CHARACTERIZATION OF THE FATIGUE BEHAVIOR OF TPU'S

J. Holzweber [1] , Z. Major [2]

Summary: *The fatigue behavior of different thermoplastic polyurethanes is discussed and compared to a cross-linked thermoset H-NBR elastomer. The characterization of the fatigue behavior is of great interest for long-term properties under cyclic loading. There is hardly any fatigue data available for these new classes of materials. There are two common ways to describe the lifetime of an elastomer fatigue behavior. One method is the classic fatigue test to generate the Wöhler curve. The other approach is focused on fatigue crack growth using the Tearing Energy or J-Integral concept. Displacement controlled cyclic test were performed and local strain based Whler curves were determined in this paper.*

Keywords: *fatigue, displacement controlled loading, local strain based Wöhler curve*

1 Introduction

Thermoplastic Polyurethanes are random copolymers consist of a hard and soft segment which are forming a two phase microstructure. The existence of the hard phase is very important for the mechanical properties. Because of their advantage in chemical resistance, abrasion, blood and tissue compatibility and their excellent mechanical properties thermoplastic polyurethanes are a very essential group of polyurethane products [1]. Thermoplastic elastomers are frequently used in harsh environmental conditions underlying high temperature deviations and cyclic loading conditions [2, 3]. Even though many different polymer blends, graft and block copolymers have already been characterized in case of fatigue properties, TPE's are a rather new class of materials which have not been widely studied up. So there is hardly any fatigue data available for these new classes of materials. Even with modern test systems the characterization of the fatigue behavior is still a major challenge. Normally, fatigue tests are performed under force controlled loadings to get the classical S-N or Wöhler curve. In this research local strain based Wöhler curves (LSWC) have been created under displacement controlled tensile loading using Diabolo specimens with a reduced cross section. There are two different ways to calculate the real local strain at the notch tip. While one method is to measure the deformation with an optical measurement system, the other uses finite element simulation with an appropriate material model for generating a calibration curve. The main methodology was:

- Displacement controlled tests with different amplitudes and measurements of F_{max}/F_{min} data
- Determination of Cycles-to-Failure, N_f (see figure 3)
- Determination of local strain with FE and derivation of a local strain calibration curve and
- Construction of the local strain based strain based Wöhler curve.

This methodology is described and discussed in this paper.

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2 Experimental and selected results

2.1 Materials

For the first experiments four different thermoplastic polyurethanes based on aromatic isocyanates and diols, and one cross-linked thermoset H-NBR were selected. Due to their excellent chemical resistance and mechanical properties this materials typically are used for different seals. Figure 1 shows the Diabolo specimen with his reduced cross section for the strain concentration. These special specimens are turned from a semi-finished casting product by DMH Dichtungs- und Maschinenhandel GmbH, Traboch, Austria.

Figure 1: Diabolo specimen

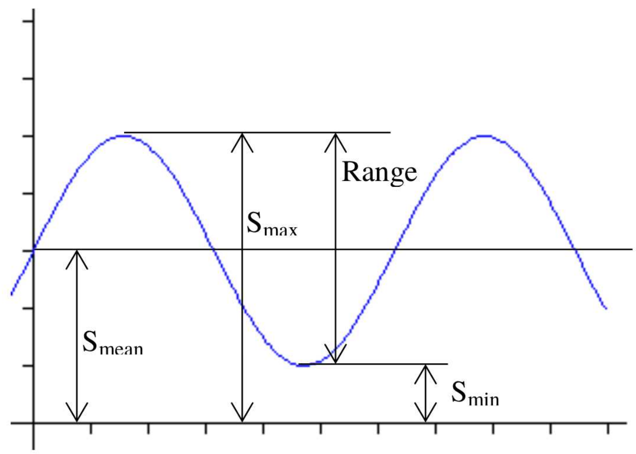

Figure 2: Signal form for the loading

2.2 Displacement controlled test

All fatigue tests were run on a servo hydraulic testing system (MTS 852.50 Damper Station, MTS Systems GmbH, Berlin, D) with an extra designed clamping device in the laboratory of the Institute of Polymer Product Engineering at the Johannes Kepler University, Linz.

$$R_\epsilon = \frac{S_{min}}{S_{max}} \tag{1}$$

As mentioned before, the tests were conducted under cyclical displacement controlled tensile loading in an ambient temperature of about $23\,^\circ\mathrm{C}$. Which means the strain ratio, R_ϵ-ratio (1) was kept constant at $0,1$ and the frequency of the sine wave was $5\,\mathrm{Hz}$ during all test runs.

2.3 Determination of Cycles-to-Failure

During each test-run the hysteresis and the maximum and minimum load values, F_{max}/F_{min} , were recorded continuously. The failure criterion was the ultimate fracture of the specimen. Based on figure 3 the number of the cycle-to-failure, N_f was determined. This experiment was repeated with different amplitudes as long as enough points are created to design the Wöhler curve. Figure 3 is also a good example to show the three different areas: The softening phase at the beginning of the cycling (cycle $1 \sim 1000$), the stationary phase where nearly no change of the hysteresis or maximum load occurs and the damage phase in which the final rupture takes place ($\sim$last 2000 cycles).

The area inside the hysteresis is the energy absorbed per unit of volume of the material. This is mostly dissipated into heat. Figure 4 shows how the stress or load level is reduced by the increase of the cycle number. In general the hysteresis loop depends on material composition, additives and loading rate. A small hysteresis loop also indicates a good compatibility or adhesion between the different phases. A bigger hysteresis loop usually leads to earlier fatigue failure. [4]

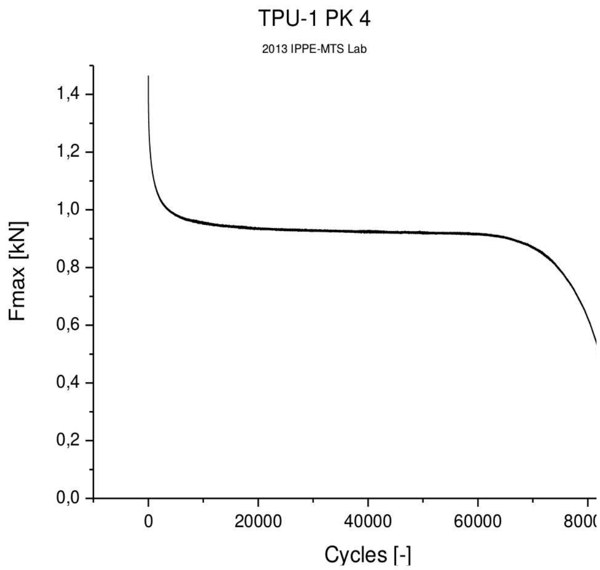

Figure 3: Determination of cycles to failure

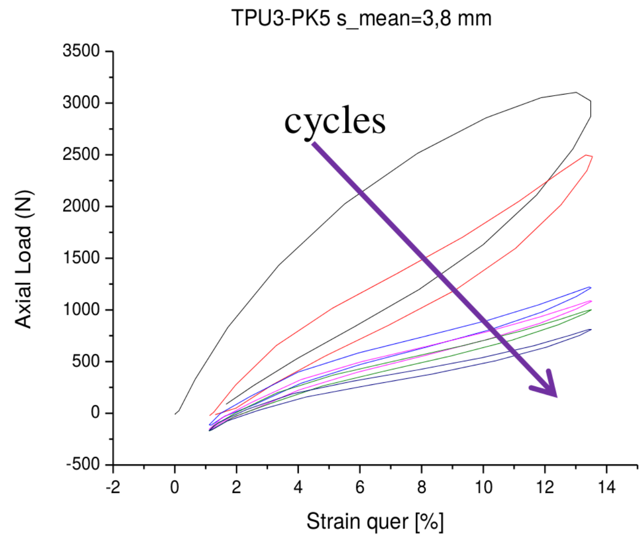

Figure 4: Hysteresis loops TPU3

2.4 Determination of local strain with FE

To create the local strain based Wöhler curve it is necessary to know about the real local strains. Therefore a finite element simulation with Abaqus 6.12 was performed to describe the local strain situation in the notch tip of the Diabolo specimen. For this simulation an appropriate hyperelastic material model was used. The required data were generated with different uniaxial or biaxial tensile tests. Furthermore, in Figure 5 a calibration curve was created to calculate the global displacement into a local strain. The details of these simulations are described by Pichler [5]. This curve was used for the construction of the local strain based Wöhler curve in figure 6. ($\epsilon_x - N_f$).

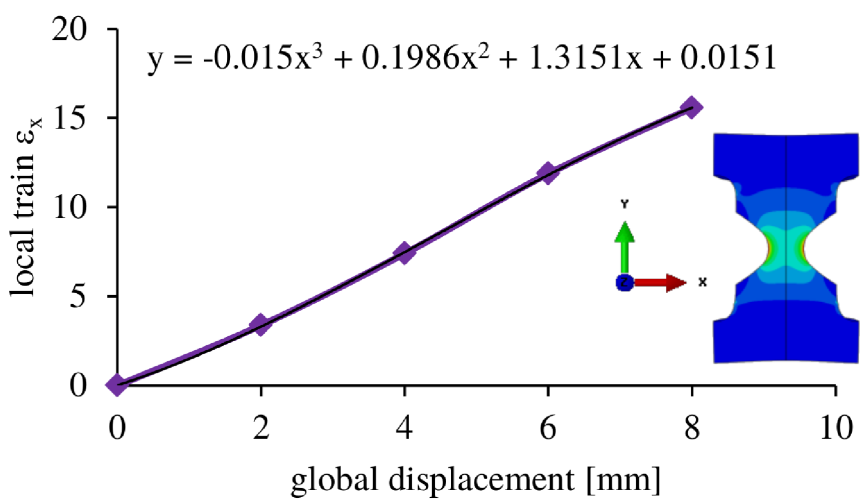

Figure 5: Local strain to global discplacement calibration curve

2.5 Local strain based Wöhler curve, LSWC

In figure 6 the local strain based Wöhler curves for the investigated materials are presented. As it is shown in this figure, the TPu2 and the filled TPu-SL nearly have the same fatigue behavior as the cross-linked thermoset H-NBR elastomer. Notably is that TPu2 and TPu3 showing an almost linear fatigue behavior in contrast to the other materials. Definitely, TPu3 displayed the best fatigue behavior. The precision of the LSWC highly depends on the quality of the material model and the FE simulation.

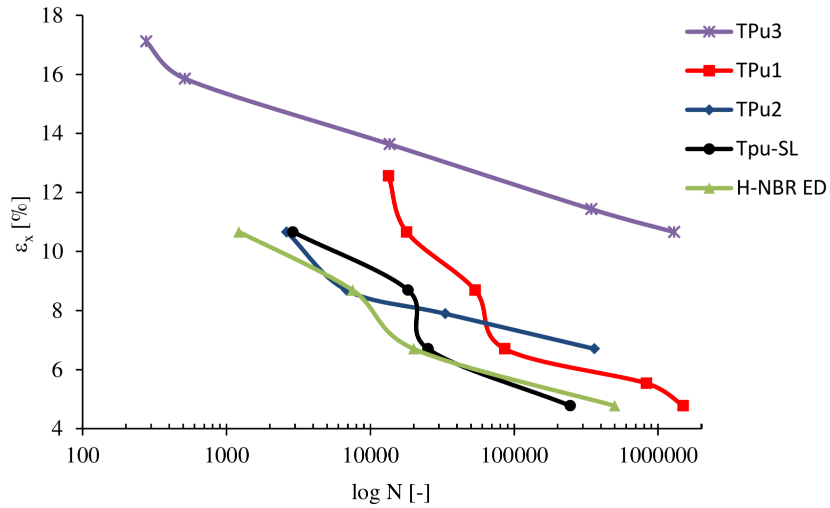

Figure 6: Local strain based Wöhler curve

3 Conclusion and Outlook

Displacement controlled tests can be performed very easily using a modern hydraulic system. Future work is focusing on a comparison between displacement controlled and force controlled tests as well as the development of an energy controlled cyclic test for elastomer and thermoplastic elastomer components. The other side of research will be concentrated on the most common failure type, the fatigue crack growth (FCG), with the comparison between the Tearing Energy and the J-Integral concepts. The final step will be the application of both theories (LSWC and FCG) on a real component.

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References

[1] Qi, H.J., Boyce, M. C., *Stress-Strain Behaviour of Thermoplastic Polyurethane*, Mechanics of Materials, Cambridge MIT (2004)

[2] Major, Z. *Applicability of Displacement Controlled Fatigue Test Methods for Compliant Structures*. IMEKO TC15 Experimental Mechanics Proceedings of 11th Youth Symposium on Experimental Solid Mechanics (2012).

[3] Major, Z., Isasi, M., Schwarz, T., *Characterization of the fracture and fatigue behavior of thermoplastic elastomer materials*, Key Engineering Materials (2010), vol. 417-418, pp. 789- 792.

[4] Bhowmick, A. K., Stephens, H. L., *Handbook of elastomers*, Marcel Dekker (2001)

[5] Pichler, P., Miron, M.C., Major, Z., *Experimental determination of material data for temperature dependent component simulation*, 13th Youth Symposium on Experimental Solid Mechanics, Decin, CZ (2014).