Use Case: Fatigue

# ACCURATELY PREDICT *FATIGUE LIFETIME OF INJECTION–MOLDED SHORT–GLASS–FIBER REINFORCED PLASTICS COMPONENTS*

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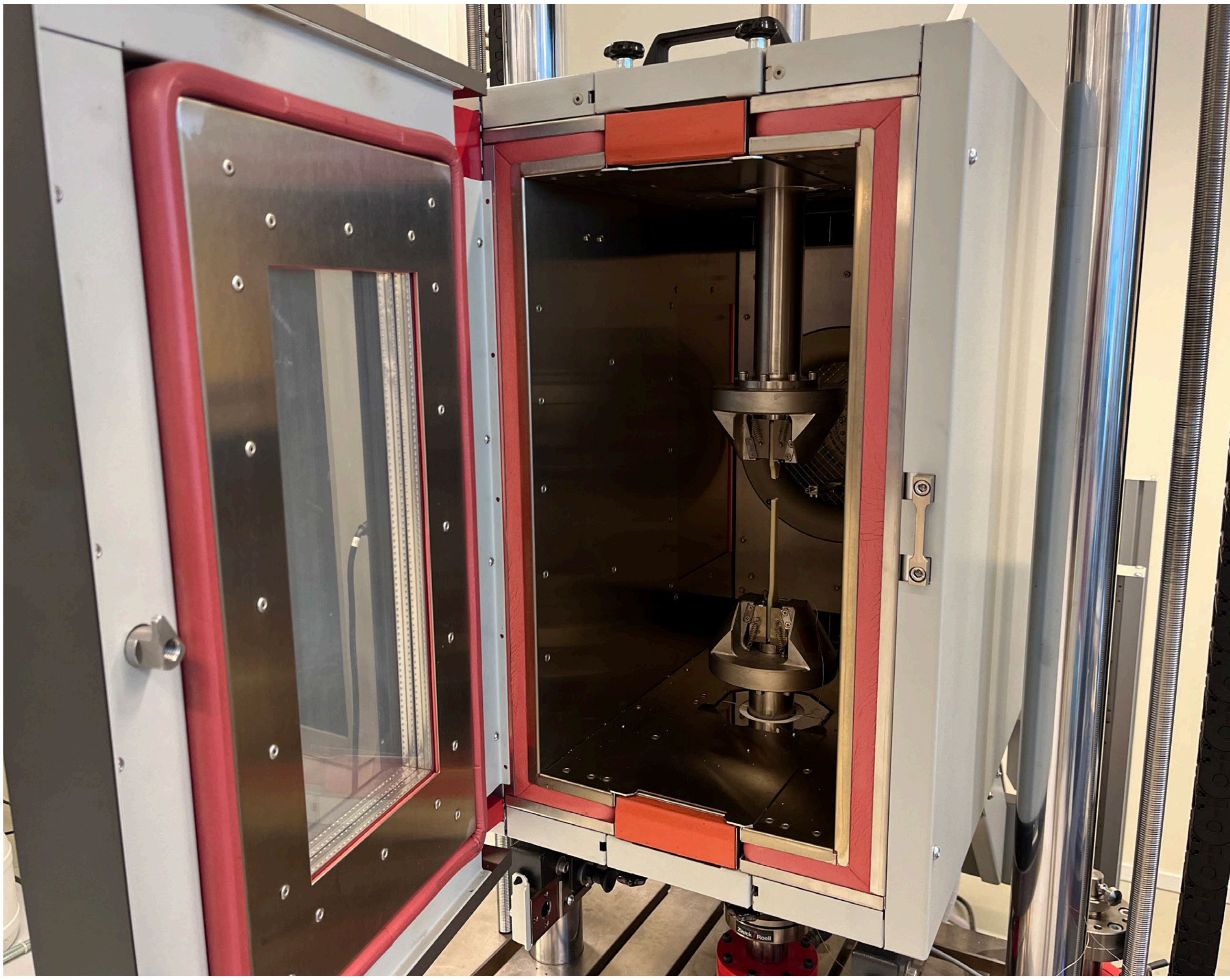
# SUMMARY

Predictability is key when designing load bearing components because it reduces development time, enables first–time–right design, and ensures part performance in service. Based on experiments we have developed a robust framework considering all essential aspects for fatigue/lifetime modeling of a part based on design, material properties, environmental conditions, and load type and load level. These are all implemented in the Digimat material modeling software, which couples to common finite experimental analysis (FEA) solvers like e.g. Abaqus.



# INTRODUCTION

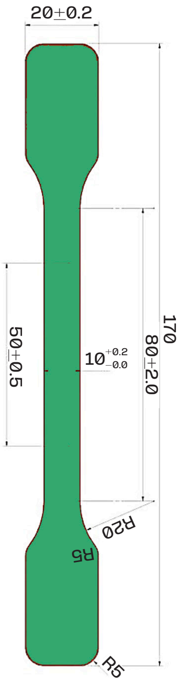
Fatigue is concerned with alternating or cyclic loads, even when the load levels are well below the strength of the applied material. Depending on the component, over time such a load will lead to part failure. Based on conducting extensive experiments, we developed a robust framework considering all essential aspects for fatigue. This Use Case focuses on results of our fatigue/lifetime modelling framework for injection molded glass–fiber reinforced plastics, using the example of the load bracket demonstrator.

CONDUCTING EXPERIMENTS AND *DEVELOPING FATIGUE/LIFETIME MODELING FRAMEWORK WHILE CONSIDERING ALL ASPECTS FOR FATIGUE.*

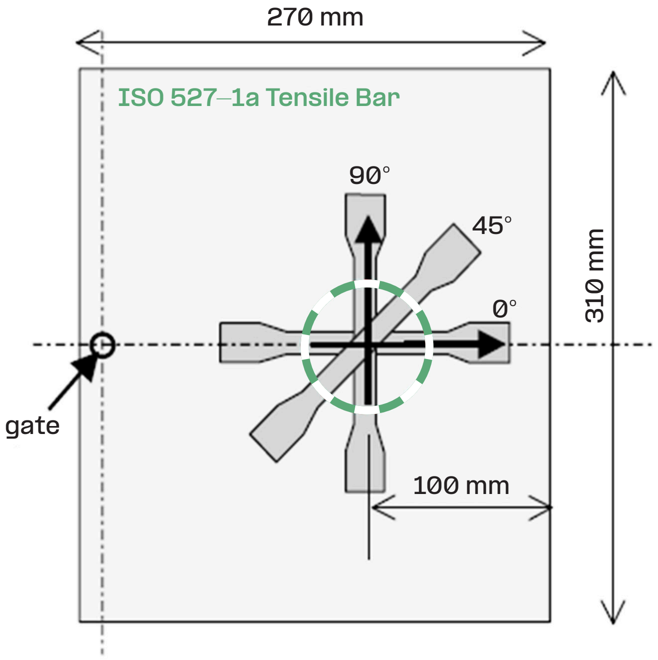
# SPECIMENS HELP CREATE A MATERIAL *PROPERTY MODEL FOR FATIGUE*

To obtain an accurate material model we need input from experimental campaigns that measure lifetime as a function of load level. We use different specimens that allows variation of fiber orientation, load ratio and stress state. Some of the specimens are even cut at different orientations from an injection molded plaque to assess the effect of a fiber induced anisotropy. Also, we measure fatigue curves on notched specimens to include the effects of stress concentrations in our modelling approach.

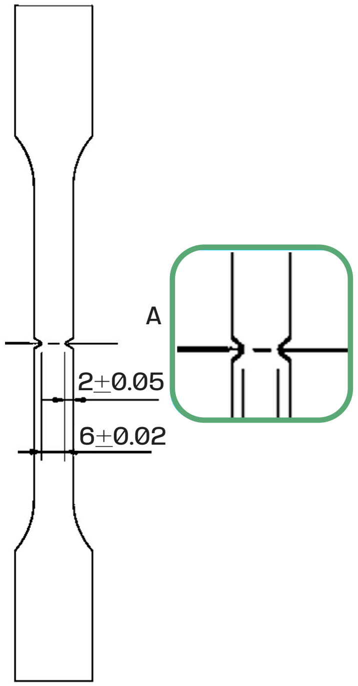
REGULAR



SPECIMENS MILLED FROM PLAQUE

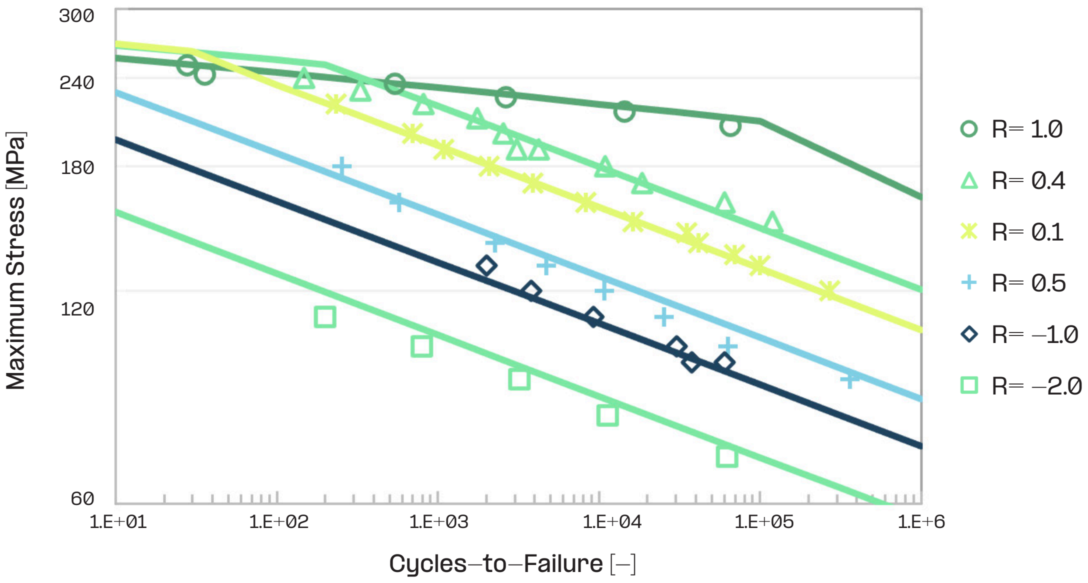


NOTCHED SPECIMENS



# MODELLING *FRAMEWORK*

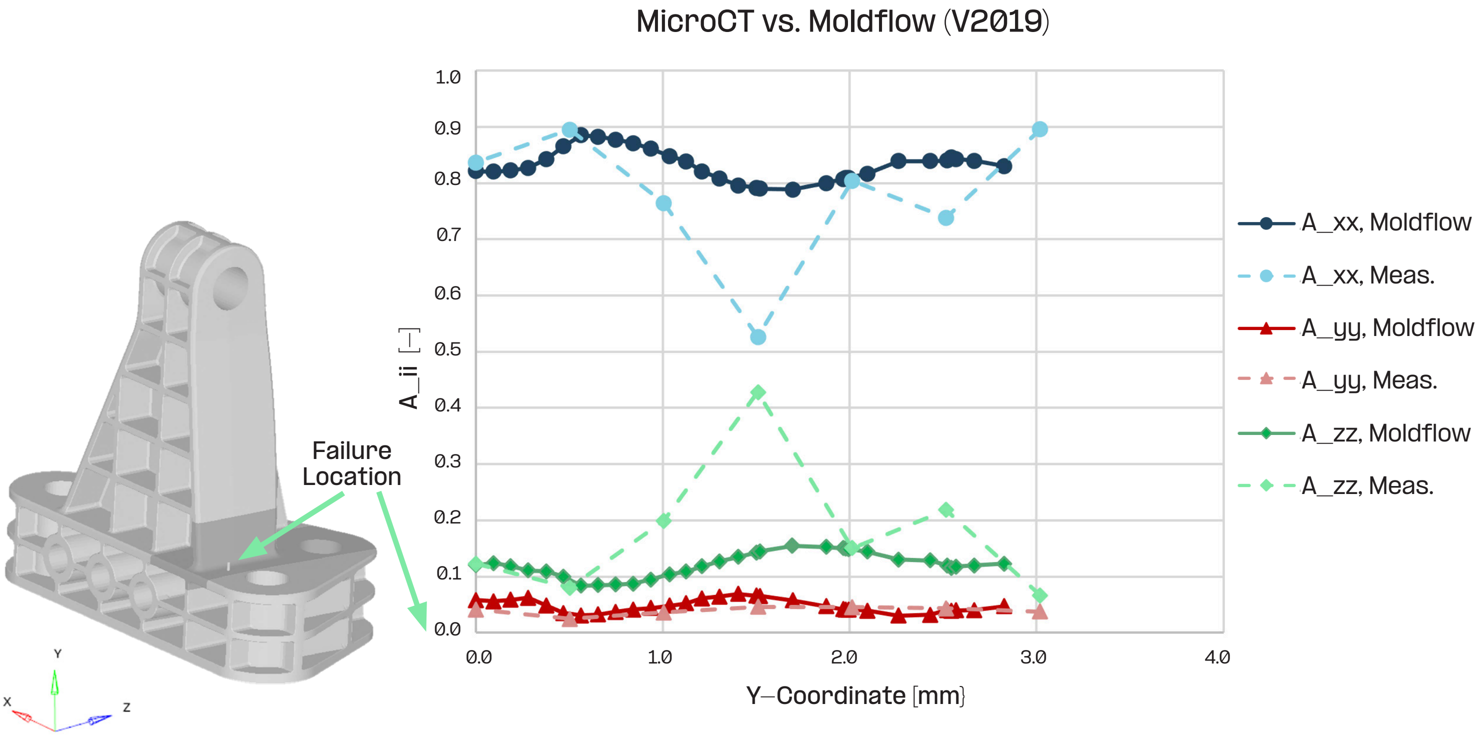
All experiments on a single type of specimen are shown in the graph below (for PA66-GF50 at 23°C). We measure so-called 'Wöhler' or SN curves: Stress vs. Lifetime (load cycles N). The load ratio 'R' represents the minimum over the maximum load during the experiment.



# FIBER ORIENTATION: *MEASURED VS. MODELED*

In parts that are injection molded with fiber–reinforced plastics, the fiber orientation varies throughout the part. Accurate prediction of fiber orientation at failure location is a requirement for accurate fatigue/lifetime prediction.

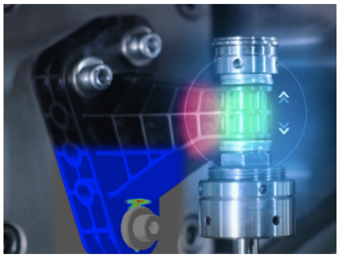
Using injection molding simulation software enables us to calculate the final fiber orientation. For validation, a portion of the molded part (dark grey in picture below) is measured in a micro–CT scanner. From that we evaluate the actual fiber orientation and compared it with simulation results.



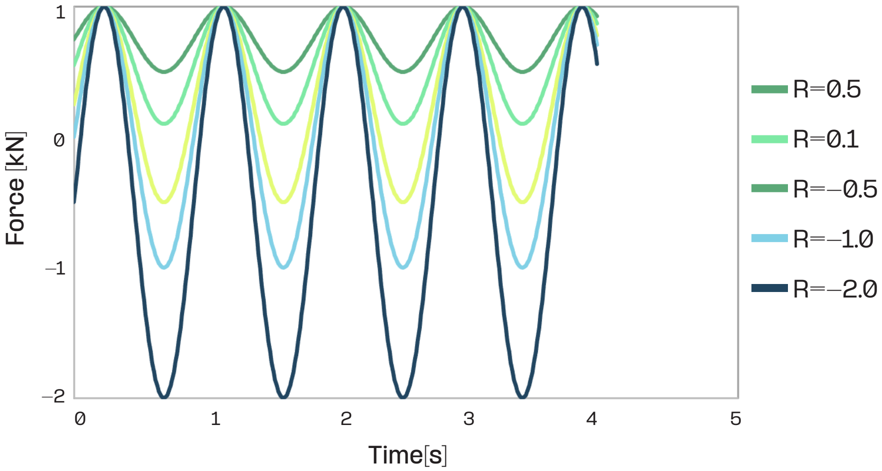
The above graph compares model predictions (solid lines) to experimental results (dashed lines). We can see that the overall trend for A_xx, A_yy, and A_zz is captured correctly. At position x=1.5 there's a small discrepancy. However, for failure of the part, the values at the surface (x=0) are most important.

# LOAD BRACKET
# *EXPERIMENTS*

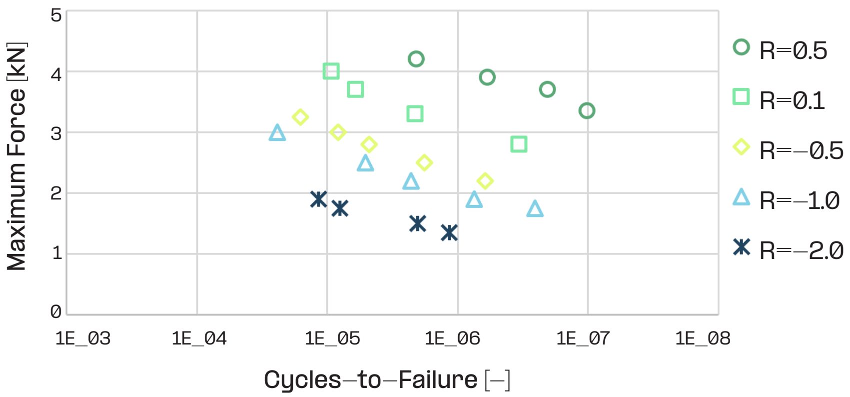
The injection molded bracket was tested at different load ratios 'R' and different load levels. The results of force vs. cycles–to–failure (Nf) show clear trends and prove the experiment's reliability.



$$R = \frac{\sigma_{min}}{\sigma_{max}}$$



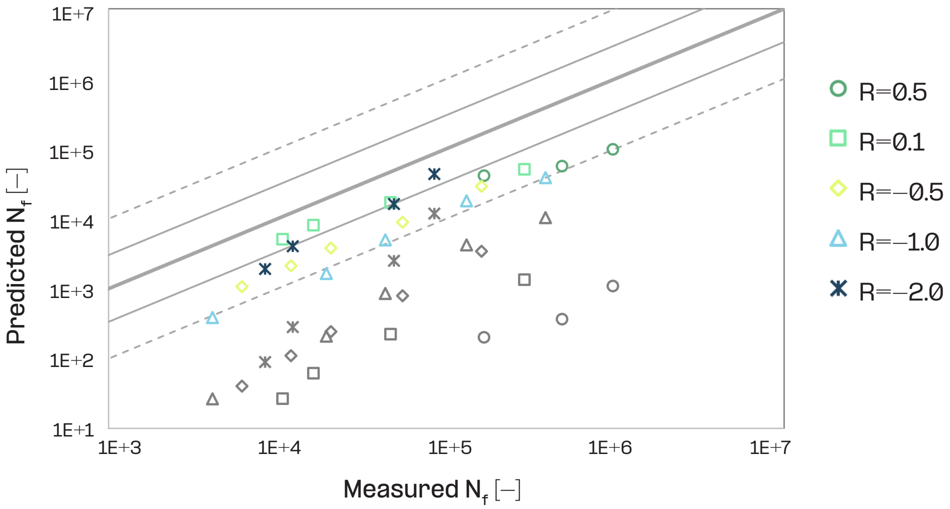
Load Bracket Test Data

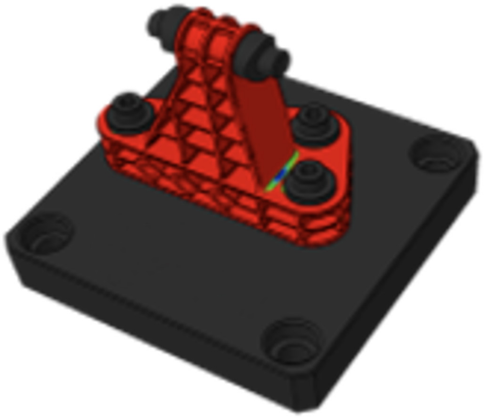


# LOAD BRACKET *EXPERIMENTS*

In the graph below we show the results of predicted vs. measured lifetimes for all experiments. The colored marker shows the results for the material card that includes all aspects of fatigue: anisotropy, R-value dependence, stress gradients, and plasticity. The right failure location is predicted. Predictions of complex parts with accuracy of factor 2-10x is achieved.

Note that if we exclude correction of stress levels based on plasticity and stress gradient effects, from our fatigue evaluation, the results become much worse. In the graph these results are represented by the grey markers.



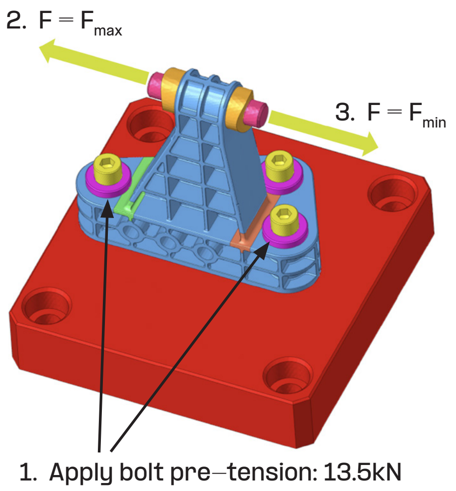


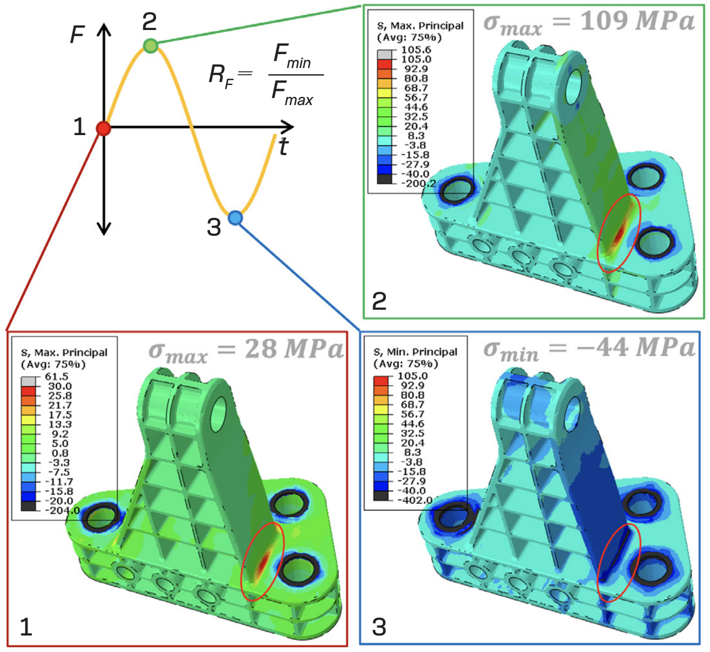
# LOAD BRACKET
# *FATIGUE MODELING*

The load bracket's geometry is defined and meshed in the FEA software. Using the fatigue material cards, we run the simulations to assess the lifetime for different loading conditions. The first step is to calculate the stress distribution in the part for the load cases defined. The standard approach in fatigue evaluation is to calculate the stress distribution based on a linear elastic (anisotropic) material model. Next is to determine the critical locations and run the lifetime calculations based on the stress results.

To get accurate results for the lifetime, we need to consider if stress levels are beyond the elastic limit. If so, we apply a correction to the stresses, before evaluating the lifetime. An additional correction may be necessary for cases where large stress gradients are present. This correction has been carefully calibrated by our fatigue measurements on specimens notched with different notch radii.

$R_F = -1$, $F_{max} = 1600$ N





$$R_\sigma \neq -1 \;\Big\downarrow\; R_\sigma = -0.4$$

# BOTTOM LINE

Our fatigue/lifetime modelling framework will enable you to accurately predict fatigue life of injection molded short glass fiber reinforced plastics parts. To predict the crack-growth dominated lifetime of injection molded short fiber reinforced plastic parts with confidence, you need to capture:

- The effect of fiber orientation and local stresses
- The influence of (local) load amplitude
- Include the effect of plasticity on (local) stresses
- Correct for the presence of stress concentrations

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