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Data set determination for lifetime assessment of short fibre reinforced polymers

In the present paper, a methodical approach to data set determination for the lifetime assessment of short fibre reinforced (sfr) polymers is presented. In particular, the issue of proper material characterisation, focusing on the required material models (for fibre orientation, temperature, notch effect, mean stress) and specimen testing, is discussed. A data set generation procedure for lifetime assessment is illustrated using the example of a short glass fibre reinforced polyphthalamide. The key points relating to data set generation are discussed and the approach presented provides a method of standardised data set generation for the lifetime assessment of components made of short fibre reinforced plastics.

Datensatzermittlung zur Lebensdauervorhersage kurzfaserverstärkter Kunststoffe

Es wird eine methodische Vorgehensweise zur Ermittlung von Datensätzen zur Lebens-dauerberechnung kurzfaserverstärkter Kunststoffe vorgestellt. Speziell wird auf die Materialcharakterisierung und die hierfür notwendigen Modelle (für Faserorientierung, Mittelspannung, Kerbeffekt, Temperatur) und Versuche eingegangen. Die Vorgangsweise zur Erstellung eines Datensatzes für die Lebensdauerberechnung wird anhand eines kurzglas-faserverstärkten Polyphtalamides erläutert. Einige entscheidende Punkte bei der Datensatz-erstellung werden diskutiert. Die gezeigte Vorgehensweise ermöglicht eine standardisierte Lebensdauerabschätzung für Bauteile aus faserverstärkten Kunststoffen.

Data set generation for lifetime assessment of short fibre reinforced polymers

A. Primetzhofer, G. Stadler, F. Grün, G. Pinter

1 INTRODUCTION

Due to decreasing product development cycles, it is necessary to determine the local lifetime tendencies for cyclic loaded parts at an early stage of development. In this context, finite element based methods can be successfully applied to transfer local material characteristic strength values, determined at a specimen level, to real components. In particular, the fatigue design of highly loaded components requires an extensive knowledge concerning design influences such as mean stress, supporting effect, temperature, etc. Until recently, the design of short fibre reinforced (sfr) parts often followed approaches based on nominal stresses, readily available data and empirical reduction factors such as that discussed in [1]. Due to the complex geometries involved and a process-dependent local material behaviour, conservative assumptions have to be made to ensure durability. For example, the worst fibre orientation has to be assumed for the whole part, even in regions where a high orientation can be achieved, meaning that the high light-weight potential of reinforced materials cannot be used. Further, it is not possible to optimise the geometry and the injection point, and thus the local material behaviour, with respect to the local fibre orientation. Of course these methods do in fact perform well for simple and well-known applications, but to meet the requirements of increasing complexity and the demand for a reduction in development time, advanced methods are needed.

To elucidate the fatigue behaviour of a material, both quasi-static and cyclic tests are necessary and based on these tests, models can be derived to describe the influences such as temperature, mean stress, etc. For lifetime assessment, a data set, including the material behaviour and models, has to be defined so that they can be used for a lifetime assessment. Since, in the past, there was little need for cyclic data, these are rarely included in data banks. Today, material suppliers often do support cyclic data, but they remain underrepresented. Further, these data are often determined on non-standardised specimen types, an issue that makes it difficult to transfer the data in order that they can be used properly. In former publications [2–4], the applicability of the local S/N-concept for lifetime assessment of short fibre reinforced polymers was demonstrated. This concept, first developed for metals [5], has been enhanced by the inclusion of anisotropic material behaviour of reinforced materials, thereby including a process simulation in the concept [6–9]. Starting with an injection moulding simulation, the local fibre orientation can be calculated and transferred to a structural analysis and subsequent lifetime assessment. Quasi-static tests have to be performed to describe the non-linear material behaviour and to define the strength limits for a data set. The anisotropic stress field is calculated based on the local fibre orientation and the provided material models. As previously mentioned, cyclic tests are performed to set up a data set and in the lifetime assessment the local damage is calculated for each node, comparing the acting and the bearable stress amplitudes. The workflow for a lifetime assessment, based on the concept of local S/N-curves, is depicted in *Figure 1*. To achieve the most accurate solutionsresults, simulation results should validated with test results or measurements. These validation steps are marked in *Figure 1* by the yellow double arrows.

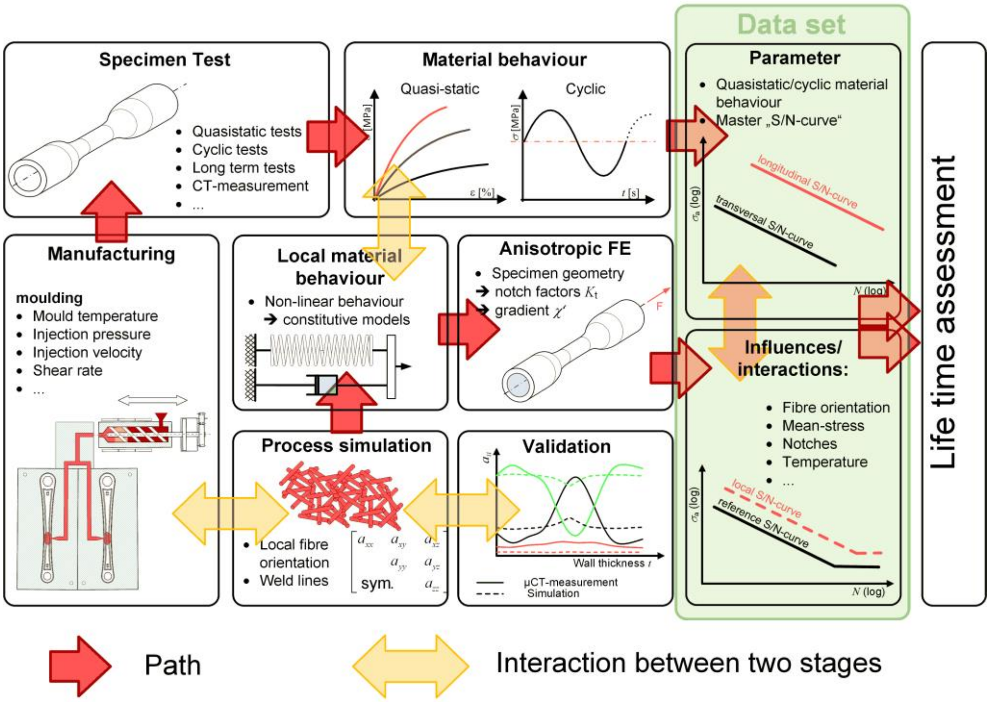


Figure 1: Workflow of the local stress concept for fibre reinforced polymers

A detailed description of an anisotropic lifetime assessment of sfr polymers is given in [10] and in this paper a short overview of the essential steps is provided. Particular focus is on the preparation of data resulting from tests on different specimen types. Since the fibre orientation and some geometrical aspects have to be derived in a simulation, the procedure is presented and the most important points for modelling and evaluation are stated for each step. The presence of different specimen types is a major issue and an approach to dealing with this is given in the second part of the paper. Some crucial points about data preparation and modelling for a comprehensive data set are outlined at the end of the paper.

2 SIMULATION

Since parameters such as fibre orientation a_{ij}, stress concentration factor K_t and stress gradient χ' must be derived from a simulation, this section briefly describes the necessary simulation steps.

2.1 Injection moulding simulation

During the filling process of melts that include fibres, the fibres are oriented due to prevailing shear/elongation flow. The melt then solidifies gradually at the cavity wall due to the extraction of heat, leading to an irregularly oriented layer near the surface. Further, the solidification process results in a changed flow behaviour. The steadily changing flow conditions across the component thickness lead to a layered structure with different fibre orientations and subsequently different local properties. The pronounced microstructure over the whole part results in a strong variability in the mechanical properties of the part. This has to be considered in a lifetime assessment by using appropriate models. A filling simulation provides the necessary local fibre orientations, characterised by a symmetric second-order tensor, Equation 1.

$$a_{ij} = \begin{bmatrix} a_{xx} & a_{xy} & a_{xz} \\ \dots & a_{yy} & a_{yz} \\ sym. & \dots & a_{zz} \end{bmatrix} \qquad \textit{Equation } 1$$

This tensor is calculated for each element of a FE-mesh by using the approach of Folgar-Tucker [11–13]. Based on these theories, the RSC or MDR-model is implemented in commercially used software tools. Some additional basics are given in [14, 15]. Using injection-moulding simulations, the local fibre orientation, represented by the second-order tensor defined in Equation 1, can be determined. The eigenvalues, λ, of this tensor are used to identify the local orientation with respect to the loading direction for all specimens, see Table 2. It should be stated that, due to complex conditions in the die and a number of simplifying assumptions, the results derived from a process simulation can differ from the real orientation. To verify the actual fibre orientation, a comparison with results from, for example, µCT-measurements is advisable [16] and the parameters used for the process simulation can be optimised to achieve results that are more appropriate. In particular, in regard to a related lifetime assessment, a validation is recommended in order to avoid any significant miscalculations of the mechanical properties as even minor discrepancies in the mechanical properties can lead to major changes in the lifetime of a part.

2.2 Structural analysis

Due to the different mesh requirements of an injection moulding simulation and subsequent structural simulation, the fibre orientation has to be transferred from one mesh to the other. This process can involve some deviations in fibre orientation due to numerical issues which should be kept in mind. To consider anisotropic non-linear material properties in a finite element analysis the so-called constitutive laws can be used. Besson describes these laws and their application in [17]. The microstructure (fibre orientation) and non-linear material behaviour are merged to the local material behaviour using so called representative volume elements (RVE). Consideration of an anisotropic material behaviour leads to an inhomogeneous stress field in the FE-analysis, whereby the effect of the local fibre orientation is considered.

In general, fatigue analysis based on nominal stresses is limited to simple geometries and strictly isotropic materials. Due to the complex geometries of real life components and the irregularly distributed stress fields caused by the microstructure, the definition of nominal cross-sections is impossible. In addition, neither the stress concentration factor, K_t, nor the relative stress gradient, χ', can be computed, although they are necessary for the commonly used engineering models and have a great influence on the fatigue behaviour. Hence, it is essential to obtain this information through the use of a FE-calculation. In addition to these numerical issues, the local material behaviour differs and influences the stress field as well as the fatigue behaviour. All of these irregularities, caused by the geometry and/or the microstructure, can be captured by an appropriate finite element analysis; however, the results of such an analysis will only be as accurate as the model on which it is based. Therefore, careful attention must be paid to the modelling of the load situation and the accuracy of the geometry discretisation with the mesh, the latter having a major influence on the FE results. Klein describes in [18] the sensitivity of the results the modelling. To avoid deviations between the specimens and the real life components, a similar mesh size and mesh type has to be used to determine the stress concentration factor and the stress gradient. The size of the models is often limited, leading to a coarse mesh; a fact that must be considered in the lifetime assessment.

3 LIFETIME ASESSMENT

A lifetime assessment based on local S/N-curves combines the anisotropic stress field, the local material behaviour and the load history. Using the influencing factors, the local material behaviour can be determined for each node in the FE mesh. These influencing factors can derived from the models described in Section 4 according to [10]. Based on the data ($S_{a,ref}$), the local fatigue limit $S_{a,local}$ can calculated according to Equation *2*.

$$S_{a,local} = S_{a,ref} \cdot f_{tot} = S_{a,ref} \cdot f_S \cdot f_{MS} \cdot f_T \cdot f_{TO} \qquad \textit{Equation 2}$$

The respective damage results from this for a given load case (mean stress, . In the case of cyclic loads, longitudinal (a_{xx} = 0.85) and transversal (a_{xx} = 0.15) "master S/N-curves" (e.g. R = 0.1, T = 23°C and χ` = 0 mm^{-1}) are used, see *Figure 2*.

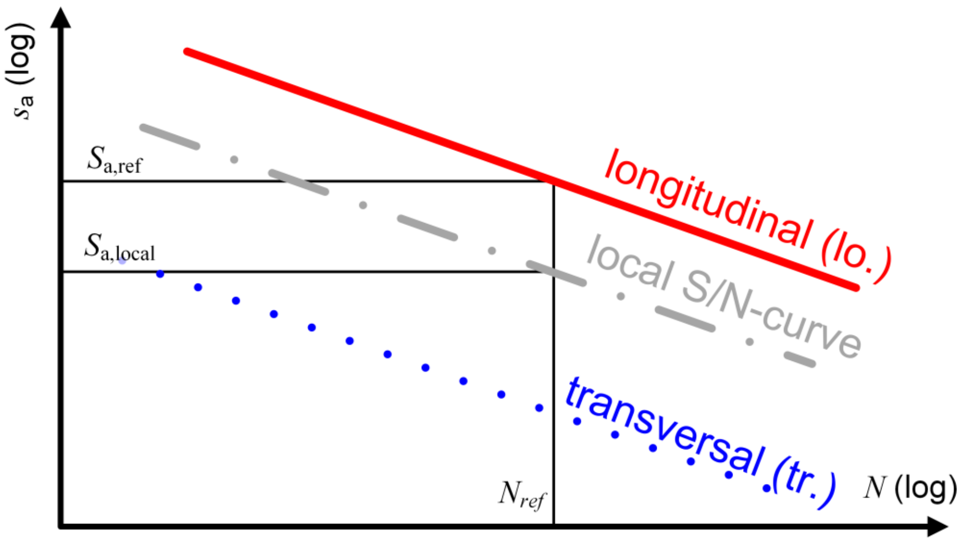


Figure 2: Longitudinal and transversal master S/N-curves

The local fatigue strength, $S_{a,local}$, at a defined number of cycles e.g. N_{ref} = 10^6, originates from the defined fatigue strength $S_{a,ref}$ by superimposing the factors of influence. Different methods for this are outlined in the literature [19, 20]. In addition to factors such as temperature, fibre orientation, mean stress and stress gradient, test result evaluation according to ASTM E 739-91 [21] also takes the statistical influence into account. Adding other influences, such as surface treatment and roughness, to the outlined method, a consideration thereof is possible. Since a huge number of elements and nodes are required to adequately discretise a real life component, a manual damage calculation is virtually impossible. Therefore, post-processing tools such as FEMFAT® provide efficient algorithms to evaluate even complex parts. The summation of single load cycles follows well-known cumulative damage rules such as the Miner rule [22], and this procedure can handle even complex load cases, including multiaxial stress states and load spectra.

4 CHARACTERISATION OF MATERIAL BEHAVIOUR

Components are subject to various internal and external loads during operation. To capture all of the relevant factors, comprehensive material models are necessary to describe the behaviour of the component under cyclic loads. In particular, the temperature (**T**), mean stress (**MS**) and support effect (**S**) and their mutual interdependencies have a major influence on the lifetime and in addition, the material behaviour is affected by the fibre orientation (**FO**). The most important influences are:

Support effect (S): effect of notches on the fatigue behaviour [19, 23–25].

$$n(T,\chi') = 1 + (n_{ref}(T) - 1) \cdot \chi'^{K_D} \qquad \textit{Equation } 3$$

Mean stress (MS): interaction between mean stress and bearable stress amplitude [26, 27].

$$M = \frac{S_a(R_1) - S_a(R_2)}{S_m(R_2) - S_m(R_1)} \qquad \textit{Equation } 4$$

Temperature (T): effect of temperature on the material behaviour W_T according [28] (further [29]).

$$W_T = W_{RT} - (W_{RT} - W_{T2})e^{-(\frac{T}{T_g})^b} \qquad \textit{Equation } 5$$

Fibre-orientation (FO): dependence of the material behaviour W_i on fibre orientation, represented by the first eigenvalue λ_1 of the fibre orientation tensor a_{ij} [30–33].

$$W_i = W_0 \cdot \exp(m \cdot \Delta\lambda) \qquad \textit{Equation } 6$$

In addition to the factors listed above, ageing and effects of media [34], absorption of moisture [35, 36], creep [37] and process-related weld lines [29, 38, 39] also decrease the mechanical properties.

This paper does not describe the effects of these influences in detail and the reader is referred to [10] in which Primetzhofer et al. describes the four main influences (FO, MS, T, NS) and their effects on the S/N-curves. For a lifetime assessment based on local S/N-curves, the material behaviour must be provided in a data set. Since a data set cannot include an individual S/N-curve for every possible load case, a large number of test data have to be combined to define the two “master S/N-curves”. A test matrix for a characteristic data set is given in *Table 1*. While the quasi-static values define the physical limits, cyclic values are used to describe the behaviour of the material. Since fibre reinforced materials show a direction-dependent material behaviour, tests have to be performed longitudinal and transversal to the main fibre orientation. During the service of components they are often loaded by pre-loads or other static loads (weights) causing a mean stress in the part. To cover the strong temperature dependency of the mechanical properties over a wide range of temperatures (especially around the glass transition temperature) tests at several temperatures are required. Tight radii of injection moulded parts lead to stress concentrations and therefore to a notch effect. To describe the change in the bearable stress amplitudes, tests on notched specimens should be performed to describe the notch support effect and to cover any interaction with the temperature, these tests should be done at two temperatures. With the data derived from all of these tests, models, such as those described in section 4, can be derived. Experience has shown that the given tests cover a wide range of different load cases, although it should be noted that this matrix can be reduced if the load case is well known.

Model	**quasi-static**	**cyclic**	T **[°C]**	R**-ratio**	**Notch type**	**orientation**
FO	✓	✓	RT	-1*	un-notched	tr. / lo.
MS		✓	T_n	-1, 0	un-notched	
T	✓	✓	T_1, T_2, T_n	-1*	un-notched	
NS		✓	RT, T_1	-1	mild, sharp,	

***other R-ratio possible**

Table 1: Recommended test matrix

4.1 Characteristic specimen types

To meet the test requirements of different material parameters a variety of specimen geometries were developed, Figure 3. The standard test specimen (NPK) is normally used to characterise the essential material characteristics and specimens, cut out of injection-moulded plates (KPK), are used to set up the fibre orientation model. The effect of fibre orientation cannot be evaluated on specimens for rotational bending such as the tubular specimen (BHP) and the RB-specimen [25]. Since these specimens differ in their notch geometries they are required in order to investigate the notch support effect. In addition, special specimen (BiAx) geometries are used to determine quasi-static and cyclic material data in the absence of factors relating to the manufacturing process.

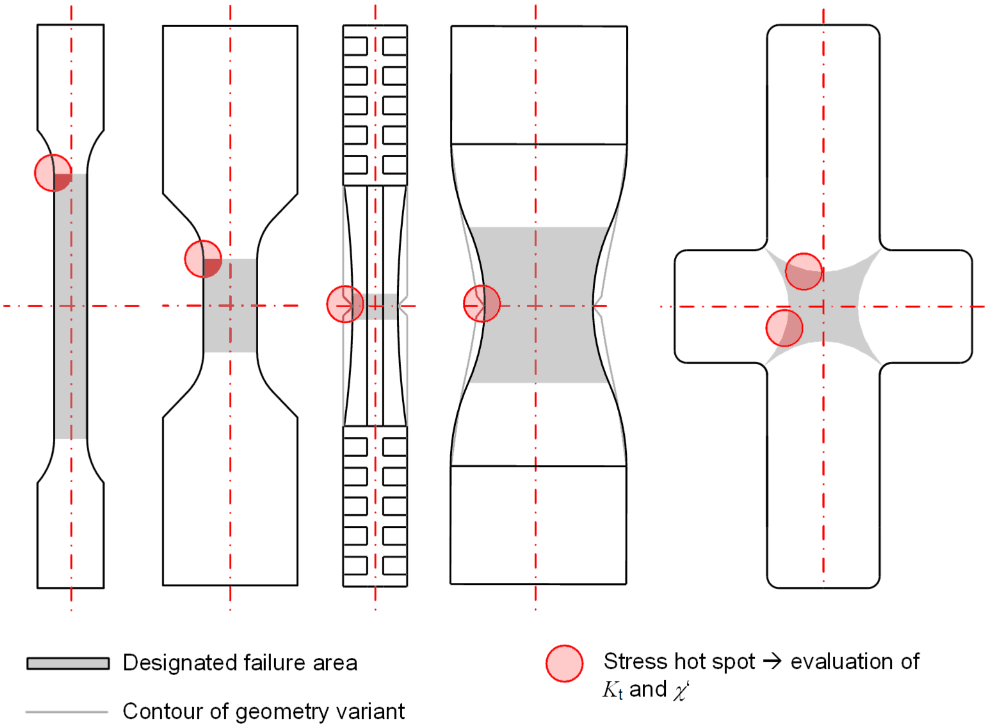


Figure 3: Specimen geometries
From left: standard specimen (NPK) [30], short specimen (KPK) [30], rotational-bending specimen (RB) [25], BOSCH tubular specimen (BHP) [40], EMS biaxial specimen (BiAx) [8]

When it comes to data processing of experimental data, the variety of the samples represents a great challenge. To define a “master S/N-curve” from the different test results, the fibre orientation and the notch effect have to be understood. Due to the injection moulding process, all specimen types possess different fibre orientations in the designated failure area, see Figure 3. The local fibre orientation is given by a symmetric tensor derived from an injection moulding simulation, Equation 1 and it is recommended the fibre orientation be validated by µCT-measurements or similar techniques. Since experimental fibre orientation determination is costly and time consuming, both measured and simulated fibre orientations are used to set up the data set. In addition to the fibre orientation, the notch effect, caused by the geometry, affects each specimen, and these factors have to be determined in a FE-analysis for each specimen type. The fibre orientation and geometry factors K_t as well as the related stress gradient χ' for four of the used specimens are listed in *Table 2*.

This information has to be taken into account when preparing a data set, a process that requires considerable effort. In particular, the interaction between the fibre orientation and the support effect is not currently well understood, although a study that discusses this factor can be found in [41].

Specimen type		λ [-]	K_t	χ' [mm^{-1}]
NPK		0.78*	1.2	0.17
RB	unnotched	0.68*	1.03	0.03
	mildly notched	0.68*	1.7	1.03
	sharply notched	0.68*	2.86	3.32
KPK	longitudinal	0.77	1.4	0.21
	transversal	0.21	1.2	0.03
BHP		0.87	1.33	0.24

***simulated fibre orientation**

Table 2: Specimen types: fibre orientation and geometric factors

This can lead to significant deviations in the determination of cyclic material parameters. Since a comprehensive lifetime assessment requires multiple test data, attention has to be paid to this fact. Therefore, the interaction between the main influencing factors has to be compensated to achieve a sufficient accuracy.

4.2 Material testing

This paper details the data set generation for a short fibre reinforced partial aromatic polyamide containing 50 wt% glass fibres (PPA GF50). Tests are performed on all of the types of specimen discussed above, see Figure 3. All of the specimens were tested dry as moulded and all cyclic as well as quasi-static tests were performed at 23°C and 50 % relative humidity. For testing an electro-mechanical and a servo hydraulic test rig were used. Both were equipped with load cells (15kN/100kN) and a contacting high accuracy strain measurement device. Three stress levels were defined to achieve a range of fatigue cycles to failure, from $N = 10^4$ to $N = 10^7$. A sinusoidal load function with a frequency of $f = 10$ Hz and constant amplitude is used to run the tests under load control and, in addition, a rotary bending machine is used to test the RB-specimen at the equivalent test conditions. The temperature at the surface was monitored with an infrared or contact thermometer to ensure that the temperature rise remained below 5°C. Estimation of the S/N-curves is done according to ASTM E 739-91 [21]. To set up the models, the relationship between the lifetime and the influencing variables, the nominal stress amplitude at $N = 10^6$ is determined. Normalised fatigue test results for different specimen types are plotted in *Figure 4*.

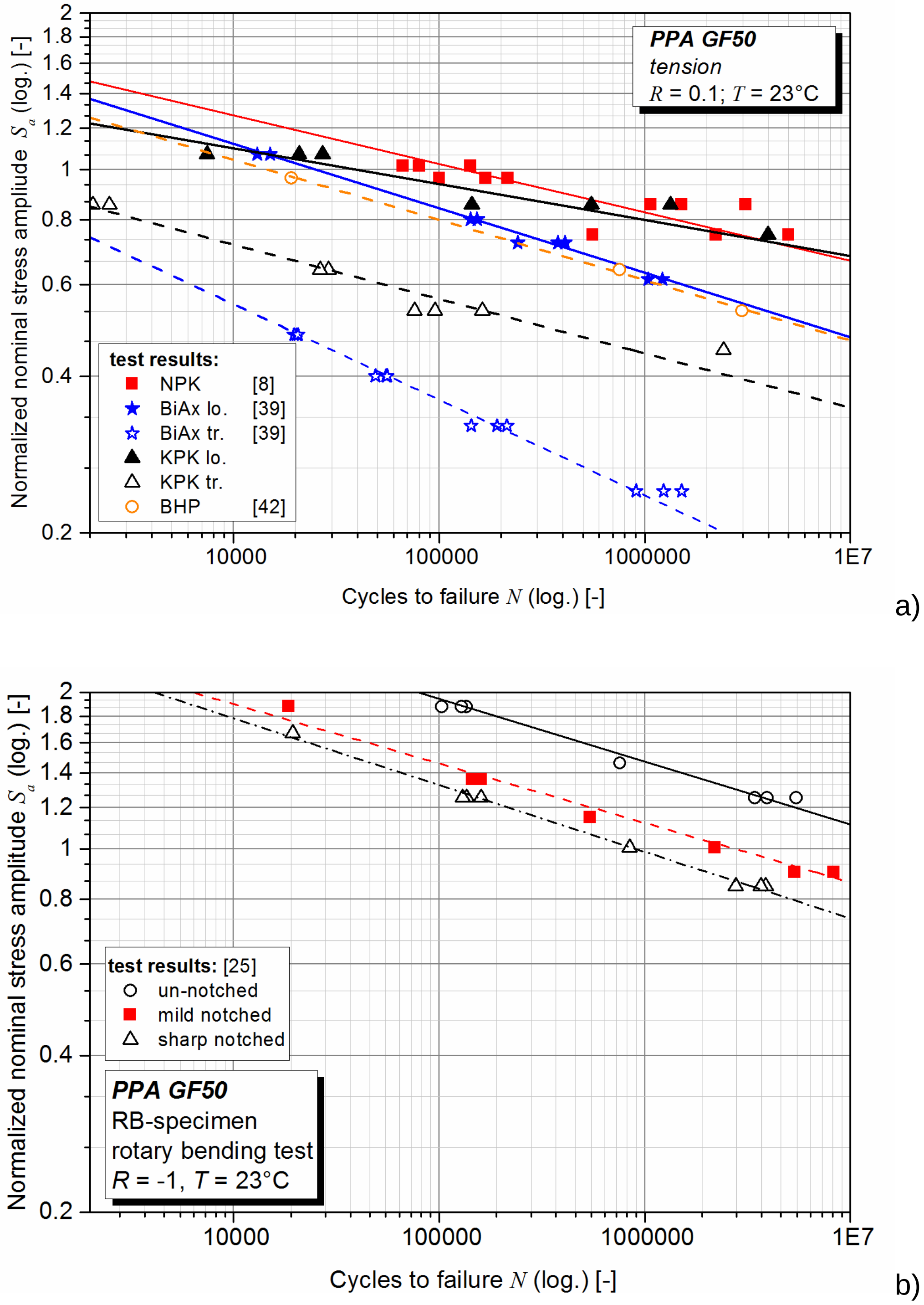


Figure 4: Fatigue test results:
a) axial tests [8, 39, 41]; b) rotary bending tests [25]

5 DETERMINATION OF A DATA SET

As previously mentioned, test data, generated using different specimens, have to be adapted to a comparable state, the principal approach to which is plotted in Figure 5. The required adaptation shall be demonstrated on the interaction between the fibre orientation and the notch effect since this is the most pronounced one.

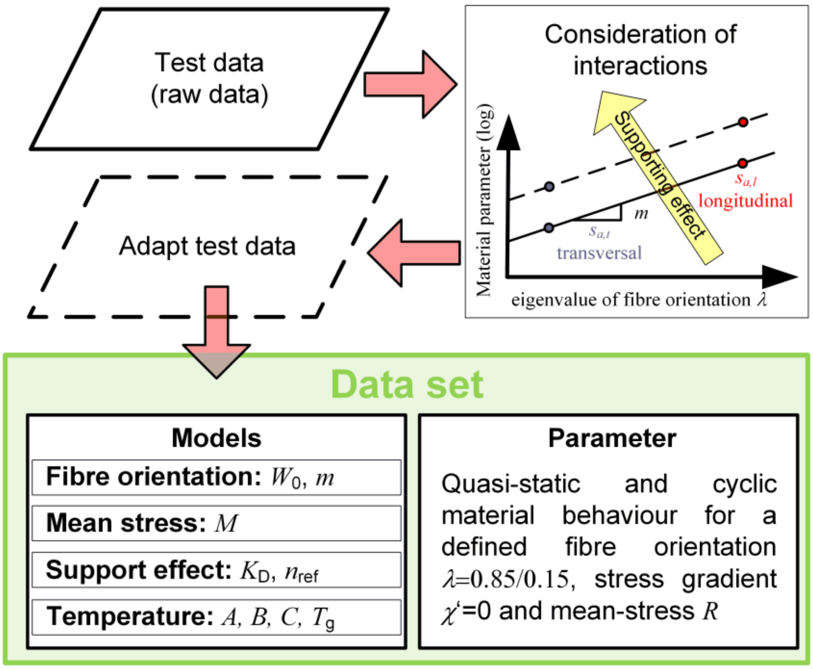


Figure 5: Schematic data set generation process

The aim of the adaptation process is to provide data for the un-notched specimen geometry with a defined fibre orientation. Therefore, a state has to be defined to deduce the “master S/N-curves”. The adaptation process basically consists of three steps and requires the definition of a longitudinal and transversal state, Table 3. It should be noted that, for statistical coverage, the state should be chosen so that a maximum of test results is available.

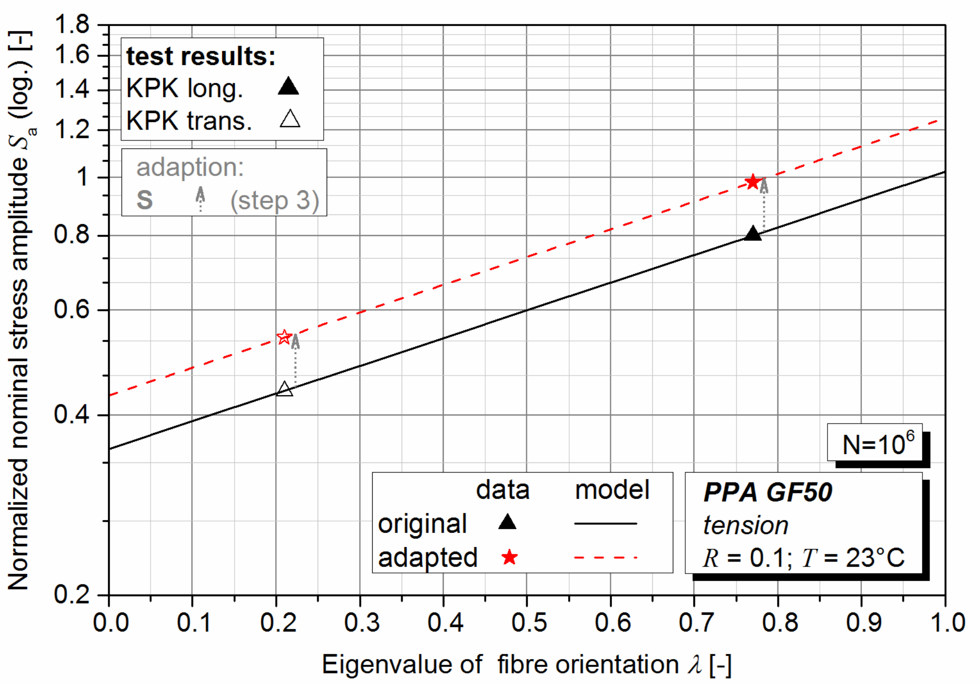
	λ [–]	χ' [mm^{-1}]	R
Longitudinal	0.85	0	0.1
Transversal	0.15	0	0.1

Table 3: Definition state – transversal and longitudinal

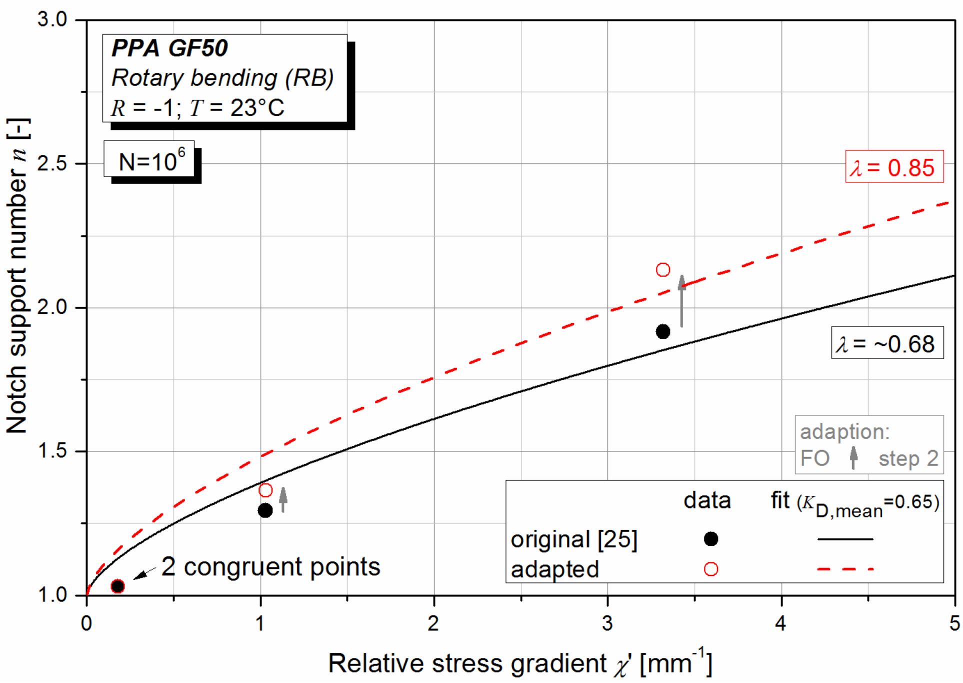
First step: First, un-corrected test data (=original) are used to derive the models and to describe the effect of fibre orientation and notch support,Figure 6 a) and b). In this figure, the filled symbols and solid lines represent the original model for fibre orientation and the support effect.

Second step: The fatigue test data of all RB-specimens (un-notched and notched) are adapted to the defined longitudinal orientation (λ = 0.85) according to Equation 6. This is represented by the solid lined arrow in Figure 6 b), in which the effect of fibre orientation on the notch support is also depicted. The notch support effect can be described based on this adapted state. A constant parameter K_D = 0.65 is used to fit the data, which represents an average value and is used as a constant parameter in the data set.

Third step: The specimen (KPK), used for the determination of the fibre orientation effect, shows a stress peak and a related stress gradient in the designated failure area, Figure 3. To take this into account, the bearable stress amplitude at $N = 10^6$ both longitudinal and transversal are adapted using the notch support model according to Equation 3. Since the stress gradient depends only on the geometry, the notch support leads to a parallel data shift in the double logarithmic scale. Now, the adapted data represents an un-notched state, as required. The supporting effect leads to slightly higher nominal stress amplitudes,Figure 6 a). In comparison to the test data, a dashed line represents adapted data. Since the slope is not changed by this procedure, there is no further effect on the notch support effect.



a)



b)

Figure 6: Effect of adaption on material model parameters
a) fibre orientation b) notch support number

In recognition of the fibre orientation and the geometry (stress concentration), all test results have to be transferred to an un-notched state $\chi' = 0$ [mm^{-1}] with a fibre orientation of $\lambda = 0.85$. Taking all influences into account, a data set can be created that relates to the illustrated test results. The cyclic material behaviour is now represented by two "master S/N-curves", shown as the red solid line (longitudinal → $\lambda = 0.85$) and blue dotted line (transversal → $\lambda = 0.15$), in Figure 7. In this figure, the non-adapted test results (see *Figure 4*) are illustrated as grey symbols and dashed lines.

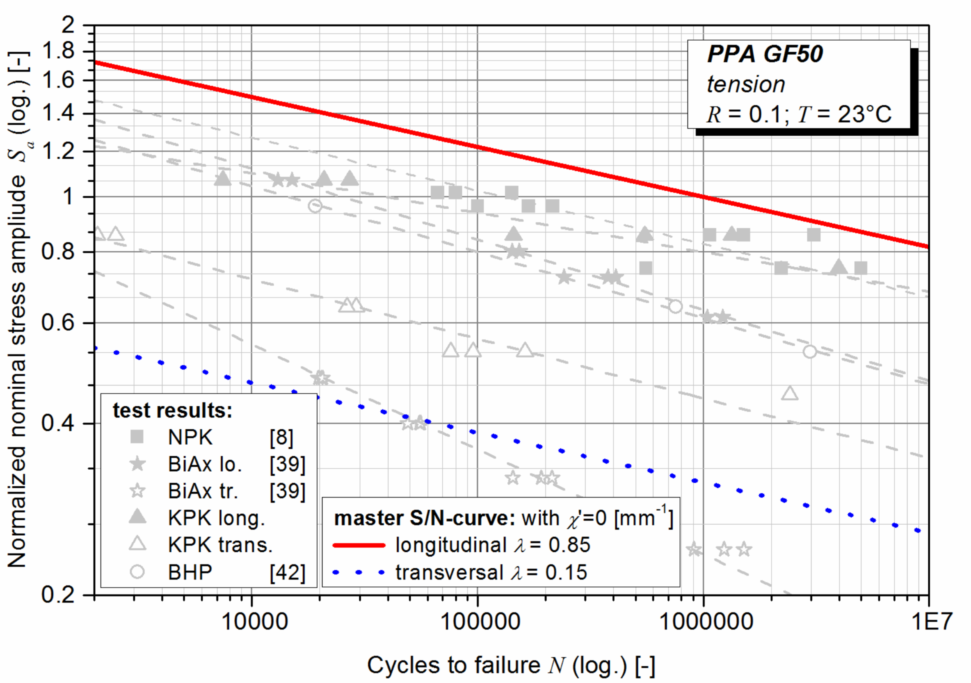


Figure 7: Master S/N-curves longitudinal and transversal

In addition to the demonstrated adjustments, consistent models describing the influence of the mean stress and the temperature can also be included in a data set, and these data must also be adapted. This procedure largely follows the described approach. A large number of tests are necessary to describe the influence of the temperature and mean stress for longitudinal and transversal fibre orientations so the model parameters are normally derived for just one fibre orientation. In this case, it is recommended that the state with the greater database be used.

If the application is well known, the number of tests necessary can be restricted to the required influences (mean stress, temperature, supporting effect, fibre orientation). However, such a reduced data set is only valid for the investigated range and should not be used for a general assessment. Depending on the number of tests, the adaptation procedure may be very time consuming and may also cause inaccuracies in the data set. To avoid this, it is recommended that a standardised specimen with a well-known fibre orientation and the same geometry be used for all test.

If further influences, such as weld lines and aging, have to be taken into account, more extensive material tests are required. Unfortunately, it is currently not possible to include the effects of aging and weld lines in the presented material data set, and t. To be able to include these effects in a lifetime assessment, enhanced data sets are required. Since weld line properties strongly depend on their quality, a data set must then describe each quality level. In most cases, the definition of a "worst-case-scenario" is sufficient, such that the range of tests can be reduced to tests perpendicular to one type of weld line. In the same way, a data set can be prepared for different aging conditions. Since the range of tests required would be costly and time consuming, enhanced data sets might be derived by shifting a material data set, such that the material parameter W_0 can be multiplied by a factor f_i, Equation 7. These factors can be determined for almost every type of factor of influence with a small number of tests. Primetzhofer showed in [39] a decline in both the ultimate and fatigue strengths in test results of a longitudinally oriented specimen and a weld line of 40%. In [43] the effect of moisture absorption is also presented. It should be stated that this process generates estimates and may cause non-negligible deviations in lifetime assessment. Therefore a validation using test results is always recommended.

$$W_i = W_0 \cdot f_i \qquad \textit{Equation } 7$$

The presented procedure can be adapted to a wide range of reinforced materials, although additional failure criteria may have to be used for other types of materials. For example, for interlaminar failure in composites, some additional failure criteria, such as the Puck criterion [44], must be implemented in the lifetime assessment.

6 VALIDATION

To validate the functionality of the data set, the lifetime of selected specimens is calculated and compared to the test results. The results for three selected specimen types are given in Figure 8, in which a solid line represents the test result and the calculated results are represented by a dot-dashed line. The calculated number of cycles for a certain stress level is marked with a cross. The two "master S/N-curves" are also included for reference (grey solid and dotted line in Figure 8). It can be shown that, for all specimens (Figure 3), the ratio of the calculated lifetime N_{calc} and test result N_{test} stays between $0.1 \geq N_{test}/N_{calc} \leq 10$ in the investigated area. The results show a good correlation for the longitudinally oriented BiAx and the notched RB-specimen. Due to a mesh-related underestimation of the relative stress gradient χ' in the FE-analysis, an offset occurred for the notched specimen (RB). In [18, 45] the effect, which depends on the mesh size and the notch radius, is described. Unlike the results for a longitudinally oriented BiAx-specimen, the transversally oriented BiAx-specimen show deviations in the calculated fatigue limit as well as for the slope of the S/N-curve. For a higher number of load cycles, this leads to non-conservative results. A more precise analysis of the results shows a deviation in the fibre orientation from process simulation as well as an underestimated notch support due to the mesh size. Further, an interaction between the fibre orientation and notches leads to changed failure mechanisms and additionally, the fibre orientation model in the used data set originates from a short specimen (KPK Figure 3). Since these specimens are only slightly notched, the interaction between the fibre orientation and the notch cannot be captured adequately. This example shows the current limits of the described method.

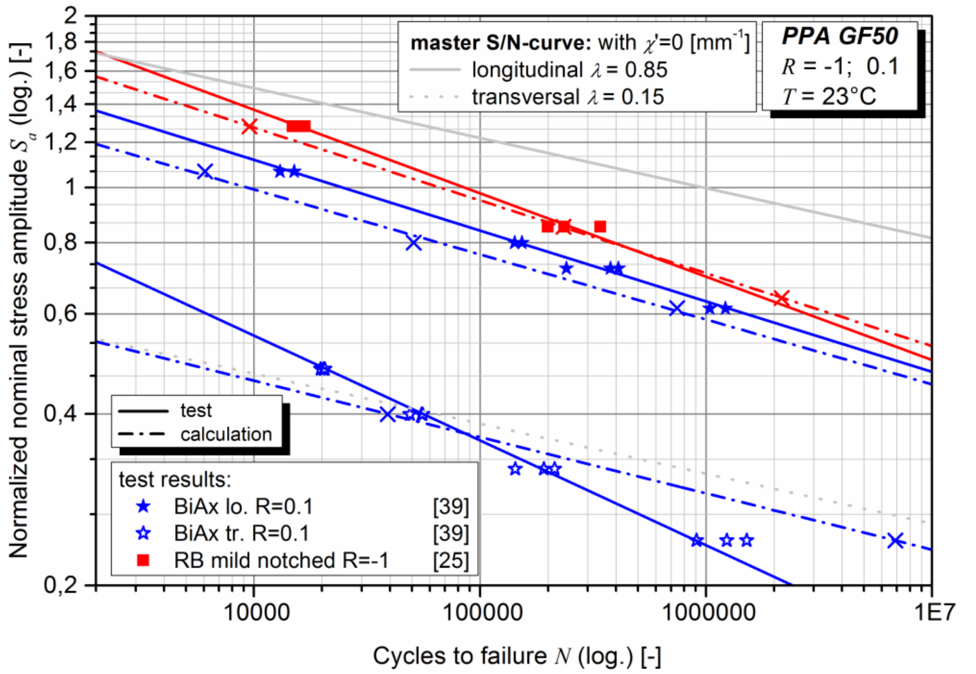


Figure 8: Comparison between test results and recalculated lifetime

The prediction of the fibre orientation in a process simulation often differs from the real orientation, even in such a simple part as a plate. Around critical areas, such as notches, these deviations can be quite high. To ensure an accurate prediction, the mesh size and simulation parameters must be chosen carefully. Although the continuous development of algorithms leads to an increasing quality of prediction, a validation of the local orientation by µCT-scans or comparable methods is advisable. While a fine mesh can be used at the specimen level, for real parts a coarser mesh often is used. To avoid deviations caused by the mesh size and quality, a strategy must be found to guarantee comparable FE-based geometric properties (K_t, χ') for data set generation and lifetime assessment [45]. Further, since the interaction between fibre orientation and notch effect is not fully understood, this influence cannot be captured properly by the currently used models, underlining the need for a more comprehensive data base. Since it is difficult to produce a transversal oriented notched specimen without machining, it is challenging to find suitable solutions to describe the more pronounced influence on the S/N-curve.

Nevertheless, the presented method enables efficient data set generation for fibre reinforced materials. Since all data are derived at the specimen level, the derived data set is independent of a part's geometry. Therefore, a data set derived using the method described can be used to calculate the lifetime of different parts made of the same material. The approach according to *Figure 1* enables variation studies at a very early stage of the development process. Therefore, different geometries and materials can be compared to determine the optimal combination and the geometry, location of the injection point and the material can be adapted with regard to the functionality and process ability at low cost so that the lightweight potential of short fibre reinforced materials can be used optimally. Depending on the range of conditions to be covered, the effort relating to the tests can be quite high. For well-known load conditions, this effort can be reduced significantly, so that, as a first step, a basic data set can be used and then extended later on. Although the method presented provides a straightforward lifetime assessment of parts. The preparation of a data set and the interpretation of simulation results require experience. In particular, the boundary conditions in the structural simulation can lead to large deviations in the calculated lifetime, and validation is thus recommended for each part.

The data set validated in this way can be now used to calculate the lifetime of a part with a much more complex geometry, following the workflow according to *Figure 1*. For example, in [10], the derived data set is used to calculate the lifetime of a ring spanner.

7 SUMMARY AND OUTLOOK

The described methodology allows for an evaluation of the lifetime of short fibre reinforced components based on a comprehensive data set. Following the modelling and evaluation techniques for the numerical simulations, necessary data set parameters can be evaluated. As input for the comprehensive data sets, quasi-static and cyclic tests are needed. From the test results, “master S/N-curves” and static material data have to be derived and combined in a data set. With this data set a lifetime assessment, following the method of local S/N-curves, can be performed.

The consideration of interactions caused by different specimen geometries and fibre orientations is time consuming and may lead to deviations in the results. Further research should therefore be performed to clarify the interaction between the different factors of influence. Especially aging effects as well as weld lines can only be taken into account by setting up enhanced data sets.

Data set generation, which is a costly and time-consuming method, and to reduce the level of effort required for the tests is therefore of great interest. In addition, standardisation through the adaption of test data is inevitable to generate comparable data sets. To enhance the accuracy of data sets with a simultaneous reduction in preparation time, a novel specimen type is currently at the develop-ment stage. Due to the novel geometry, a well-known fibre orientation and notch effect should be ensured. This specimen geometry should cover a wide range of applications and support the evaluation of all material properties with just one specimen type.

Based on the described approach in combination with a novel standardised specimen, a comprehensive database should be established for cyclic material data. Further research should enable a deeper understanding of the interactions between fibre material and matrix as well as fibre content. This should enable a time efficient data set generation process.

In addition, previously neglected viscoelastic material behaviour should be included in the lifetime assessment based on local S/N-curves, especially in cases of a long service time, and an improvement of the accuracy of prediction is expected.

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