European Major Research Infrastructure
Aerospace Materials Technology Testhouse
AMTT
EC- Program "Improving the Human Research Potential and
Socio-Economic Knowledge Base"

# Creep resistance and creep bending resistance of light metal matrix composites for research in airframe structural effiency

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## 1 Introduction

Main aim of the research in the frame of the AMTT programme was the testing of a fiber reinforced Al-alloy. For investigation of the creep behaviour of this material, creep tests under bending were performed. The tested material was Al99.85+0.1%Mg reinforced with $Al_2O_3$ fibers (Altex/Sumitomo), which was prepared by means of gas pressure infiltration. Main benefit of such a material for application would be the lowering of the weight of the material without a loss of properties.

## 2 Experimental Procedure

### *2.1 Sample description and testing conditions*

For the determination of the creep behaviour, samples with three different thicknesses were tested. Because of the preparation route of the samples, the fiber volume content of the test samples varied between 35% and 47%. The detailed information of the tested samples with the geometry and the fiber volume content can be found in table 1.

For all investigations the applied load was sellected in that way that in each sample - independent of sample thickness - the edge fiber strain was equal. This strain can be calculated from the correlation:

$$s_R = \frac{3}{2} \cdot \frac{(l-s)}{ab^2} \cdot F$$

In this correlation a, b, l and s are given from the geometry of the sample and the testing set-up. (See annex 1). In addition a simple correlation can be used for the determination of fracture strength R and E-Modul E by knowing the fiber volume content ξ. For calculation of these values the „Rule of Mixture“ (ROM) can be used:

$$E = E_m \cdot (1-x) + E_f \cdot x \qquad \text{and} \qquad R = R_m \cdot (1-x) + R_f \cdot x$$

**Table 1: Overview of Samples and Testing Conditions:**

**Samples A**

Thickness: 1mm Fiber volume content: 35% $E_{ROM}$ = 115 GPa
$R_{ROM}$ = 643 MPa

| Sample# | b [mm] | F [N] | $\sigma_R$ [MPa] |
|---|---|---|---|
| (A 1)* | 1,1 | 25 | 139 |
| A 2 | 1,12 | 30 | 161 |
| A 3 | 1,10 | 73,5 | 410 |
| A 4 | 1,09 | 60 | 340 |
| *A 5* | *1,09* | | |
| *A 6* | *1,06* | | |

Tabelle 1a; * experimental material

**Samples B**

Thickness: 1.5mm Fiber volume content: 47% $E_{ROM}$ = 133 GPa
$R_{ROM}$ = 857 MPa

| Sample # | b [mm] | F [N] | $\sigma_R$ [MPa] |
|---|---|---|---|
| B 1 | 1,57 | 165 | 451 |
| B 2 | 1,55 | 80 | 225 |
| B 3 | 1,52 | 135 | 395 |
| *B 4* | *1,50* | | |
| *B 5* | *1,50* | | |
| *B 6* | *1,57* | | |

Tabelle 1b

**Samples C**

Thickness: 2.5mm Fiber volume content: 42% $E_{ROM}$ = 126 GPa
$R_{ROM}$ = 768 MPa

| Sample # | b [mm] | F [N] | $\sigma_R$ [MPa] |
|---|---|---|---|
| C 1 | 2,55 | 185 | 192 |
| (C 2)* | 2,51 | 380 | 407 |
| (C 3)* | 2,41 | 380 | 441 |
| C 4 | 2,43 | 380 | 434 |
| C 5 | 2,44 | 450 | 510 |
| C 6 | 2,48 | 305 | 334 |
| C 1-Vers2 | 2,55 | 450 | 467 |

Tabelle 1c; * experimental uncertainties

## 2.2 *Experimental Set-up*

For performing of creep experiments a set-up based on a 4-point bending test was used. During the experiments the deflection of the sample was recorded as a function of time. Because of the limitation of the sensor within a range of 0-2mm, it was necessary to correct deflections larger than 2mm by putting a flat plate in between.

The load of the specimen during testing can be influenced by variation of the amount of lead balls. Measurement of the actual load was done using a sensor for measuring load.

The temperature during the experiments was controlled with a thermocouple and the used set-up allows to control temperature using three seperated control loops. The temperature varied between the measurements of different samples within the range of 280°C and 320°C. Within the measurement of one sample temperature, variations near the sample were detected in the range of +/-5°C. This variation is due to the fact that the testing equipment is located in a large hall and therefore different temperatures during day and night have an influence to the measured deflection signal.

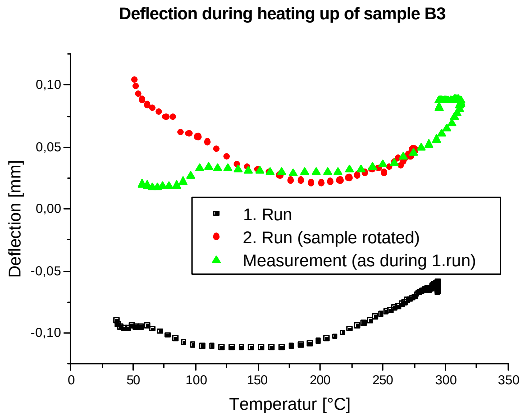
For Measurement of creep behaviour the following steps were performed:

1 Heating up of sample up to 300°C
2 Loading of sample
3 Measurement of creep behaviour
4 Unloading of sample
5 Cooling down of sample

During all these steps the deflection, time, load and temperature was recorded using a turbopascal programme. All these parameters were recorded in intervall of 1s (step 2 and 4), of 60s (step 1 and 5) or of 10 minutes (step 3).

During testing the first sample a deflection during heating up was detected. To gurantee that this detected deflection was not due to internal stresses in the sample produced by the preparation process, one sample was heated up, cooled down, rotated and heated up again. Both heating up curves show a similar behaviour. Beside this a heating up process was performed using a reference sample to detect the deflection which comes from the whole system. Both measurements can be found in figure 1 and 2.

From figure 2 one can expect that the influence of a temperature change in the range of +/-5°C leads to a detected deflection in the range of about 0,005mm.



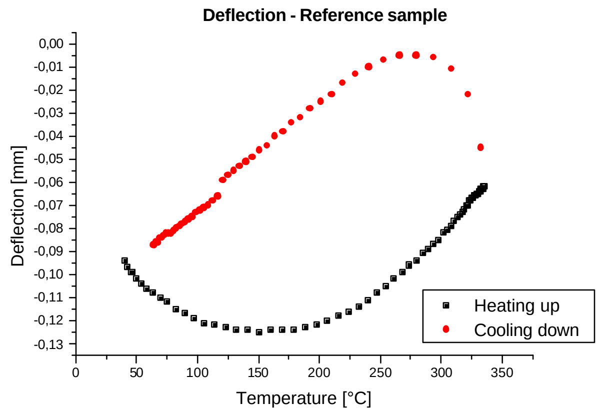




Figure 1: Deflection during heating up of sample B3 depending on the side
Figure 2: Deflection signal during heating up and cooling down of a reference sample

### *2.3 Temperature stability*

During the measurement of each sample the temperature was recorded. The heating up process up to a temperature of 300°C was possible within 2 hours. Because of the influence of the external temperature to the temperature measured near the sample, oscillations were observable. See figure 3.

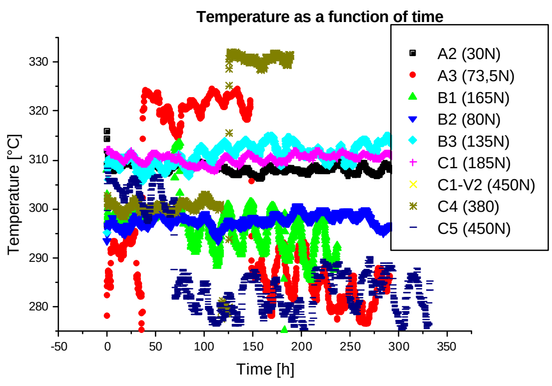



Figure 3: Measured temperature variation as a function of time.

# 3 Results

From the measured deflections the following values can be derived. These values can be found in the table 2.

- $t_b$ ..... time period during which the specimen was loaded at 300°C

- $f_i/f_f$ ..... initial deflection/final deflection
  initial deflection or final deflection is the deflection which was detected before loading the specimen at 300°C and after the unloading process at 300°C.

- $f_r$ ..... Residual deflection
  This value corresponds to the deflection which remains after cooling down of the sample.

- f(t)...... Deflection as a function of time in [mm]

- ε(t)...... Edge fiber strain
  This value was calculated using the correlation

$$e = \frac{1200 \cdot f \cdot b}{2 \cdot (l - s) \cdot (2s + l) + 3s^2}$$

- dε/dt..... creep rate [$s^{-1}$]

Calculation of the creep rate was not so easy to perform because of the strong oscillations. To avoid this the measured values were flattened using the previous 25 data points and the following 25 data points.

$$\frac{de}{dt} = \left( \frac{(2N+1)\sum_{-N}^{N} t_i e_i - \sum_{-N}^{N} e_i \sum_{-N}^{N} t_i}{(2N+1)\sum_{-N}^{N} t_i^{\,2} - \sum_{-N}^{N} t_i \sum_{-N}^{N} t_i} \right)$$

- df/dt..... velocity of deflection
  This value is proportional to the creep rate

$$\frac{df}{dt} = \frac{2 \cdot (2s + l) \cdot (l - s) + 3s^2}{1200 \cdot b} \cdot \frac{de}{dt}$$

In table 2 these values can be found for all measured samples.

**Table 2: Load, initial, final and residual deflection**

| Sample # | F[N] | $t_b$ [h] | $f_i$ [mm] | $f_f$ [mm] | $\Delta f$ [mm] | $f_r$ [mm] |
|---|---|---|---|---|---|---|
| A 2 | 30 | 330 | 1,576 | 1,739 | 0,163 | 0,376 |
| A 3 | 73,5 | 290 | 3,904 | 4,878 | 0,974 | |
| A4 | 60 | >80 | 3,433 | >4,334 | >0,901 | |

| Sample # | F[N] | $t_b$ [h] | $f_i$ [mm] | $f_f$ [mm] | $\Delta f$ [mm] | $f_r$ [mm] |
|---|---|---|---|---|---|---|
| B 1 | 165 | 235 | 2,463 | 2,733 | 0,27 | |
| B 2 | 80 | 330 | 1,372 | 1,355 | -0,02! | 0,173 |
| B 3 | 135 | 330 | 2,217 | 2,367 | 0,15 | |

| Sample # | F[N] | $t_b$ [h] | $f_i$ [mm] | $f_f$ [mm] | $\Delta f$ [mm] | $f_r$ [mm] |
|---|---|---|---|---|---|---|
| C 1 | 185 | 330 | 0,723 | 0,806 | 0,083 | 0,179 |
| C 4 | 380 | 330 | 1,685 | 3,703 | 2,018 | broken |
| C5 | 380 | 85 | 2,047 | 3,74 | 1,693 | broken |
| C 1-Vers2 | 450 | 330 | 1,922 | >3,77 | 1,847 | broken |

# 4 Diagrammes

## 4.1 Deflection versus load

Comparing the load-deflection curves of samples with different thickness, in all three cases a linear correlationship can be observed. The reason why parts of some curves are missing is due to the limitation of the deflection sensor. An overview over all samples is given in figure 4.

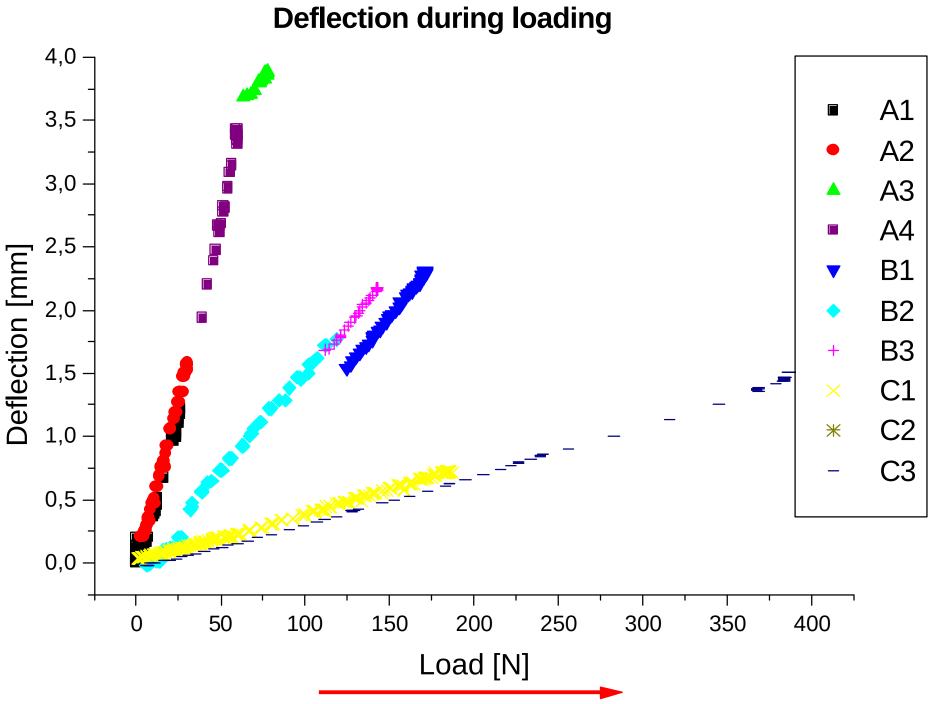



Figure 4: Deflection versus load for different sample thickness (A=1mm, B=1.5mm, C=2.5mm)

## 4.2 Deflection versus time

The measured deflection versus time curve can be seen in figure 5. Depending on the sample thickness the following statements are possible:

- For loads which correspond to a edge fiber strain of approximately 200 MPa for a certain sample thickness (30N, 80N bzw. 185N) there is no significant change of the deflection over the time.
- For loads which correspond twice that value (75, 165 bzw. 380N) larger changes during the measuring period are observable. Samples with a thickness of 2.5mm were tested up to loads of 380 to 450N and they showed buckling. One sample, C1-V2, which was tested already at 185N was tested again and broke at 450N.

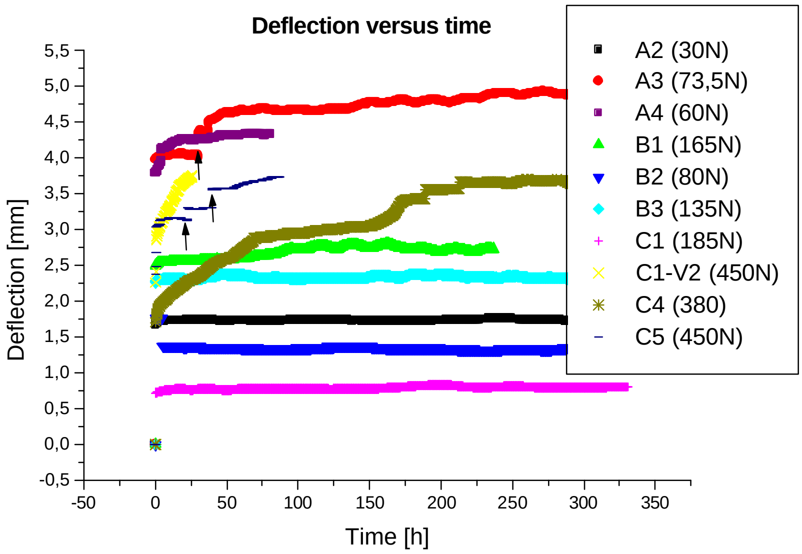



Figure 5: Deflection as a function of time. Sample C1-V2 and C4 show buckling and sample C5 was broken. The arrows indicate an interruption of measurement due to electric power failure. Sample C1-V2, C4 and C5 showed buckling.

## *4.3 Edge fiber strain*

Figure 6 shows the edge fiber strain which was calculated using the above described correlation.

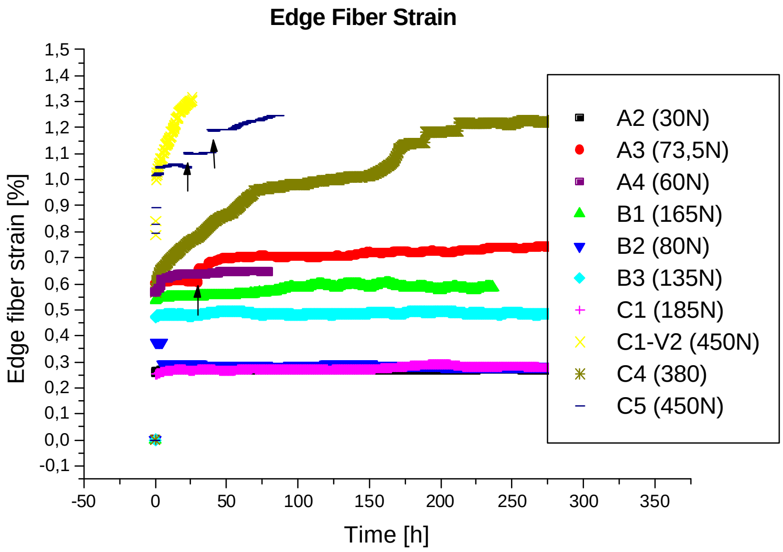



Figure 6: Edge fiber strain creep rate. The arrows indicate an interruption of measurement due to electric power failure. Sample C1-V2, C4 and C5 showed buckling.

The evaluation of the creep rate from measured deflection showed some difficulties because of the strong oscillations of measured values. Therefore flattening of the measured values was necessary. The flattening procedure always linked each data point with the previous 25 and the following 25 data points. In the figures 7 to 9 also the influence of the temperature oscillations to the measured signal can be observed. Since in all tested samples the creep rate is at the beginning relatively high, the table 3 shows a value of the deflection within the first five hours ($\Delta f/\Delta t_{\Delta t=5h}$), and also the change of deflection within the test period ($\Delta f/\Delta t_{\Delta t=tb}$). From these values the strain within these periods and therefore the mean creep rate can be determined ($\Delta\varepsilon/\Delta t_{\Delta t=5h}$ or $\Delta\varepsilon/\Delta t_{\Delta t=tb}$). The negative value of sample B2 can be explained because of the very low load combined with temperature oscillations. In the following table these values can be found for all measured samples.

| Sample # | F[N] | σ [MPa] | $\Delta f/\Delta t_{\Delta t=5h}$ | $\Delta f/\Delta t_{\Delta t=tb}$ | $\Delta\varepsilon/\Delta t_{\Delta t=5h}$ | $\Delta\varepsilon/\Delta t_{\Delta t=tb}$ |
|---|---|---|---|---|---|---|
| A 2 | 30 | 161 | 8,5E-06 | 1,4E-07 | 1,3E-6 | 2,1E-8 |
| A 3 | 73,5 | 410 | 6,4E-06 | 9,3E-07 | 9,6E-7 | 1,4E-7 |
| A 4 | 60 | 340 | 2,0E-05 | | 2,9E-06 | |

| Sample # | F[N] | σ [MPa] | $\Delta f/\Delta t_{\Delta t=5h}$ | $\Delta f/\Delta t_{\Delta t=tb}$ | $\Delta\varepsilon/\Delta t_{\Delta t=5h}$ | $\Delta\varepsilon/\Delta t_{\Delta t=tb}$ |
|---|---|---|---|---|---|---|
| B 1 | 165 | 451 | 4,6E-06 | 3,2E-07 | 9,8E-7 | 6,9E-8 |
| B 2 | 80 | 225 | 0,0E+00 | -1,4E-07 | 0 | -3,0E-8 |
| B 3 | 135 | 395 | 5,2E-06 | 1,3E-07 | 1,1E-6 | 2,7E-8 |

| Sample # | F[N] | σ [MPa] | $\Delta f/\Delta t_{\Delta t=5h}$ | $\Delta f/\Delta t_{\Delta t=tb}$ | $\Delta\varepsilon/\Delta t_{\Delta t=5h}$ | $\Delta\varepsilon/\Delta t_{\Delta t=tb}$ |
|---|---|---|---|---|---|---|
| C 1 | 185 | 192 | 1,5E-06 | 7,0E-08 | 5,2E-7 | 2,4E-8 |
| C 4 | 380 | 434 | 1,6E-05 | 1,7E-06 | 5,3E-6 | 5,6E-7 |
| C5 | 380 | 510 | 6,1E-05 | 5,5E-06 | 2,0E-5 | 1,8E-6 |
| C 1-Vers2 | 450 | 467 | 6,6E-05 | 1,6E-06 | 2,3E-5 | 5,6E-7 |

Table 3: $\Delta f/\Delta t$ in [mm/s] and $\Delta\varepsilon/\Delta t$ in [1/s]

In the following section some diagrams of the creep behaviour are shown:

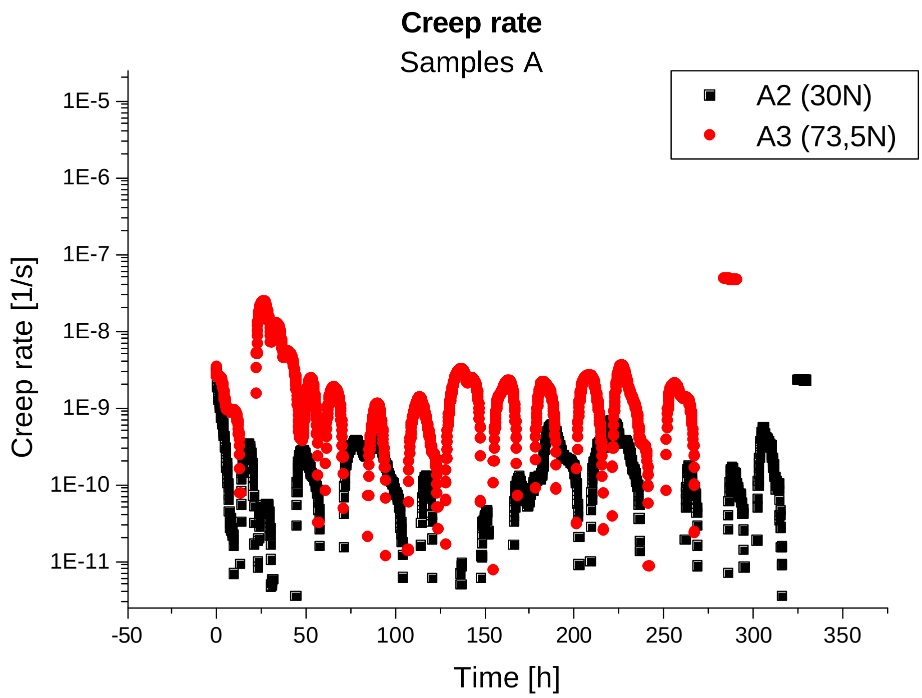



Figure 7: Creep rate for a 1mm thick samples tested under different loads

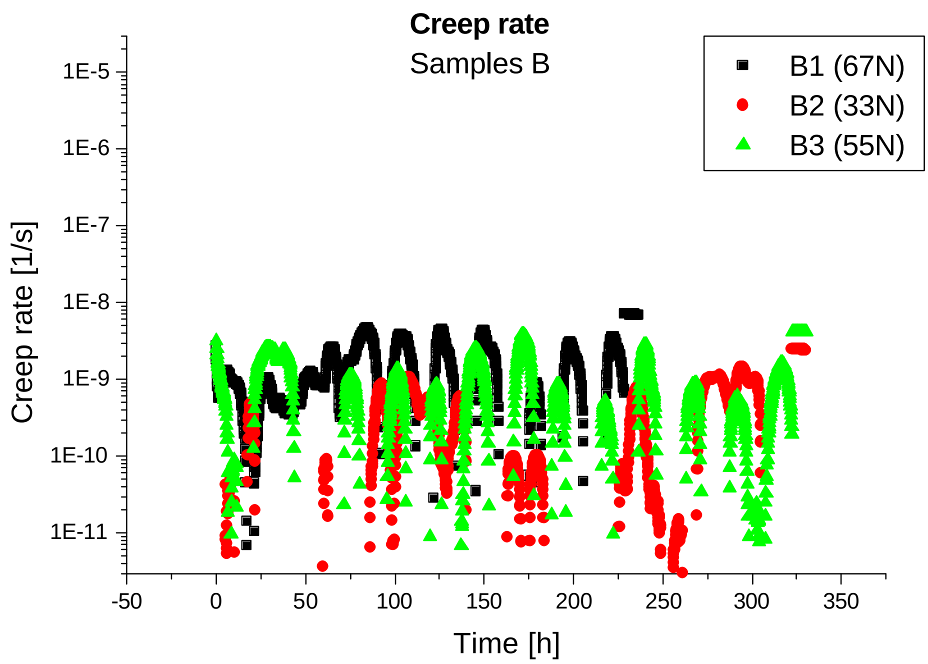



Figure 8: Creep rate of a 1.5mm thick sample tested under different loads.

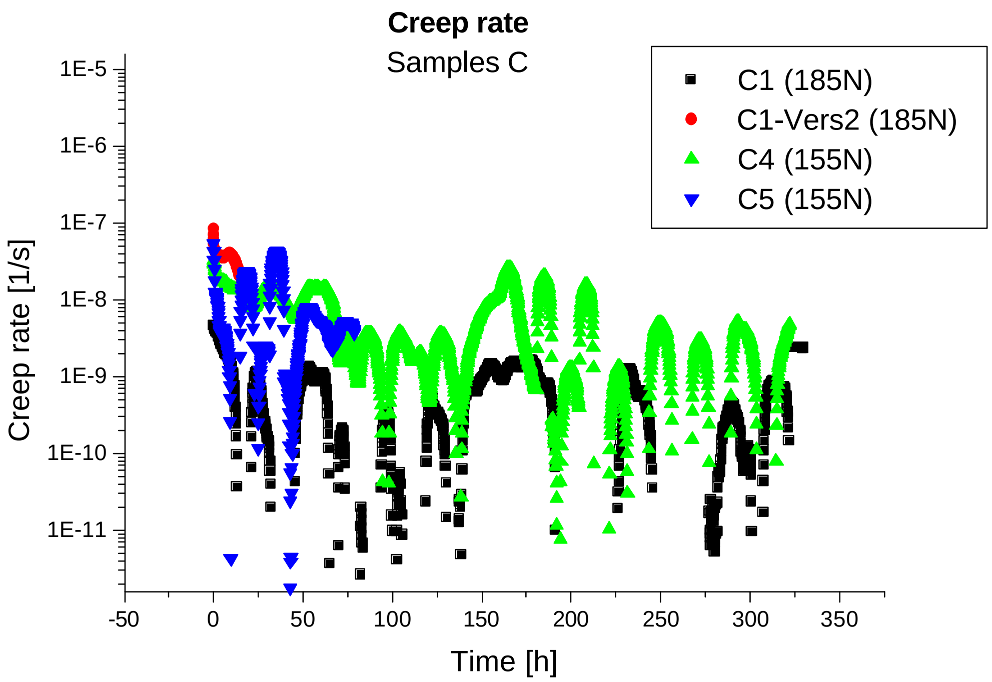



Figure 9: Creep rate of a 2.5mm thick sample tested under different loads.

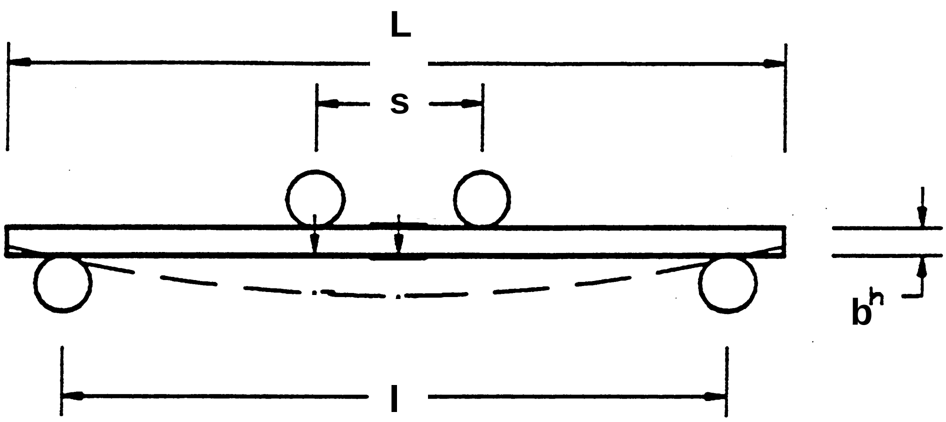
### *4.4 Conclusion*

From the above decribed experiments the main conclusion is that for all sample geometries and volume contents the deflection only changes at the beginning of the measurements. After a few hours there is no significant change of the deflection. Oscillations of the measurement signal occur just from the temperature change of the environment which has an influence on the measurement equipment. From the measurement of a reference sample this influence was observable.
Therefore for further investigations measuring time can be reduced. It is enough just by measuring during the time intervall in which this change of deflection is observed (< 1 day).

After the measurement of the creep behaviour we could observe a very small remaining deflection at samples tested below $\sigma$=400MPa. 2.5mm thick samples which were tested at $\sigma$>400MPa showed damage but catastrophic failure was only observable at $\sigma$>450MPa. Specimens with a thickness of 1 or 1.5mm showed no damage at $\sigma$ values up to 450 MPa. In order to get more information about the reason of this behaviour current work is focused on microstructural characterisation of the tested material and further investigations of the creep behaviour of the material are planned.

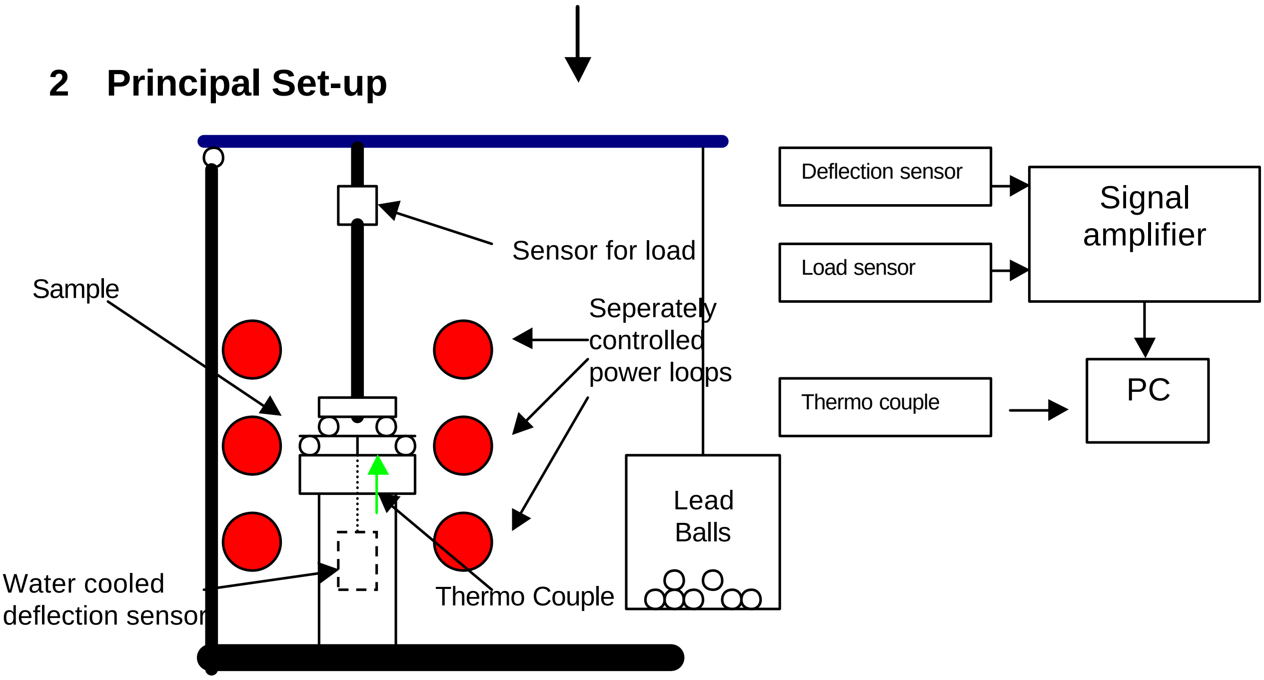
## ANNEX 1: 4-Point-Bending Test

## 1 Geometry and Dimensions




| | | |
|---|---|---|
| Dimensions : | s: | 15mm |
| | l: | 60mm |
| | L: | 70mm |
| | b: | ca. 1, 1.5, 2.5mm |

## 2 Principal Set-up



# SIMULATION OF 4-POINT BENDING-CREEP TEST

*Javier Segurado Escudero, Heinz Pettermann*
AMTT-Report

## Introduction:

A 4-point bending test for a MMC material has been investigated by computational simulation. The aim was to identify the basic physical mechanisms, their interaction, and how they determine the overall and local response. A finite element model has been generated for the FEM program ANSYS, including thermo-elastic, plastic, and creep properties for the aluminum matrix and thermo-elastic properties for the fibers, all with temperature dependence. A parametric input-file is generated which allows easy modifications of the geometry. The results of a particular case has also been studied.

## Approaches:

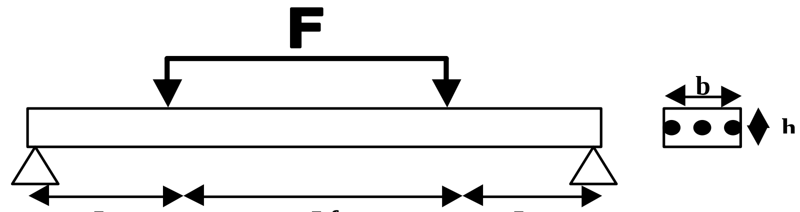



**Figure 1: Schematic 4-point bending test.**

The 4-point bending test, see **Figure 1,** generates a state of pure and constant bending moment in the central part of the beam. It is in this point where experimental results are measured (i.e. deflection). In the lateral parts of the beam, shear deflection is not taken into account within the simulations.

***FE-model***

A 2-D model, with plane stress properties, of a short portion of the length has been generated. Symmetry boundary conditions (B.C.s) are selected for left line, and multi point constrain (MPC) equations are written in the other side in order to ensure cross sectional surface remain plane but allow to rotate (Bernoulli hypothesis).

To model the inhomogeneous material, fibers are substituted in the model for layers of fiber material, keeping the same volume fraction (number of layers used is 30, but is also a model parameter). This approach gives accurate results for uniaxial stress in the fiber direction, like the case is studied here.

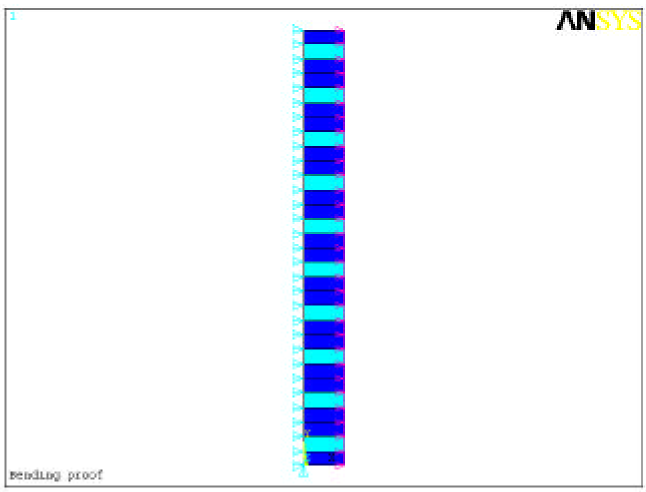



**Figure 2: Model of the Beam, showing the different materials, and B.C.s**

***Material properties***

A MMC of aluminum matrix reinforced with $Al_2O_3$ fibers is to be modeled. Fiber volume fraction is between 35% and 45%.

**The fiber material** is $Al_2O_3$, and is supposed to be linear elastic for the whole experiment, and with temperature dependence properties. The data used in the simulation is given in **Table 1.**

**Table 1: Elastic properties of $Al_2O_3$ fibers at 100, 150, and 250 °C, see ref. (1)**

| | T=100°C | T=150°C | T=250°C |
|---|---|---|---|
| **E (GPa)** | 179.7 | 179.4 | 179.0 |
| u | .2 | .2 | .2 |
| a | 6.027E-6 | 6.355E-6 | 6.801E-6 |

**The matrix** is aluminum 99.9%. Two kind of non-linearities in the behavior has been then taken into account:
*Elastoplastic behavior*, which is implemented using an isotropic hardening law, with Mises yield surface. Strain-stress curves are given next for the three different temperatures, taken form experimental data, as shown in **Figure 3**
*Creep*, because of the high temperature and large loading times. Strain rate is approximated by the law $\dot{e} = A s^{n}$, where both values are also obtained from experimental data for the three temperatures used for σ–ε curves, **Table 2** from (3).

**Table 2 Creep properties of Aluminuim, from ref. (3)**

| | T=100°C | T=150°C | T=200°C | T=300°C |
|---|---|---|---|---|
| **A ($s^{-1}Mpa^{-n}$)** | 27 | 13 | 4.9 | 3.9 |
| **n** | $0.5\ 10^{-46}$ | $0.39\ 10^{-21}$ | $0.36\ 10^{-6}$ | $0.16\ 10^{-3}$ |

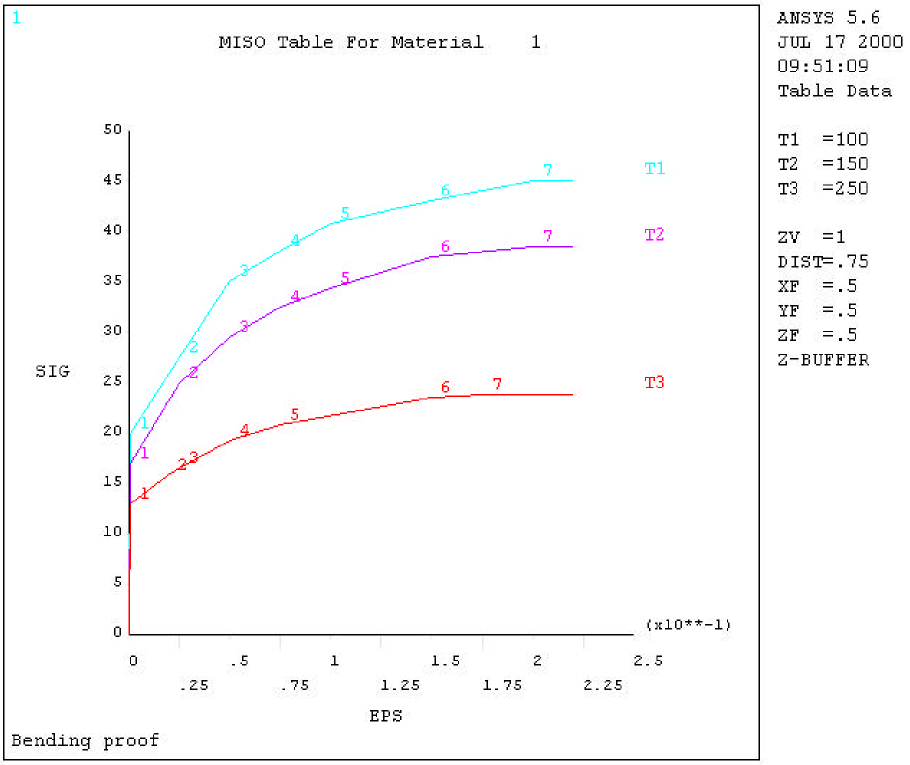



**Figure 3: Strain-stress curves for the aluminum matrix at temperatures of 100, 150, 250°C.**

## Load history:

A load history is applied to the specimen in five different steps: First, temperature is increased from stress free state to T (300°C), from this point, a pure bending moment is applied according to the load and support conditions in **Figure 1**. This moment is applied to the model using two opposite loads in the upper and lower layers of the beam. Then the third step is only leaving the specimen with that load for long time (300 h) to observe creep. Fourth is removing the bending moment, and fifth is cooling to room temperature. In order to compare results with the experiments, the curvature is obtained geometrically from the model and the deflection is calculated from this value.

## Example and results:

A particular case has been studied, with h=1.1mm, b=10mm, fiber volume fraction ξ=0.35, T=300°C, t=300h, F= 30 N. The curve of the deflection evolution is shown in **Figure 4.** The sample is assumed to be stress free at room temperature.
The explanation of the processes that happens in each step of **Figure 4**, is the next.:
(0→1) Heating step produces no deflection in the specimen. Thermal stresses appear, of compression in matrix and tensile stresses in the fibers, because of the different CTE values. Compressive stresses cause yielding of the matrix. No meso-stresses are present.

(1→2) The bending moment produces a deflection in the center of 1.61mm. The stress in the matrix of the upper material layer is always in the plastic range in compression (starting from the value of residual thermal stress), the lower one goes from compression for thermal loading to tensile stress because of the bending.

(2→3) The evolution of strain is a typical creep law (logarithmic), at the end the deflection is 1.75mm. Stress in matrix decreases from 14 to 0.5 MPa, and in fibers increases. This is the only step where time dependence occurs. The time interval is equivalent to 300h.

(3→4) Most part of deflection disappears when removing the bending moment (0.144 mm at the end) and, because of the accumulated elastic-energy, the matrix yields again.

(4→5) When cooling, the deflection almost disappears (0.024mm). The matrix is at the end under tensile stress because of the thermal contraction. At the end, residual overall stress is almost 0, but there are residual local strains, and residual stresses and strains present in matrix and fibers.

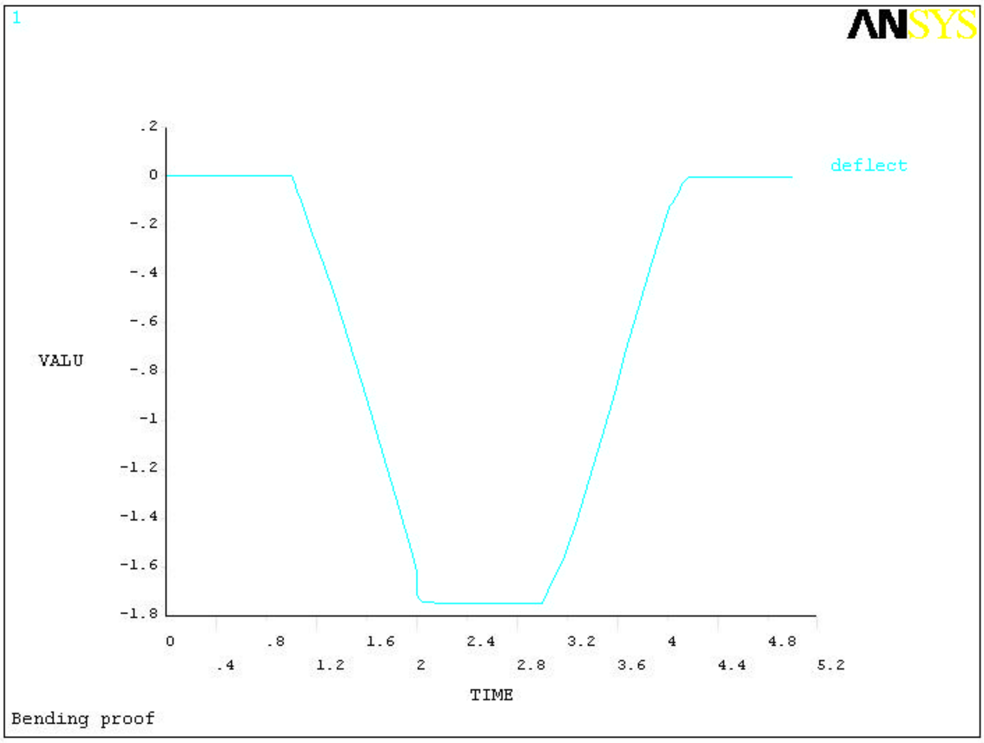



**Figure 4: Evolution of the deflection in the central point of the specimen.**

## Conclusions:

The values obtained for the deflection are very near to the experimental ones (e.g. the deflection after heating, bending, and creep is in experiment 1.7 and 1.74 in the model). About the qualitative behavior of the curves it can be explained for all the steps (no deflection in heating, logarithmic shape of creep).

In fact the time dependent response of the matrix is neither pure creeo nor pure relaxation, but a combination of both. The overall response, however, is close to pure creep (i.e. the meso-stresses are naearly constant).

A point that has to be remarked is the value of deflection at the end of the test. It is very near to zero, after the big plastic strains that have appear in the matrix. The reason is the presence of fibers, that behave linear the whole time, and accumulate high strain energy.

## References:

(1) WEISSENBEK, E. *Finite Element Modelling of Discontinuously Reinforced Metal Matrix Composites.* VDI-Verlag (Reihe **18**,Nr.164), 1994, Düsseldorf, Germany

(2) MURALI, K.; WENG, G.J. *Theoretical Calculation of Anisotropic Creep and Stress-Strain Behavior for a Class of Metal-Matrix Composites.* 1992. Metallurgical Transactions A, **24A**, 1993, 2049-2059

(3) DEGISCHER,H-P, data for Creep properties from private conversartion (AMAG, Internal Report, 1990)

# Results of Finite Elemente Simulations and Influence of Temperature Oscillations on Creep Experiments

## 1 Creep Behaviour – Simulation and Experiments

### *1.1 Finite Elemente Simulation*

By using a FE model a sample with a thickness of 2.5mm and a volume fracture of $Al_2O_3$-fibers of about 42% was simulated to be tested at different loads (160-515N). The simulation includes the following steps (a detailed description of the used method is given in ANNEX 1): heating up of the sample, loading of the sample, creep deformation, unloading of the sample and cooling down. The measuring times of the simulated creep behaviour were comparable to the performed experiments. The calculated loading and unloading curves for the different loads can be found in figure 1 and 2. Simulations show the expected linear relationship between deflection and load, also up to high loads.

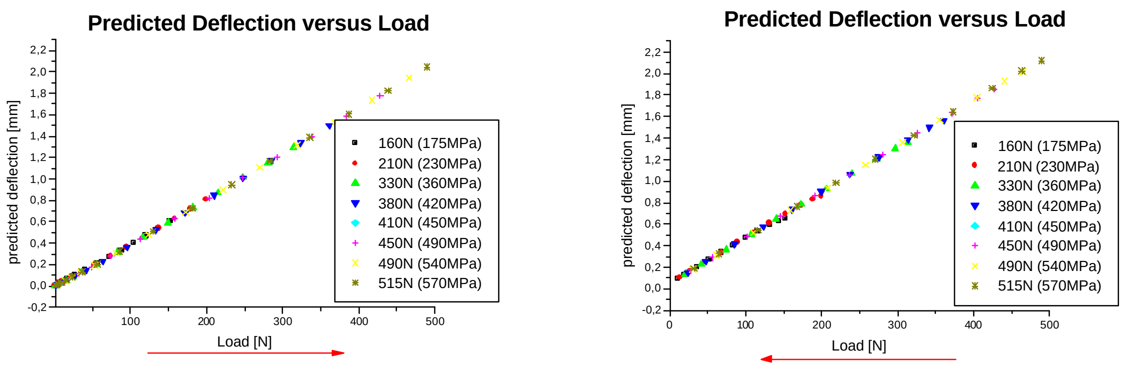



Figure 1&2: Predicted loading and unloading behaviour of a 2.5mm thick sample.

After the simulation of the deflection versus time, the unloading process was simulated. Simulations showed that after the unloading nearly no deflection remains (this was also observed for high loads!!) which was comparable to experiments at low load (160 and 210N). The residual deflection of the calculations after unloading is always below 0.1mm. This is caused due to the fact, that within the frame of the programme only a simple model was used, which assumes an ideal bending of the sample. Nevertheless the performed computational experiments showed that the predicted deflection and the experiments fit well for loads bellow 330N. The main information we got from these calculations is, that there is creep only observable within the first hour of the experiment. Such a behaviour was also observed in the experiment, but due to the uncertainties during the experiments (temperature changes of the environment, which had an influence to the deflection signal) this was not as clear as it turned out from the simulations.

The results of the simulated creep behaviour at a temperature of 300°C can be seen in figure 3. From this calculations a basic information can be derived: there is only a significant change of deflection within the first 10 minutes after loading and after this period the deflection stays constant. So creep can only be observed in this short period of time.

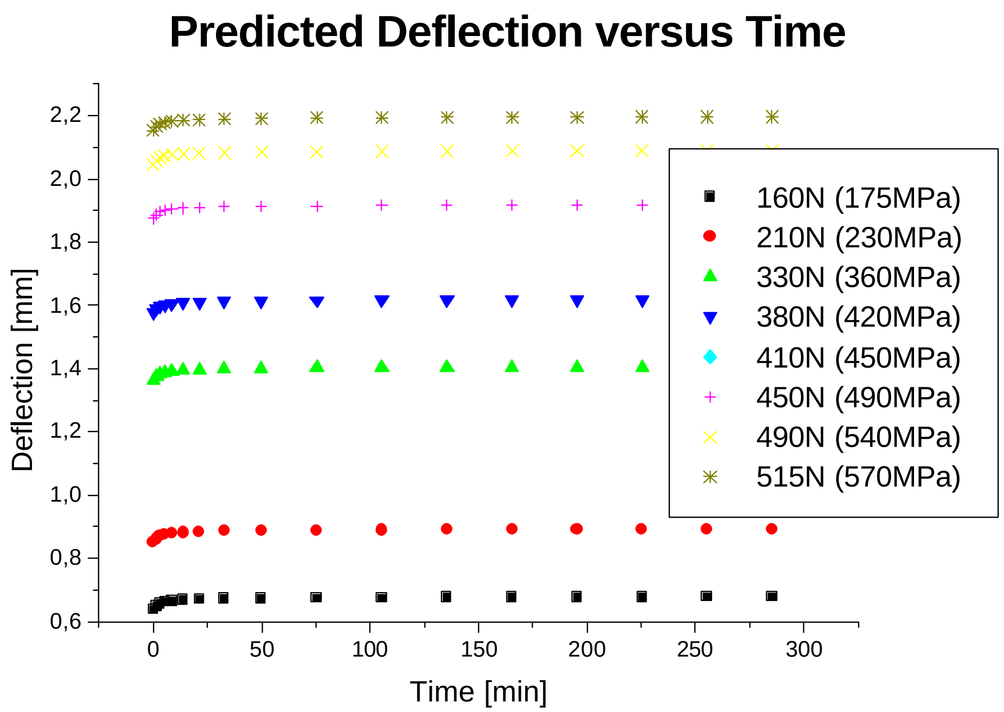



Figure 3: Predicted deflection as a function of time for different loads (edge stress).

## 1.2 Creep Experiments

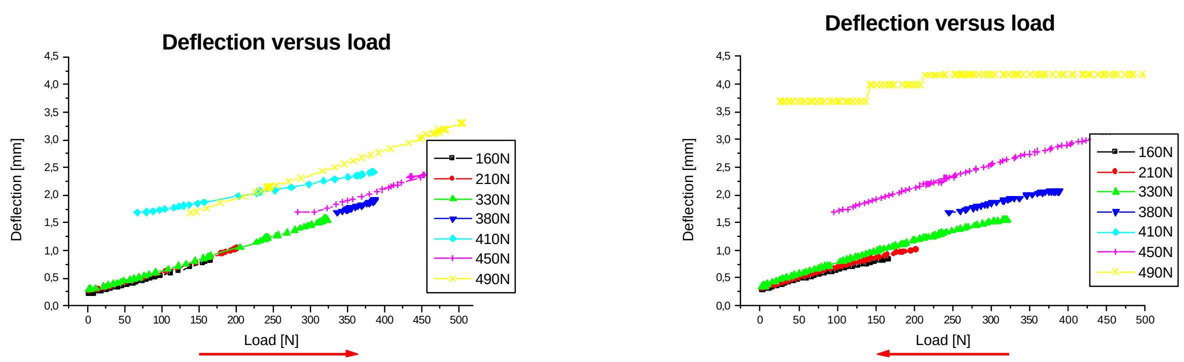



Figure 4&5: Loading and Unloading behaviour of a 2.5mm thick sample tested at different loads.

From the first tested samples and from the FE simulations it turned out that during the creep tests only significant changes were observed at the beginning of the measurements. Therefore one sample (#C6) was tested for a very short time (approx. 5 hours) by increasing the load stepwise from 150 to 490N ($\sigma$=175-540MPa) after each period of time. In figure 4 and 5 the measured loading and unloading curves can be seen. From these curves we get an information about the residual deflection in the sample by comparing the loading and unloading curve. Further we can see that the loading and unloading behaviour up to loads of 380N is as expected. The loading curve during the measurement at 410N shows a different behaviour. What we see from figure 7 is, that damage occurs in this sample during the measurement. On the other hand we can find an unexpected linear behaviour during the loading up to 450N. The reason for this unexpected behaviour needs further investigations.

The results from the measured deflection as a function of time can be seen in figure 6. The measured deflection up to loads of 330N shows always a similar behaviour. There is a small increase at the beginning of the measurement and then the deflection remains constant. At a load of 380N the deflection increases with increasing time and there is a „jump" in the deflection-load curve (Figure 7) . From the unloading curve one can expect that there is a residual deflection of about 0.5mm.

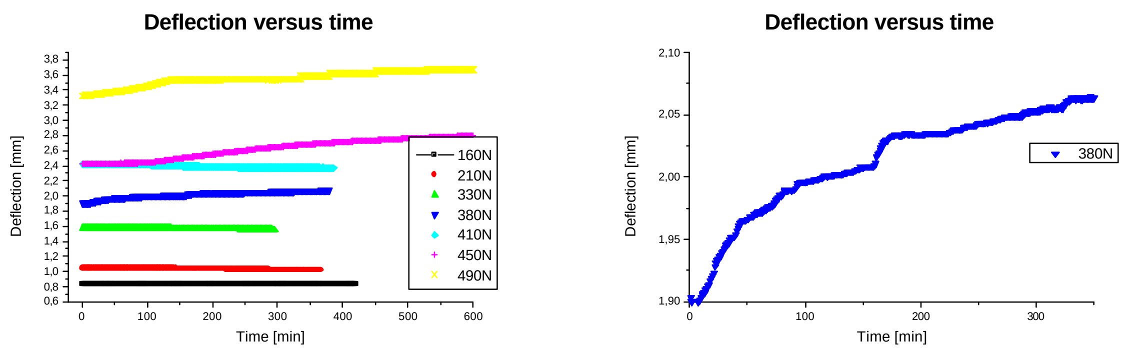



Figure 6&7: Deflection as a function of time at different loads

By increasing the load more and more, the residual deflection increases and buckling starts to arise. After measuring at 490N the sample shows two visible „notches".

From the measured deflection the edge fiber strain can be calculated. These values can be found in figure 8.

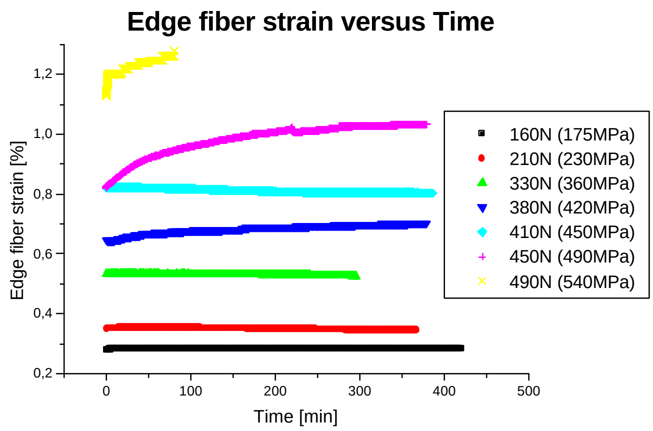



Figure 8 shows the edge fiber strain for sample C6, which was calculated from the deflection.

So the results of these investigations can be concluded: we find no damage up to loads of 380N (420MPa). By a further increase of the load damage occurs but no catastrophic failure was obserable even at loads of 490N (540MPa).

# 2 Influence of temperature changes – Simulation and Experiment

During the measurements of the creep behaviour under bending, oscillations of the deflection were observed which made the evaluation of the creep rate very difficult. The reason for this oscillation was the temperature change in the room were the experiment was performed. This temperature change in the environment leads to a temperature change at the sample which was measured with a thermocouple. The temperature oscillations were in the range of +/- 5°C. To answer the question whether these temperature oscillations have an influence to the deflection of the sample, experiments with a reference sample were performed. Beside this, Finite Elemente Simulation were used in order to predict the behaviour of a sample during the whole creep experiment.

## *2.1 Results of Reference Measurement*

In order to get an information how the deflection sensor is influenced by temperature changes, a reference sample was used and the whole equipment was heated up to 300°C. Just by the variation of the temperature a deflection was measured. The curves can be found in figure 9. From these curves we get an information about the influence of a temperature change to the deflection signal. From figure 9 one can expect that the influence of a temperature change in the range of +/-5°C leads to a detected deflection in the range of about 0,005mm.

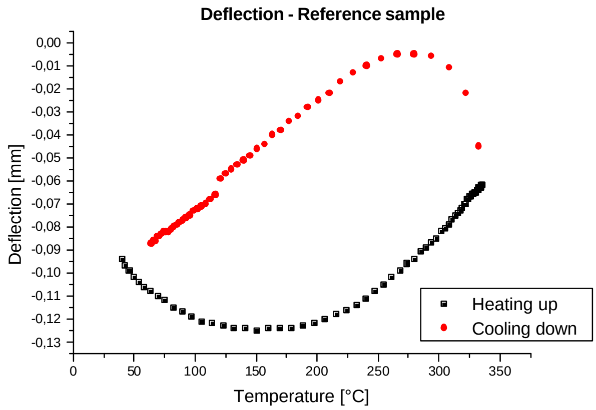



Figure 9: Influence of the temperature on the detected deflection signal

## *2.2 Results of FE simulations*

To investigate the temperature change on the deflection produced from the sample, FE methods were used to simulate the influence of temperature oscillations on the deflection of the sample. The results can be found in figure 10.

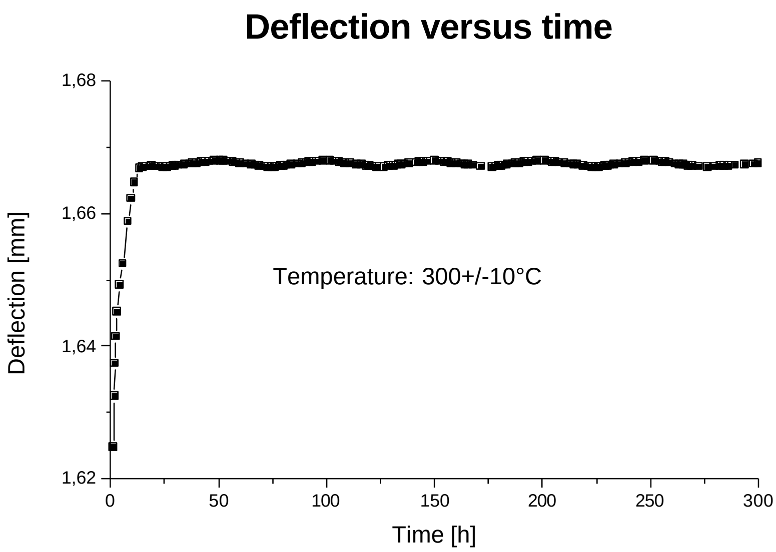



Figure 10: Simulation of the influence of temperature oscillations caused by the deflection of the sample

The temperature oscillation in the range of +/-10°C would cause a change of the deflection in the range of 0.001mm. Therefore temperature oscillations of the environment will have a much bigger influence on the whole measuring equipment and the deflection sensor and should be avoided during further experiments.