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A Strain-energy-based Prediction Model of Fatigue life

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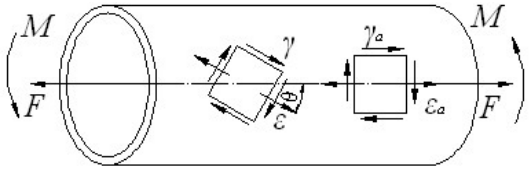
Definition of critical plane

Stress and strain tensor of thin-walled tube obtained from strain and stress Mohr's circle：

$$\Delta\sigma_{ij}=\begin{bmatrix}\sigma_{xx} & \tau_{xy} & 0\\ \tau_{xy} & 0 & 0\\ 0 & 0 & 0\end{bmatrix}\qquad \Delta\varepsilon_{ij}=\begin{bmatrix}\varepsilon_{xx} & 1/2\gamma_{xy} & 0\\ 1/2\gamma_{xy} & -\nu_{eff}\varepsilon_{xx} & 0\\ 0 & 0 & -\nu_{eff}\varepsilon_{xx}\end{bmatrix}$$

$$\varepsilon_\theta=\frac{\varepsilon_{xx}+\varepsilon_{yy}}{2}+\frac{\varepsilon_{xx}-\varepsilon_{yy}}{2}\cos(2\theta)+\frac{\gamma_{xy}}{2}\sin(2\theta)$$

$$\frac{\gamma_\theta}{2}=-\frac{\varepsilon_{xx}-\varepsilon_{yy}}{2}\sin(2\theta)+\frac{\gamma_{xy}}{2}\cos(2\theta)$$

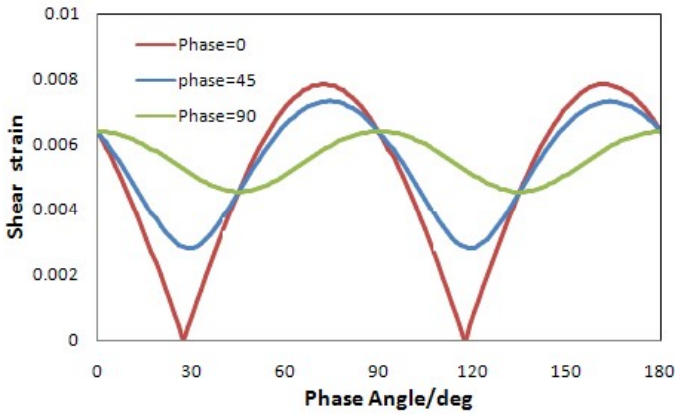


calculate γ for θ=0 to → print out the maximum value of γ =γ1,γ2,γ3 and θ=θ1,θ2,θ3 → calculate ξ,η,ε for γ =γ1,γ2,γ3and θ=θ1,θ2,θ3 → Print out maximum value of γ_{max}, ε_{ns} and corresponding θ

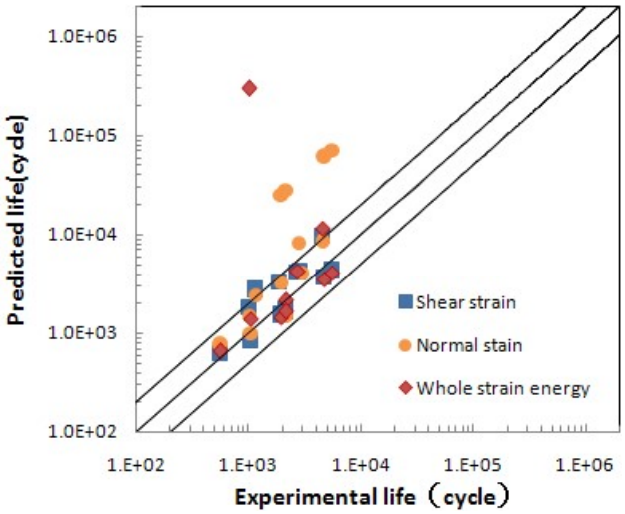
The simple flowchart to find critical plane and critical angle of thin-walled tube

Comparation of Different Critical Plane Method

Shear strain is taken as critical plane parameter



Critical angle changes with phase angle



Comparison of predicted and experimental lives for different critical plane definition method

A New fatigue life model

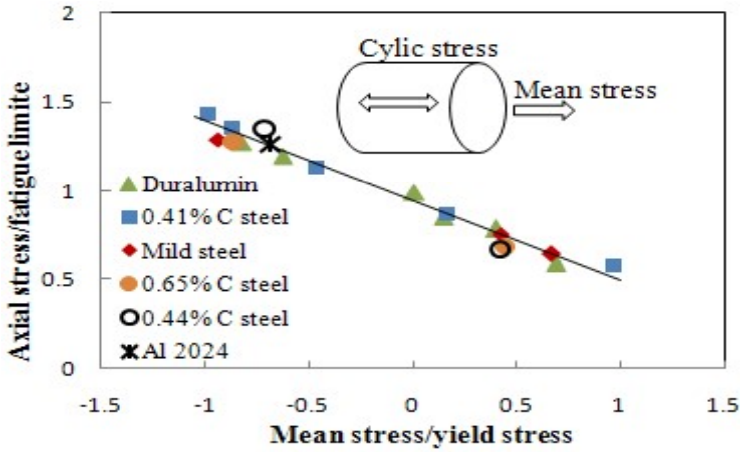
The modified fatigue life model:

Manson-coffin

$$\varepsilon_a = \varepsilon_a^e + \varepsilon_a^p = \frac{\sigma_f'}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c$$

$$\varepsilon_a = \frac{\sigma_f' - \sigma_m}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c$$

Morrow



A New fatigue life model

The modified fatigue life model:

$$\begin{cases} \varepsilon_a = \dfrac{\sigma_f' - \sigma_m}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c \\ \varepsilon_a \sigma_{\max} = \dfrac{\sigma_f'^2}{E}(2N_f)^{2b} + \sigma_f'\varepsilon_f'(2N_f)^{b+c} \end{cases}$$

$$\Downarrow$$

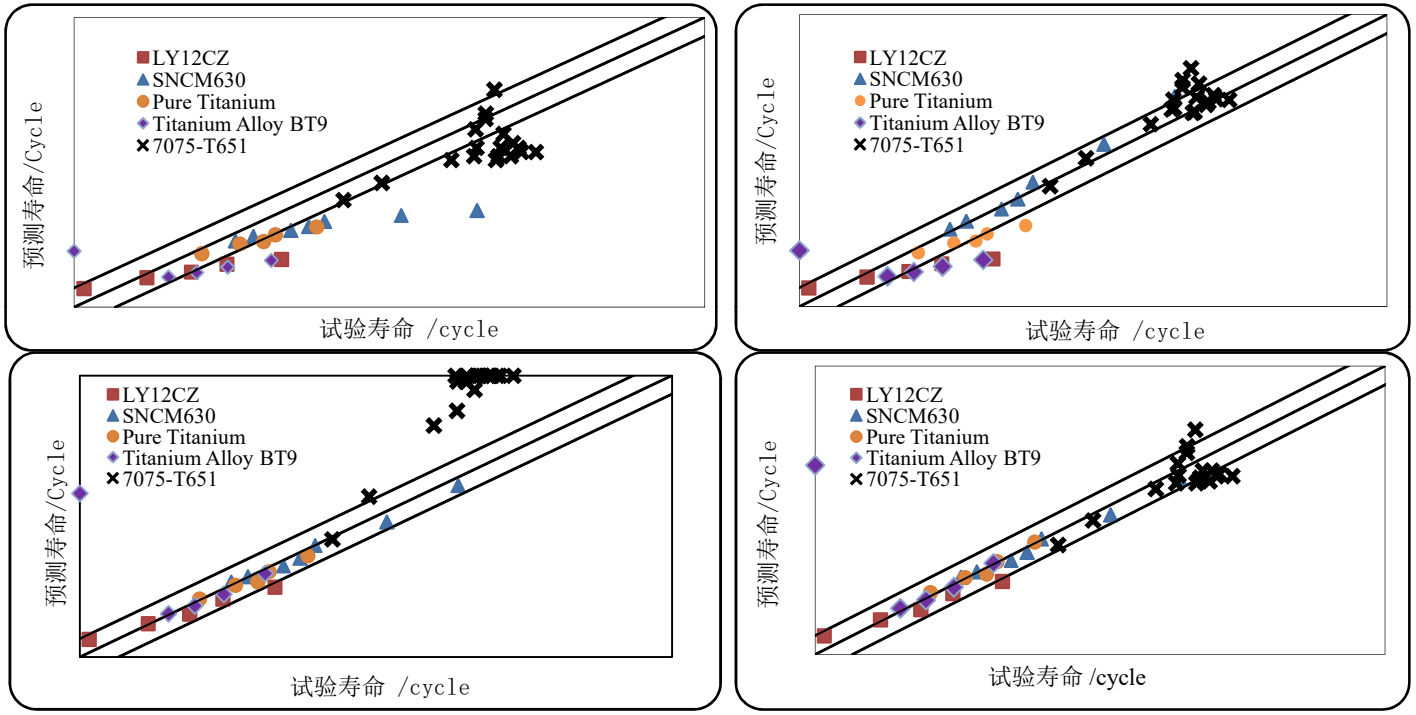
$$\varepsilon_a\sigma_a = \frac{\sigma_f'^2}{E}(2N_f)^{2b} + \sigma_f'\varepsilon_f'(2N_f)^{b+c} - \frac{\sigma_f'\sigma_m - \sigma_m^2}{E}(2N_f)^{2b} - \sigma_m\varepsilon_f'(2N_f)^{b+c}$$

$$\Downarrow$$

$$\varepsilon_a\sigma_a = \frac{\sigma_f'^2 - \sigma_f'\sigma_m + \sigma_m^2}{E}(2N_f)^{2b} + (\sigma_f' - \sigma_m)\varepsilon_f'(2N_f)^{b+c}$$

Comparison of Different Fatigue life model

Comparison of predicted and experimental lives for several different models:



Comparison of predicted and experimental lives for the Manson-coffin/ Morrow model/ the SWT model and the proposed new model

Data Sources

All the material properties and material data are obtained from research papers:

材料名称	σ_f' /MPa	b	ε_f'	c
SNCM630	1272	-0.073	1.54	-0.823
Pure Titanium	647	-0.033	0.548	-0.646
Titanium Alloy BT9	1180	-0.025	0.278	-0.665
Titanium Alloy TC4	1117	-0.049	0.579	-0.679
LY12CZ[29,30]	724	-0.063	0.137	-0.654
7075-T651 AL Alloy	860	-0.1	0.9	-0.909

① Han C, Chen X, Kim K S. Evaluation of multiaxial fatigue criteria under irregular loading[J]. International Journal of Fatigue, 2002, 24(9): 913-922.

② Shamsaei N, Gladskyi M, Panasovskyi K, et al. Multiaxial fatigue of titanium including step loading and load path alteration and sequence effects[J]. International Journal of Fatigue, 2010, 32(11): 1862-1874.

③ Wang YY. Fatigue behaviors of LY12CZ aluminum alloy under nonproportional load[J].Journal of Nanjing University of Aeronautics&Astronautics, 2008,40:484-488.

④ 王英玉.金属材料的多轴疲劳行为与寿命估算[D].南京:南京航空航天大学,2006.

⑤ Wu Z R, Hu X T, Song Y D. Multiaxial fatigue life prediction for titanium alloy TC4 under proportional and nonproportional loading[J]. International Journal of Fatigue, 2014, 59: 170-175.

1. Critical plane method is proved to be effective in the process of fatigue life estimation.

2. Shear strain is taken as critical plane parameter and strain energy is taken as damage parameter .

3. Through a series of comparisons, almost all the predicted data can be located in the double error strip of experimental data.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