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Fatigue simulation of a short fiber re-inforced oil-filter under high temperature and pressure load

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Abstract

Short-fiber reinforced parts show a distinct anisotropic behavior, caused by the alignment of the fibers during the injection molding process. The injection molding simulation provides the local probability distribution of the fibers (orientation tensor). By applying multi-scale material models it is possible to estimate the local anisotropic stiffness. This leads to considerable more accurate results in a subsequent FEA as with isotropic approaches. This is true even if higher temperatures lead to local plasticity. Tools that enable this integrative simulation approach have been established in the last years. To account for the anisotropic fatigue behavior an interpolation of fatigue strength at a discrete fiber orientation distribution is often used by estimating the anisotropic stiffnesses in direction of the orientation tensor principal directions. This is in most cases not appropriate. In the paper an approach is described that uses a so-called Master SN curve concept which estimates SN curves for varying local fiber orientation distributions. For the application case of high temperatures and local plasticity several enhancements were implemented and tested. The methodology is verified at the example of an oil-filter system under pressure at elevated temperature.

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1. Introduction

Fatigue of metals is studied since the beginning of the 19th century. It started by testing full components like steel chains and later rail axels as these parts had shown failure after the repetition of many load cycles, where each individual load cycle did not damage the part on the macroscopic level. Hence approaches in fatigue for metals typically started from a full macroscopic point of view, the behavior at the microscopic level had not been modelled but taken into account by fitting test data to those microscopic models.

For composite structures it is necessary to take the local microscopic structure into account as it defines the basic structural behavior. For injection molded short fiber reinforced plastics the local distribution of the fiber orientation directly influences the (anisotropic) local stiffness of the structure and also defines the damage behavior.

Also the global damage behavior of composites is different compared to metals. Whereas metal parts do not show changes in the global stiffness until failure, stiffness losses and global stress redistribution in composite structures can be observed.

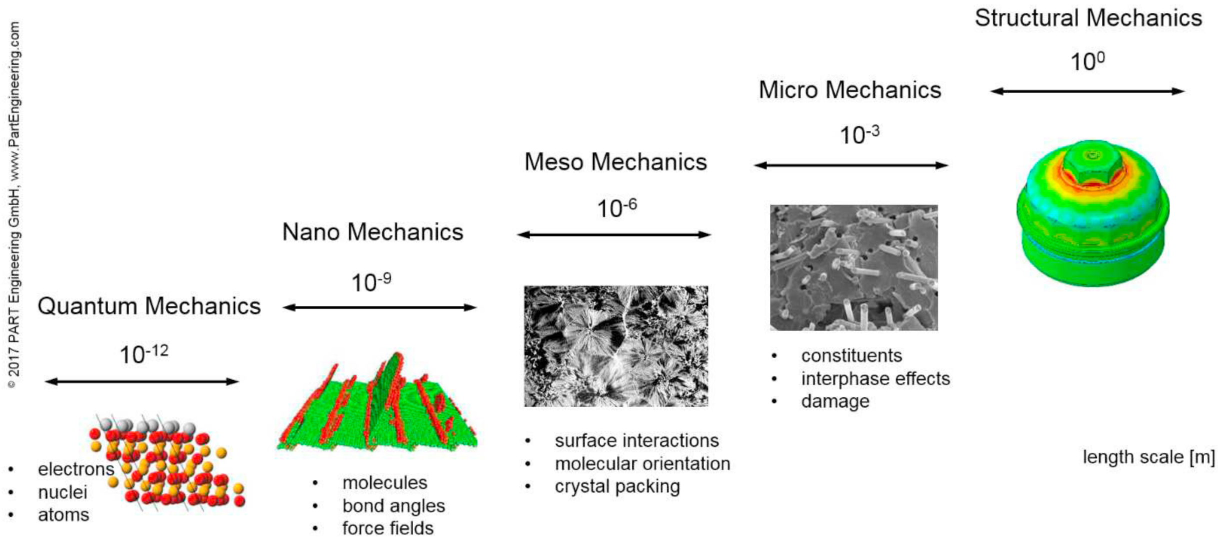

Figure 1: Different length scale domains of a material

Hence it is clear that the process to simulate damage should be modified for composite structures. Here the behavior on Meso and Macro scale is to be considered see Figure 2

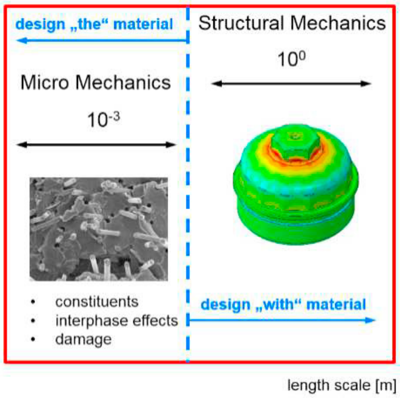

Figure 2: Micromechanics determines the behavior on the component level

2. The simulation process

In order to study the behavior of injection molded short fiber reinforced plastic components the evaluation of the local mechanical behavior is necessary. In a first step the simulation of the manufacturing process itself has to be conducted. An outcome of such a simulation is the local distribution of the fibers (to be more precise the probability distribution of the fiber orientations).

Nowadays the usage of injection molding simulation software is a standard in the development process. Such simulation software provide the local fiber orientation distribution as output. The fiber orientation subsequently has to be transferred from the model for the injection molding simulation into the model for the structural simulation. In the scope of this investigation the software Converse [6] has been applied for that. Further analysis of the fatigue behavior is then done by the Master SN approach as described in the following chapter.

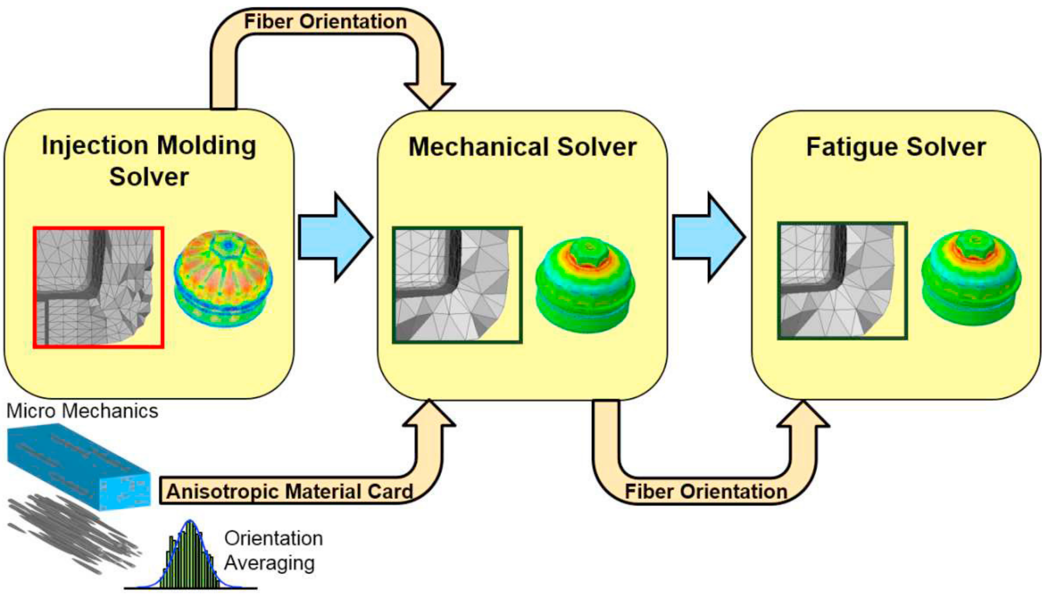

Figure 3: The simulation process

3. The Master SN curve approach

The local distribution of fibers lead to different fatigue behavior at each point in the structure and each direction against the local load. Therefore it is necessary that for a given material the fatigue behavior is known for any fiber distribution. In a joint research project the KU Leuven and Siemens developed a hybrid master SN curve approach [1-3]. The basic idea is to separate the influences of the orientation from the basic influences of the material (incl. temperature, wetness, etc.). It was found that taking into account the effect of fiber matrix debonding and fiber cracking on micro-level enables to split the effect of the fiber orientation from the effects of the base materials and the environment [2,3].

The basic idea behind the approach is to calculate the damage on microscopic level. The first cycle of loading is modelled. Onset, progression of fiber matrix debonding and subsequent loss of stiffness is based on the concept of "equivalent bonded inclusions". A thorough mathematical treatment of this concept has been presented in [4]. In order to calculate a point on a SN-curve for an arbitrary but given orientation one starts from the point of same (macroscopic) damage on a given Master SN curve, calculates the progressive damage on the microscopic scale for the orientation of the SN curve. In order to get the point on the new SN curve the load that is needed to reach the same microscopic damage for the new orientation is evaluated by an iterative process.

A validation of the entire process has been conducted with specimen and component data .

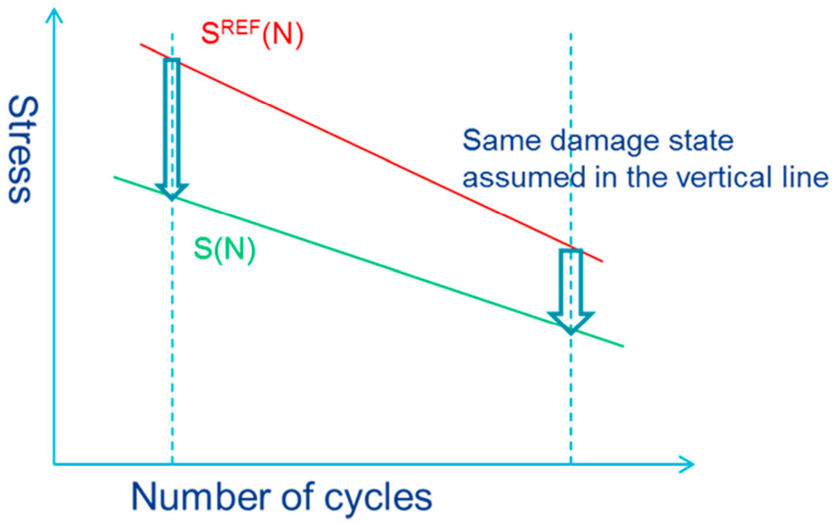

Figure 4: Idea of SN curve shift

While this paper is not intended to describe the methodology in detail, it is necessary to analyze the basic ideas and assumptions in the method to be able to adapt it to the additional needs of the environment of the component (oil-filter system) that we analyzed.

Basic assumptions in the master SN curve approach as implemented in [1-3] are:

- The approach is developed for the High Cycle Fatigue (HCF) area. Hence plasticity is not assumed on a macroscopic level. (Plasticity on a microscopic level can be included)
- In the HCF area a pure shift factor on the SN curves describes the influence of the orientation distribution well enough. (i.e. the SN curves used in the area of HCF all have a very similar slope)

It must be noted that these assumptions have been posed to simplify the approach for the typical situations of fatigue life and are not intrinsic of the methodology itself, such that they can be overcome for more complex situations as in the project described here.

4. Local and Global Stiffness reduction

As opposed to metal structures in composite structures a change in the local and global stiffness before failure of the complete structure is observed. It can be seen in the matrix material as well as in the composite. Detailed analysis on different specimen had shown [3] that this stiffness reduction over the lifetime does largely not depend on the local fiber orientation.

These local stiffness changes lead to a redistribution of stresses. The influence of these redistributions lead to large differences between the component behavior and specimen behavior. The slopes of specimen SN curves are typically much smaller than those of the component SN curves. Without taking stiffness reduction into account a correct simulation of the component behavior was not possible (See [1,2]).

For short-fiber reinforced composites an exponential decay down to 90% - 85% during the lifetime gives a good estimate.

How to apply the stiffness reduction in a fatigue calculation process is explained in more detail in [5]

5. Elevated temperatures and large plastic strains

In case of higher temperatures macroscopic plastic behavior becomes relevant even for smaller loads that still can be endured for considerable load cycle numbers.

This means that

- Plasticity on microscopic level must be considered
- A single shift factor is not sufficient. An extension to multiple points to evaluate the SN-curve shift as already discussed in [1] is used
- Plasticity on macro level is necessary

For the latter a traditional approach was chosen, namely a Neuber type approximation of the local stress-strain data. Input to the fatigue calculation can still be the local elastic stresses. These stresses then are than compared to the back-calculated local SN curves. See figure 5

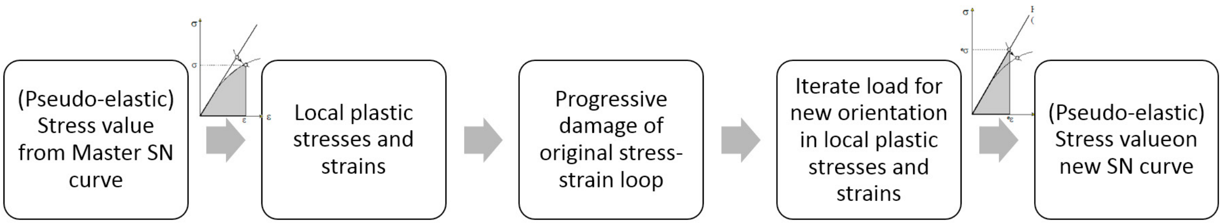

Figure 5: Process of the SN curve estimation using Neuber correction

Using all these methodologies for simulation the analysis of the oil-filter system was performed

6. Application example

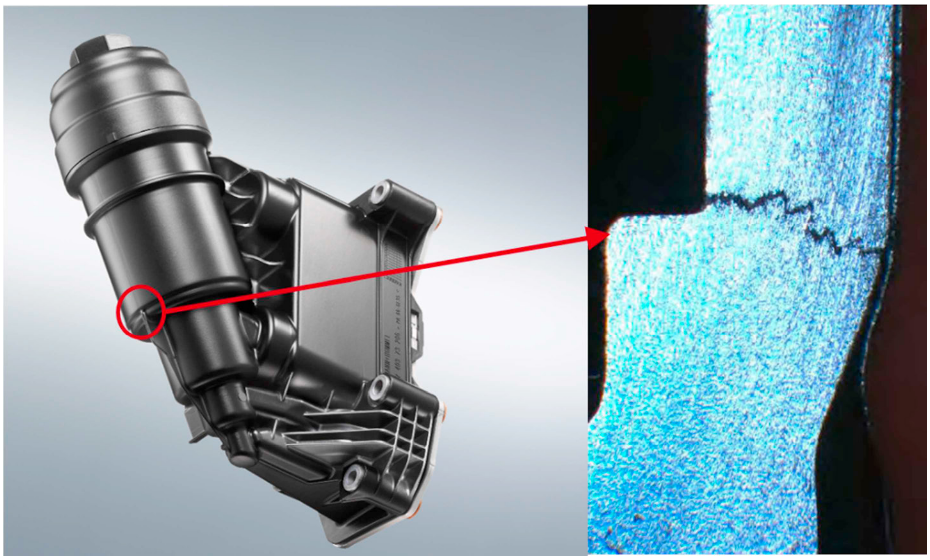

Figure 6: Application example: Oil-filter system at 150°C under pulsating pressure load, damage in test

The example we analyzed was an oil-filter system (figure 6) from MANN+HUMMEL. In this paper the results are shown in normalized scales.

As first step in the required CAE process chain, an injection molding simulation has to be conducted in order to obtain the local orientation tensor. Figure 7a shows the fiber orientation in the critical area of the component. The fiber orientation has to be mapped from the manufacturing simulation model onto the structural simulation model. Most probably both models use a different mesh topology. For that the software Converse [6] was applied. Which provides not only the local orientation tensor but is as well capable to provide a full set of anisotropic material properties if requested.

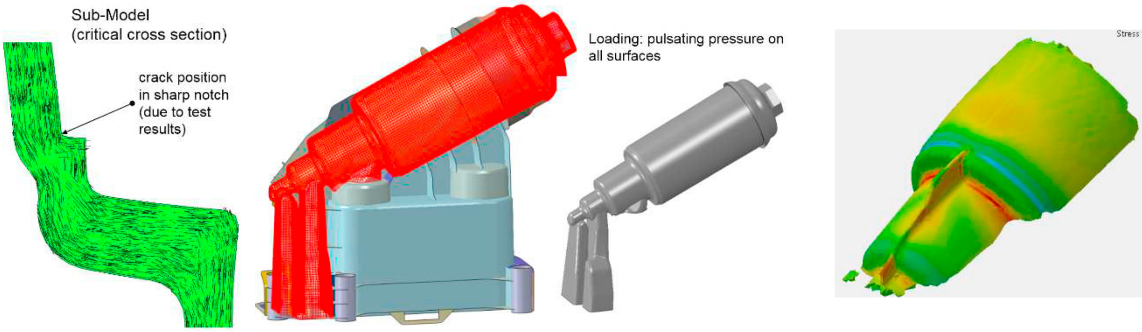

Figure 7: (a) Fiber distribution in the critical area, (b) Finite element model, (c) Stress results in LMS SAMCEF

Then finite element analysis can be performed. As the Master SN curve approach uses automatic stiffness reduction the finite element calculation is using the internal finite element solver (LMS SAMCEF). A result in the critical area is shown in Figure 7c.

The next step for fatigue analysis is a preprocessing step that calculates the SN curves for all orientations in the model. As we encounter high plastic stresses the method as described in chapter 5 was used. Figure 8 shows a few SN curves at a given orientation under different load directions.

Then the full life time of the component under consideration of the stiffness reduction is simulated. See two states of the damage accumulation and stiffness reduction over time in Figure 9.

Figure 10 finally shows the test results versus simulation results at 3 different load levels. It can be seen that the simulation being slightly conservative not only predicts the life time (and damaged area) but is able to predict as well the correct component behavior even for high loads and therefore large plasticity.

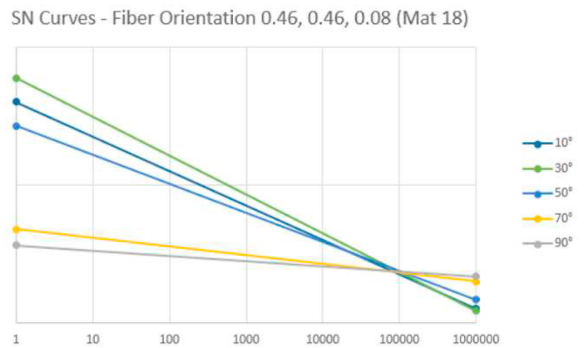

Figure 8: Orientation dependency of local SN curves

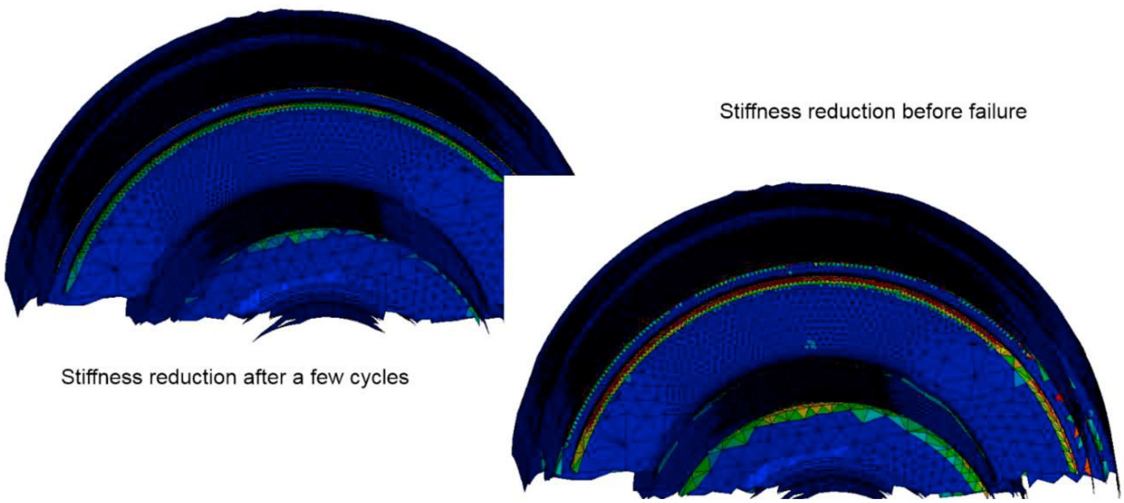

Figure 9: High stiffness reduction in the notch, leading to stress redistribution

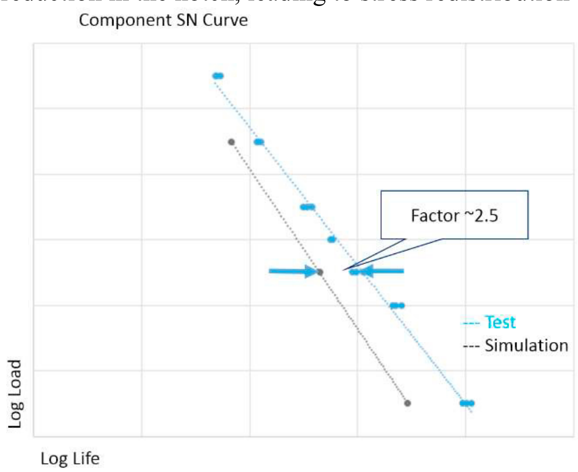

Figure 10: Comparison between simulated and tested life time.

7. Conclusion and Outlook

The Master SN curve approach was extended to allow the simulation of components that show locally large plastification due to elevated temperature. The extension is using a traditional Neuber based approach to include the effect of plasticity. Locally the macroscopic effect is taken into account by the stress redistribution due to local damage and stiffness losses. It was included as an option in the software implementation of the Master SN-curve approach.

The extended approach has shown good results on the example of an oil-filter system under pressure loads. Here it could predict not only the fatigue life at a given load level but also nicely predict the dependency on the load level (slope on the component SN-curve) as opposed to the behavior of the pure material.

Further investigations on the extension of the Master SN-curve approach to higher temperatures and large plastification are planned.

References

[1] A.Jain, Hybrid Multi-Scale Modelling of Damage and Fatigue in Short Fiber Reinforced Composites, PhD Thesis, Leuven, 2015

[2] A. Jain, Y.Abdin, S.Straesser,W. Van Paepegem, I.Verpoest, S.V. Lomov, Master SN-Curve approach - A Hybrid Multi-Scale approach to fatigue simulation of short fiber composites, Copenhagen , 2015

[3] A. Jain, W. Van Paepegem, I.Verpoest, S.V. Lomov, A feasibility study of the Master SN curve approach for short fiber reinforced composites, I.J.Fatigue, 91(1), 2016, pp 264-274.

[4] Jain, A.,. Y.Abdin,W.Van Paepegem, I.Verpoest, S.V. Lomov, *Effective anisotropic properties of inclusions with imperfect interface for* Eshelby-based models. Composite Structures 131, 2015, pp. 692-706

[5] M.Hack, D. Carrella-Payan, B. Magneville, T.Naito, Y.Urushiyama, T.Yokozeki, W.Yamazaki, W.Van Paepegem: A Progessive Damage Fatigue model for unidirectional laminated composites based on finite element analysis, theory and practice, Cambridge, 2017

[6] Part Engineering, Converse – Software for Simulation Plastic Parts, User Manual, Bergisch-Gladbach 2017