Fatigue life estimation of polymers

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Introduction: Static Fatigue

Life time-estimation is imperative for reliable design of polymer components. Previous research showed for static fatigue:

- Quantitative life time prediction possible, taking thermal history into account.
- Failure governed by strain softening triggered by accumulation of plastic strain.

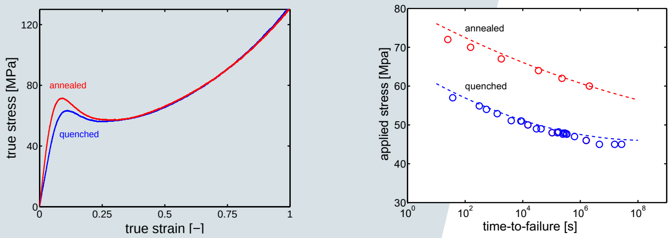

Figure 1 *Left: Intrinsic deformation of quenched and annealed PC. Right: Life time prediction of static fatigue on PC.*

Impact of the Dynamic Component

From cyclic fatigue experiments and simulations having a sawtooth-shape, it appears that (see figure 2):

- Again quantitative life time prediction is possible.
- The dynamic component shifts the life time to lower values on the log(t)-axis with increasing amplitude.

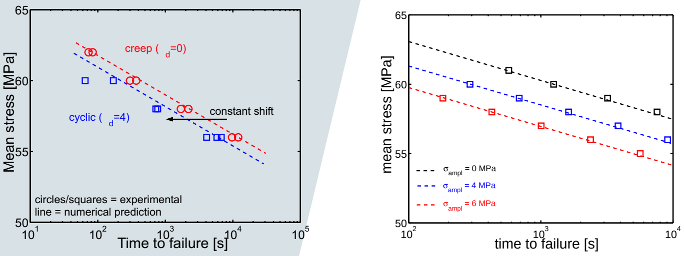

Figure 2 *Left: Life time prediction of cyclic fatigue on PC. Right: Numerical simulations indicate a shift in life time due to the dynamic component*

Based on the results from the simulation, an impact factor a_{impact} is defined. This relates the dynamic life time to the life time of the static mean stress, as follows:

$$a_{impact} = \frac{t_{fail,static}}{t_{fail,dynamic}}$$

It is proposed that such a impact factor can also be derived from the plastic strain γ_{pl} developed during a cycle, as depicted in figure 3a. Since numerical simulations of cyclic fatigue are time-consuming, such an impact factor could save simulation time.

$$a_{impact} = \frac{\gamma_{pl,dynamic}(t_{cycle})}{\gamma_{pl,static}(t_{cycle})}$$

Using the plastic strain evolution in the model, this can be solved analytically for a sawtooth signal.

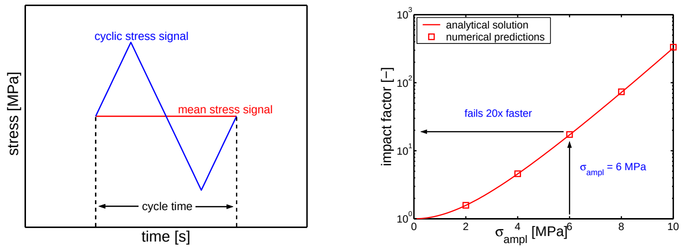

Figure 3 *Left: Impact of sawtooth signal on mean stress. Right: Impact factor a_z for a sawtooth signal.*

This approach yields the following impact factor for a sawtooth wave shape:

$$a_z = \frac{sinh(\sigma_{ampl}/\sigma_0)}{(\sigma_{ampl}/\sigma_0)}$$

Remarkably, for this wave-shape only the stress amplitude σ_{ampl} affects the acceleration factor a_z. From this analytical approach, it appears that frequency and mean stress do not play a role at all.

Fatigue simulations, which are performed to validate the analytical result show that the impact factor derived from these simulations closely matches the analytical result. Next to a sawtooth-wave, also simulations of a sine-wave and a square-wave match the derived impact factor, see figure 4a.

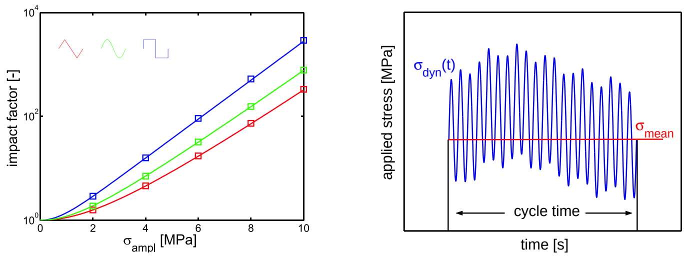

Figure 4 *Left: Impact factor a_z for a sawtooth, square and sine signal. Right: Any periodic stress signal has impact factor.*

Discussion

It is shown that cyclic fatigue life time can be estimated from the static life time. Based on the development of plastic strain during a cycle an impact factor was defined. Using this impact factor, failure due to any periodic dynamic stress signal (figure 4b) can be estimated from the plastic strain developed during a cycle. This means that time-consuming simulations can be avoided.

References:

[1] Klompen, E.T.J., PhD-Thesis, TU/e, 2005

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