SHORT GLASS FIBRE REINFORCED POLYAMIDE UNDER LOW CYCLE FATIGUE

A. Primetzhofer[1], G. Stadler[1], G. Pinter[2, 3], Christian Schneider[2] and F. Grün[1]

[1]Chair of mechanical engineering, Montanuniversität Leoben, Franz-Josef-Straße 18, 8700 Leoben Austria
Email: andreas.primetzhofer@unileoben.ac.at
Email: gabriel.stadler@unileoben.ac.at
Email: florian.gruen@unileoben.ac.at
[2]Chair of material science and testing of polymers, Montanuniversität Leoben, Otto Glöckel-Straße 2, 8700 Leoben, Austria
Email: gerald.pinter@unileoben.ca.at
Email: christian.schneider@unileoben.ac.at
[3] Polymer Competence Center Leoben GmbH (PCCL), Roseggerstrasse 12, 8700 Leoben, Austria

Keywords: low cycle fatigue, short glass fibre reinforced plastics, polyamide, viscoelastic material behaviour

Abstract
Based on an improved material knowledge, especially on the fatigue behaviour of short glass fibre reinforced (sgfr) polymers, highly stressed parts can be developed for industrial purposes. Especially in automotive applications, high load amplitudes within load histories as well stress concentrations in complex geometries can lead to plasticisation’s. This has to be considered in a lifetime assessment in an early stage of the development process. Therefore, it is indispensable to understand the effects of the main fatigue influence factors. To establish a closed simulation chain, the applicability of common material models (e.g. fatigue criteria according to Ramberg-Osgood) has to be studied first, the models have to be adapted or even new models have to be found for sgfr materials. This paper will focus on the feasability of strain controlled fatigue tests. Therefore, tests were performed on a 50 wt% sgfr partial aromatic polyamide. Un-notched, injection moulded specimen are used for the fatigue tests. To investigate the influence of mean-strain, tests were performed at two different strain ratios, R = -1 and R = 0.1 at standard conditions. The test results show a principal applicability of LCF-tests for sgfr polymers.

1. Introduction

Proven approaches for life time assessment of short fibre reinforced polymers (sgfr) are based on the concept of local S_a/N-curves, where the bearable stress amplitude S_a is plotted over the cycles to failure N. [1, 2] This concept manly describes the material behaviour in the regime of fatigue strength (HCF) and the acting influences, Figure 1. Rarely appearing high loads during load history and stress concentration leads to high stresses in real life parts. Hereby the fatigue life is influenced. Former investigations show that plastic proportion of the total strain amplitude during a load cycle has an indispensable share on the damage. Therefore, the primary strain based damage in the area of low cycle fatigue (LCF) has to be described.

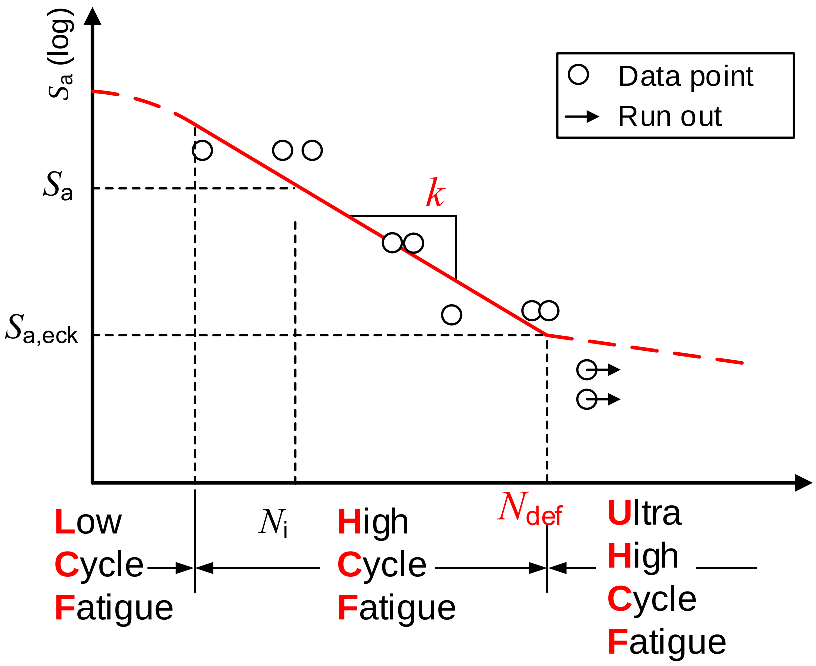


Figure 1. *areas of S_a/N-curves*

Unlike classical stress controlled S_a/N-curves, strain controlled ε/N-curves are needed. To describe the cyclic material behaviour in LCF-range of the S_a/N -curve the ε/N-curves as well as the cyclic stabilized σ-ε-diagram has to be derived from strain controlled tests. While the cyclic stabilized σ_a-ε-curve depicts the cyclic hardening or softening, the ε/N-curves characterizes the material behaviour at low amount of load cycles (N < 10000). Since both curves are derived with the same test, a direct relation can be found, so that both diagrams include the same information, Figure 2. The black dotted line represents the connection between this two curves. [3]

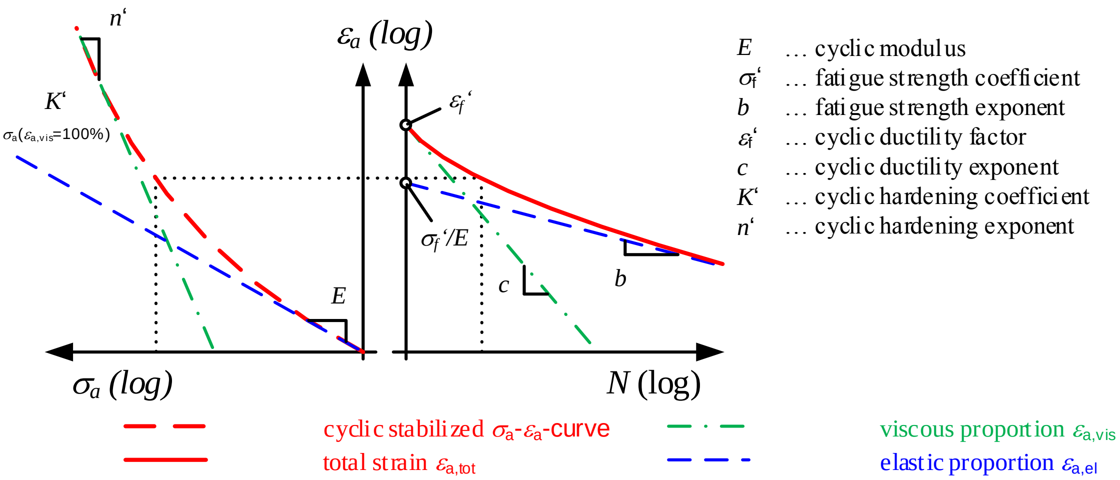


Figure 2. *cyclic stabilized σ/ε-curve and ε/N-curves*

According to works of Coffin [4], Manson [5] and Morrow [6] the elastic as well as the plastic strain amplitudes can be approximated by straight lines in a double-log diagram. Equation (1) describes the relationship between the cycles to failure (N) and the strain amplitude (ε_a).

$$\varepsilon_{a,tot} = \varepsilon_{a,el.} + \varepsilon_{a,vis.} = (\sigma_f'/E)\cdot(2N_f)^b + \varepsilon_f \cdot (2N_f)^c \quad (1)$$

As mentioned before, a direct relationship is given by the vertical cut in the ε/N-curve and the horizontal cut in the cyclic stabilized σ_a-ε-curve. This is known as the Ramberg-Osgood-relations [7] according to Equation (2).

$$\varepsilon_{a,tot} = \varepsilon_{a,el.} + \varepsilon_{a,vis.} = (\sigma_a/E) + (\sigma_a/K')^{(1/n')} \tag{2}$$

This relation is only possible if the compatibility conditions according Equation (3) and (4) are fulfilled.

$$n' = b/c \tag{3}$$

$$K' = \sigma_f' \cdot \varepsilon_f'^{(-n)'} \tag{4}$$

2. Test and specimen

Strain controlled tests were performed on a servo hydraulic test rig MTS810. The machine was equipped with a 100 kN load cell. For strain measurement a contacting high accuracy strain measurement device by MTS was used. The test setup is shown in Figure 3. All tests were performed at constant temperature of $T = 23°C$ and relative humidity of 50 %. To prevent overheating, a fan ensures additional cooling. During the whole test the temperature was monitored by a non-contact infrared thermometer. A triangular signal with constant strain rate of $d\varepsilon / dt$ of 100% / min. was used. A constant strain rate was chosen to avoid deviations caused by strain rate dependend material behavior. By using a constant strain rate the frequency differs depending on strain level between $f = 0.2$ Hz to $f = 0.6$ Hz. Strain levels were defined to achieve a range of cycles to failure from $N = 100$ to $N = 10^4$. The total specimen separation, or exceeding a number of cycles of $N = 10^5$ are set as abort criterion. To cover the influence of mean-strain, strain ratios of $R = -1$ and $R = 0.1$ were chosen. Test results were estimated according to ASTM E 739-91 [8].

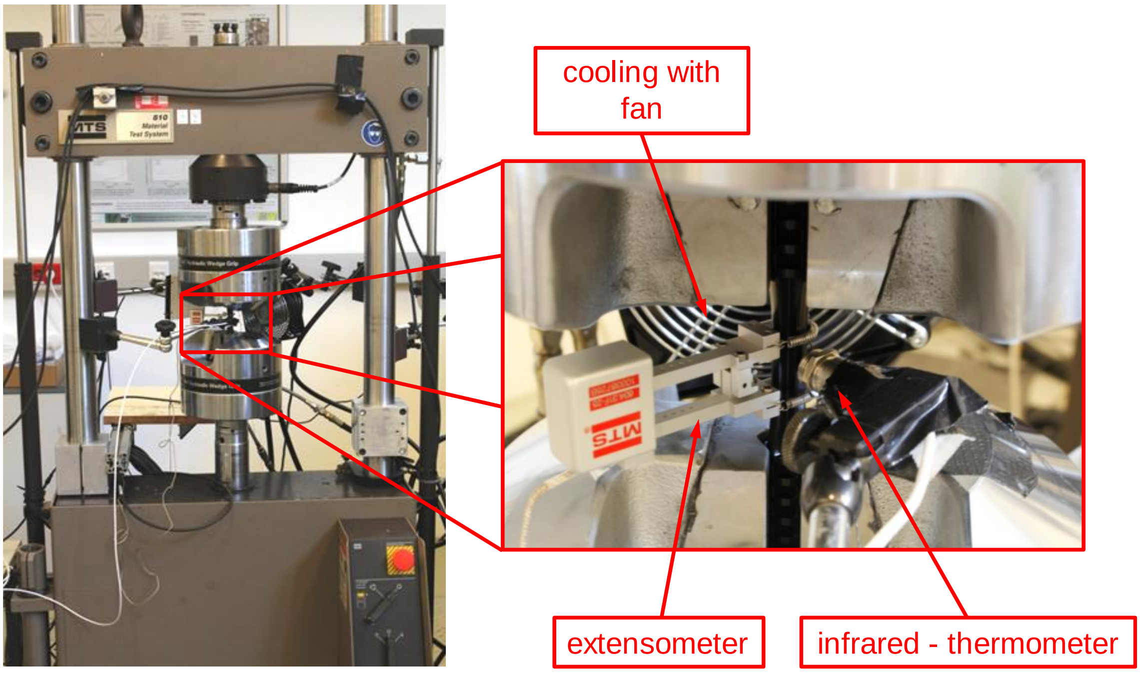


Figure 3. *test setup for strain controlled tests*

A parallel area on the specimen is needed to ensure accurate strain measurements. Therefore unnotched rotary bending specimen were used. The geometry of T-shaped specimen are shown in Figure 4. The specimen were produced by injection molding and tested dry as molded.

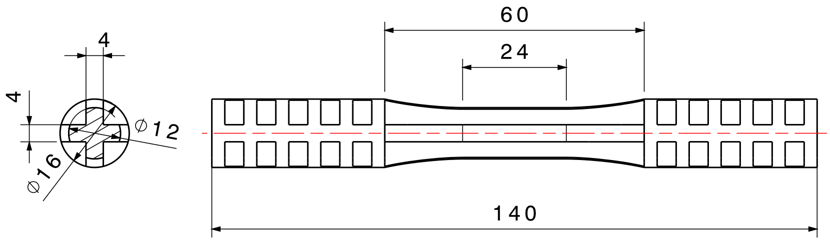
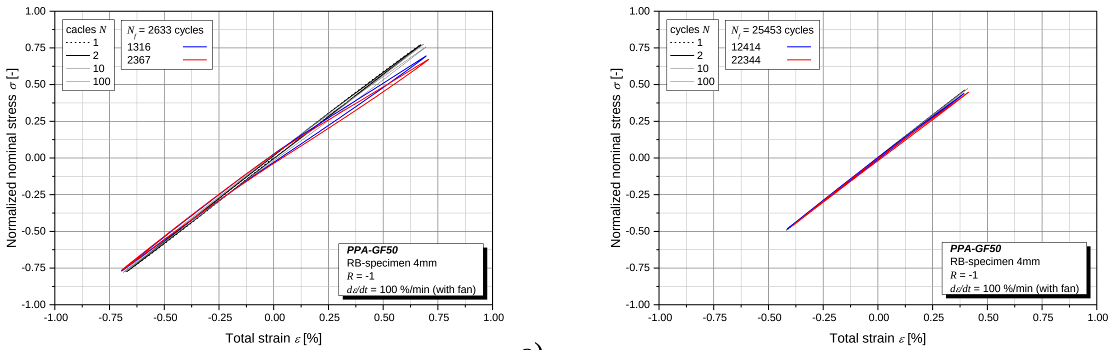


Figure 4. *unnotched rotary bending specimen according to [9]*

3. Test results

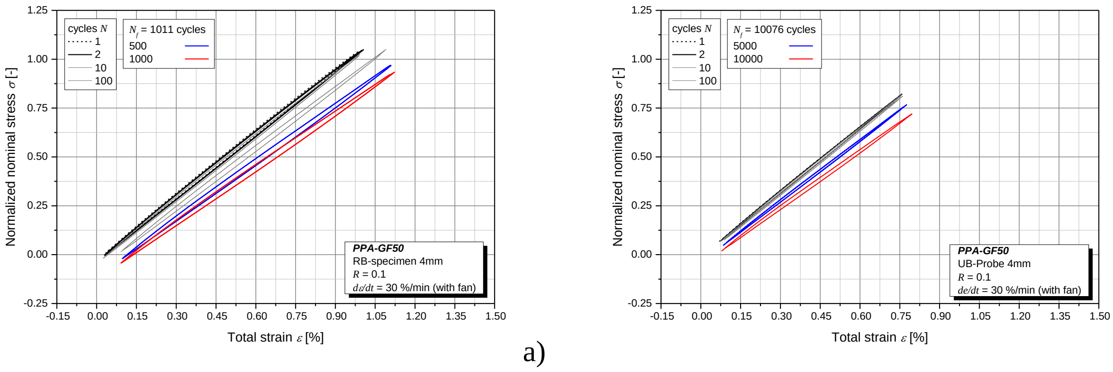
The Test results show just a small expansion of the hysteresis, whereby the expansion under tensile load is more pronounced. The small change in hysteresis-shape indicates a low amount of viscoelastic behavior at the investigated strain levels. A low reduction in strain amplitudes, even at high strain levels, indicates just a low material softening. Due to the stiff material behavior, for polymers well-known cyclic creep and relaxations, are not very pronounced for the investigated material. Recorded hysteresis for two exemplary strain amplitudes are shown in Figure 5. Stress data are normalized by the tensile stress evaluated at a related strain of $\varepsilon = 1$ % in a tensile test. For small strain amplitudes neither a noticeable stress reduction nor a change in strain occurs, so that the deformation of the specimen can be seen as elastic.



a) b)

Figure 5. *test results for R = -1 at: a) $\Delta\varepsilon_a$ = 0.7%; b) $\Delta\varepsilon_a$ = 0.45%*

Under pulsating strain (R = 0.1) quite similar results can be derived from the tests. Equal to tests at R = -1 the hysteresis shape do not change significantly. Due to mean-strain, cyclic creep and relaxation processes are provoked in the material. This is shown by a reduction in stress with simultaneous increase of strain. Even at high strain amplitudes the material shows just minor changes. Small variations around upper and lower strain level, especially at the beginning of a test, are caused by control deviations. The normalized hysteresis is shown in Figure 6.

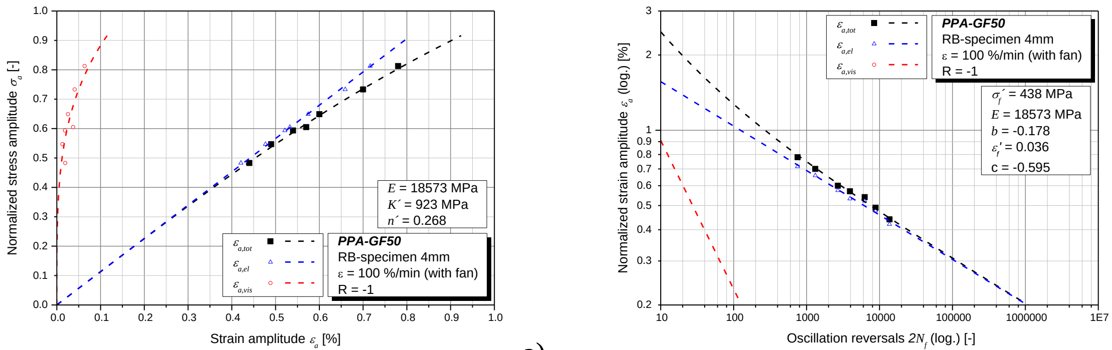


a) b)

Figure 6. *test results for R = 0.1 at: a) $\Delta\varepsilon_a$ = 0.5%; b) $\Delta\varepsilon_a$ = 0.35%*

4. Models

Based on the test results, the cyclic stabilized σ_a-ε-curve as well as the ε/N-curves can be derived to describe the material behaviour for LCF-area. As already mentioned the material shows a very stiff behaviour with just a small amount viscoelasticity. In Figure *7* the derived curves are shown. It should be noted, that for strain based ε/N-curve the strain amplitude is plotted versus the number of oscillation reversals N_f. As a result of these tests, parameters for Equation (1) and (2) can be derived. Based on the gained curves a realistic stress rearrangement can be achieved for the life time assessment according to the local stress approach. Further the results can be applied in the concept of notch root stress. [3]



a) b)

Figure 7. test results for R = -1: a) cyclic stabilized σ-ε-curve; b) ε/N-curves

Plotting the measured stress amplitudes (at $N_f/2$) versus the cycles to failure, it can be shown that a roughly linear extrapolation of the S/N-curve down to N = 2000 cycles delivers a good correlation for the investigated material, Figure 8. For higher loads the viscoelastic share has to be considered by the shown models.

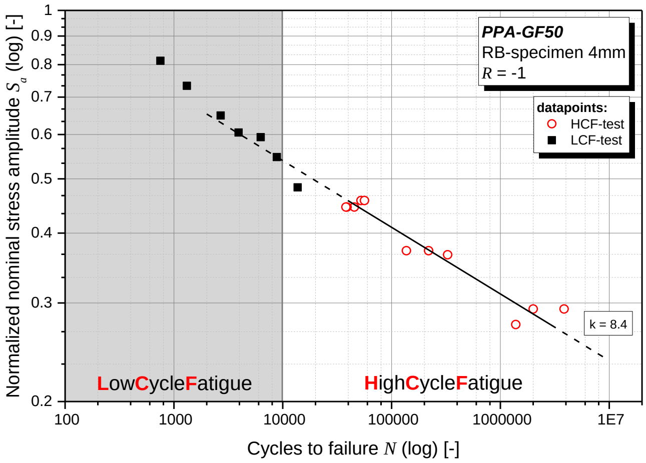


Figure 8. compared test results for R = -1

5. Summary and Outlook

Strain controlled tests were performed at two different strain ratios on injection moulded T-shaped specimen. The test results show a very stiff material behavior with just a small amount of viscoelasticity, so that cyclic creep and stress relaxation are slightly pronounced. Even an applied mean-strain does not lead to these phenomenons. With an increase of mean-strain, a decrease in fatigue limit is observed, as expected. For the investigated material, a life time assessment, based on S/N-curves, can be conducted to a low number of cycles.
The test results show a good applicability of the considered models, so that they can be used for the investigated material. Determined parameters for the cylic σ-ε-curve and the ε/N-curve provide the basis for strain rearrangement according to Neuber's rule. Hereby high load amplitudes and stress concentrations can be handeled in an early stage of the development process.
Since the matrix material, the fibre material and fibre content influence the material behavior strongly, the shown models may not be applicable for materials with more pronounced viskoelasticity. Furthermore polymers show a strong dependency of the material behavior on the temperature and the fibre orientation. Further investigation needs to be done to describe these influences.

Acknowledgment

The research work of this paper was performed at the Department of Product Engineering at the Montanuniversität of Leoben in collaboration with the Polymer Competence Center Leoben GmbH (PCCL, Austria) within the framework of the COMET-program of the Austrian Ministry of Traffic, Innovation and Technology with contribution by BMW-Group, Robert Bosch GmbH, Engineering Center Steyr (MAGNA Powertrain ECS), EMS-Grivory, VW-Group, Schäffler Technologies AG & Co KG and Qualitech AG. The PCCL is founded by the Austrian Government and the State Governments of Styria, Lower and Upper Austria.

References

[1]. C. Guster; W. Friesenbichler and T. Gröger: Simulating the Fatigue Life of Fibre-Reinforced Injection Moldings; *Kunststoffe* (2013) 9, pp. 92–94.

[2]. A. Mösenbacher; J. Brunbauer; Pichler P.F.; C. Guster et al.: Modeling and validation of fatigue life calculation method for short fibre reinforced injection moulded parts; in *16th European Conference of Composite Materials* (ECCM Ed.), 2014.

[3]. E. Haibach: Betriebsfestigkeit, Springer, Berlin, 2006.

[4]. L. F. Coffin: A Study of the Effects of Cyclic Thermal Stresses on a Ductile Metal; *Transactions of the ASME* 76 (1954), pp. 931–950.

[5]. S. S. Manson: Fatigue; *Experimental Mechanics* 5 (1965) 4, pp. 193–226.

[6]. J. Morrow: Cyclic Plastic Strain Energy and Fatigue of Metals; in *Internal Friction, Damping, and Cyclic Plasticity* (Lazan, B. J. Ed.), American Society for Testing & Materials, [Place of publication not identified], 1965, 45-45-43.

[7]. W. Ramberg and W. R. Osgood: Description of stress-strain curves by three parameters, National Advisory Committee for Aeronautics, Washington D.C, 1943.

[8]. ASTM E739: Standard Practice for Statistical Analysis of Linear or Linearized Stress-Life (S-N) and Strain-Life (e-N) Fatigue Data, ASTM International, 1991.

[9]. A. Mösenbacher and C. Guster: Fatigue behaviour of a short glass fibre reinforced polyamide; in *3nd Fatigue Symposium Leoben* (Chair of Mechanical Engineering Ed.), Chair of Mechanical Engineering, Leoben, 2012, pp. 152–160.