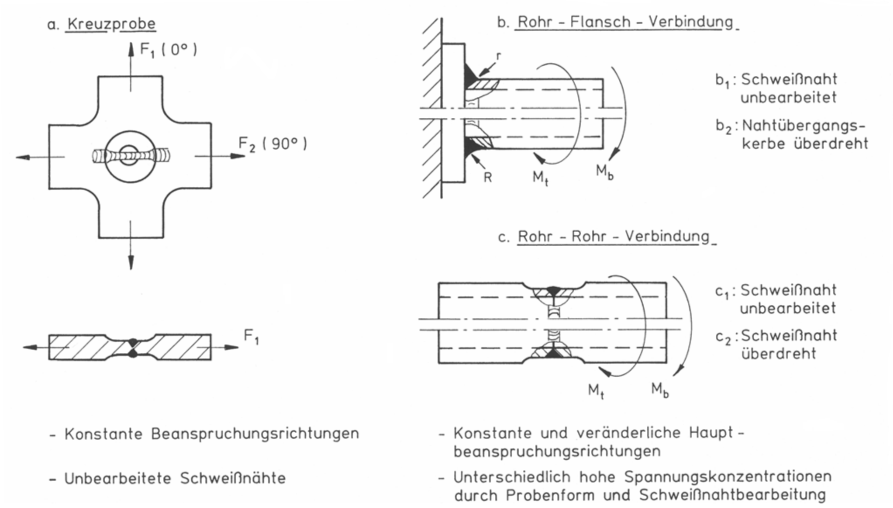
DIA 3707e

Verbundwerkstoff Schweißnaht



DIA 5184 d

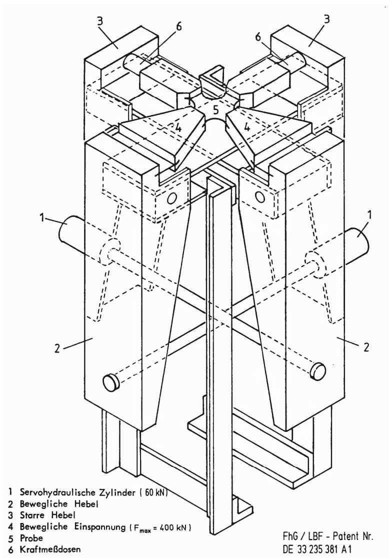
Probenformen zur Untersuchung des Einflusses von mehrachsigen Beanspruchungen auf das Festigkeitsverhalten von Schweißverbindungen

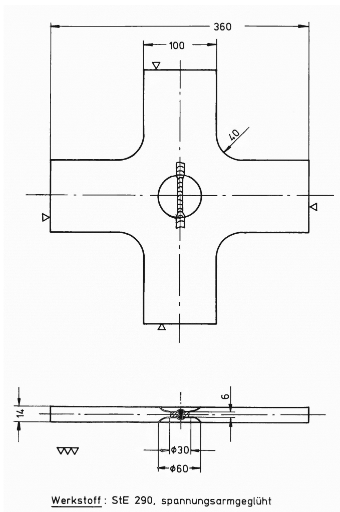


DIA 5185d.ppt

Fraunhofer LBF

Biaxialer Kreuzprobenprüfstand und geschweißte Kreuzprobe

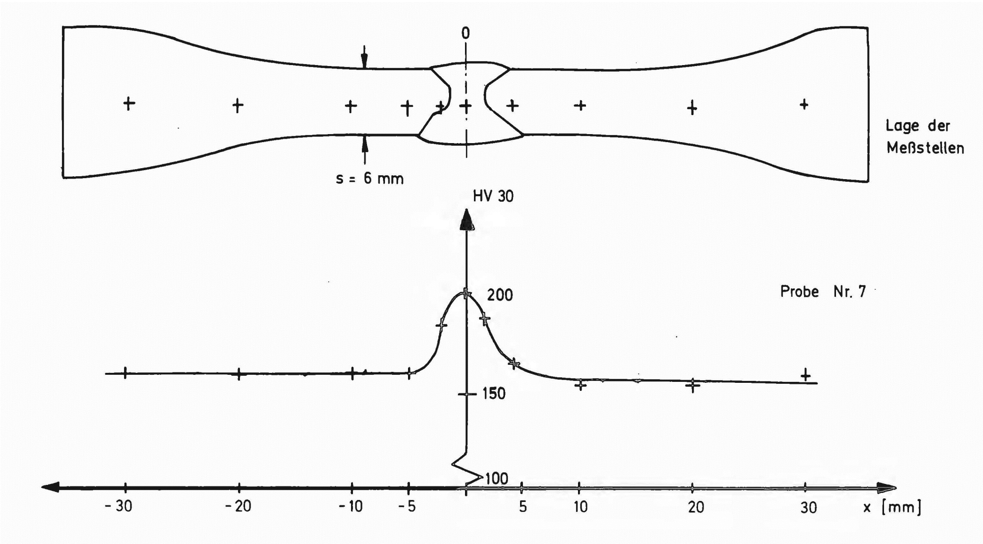




DIA 8702 d

Fraunhofer LBF

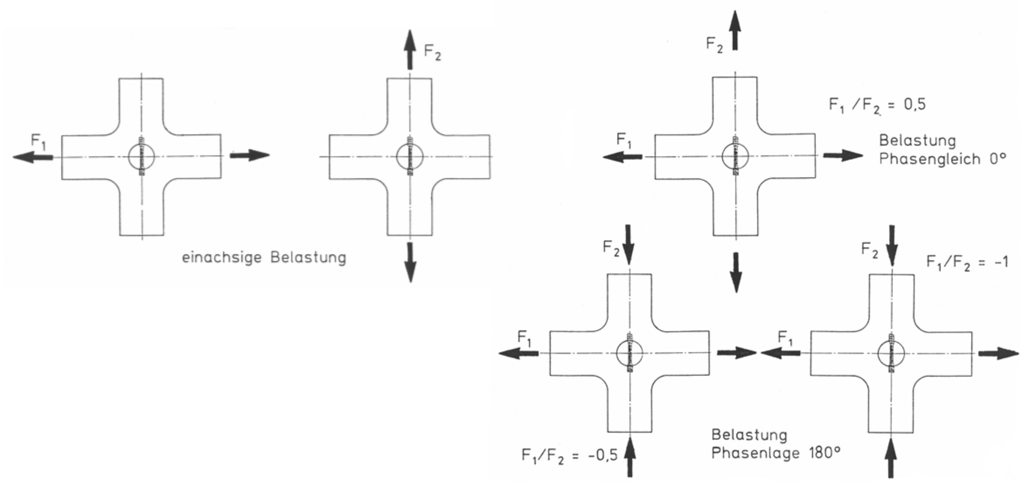
Härteverteilung quer zur Schweißnaht der Kreuzproben



DIA 5713 d

Fraunhofer LBF

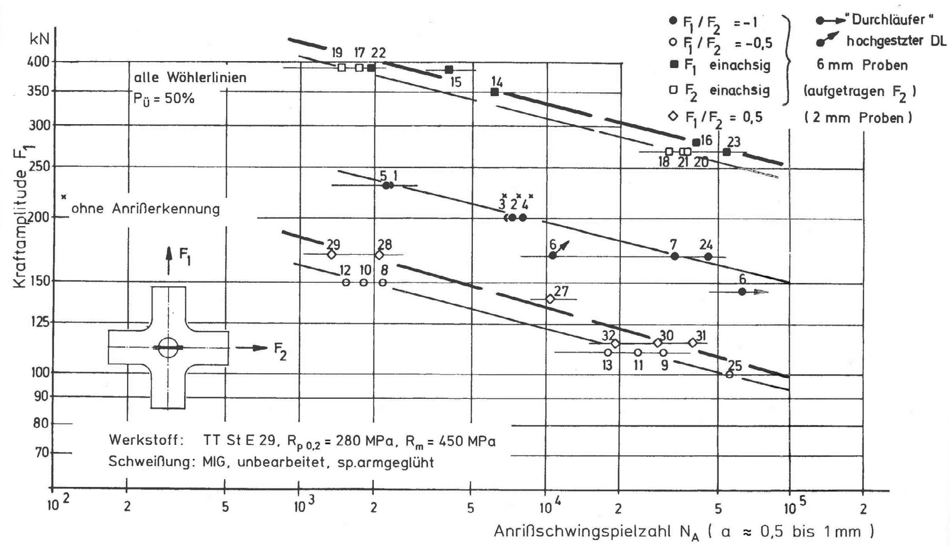
Untersuchte Belastungsverhältnisse



DIA 5189d.ppt

Fraunhofer LBF

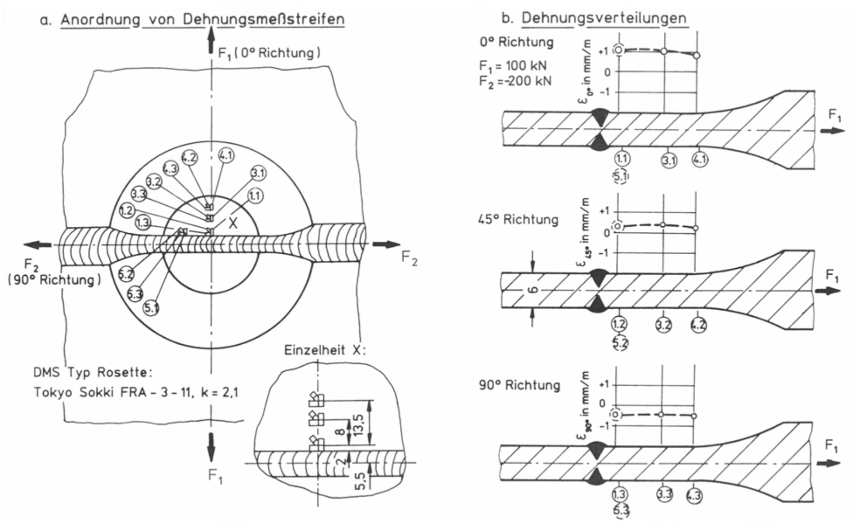
Uni- und biaxiale Schwingbelastung der geschweissten Kreuzproben



DIA 5190 d

Fraunhofer
LBF

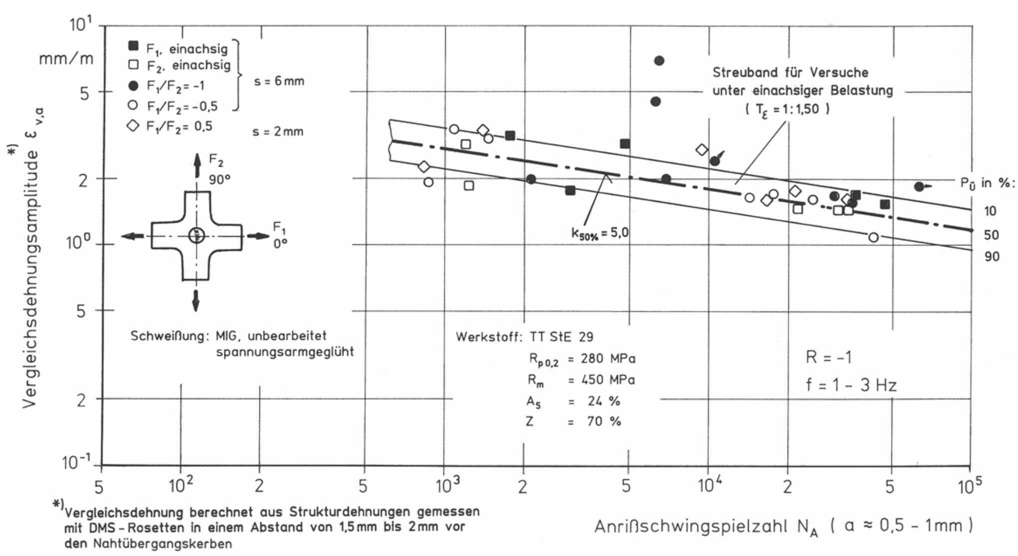
Anordnung von Dehnungsmessstreifen und Beispiel einer Dehnungsmessung



DIA 5188d.ppt

Fraunhofer
LBF

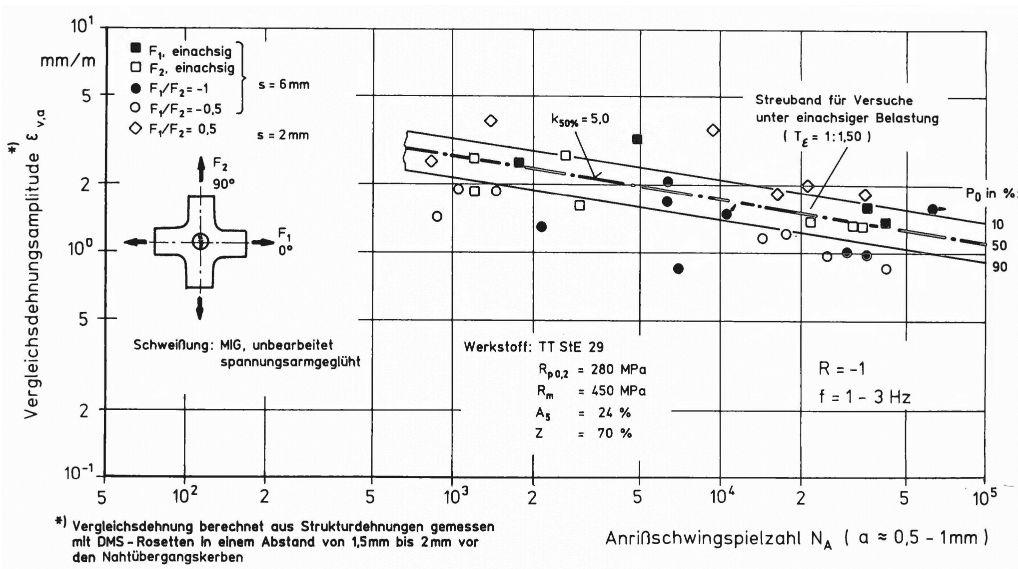
Bewertung der Ergebnisse nach der Gestaltänderungsenergiehypothese



DIA 5205d.ppt

Fraunhofer LBF

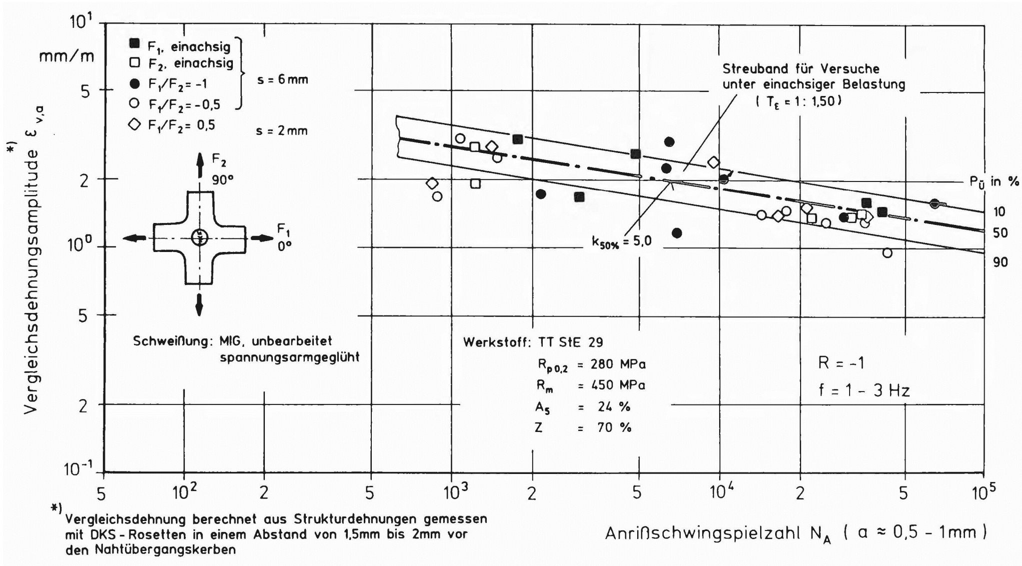
Bewertung der Ergebnisse nach der Normalspannungshypothese



DIA 5206 d

Fraunhofer LBF

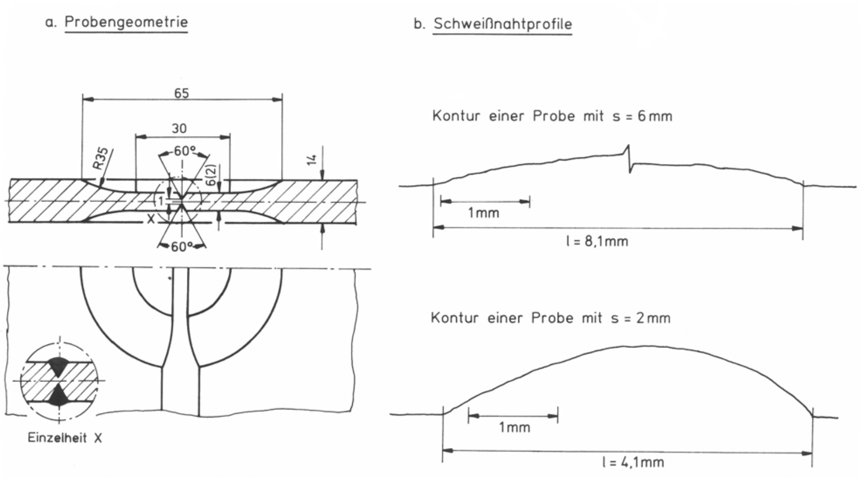
Bewertung der Ergebnisse nach der Normaldehnungshypothese



DIA 5207 d

Fraunhofer LBF

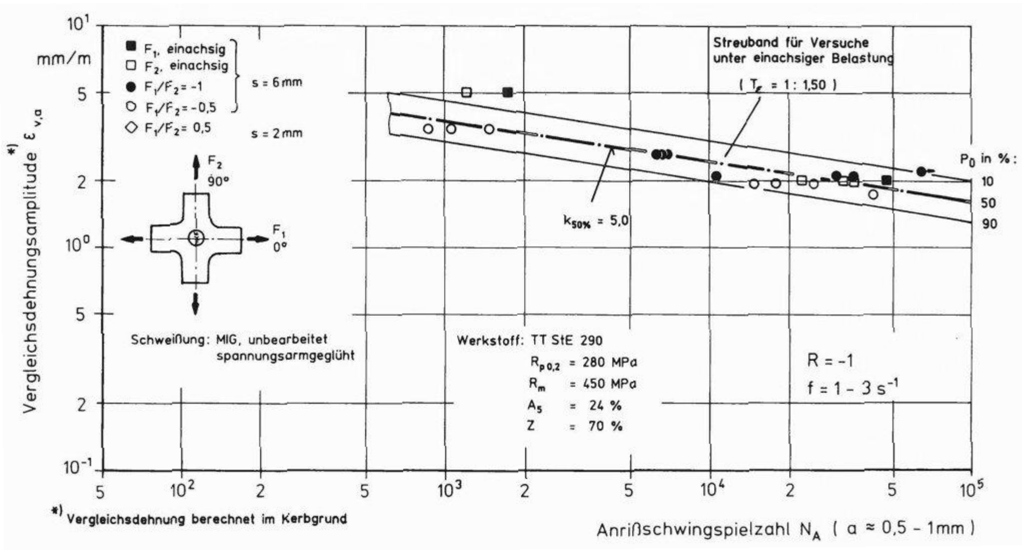
Angaben zur Probengeometrie



DIA 5187d.ppt

Fraunhofer LBF

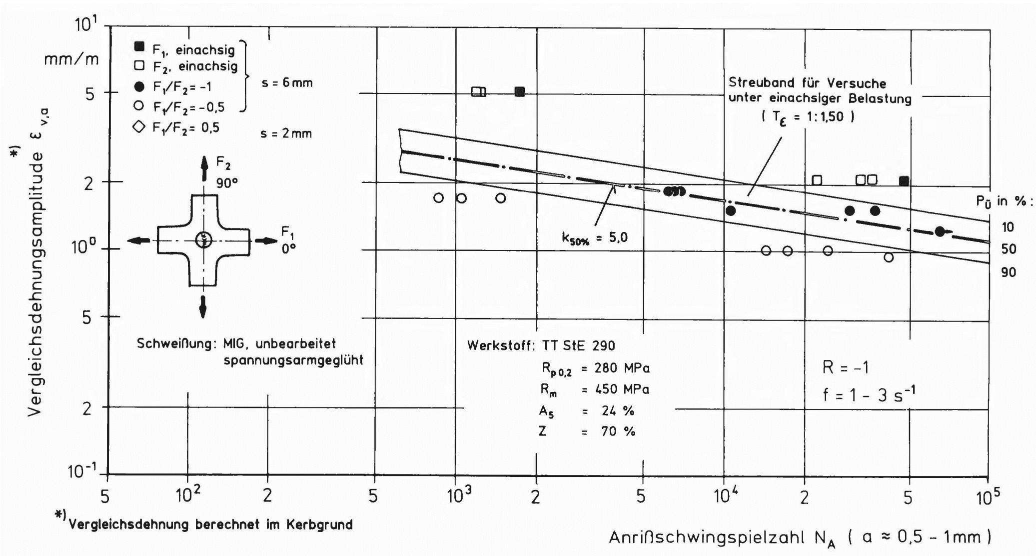
Bewertung der Ergebnisse nach der Gestaltsänderungsenergiehypothese



DIA 5469 d

Fraunhofer LBF

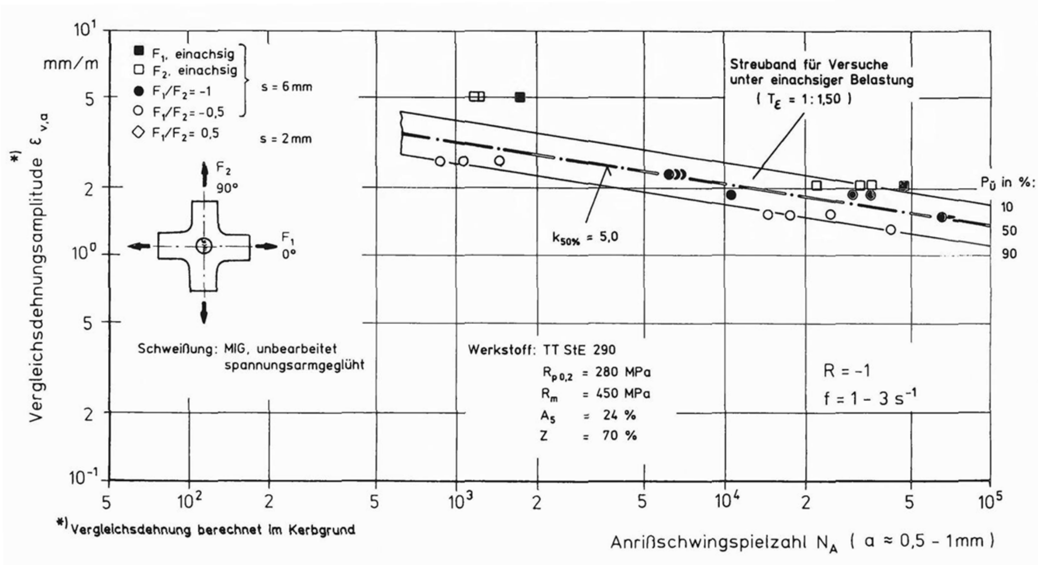
Bewertung der Ergebnisse nach der Normalspannungshypothese



DIA 5470 d

Fraunhofer LBF

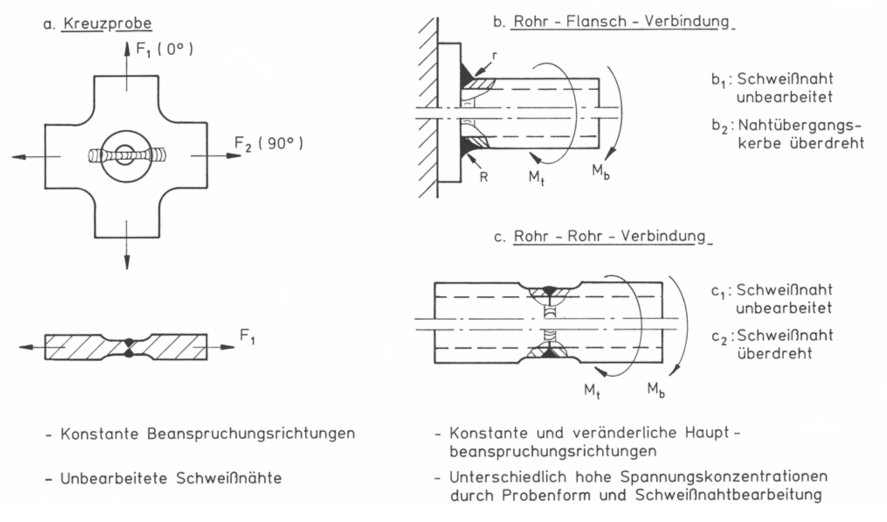
Bewertung der Ergebnisse nach der Normaldehnungshypothese



DIA 5471 d

Fraunhofer LBF

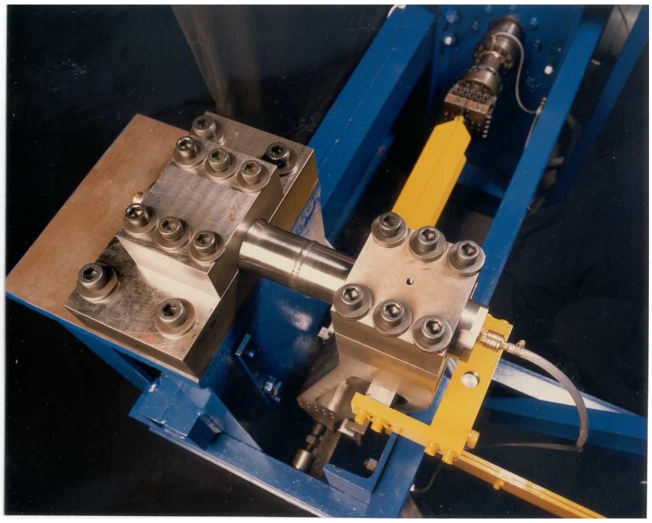
Probenformen zur Untersuchung des Einflusses von mehrachsigen Beanspruchungen auf das Festigkeitsverhalten von Schweißverbindungen



DIA 5185d.ppt

Fraunhofer LBF

Mehrachsigkeit - Winkelprüfstand



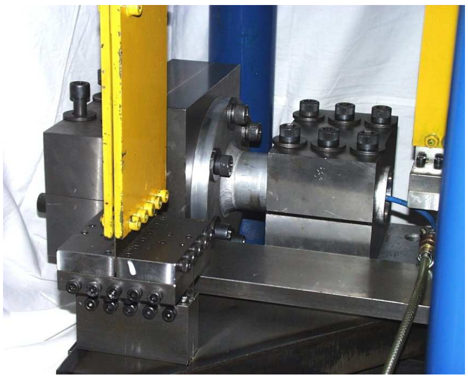
DIA 5139d

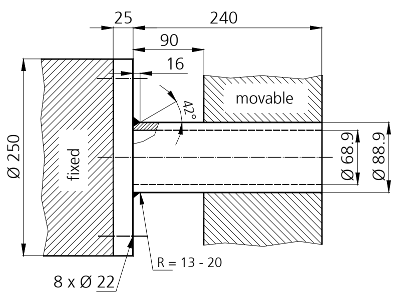
Fraunhofer LBF

Test Rig and Specimen Geometry for Aluminium Connections

a. Experimental setup for biaxial testing

b. Flange-tube specimen and clamping



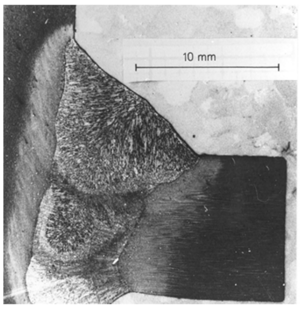


DIA 6713e.ppt

Fraunhofer LBF

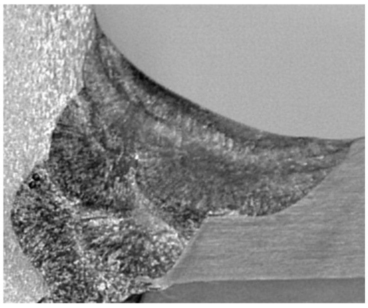
Geometry of the Welds

a. Steel St E 460



r_m = 0,45 mm , θ = 45°
K_{tb} = 3,93 , K_{tt} = 1,85

b. Aluminium AlSi1MgMn T6

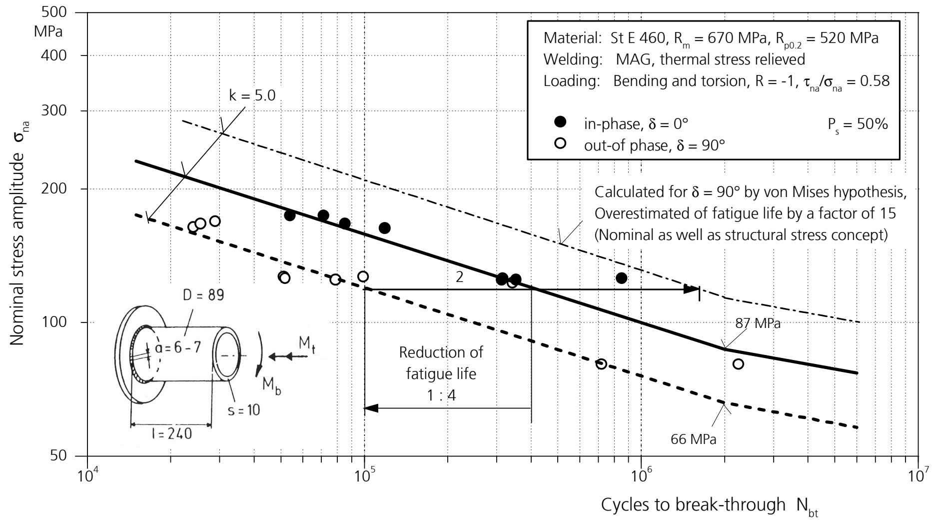


r_m = 17,0 mm , θ = 38°
K_{tb} = 1,62 , K_{tt} = 1,14

DIA 6763e

Fraunhofer LBF

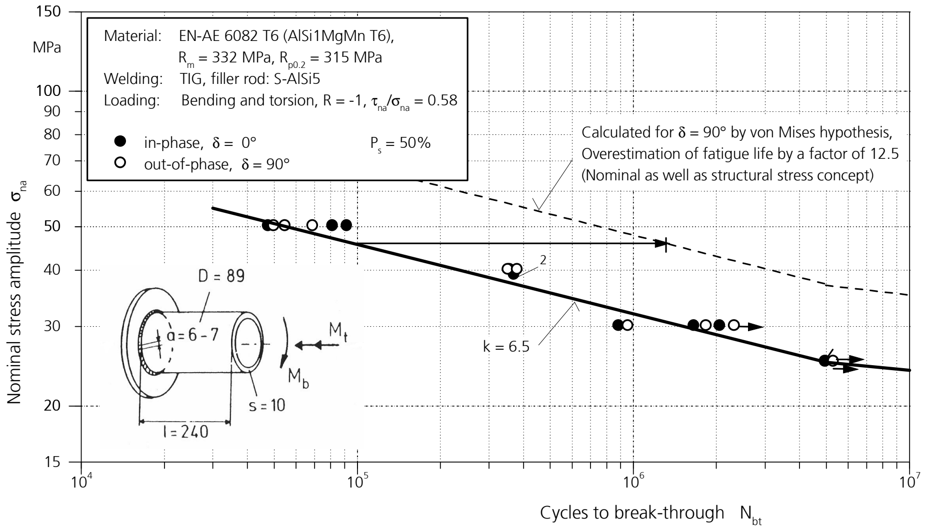
Multiaxial Fatigue Behaviour of Welded Steel Joints under Constant Amplitude Loading



DIA 6659e.ppt

Fraunhofer LBF

Multiaxial Fatigue Behaviour of Welded Aluminium Joints under Constant Amplitude Loading



Effective Equivalent Stress Hypothesis (EESH)

$$F(\delta) = \frac{1}{\pi} \int_{0}^{\pi} f_p(\varphi)\, d\varphi \qquad (1)$$

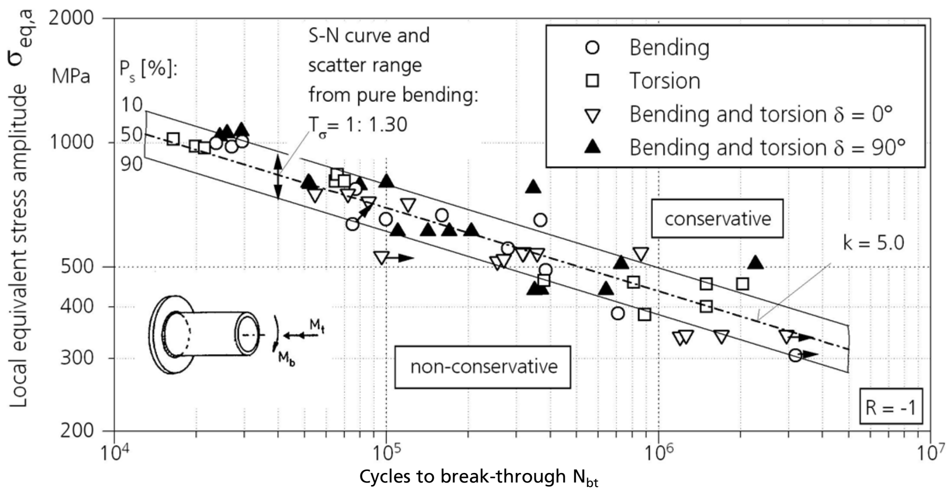
$$f_p(\varphi) = \tau_n(\varphi) \qquad (2)$$

$$f_p(\varphi) = \frac{1}{L_s} \sum_{i=1}^{L_s} \tau_{n,i}(\varphi) \qquad (3)$$

$$\sigma_v(\delta) = \sigma_v(\delta = 0°) \cdot \frac{F(\delta)}{F(\delta = 0°)} \qquad (4)$$

$$\sigma_v(\delta = 0°) = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3\,\tau_{xy}^2} \qquad (5)$$

Application of the Effective Equivalent Stress Hypothesis for As-Welded Flange-Tube Connections under Combined Constant Amplitude Loading



DIA 6726e

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Hypothesis of the Combined Normal and Shear Stress (KoNoS)

$$S\,(\varphi,\delta) = \sqrt{\sigma_n{}^2(\varphi,\delta) + 3\,\tau_n{}^2\,(\varphi,\delta)} \qquad (1)$$

$$\sigma_V\,(\delta) = \sigma_V\,(\delta = 0°) \cdot \frac{S(\varphi^{**},\delta)}{S(\varphi^{*},\delta = 0°)} \qquad (2)$$

$$\sigma_V(\delta = 0°) = \sqrt{\sigma_x{}^2 + \sigma_y{}^2 - \sigma_x \cdot \sigma_y + 3\,\tau_{xy}{}^2} \qquad (3)$$

DIA 6859e

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Application of the Hypothesis KoNoS for Tube-to-Plate Weldings under Constant Amplitude Loading

Material: AlSi1MgMn T6
EN-AW 6082 T6
$R_{p\,0.2}$ = 315 MPa
R_m = 332 MPa

Welding: TIG
Filler rod: S-AlSi5

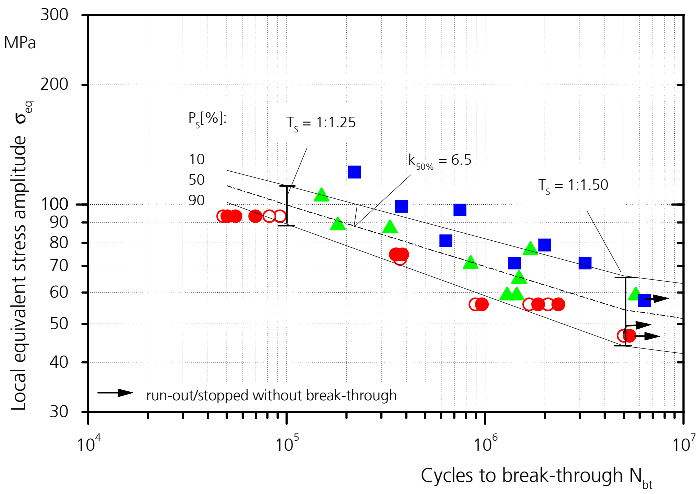
Test series: Flange-tube
R = -1
Constant amplitude loading

▲ **Bending**

■ **Torsion**

○ **Bending and Torsion**
(δ = 0°, T_a/S_a = 0.58)

● **Bending and Torsion**
(δ = 90°, T_a/S_a = 0.58)



DIA 7523e

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Introduction of Local Normal and Shear Stresses into the Gough-Pollard Equation According to Different Hypotheses

Modified Gough-Pollard Equation:

$$\left(\frac{\Delta\sigma_{Load}}{\Delta\sigma_{SN}(N)}\right)^{k_\sigma} + \left(\frac{\Delta\tau_{Load}}{\Delta\tau_{SN}(N)}\right)^{k_\tau} \leq D_{MA} \qquad k_\sigma = k_\tau = 2$$

Stress tensor:

$$\Delta\bar{\sigma}_{Load} = \begin{bmatrix} \Delta\sigma_{x,Load} & \Delta\tau_{xy,Load} \\ \Delta\tau_{xy,Load} & \Delta\sigma_{y,Load} \end{bmatrix}$$

Shear stresses:

$\Delta\tau_{load} = \Delta\tau_{xy,load}$
with $\Delta\tau_{SN}(N)$ from pure torsion

Principal stress:

$\Delta\sigma_{Load} = \Delta\sigma_{Load,1} = \Delta\sigma_{x,Load}$
with $\Delta\sigma_{SN}(N)$ according to PSH

von Mises:

$$\Delta\sigma_{Load} = \Delta\sigma_{Load,von\,Mises} = \sqrt{\Delta\sigma_{x,Load}^2 + \Delta\sigma_{y,Load}^2 - \Delta\sigma_{x,Load}\cdot\Delta\sigma_{y,Load}}$$

with $\Delta\sigma_{SN}(N)$ according to von Mises

DIA 8070e.ppt

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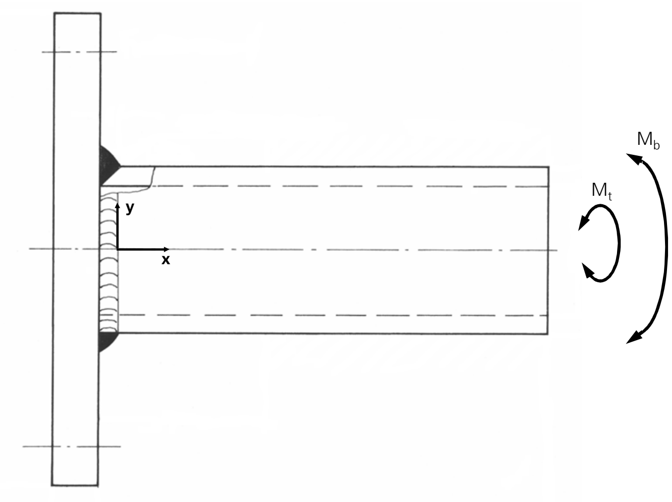
Coordinate System for Normal and Shear Stress Components



$$\Delta\bar{\sigma}_{Load} = \begin{bmatrix} \Delta\sigma_{x,Load} & \Delta\tau_{xy,Load} \\ \Delta\tau_{xy,Load} & \Delta\sigma_{y,Load} \end{bmatrix}$$

DIA 8080e.ppt

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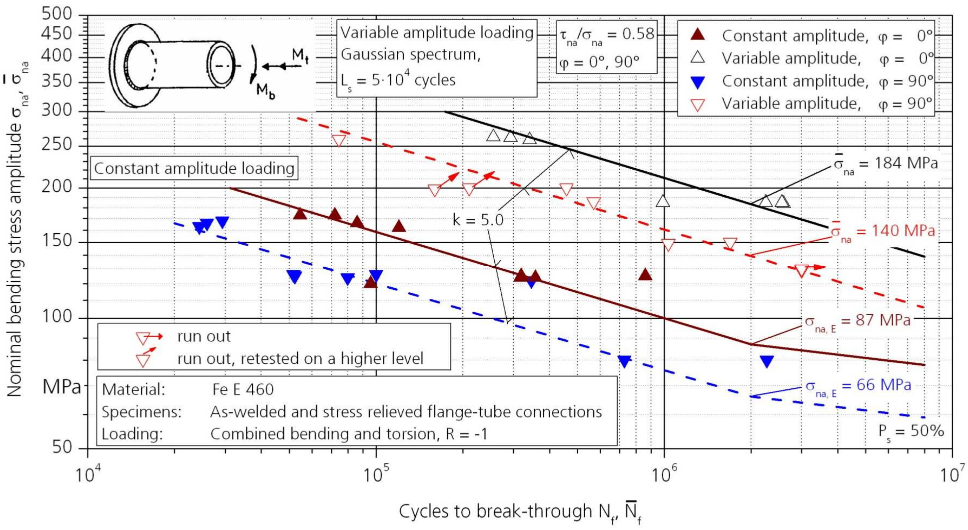
Fatigue Testing Results Obtained with As-Welded Steel Specimens under Combined Bending and Torsion (φ =0° and 90°)



DIA 8075e

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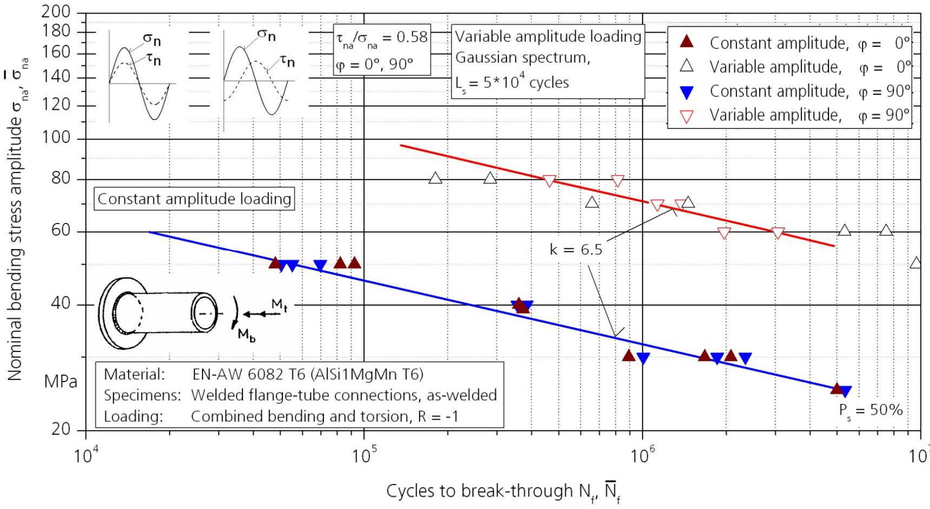
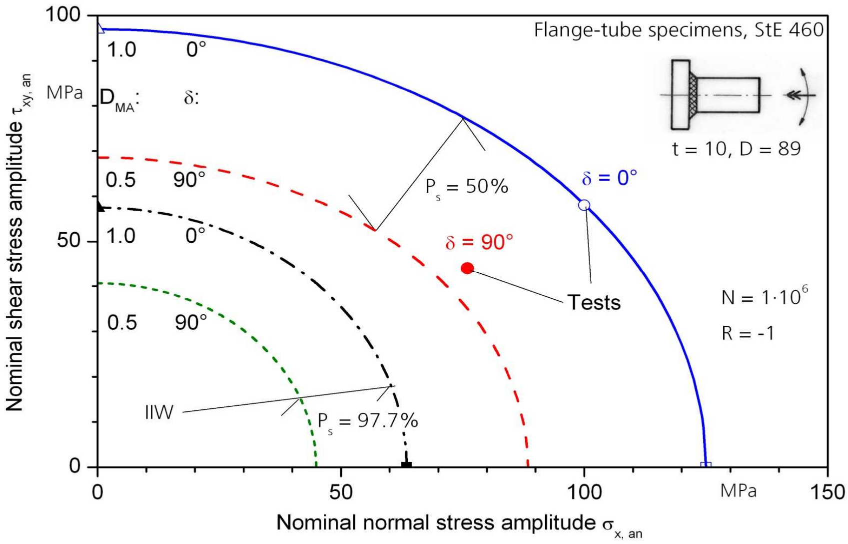
Fatigue Testing Results Obtained with As-Welded Aluminium Specimens under Combined Bending and Torsion (φ =0° and 90°)



DIA 8076e

Fraunhofer LBF

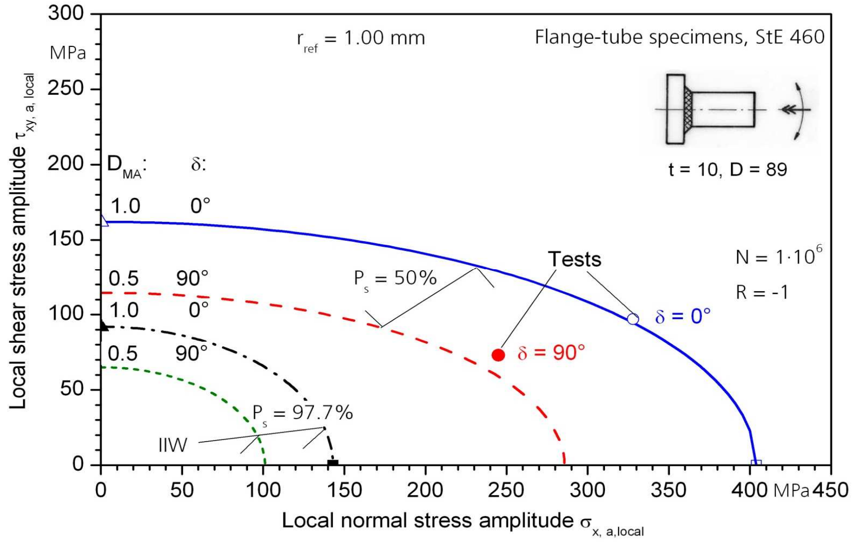
Assessment of Fusion Welded Thick Steel Flange-Tube Joints under In- and Out-of-Phase Multiaxial Loading (Nominal Stress System)



DIA 8356e

Fraunhofer LBF

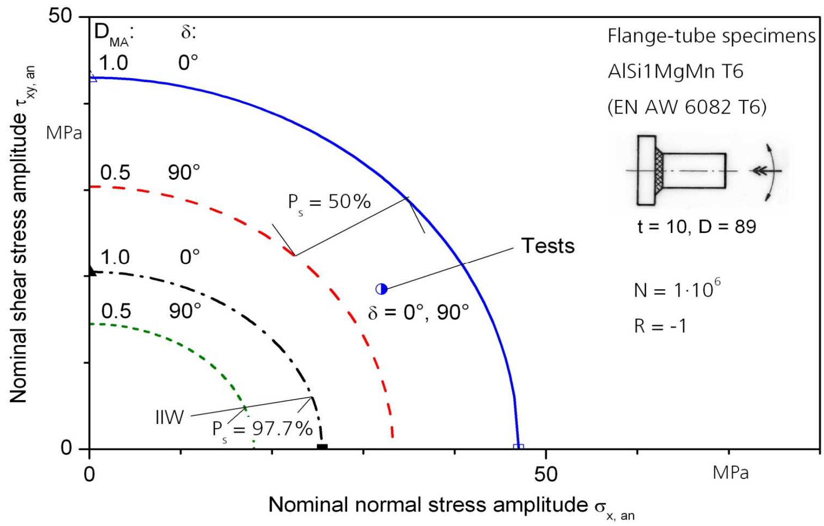
Assessment of Fusion Welded Thick Steel Flange-Tube Joints under In- and Out-of-Phase Multiaxial Loading (Local Stress System)



DIA 8358e

Fraunhofer LBF

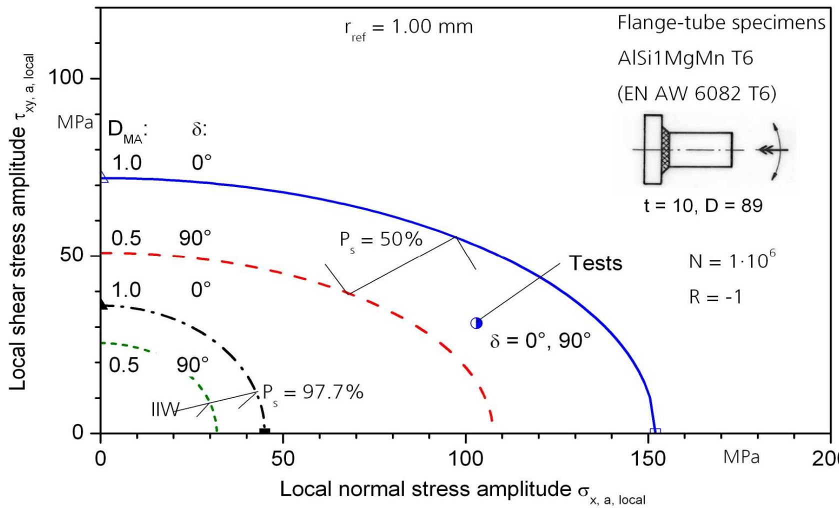
Assessment of Fusion Welded Thick Aluminium Flange-Tube Joints under In- and Out-of-Phase Multiaxial Loading (Nominal Stress System)



DIA 8361e

Fraunhofer LBF

Assessment of Fusion Welded Thick Aluminium Flange-Tube Joints under In- and Out-of-Phase Multiaxial Loading (Local Stress System)



DIA 8363e

Recommended Assessment Procedure for Multiaxial Loading (2010)

$$\left(\frac{\Delta\sigma_{load}}{\Delta\sigma_{SN}(N)}\right)^{k_\sigma} + \left(\frac{\Delta\tau_{load}}{\Delta\tau_{SN}(N)}\right)^{k_\tau} \leq D_{MA}$$

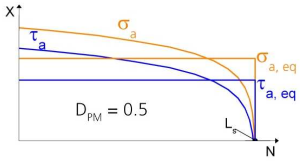
$k_\sigma = k_\tau = 2$	Exponents of the Gough-Pollard equation
$D_{MA} = 1.0$	For constant principal stress directions, in-phase (proportional) loading for steel (Eurocode 3, IIW) and aluminium
$D_{MA} = 0.5$	For changing principal stress directions, out-of-phase (unproportional) loading for steel and ductile aluminium alloys*)
$\Delta\sigma_{load} = 2\cdot\sigma_{a,load}$ $\Delta\tau_{load} = 2\cdot\tau_{a,load}$	Nominal, hot-spot or local stress components of the biaxial stress state induced by external loading
$\Delta\sigma_{SN}(N) = 2\cdot\sigma_{a,SN}(N)$ $\Delta\tau_{SN}(N) = 2\cdot\tau_{a,SN}(N)$	Endurable nominal, hot-spot or local stresses at N cycles under pure axial loading (or bending) and pure torsion

*)For semi-ductile aluminium alloys $D_{MA} = 1.0$

DIA 7898e

Prerequisites and Equations for the Assessment of Multiaxial Spectrum Loading

1 Cumulative damage



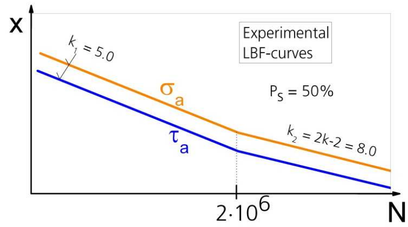
$$x_{a,eq} = \sqrt[k_1]{\frac{1}{D_{PM}} \cdot \frac{\sum \left(n_i \cdot x_{a,i}^{k_1}\right) + x_{k,a}^{(k_1 - k_2)} \cdot \sum \left(n_j \cdot x_{a,j}^{k_2}\right)}{\sum n_i + \sum n_j}}$$

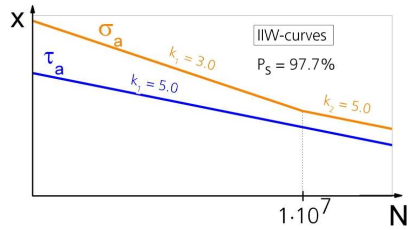
2 Multiaxial assessment

$$\left(\frac{\sigma_{a,eq}}{\sigma_{a,SN}(N)}\right)^2 + \left(\frac{\tau_{a,eq}}{\tau_{a,SN}(N)}\right)^2 \leq D_{MA}$$

Material	Proportional loading D_{MA}	Non-proportional loading D_{MA}
Steel / Aluminium	1.0	0.5

3 SN curves





DIA 7955e.ppt

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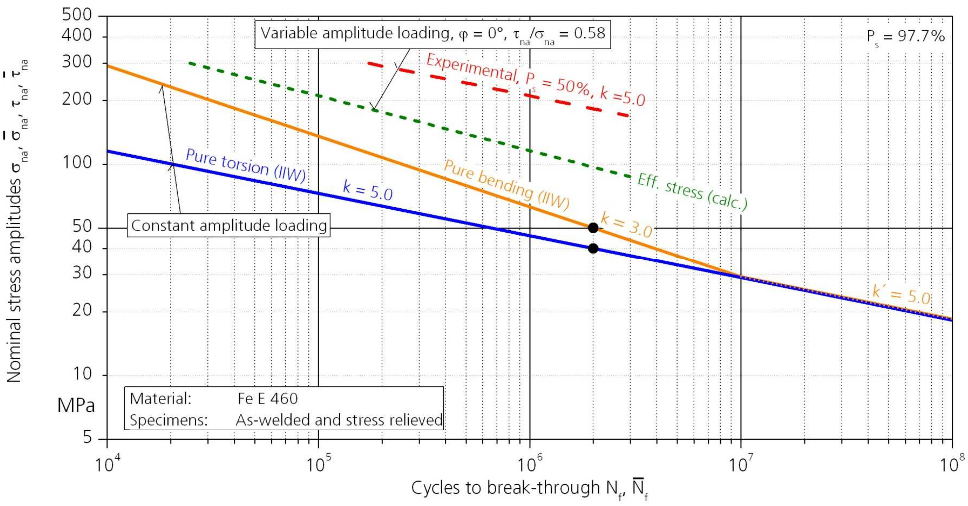
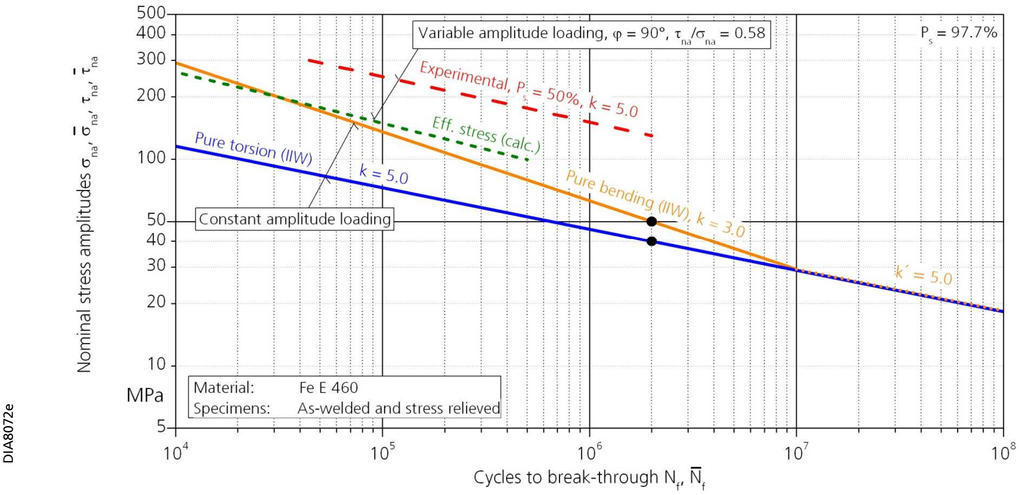
Evaluation of Multiaxial Spectrum Loading on As-Welded Steel Joints with IIW-SN-Lines



DIA8071e

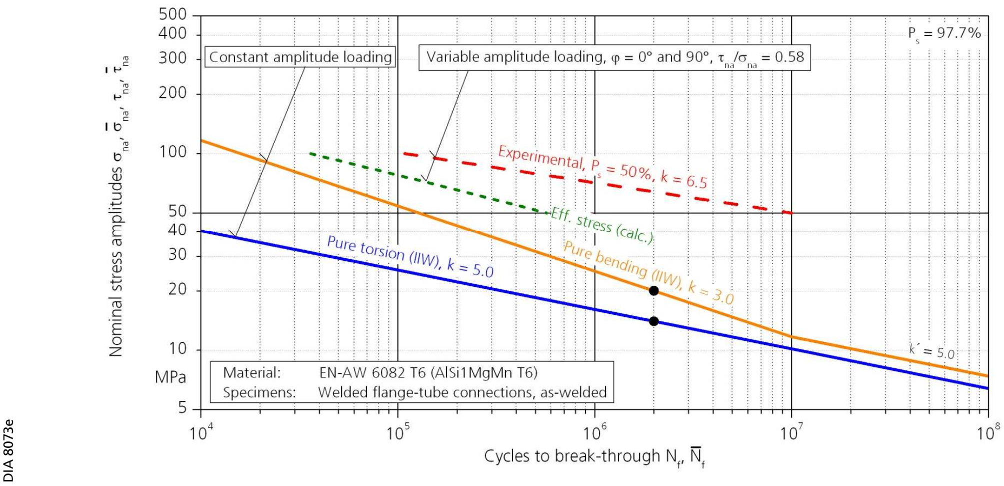
Fraunhofer LBF

Evaluation of Multiaxial Spectrum Loading on AS-Welded Steel Joints with IIW-SN-Lines



Fraunhofer LBF

Evaluation of Multiaxial Spectrum Loading on AS-Welded Steel Joints with IIW-SN-Lines



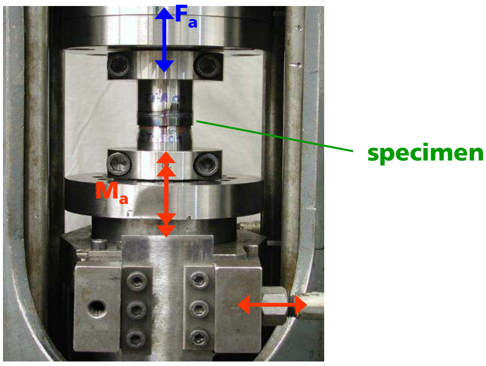
Fraunhofer LBF

Biaxial Testing of Overlapped Laserbeam-Welded Tube-Tube Specimens

Test conditions:

- Constant and variable amplitudes under load control
- Load ratio: R = -1
- Test frequency: 20 Hz
- Laboratory conditions: In air at room temperature

Biaxial test rig:



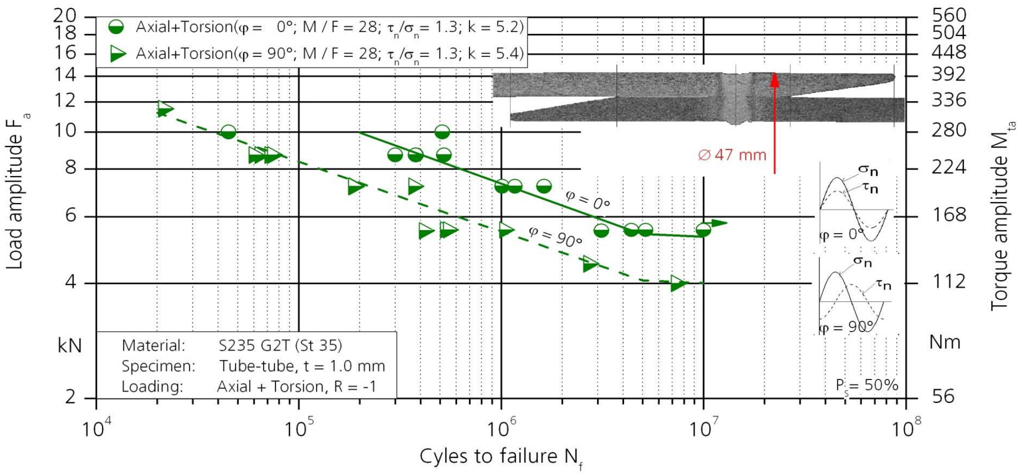
$F_{a,\,max}$ = 80 kN

$M_{a,\,max}$ = 3 kNm

DIA 8529 e

Fraunhofer LBF

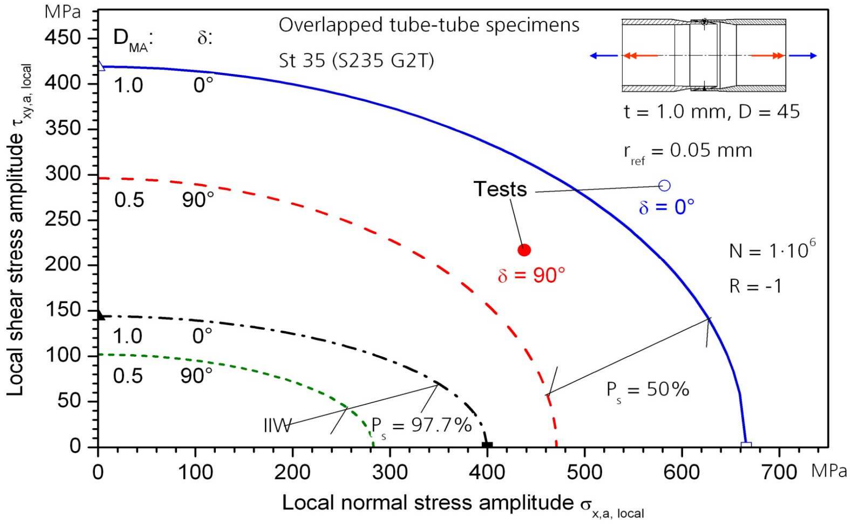
Laserbeam-Welded Overlapped Steel Tube-Tube Specimens under Constant Amplitude Multiaxial Loading



DIA 8302e

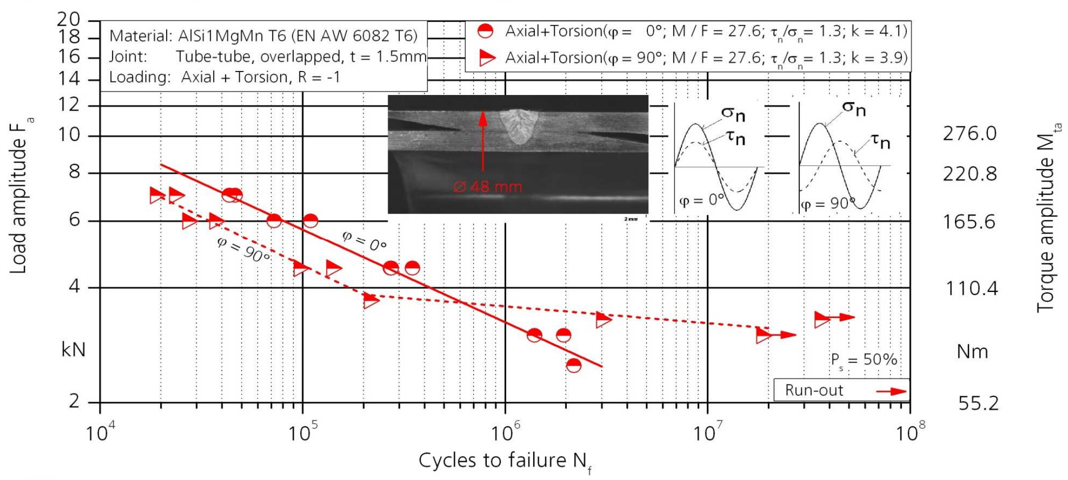
Fraunhofer LBF

Assessment of Laserbeam-Welded Thin Steel Tube-Tube Joints under In- and Out-of-Phase Multiaxial Loading (Local Stress System)



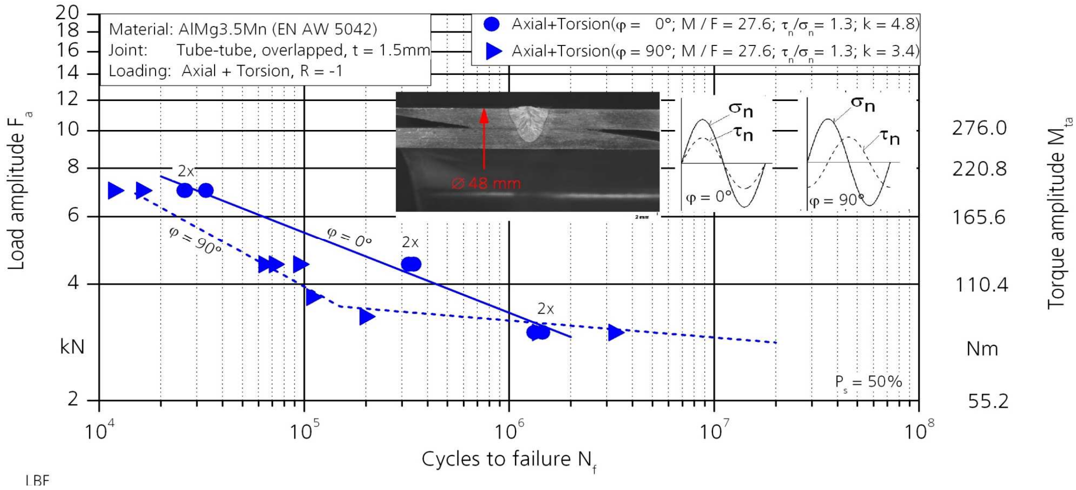
DIA 8360e

Laserbem-welded Overlapped Aluminium Tube-Tube Specimanes under Constant Amplitude Multiaxial Loading



DIA 8297e

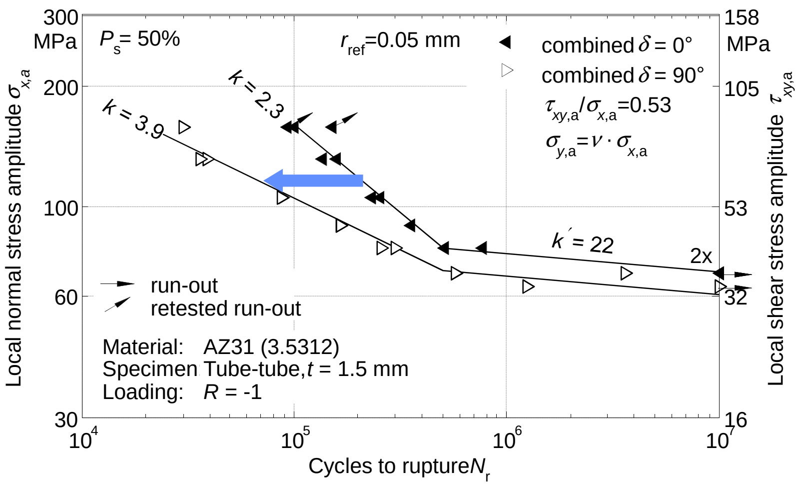
Laserbeam-welded Overlapped Aluminium Tube-Tube Specimens under Constant Amplitude Multiaxial Loading



DIA 8298e

Fraunhofer LBF

Experimental Results for Laserbeamwelded Magnesium Tubes



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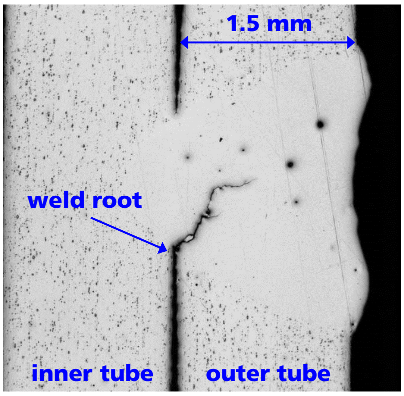
Typical failures

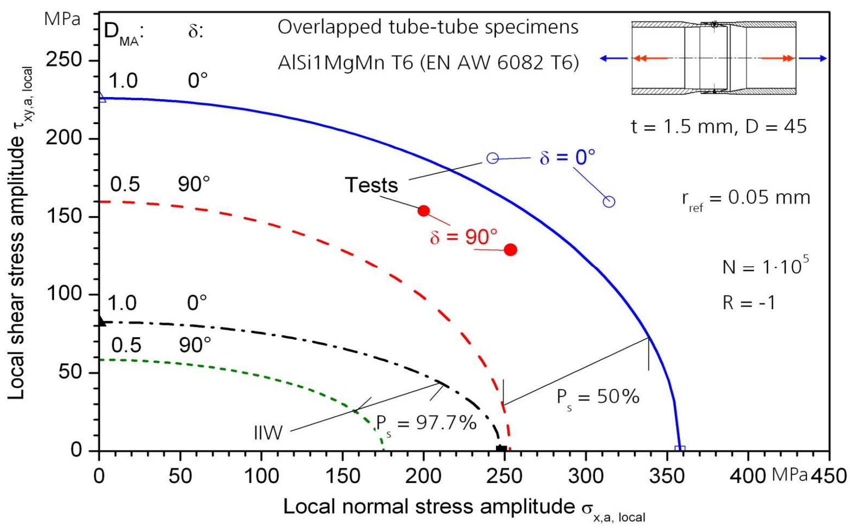
Independent of load combination and level!



DIA 8532 e

Fraunhofer LBF

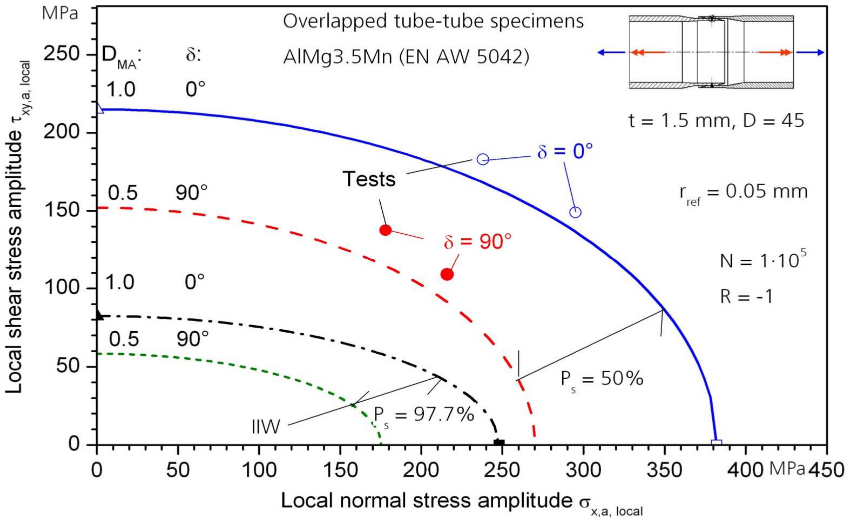
Assessment of Laserbeam-Welded Thin Aluminium Tube-Tube Joints under In- and Out-of-Phase Multiaxial Loading (Local Stress System)



DIA 8365e

Fraunhofer LBF

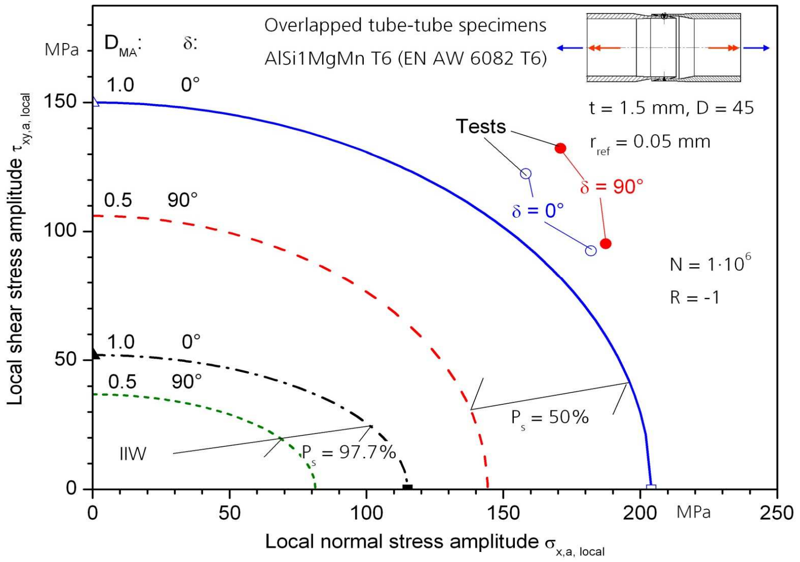
Assessment of Laserbeam-Welded Thin Aluminium Tube-Tube Joints under In- and Out-of-Phase Multiaxial Loading (Local Stress System)



DIA 8366e

Fraunhofer LBF

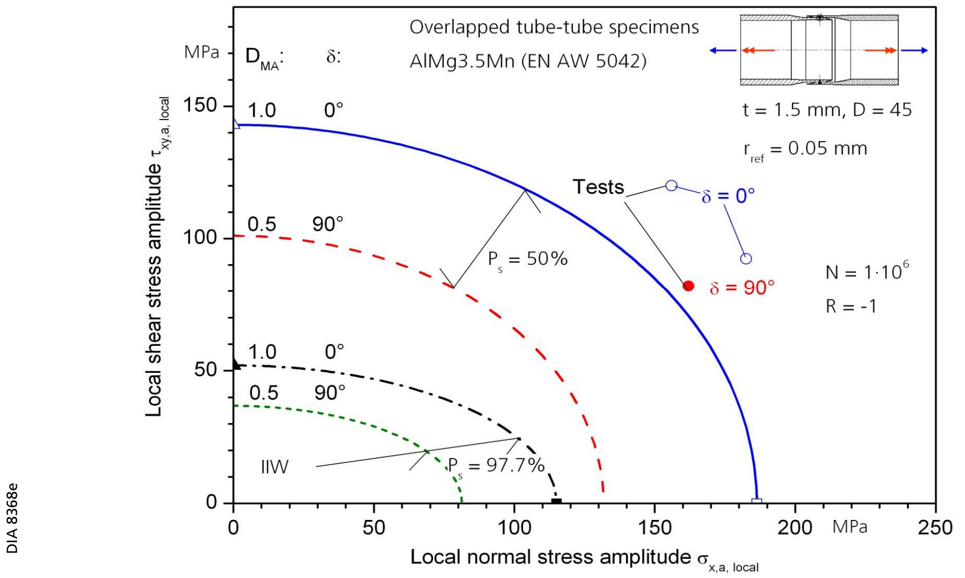
Assessment of Laserbeam-Welded Thin Aluminium Tube-Tube Joints under In- and Out-of-Phase Multiaxial Loading (Local Stress System)



DIA 8367e

Fraunhofer LBF

Assessment of Laserbeam-Welded Thin Aluminium Tube-Tube Joints under In- and Out-of-Phase Multiaxial Loading (Local Stress System)



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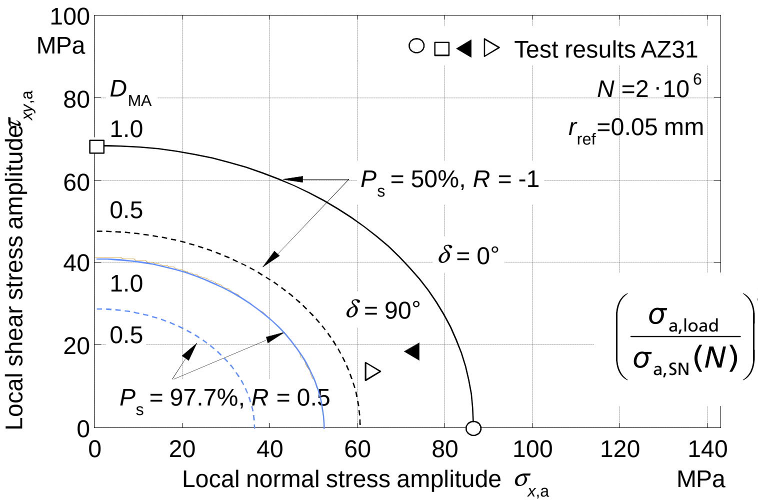
Evaluation of Test Results from Laserbeamwelded Magnesium Tubes According to Gough-Pollard Equation



$$\left(\frac{\sigma_{a,load}}{\sigma_{a,SN}(N)}\right)^2 + \left(\frac{\tau_{a,load}}{\tau_{a,SN}(N)}\right)^2 < D_{MA}$$

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Bewertung mehrachsiger Spannungszustände nach den IIW-Empfehlungen (2010)

$$\left(\frac{\Delta\sigma_{Last}}{\Delta\sigma_{WL}(N)}\right)^{k_\sigma} + \left(\frac{\Delta\tau_{Last}}{\Delta\tau_{WL}(N)}\right)^{k_\tau} \leq D_{MA}$$

$k_\sigma = k_\tau = 2$	Exponenten der Gough-Pollard Beziehung
$D_{MA} = 1.0$	Für konstante Hauptspannungsrichtungen, phasengleiche (proportionale) Belastung für Stahl (Eurocode 3, IIW) und Aluminium
$D_{MA} = 0.5$	Für sich ändernde Hauptspannungsrichtungen, phasenverschobene (nicht proportionale) Belastung für Stahl und duktiles Aluminium*)
$\Delta\sigma_{Last} = 2 \cdot \sigma_{a,Last}$ $\Delta\tau_{Last} = 2 \cdot \tau_{a,Last}$	Nenn-, Hot-Spot oder örtliche Spannungskomponenten des zweiachigen Spannungszustandes infolge der äußeren Belastung
$\Delta\sigma_{WL}(N) = 2 \cdot \sigma_{a,WL}(N)$ $\Delta\tau_{WL}(N) = 2 \cdot \tau_{a,WL}(N)$	Ertragbare Nenn- , Hot-Spot oder der örtliche Spannungen bei N Schwingspielen unter reiner Axialbelastung bzw. Biegung und reiner Torsion

*) Für semi-duktile Aluminiumlegierungen $D_{MA} = 1.0$

DIA 7898d

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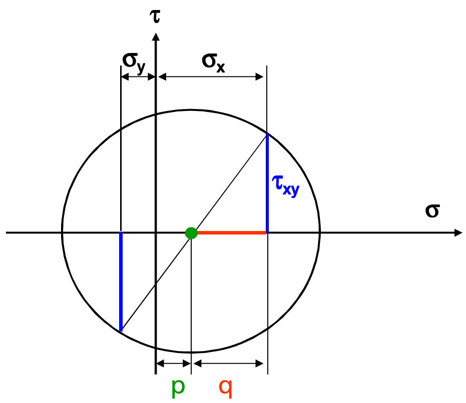
The Stress Space Curve Hypothesis SSCH

$$\sigma_{eq} = \sqrt{I_1^2 - (4-\alpha)\cdot I_2}$$

$$\Downarrow$$

$$\sigma_{eq} = \sqrt{\alpha \cdot \mathbf{p}^2 + (4-\alpha)\cdot(\mathbf{q}^2 + \tau_{xy}^2)}$$

with
- $p = (\sigma_x + \sigma_y) / 2$
- $q = (\sigma_x - \sigma_y) / 2$
- τ_{xy}



This approach can be linked to other hypotheses:

$\alpha = 1 \rightarrow$ v. Mises
$\alpha = 0 \rightarrow$ Tresca

DIA 8524 e

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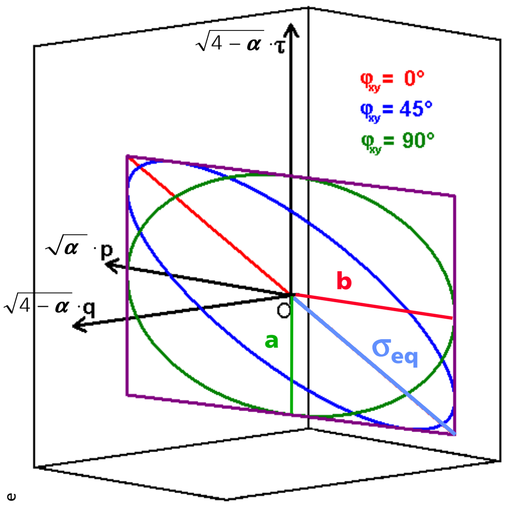
Assessment of Multiaxial Loading



$$\sigma_{eq} = \sqrt{a^2 + b^2}$$
$$= \sqrt{\alpha \cdot p_a^{\,2} + (4-\alpha)\cdot\left(q_a^{\,2} + \tau_a^{\,2}\right)}$$

a: semi minor axis of the ellipses
b: semi major axis of the ellipses

Consideration of out-of phase effects:

$$\sigma_{eq} = \sqrt{a^2 + b^2} \cdot \left(1 + \frac{\rho \cdot a \cdot b}{a^2 + b^2}\right)$$

Free parameter ρ**:**

ρ > 0 → lifetime decrease
ρ = 0 → neutral behaviour
ρ < 0 → liftetime increase

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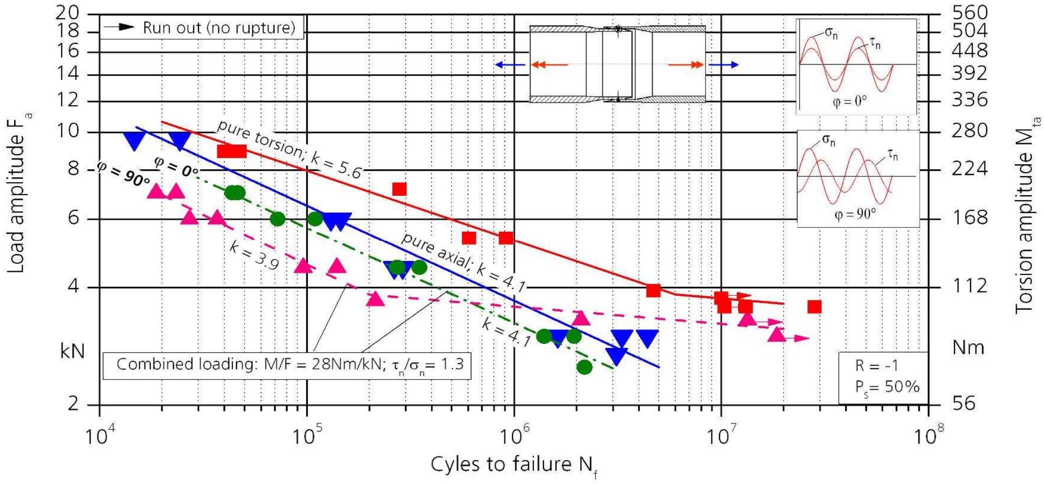
Experimental Results Constant Amplitude Loading



DIA 8530 e

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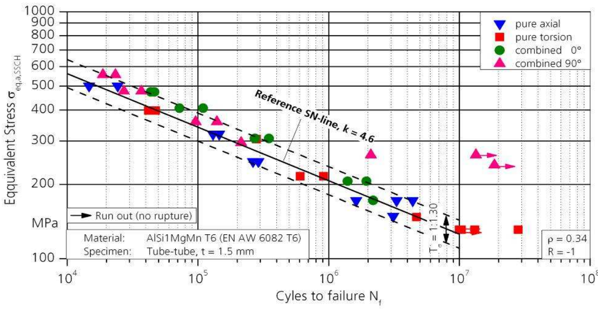
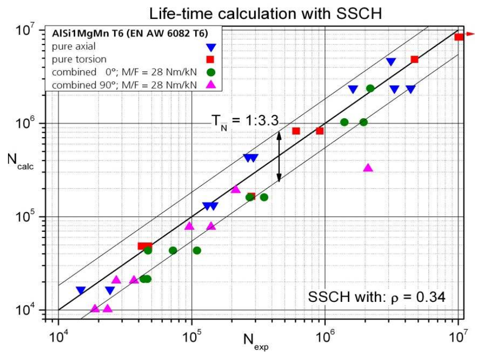
Assessment of Multiaxial Loading with SSCH

$\sigma_{eq,\ SSCH}$ vs. N_{exp}



N_{calc} vs. N_{exp}



DIA 8526 e

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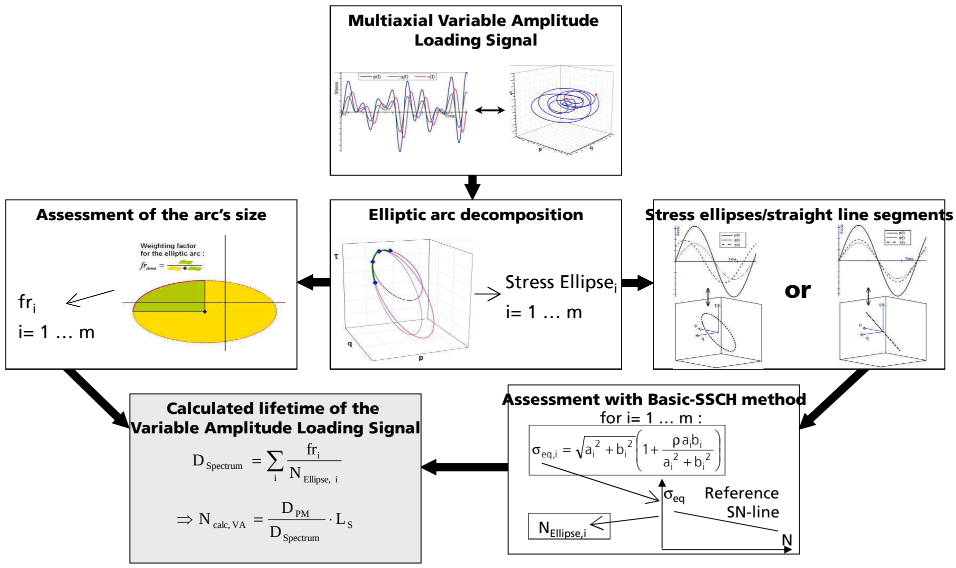
Assessment of Multiaxial Loading



DIA 8527 e

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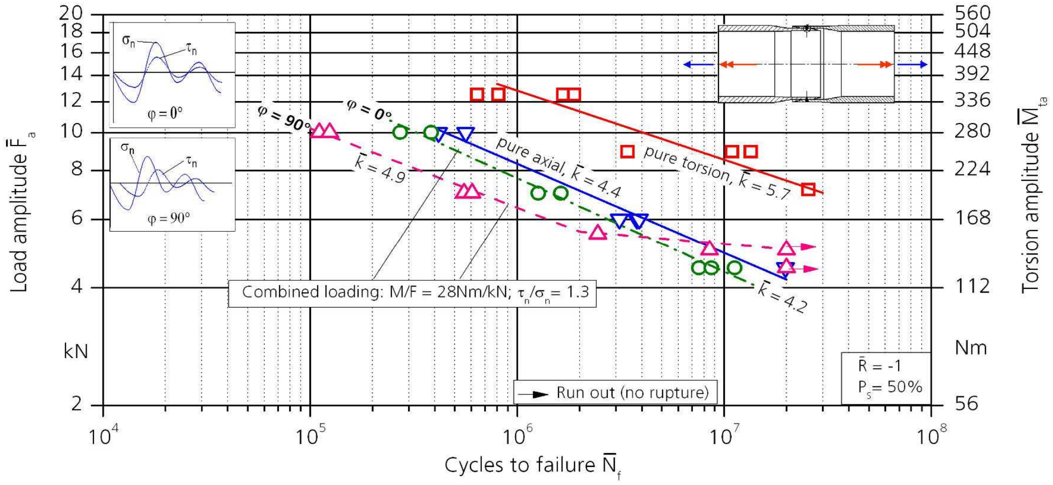
Experimental Results Variable Amplitude Loading



DIA 8531 e

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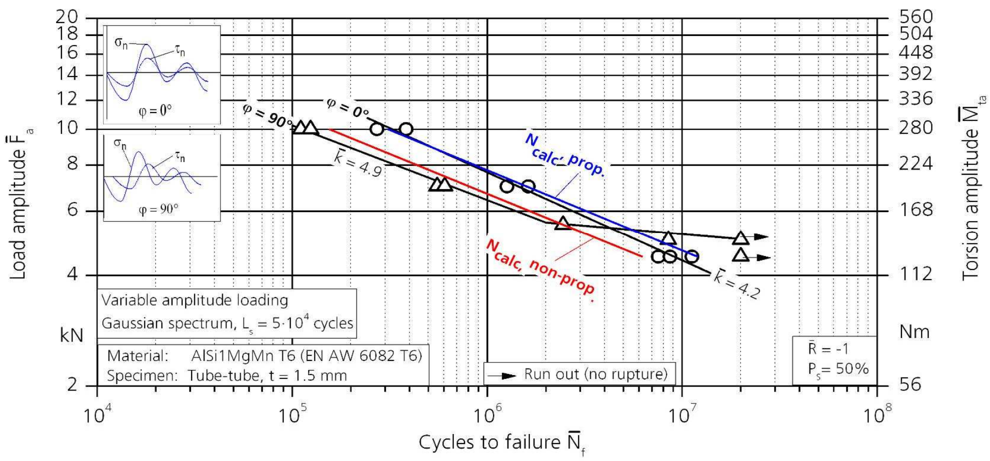
Assessment of Multiaxial Loading

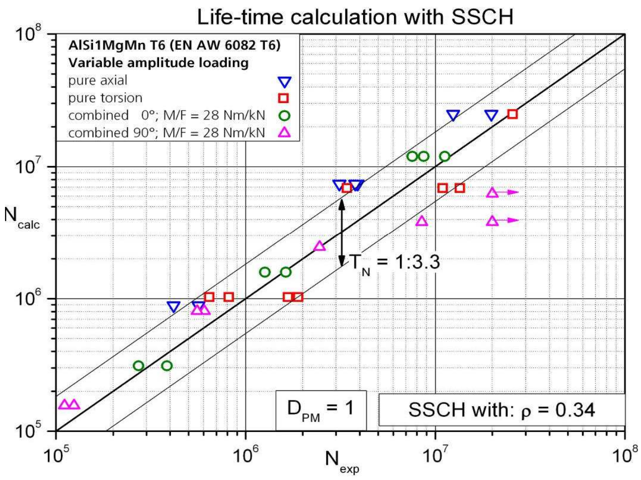
Calculated Lifetime N_{calc} for multiaxial spectrum loading



DIA 8533 e

Fraunhofer LBF

N_{calc} versus N_{exp} for Variable Amplitude Loading



DIA 8528 e

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Praktische Hinweise für die Auswahl einer geeigneten Hypothese

- Eine allgemeingültige Festigkeitshypothese ist nicht verfügbar.
- Für Werkstoffe mit geringer Bruchdehnung (A_5 etwa < 5%) liefert die Normal- (Hauptspannungs-) Hypothese sowohl bei konstanten als auch drehenden Hauptspannungsrichtungen (infolge von Phasenverschiebungen), die die Lebensdauer verlängern, zufriedenstellende Ergebnisse (wenig duktiles / sprödes Werkstoffverhalten); maßgebend ist die Schnittebene mit der größten Normalspannung.
- Semiduktile Werkstoffe (5% < A_5 < 15%) zeigen ein neutrales Verhalten bezüglich der Drehung von Hauptspannungsrichtungen, keine Lebensdauerverlängerung oder –verkürzung. Die ungünstigste Kombination aus schnittebenen bezogenen Normal- und Schubspannungen ist für das Versagen verantwortlich. Die Gestaltänderungsenergiehypothese, als ob keine drehende Hauptspannungen (keine Phasenverschiebung) vorliegen würden, anwenden; dabei Vorzeichen (Druck oder Zug) beachten.
- Duktile Werkstoffe (A_5 etwa > 15%) reagieren auf drehende Hauptspannungsrichtungen mit einer Verkürzung der Lebensdauer. Für das Versagen sind über verschiedene Schnittebenen interaktiv wirkende Schub- und Normalspannungen verantwortlich. Die Gestaltänderungsenergiehypothese, als ob keine drehende Hauptspannungen (keine Phasenverschiebung) vorliegen würden, anwenden; dabei Vorzeichen (Druck oder Zug) beachten. Allerdings die sich ergebende Vergleichsspannung pauschal um 20% erhöhen, um dem schädigenden Einfluß der drehenden Hauptspannungen auf die Lebensdauer Rechnung zu tragen.
- Die Grenzen von Hypothesen sind nur durch Einbeziehung von Labor- und Felderfahrungen feststellbar und so in die Berechnung einzubeziehen.

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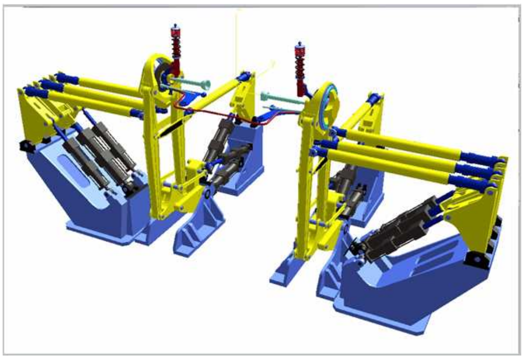
12 Channel Road Simulator at LBF and Numerical MBS Model



DIA8074e

Design life: 300.000 km
Spectrum occurance: P_o= 1%

Fraunhofer LBF

27-Kanal Ganzfahrzeugprüfstand

- ❿ Iterationsgrößen sind Radlasten & lokale Messstellen
- ❿ Lokale Messstellen zur Sicherstellung des gleichen Lastflusses im Prüfstand und Strecke
- ❿ Lokale Messstellen zur Bewertung der Simulationsgüte
- ❿ Lokale Messstellen kalibriert in kN oder in kritischen Bereichen in MPa

Fraunhofer LBF

Thanks for the kind invitation
and for your kind attention!

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