Creep of discontinuous long fiber C/PEEK above T_g

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Abstract:
Discontinuous long fiber (DLF) materials are increasingly used by aircraft manufacturers to replace complex shaped metal parts. DLF is produced by cutting C/PEEK UD tape with 59 % fiber content into flakes that are then near net molded into parts. The use of this material has often been limited to temperatures below the glass transition temperature (T_g) as the polymer matrix is subject to increased creep above T_g. While it is known that the addition of carbon fibers reduces creep, there is no published data available that shows long term behavior at temperatures above T_g for DLF materials. In this presentation, we show the results of 1000 hours creep tests at temperatures up to 288°C. The creep modulus of DLF is significantly higher than that of a 30 % short fiber filled injected C/PEEK and offers remarkably good long-term stability.

Keywords: Creep, High Temperature, Discontinuous Fiber

Introduction

Discontinuous long fiber (DLF) materials are increasingly used by aircraft manufacturers to replace complex shaped metal parts. Such parts can be made through compression molding of C/PEEK unidirectional tape that is cut into DLF flakes. While there are still difficulties related to design by analysis, the rapid adoption rate in the aero market can be explained by the remarkable combination of properties, namely a good chemical and high thermal resistance, combined with high stiffness and impact resistance as well as the ability to mold very complex shapes.
The chemical and thermal oxidative resistance of PEEK is well known [1] and suggests that it could be in continuous use up to 250°C. However, as for any thermoplastic polymer, the passage of the glass transition temperature (T_g) is often seen as a somewhat hard boundary for mechanical performance, even for semi crystalline polymers. Indeed, around T_g the stiffness drops and creep becomes significant already at low stress levels. The addition of carbon fibers to the PEEK matrix increases the stiffness and reduces the creep. Previous publications have shown that an increased fiber length and increased fiber content improves creep resistance [2, 3]. With 59% by volume of fibers (67% by weight) and a fiber length that is determined by the flake size, both stiffness and creep performance of DLF above T_g are therefore expected to be higher than for injection molded PEEK-based composite. Nevertheless, as the fibers are not continuous, creep remains an important concern for the design of parts that need to function above T_g.
In this work, we present the results of 1000hr tensile creep tests for randomly oriented DLF with 12.7mm (1/2") long carbon fibers, at temperatures ranging from 93°C to 288°C. For comparison, we run the same tests with 30% carbon fiber reinforced PEEK injection molded samples.

Material

We prepared the raw material for the DLF samples by cutting an aero grade C/PEEK UD tape with 59% Vf into flakes of 12.7mm x12.7mm. The flakes were then compression molded into nominal 2.54mm thick plates with random fiber orientation from which we machined the samples. For the high flow DLF samples we used a mold where the material is pushed through a 330mm long, 2.54mm thick cavity to form a plate with strongly oriented fibers from which we machined samples in both the flow and the transverse direction.
The samples with 30% (wt) short carbon fiber reinforced PEEK were produced on an injection-molding machine, net molding the dogbone geometry. The reinforcing fibers are therefore mainly aligned with the direction of the load during the test.

Method

Figure 1 shows the testing jig with six simultaneous positions. The load is applied by a dead weight at the end of a 10x lever. The displacement of the weight over time is continuously recorded with LVDTs on top of the lever taking advantage of the 10x lever to measure a larger signal. While it would clearly be best to measure the strain with a gauge right on the material, the high temperature (up to 288°C) made it difficult to use conventional strain gauges. Therefore, we calculated the strain values based on the LVDT measurements (displacement of the weight) and the instant modulus measured at the same temperature in a separate experiment (see Fig. 3). The calculation assumes an instant strain proportional to the applied load. Any additional displacement that is measured is attributed to creep of the material in the loaded test length. This procedure eliminates all displacements related to the loading mechanism and jig compliance.

Fig. 1: *Creep testing jig with 6 positions*

It is clear that any slipping in the grips would lead to an overestimation of creep. Therefore, we have designed special grips (see Fig. 2). They have hardened teeth holding the sample back. The clamping force is maintained with a stack of spring washers. Additionally, the sample is positioned and held in place with two adjusted pins going through the grip and the sample. Upon inspection of the traces left by the gripping teeth on the sample, there was no indication of slipping during the tests.
Due to the relative large dimension of the frame and lever it is also important to monitor the environmental temperature (room temperature) and correct for variations. Alternatively, a steel sample can be used as reference in one of the six positions to retrieve all the noise in the measurements related to daily and seasonal temperatures variations

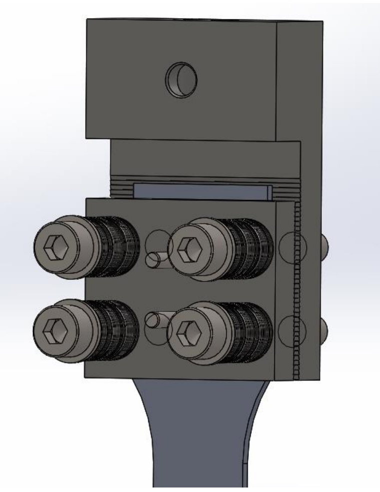

Fig. 2: *Grip design to avoid slipping*

After heating the ovens with the samples to the test temperature, all samples were individually loaded to create a stress level of 70% of the typical strength at a given temperature.

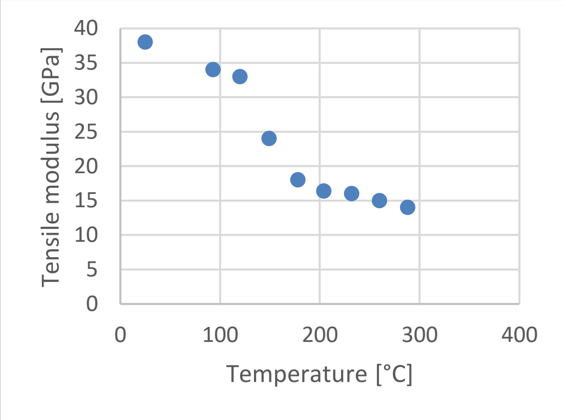

Fig. 3: *Instantaneous modulus as a function of temperature*

Results

Figure 4 shows the creep modulus that was obtained from the displacement measurements at various temperatures over the 1000hr test time. By shifting these results to fit a single curve at one selected temperature, a master curve is created. It allows for accurate prediction of creep behavior for durations several order of magnitude longer [4, 5].
The shift factor *a* that was found when manually shifting the curves on the log-log scale is shown in Figure 5. As reported in previous studies [4] we have observed a change in the slope of the shift factor between below and above T_g. The shift factor above T_g is the same for both, DLF and 30% carbon fiber reinforced PEEK.

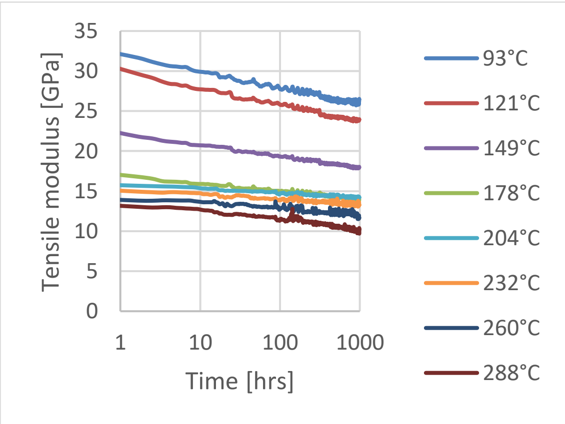

Fig. 4: *Creep modulus for DLF at various temperatures*

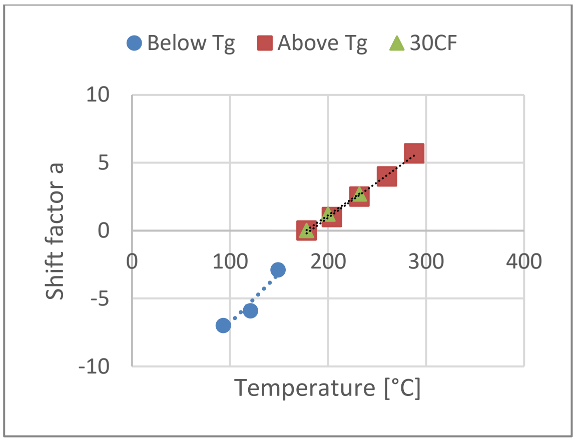

Fig. 5: *Shift factor to obtain the master curve*

The resulting mastercurve is shown in Fig. 6 using 178°C as reference temperature. The tests on samples in flow direction and transverse-to-flow direction give an upper and lower boundary for DLF material. For comparison, we show the results of the same tests with 30% short fiber filled injected PEEK (in flow direction). Note that load is applied in the injection direction of the samples.

Conclusions

DLF has a remarkable high resistance to creep. Our results confirm that the increased fiber content and the increased fiber length strongly improve the creep performance by comparing DLF to 30% short fiber reinforced injection molded PEEK.

The remarkably stable long-term behavior of this material suggests that C/PEEK DLF has a very good dimensional stability even above Tg and can be used in continuously loaded high temperature applications. For example, if DLF is subject to a tensile stress level of 70% of its UTS at 178°C, the expected creep strain after 100’000 hrs (11 years) is 0.72% whereof 0.51% are due to initial elastic deformation.

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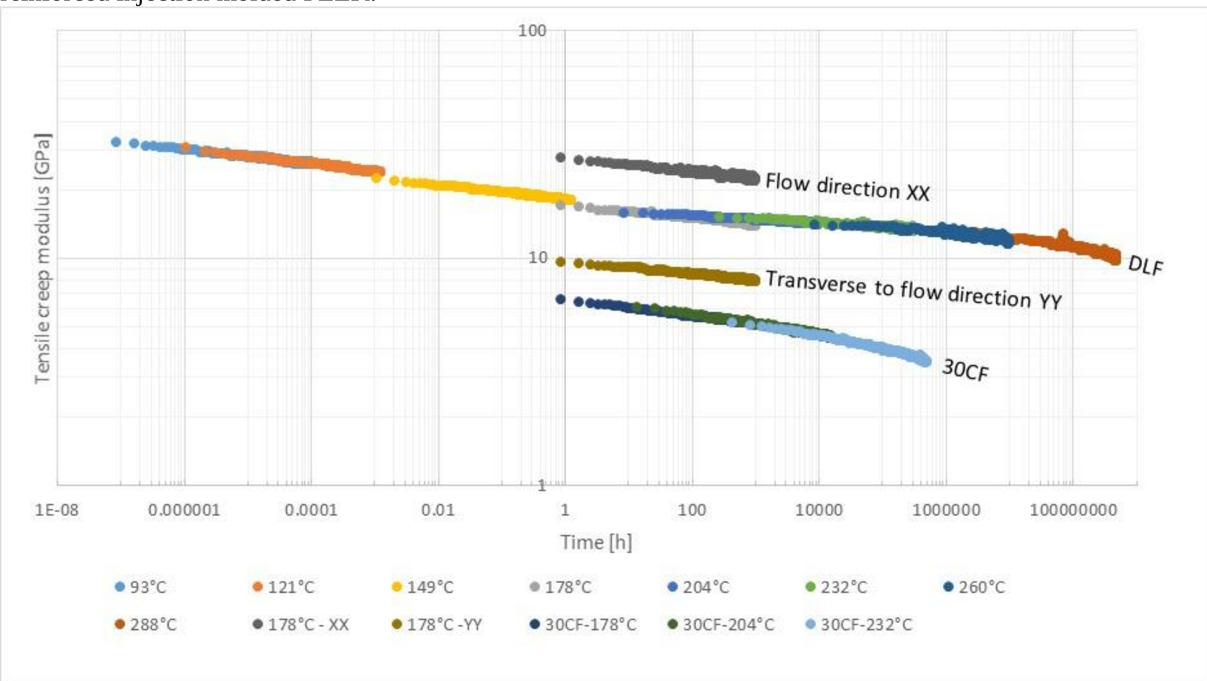

Fig. 6: *Mastercurve of DLF. For comparison we added High flow* DLF in flow and transverse to flow direction as well as 30% short carbon fiber filled PEEK. The data is shifted to the reference temperature of 178°C using time-temperature-superposition.