MATERIAL OPTIMISATION FOR RTM FABRICATION OF GFRP FLANGES SPECIFICALLY IN TERMS OF THE CREEP COMPLIANCE

A. Eggers[a*], D. Meiners[a], G. Ziegmann[a], S. Moritz[b], K. Maile[b]

[a]*Institute of Polymer Materials and Plastics Engineering, TU Clausthal, D-38678, Germany*
[b]*Materials Testing Institute, University of Stuttgart, D-70569, Germany*
**amke.eggers@tu-clausthal.de*

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Abstract

Besides a lot of advantages GFRP flanges have the disadvantage of a high creep compliance, which causes a bolt force relaxation and therefore a potential leaking of the pipe joint. A reduced creep compliance is achieved by using the RTM technique rather than the SMC technique, realising a higher fibre volume content and an optimised design of the part. However, there is still potential for the material optimisation of the GFRP flanges made by RTM technique. In this paper, the flexural properties and the creep behaviour of laminates with non crimp glass fibre textile reinforcement are compared with laminates made of woven fabric. The creep behaviour was tested with a real time method and the TTS method. A conclusion regarding the favoured material selection is made.

1. Introduction

The usage of GFRP flanges in the chemical industry has a lot of advantages compared to the usage of steel flanges, especially the high chemical resistance and the low weight and costs. A disadvantage of GFRP flanges is the high creep compliance, which causes a bolt force relaxation and therefore a potential leaking of the pipe joint. Currently used fabrication methods, like the SMC (sheet moulding compound) press technique, do not exploit the full potential of the material GFRP mainly due to a random fibre orientation. A reduced creep compliance is achieved by using RTM technique, realising a higher fibre volume content and using the anisotropic properties of the GFRP to realise an optimised design of the part [1].

In the earlier studies [1], the focus was on fabricating a flange with preferably high mechanical properties and simultaneously low creep compliance. For reinforcement a glass fibre woven fabric with a low area weight of 280 g/m² was selected. This fabric is very difficult to handle in terms of the cutting process and the form stability while transferring it from one mould to another. Shear effects and the loss of fibre bundles in the preform occur. Additionally a high amount of layers is required to fill the mould, causing severe production costs.

In this paper the focus lies on the material optimisation for the RTM production of GFRP flanges in consideration of low production costs and easy handling of the material but still high mechanical properties as well as a low creep compliance of the part. For this purpose the flexural and creep properties of GFRPs made of non crimp glass fibre textiles with high area weight were analysed. Due to the sewing thread these kinds of textiles are easy to handle and the costs per square meter in relation to the area weight are lower than the costs of the woven fabric. Hereby the creep behaviour [2, 3] is tested on the one hand with a real time bending process and on the other hand with an accelerated test method called time temperature superposition (TTS) [3, 4], by which the long term creep compliance can be obtained in a short amount of time.

2. Experiments and Methodologies

2.1 Materials

The matrix used for the GFRP is vinyl ester resin VIAPAL VUP-4652/67 with the corresponding inhibitor NLC-10, accelerator MB-12 and hardener Butanox LPT-IN with a mixing ratio of 100:0.75:1:2, from Lange & Ritter. The glass fibre textile reinforcements used are shown in table 1.

Kind of textile	Name	Area Weight [g/m²]	Orientation	Producer
Biaxial non-crimp	HP-B600E-10	600	+45°/-45°	HP Textiles
Quadraxial non-crimp	HP-Q850E-10	860	0°/-45°/90°/+45°	HP Textiles
Quadraxial non-crimp	S35EQ290	635	+45°/90°/-45°/0°	Saertex
Quadraxial non-crimp	S32EQ260	1232	+45°/90°/-45°/0°	Saertex
Biaxial fabric	VR 48/L	280	0°/90°	Lange & Ritter

Table 1. Glass fibre textiles used in this paper

2.2 Manufacturing process

For the comparison of the TTS method with the real time determination of the creep behaviour the test plates were manufactured via RTM. The manufacturing process for the other test plates was VARI (vacuum assisted resin infusion). For all samples the fibre orientation at the bottom is 0° in length of the sample. All layers of the laminate are orientated in the same direction.

2.3 Flexural properties

The flexural properties of the samples were tested by a three point bending test in a universal material testing machine (Z100, Zwick GmbH Co. KG). The sample specifications and the testing parameters are defined according to DIN EN ISO 14125 standard [5].

2.4 Real time creep behaviour

The real time creep behaviour of the samples was tested by a three point bending test in a specific testing machine with a constant force of 200 MPa. The sample specifications are 100×15×5 mm. The ratio of bearing distance to sample thickness is 16:1. The testing time was 120 h. An extrapolation of the creep behaviour to 10000 h was made with an empirical approach of a potential equation, where J is creep compliance, t is time and C_1, C_2 and C_3 are constants [1].

$$J(t) = C_1+C_2*t\hat{}(C_3) \quad (1)$$

2.5 Creep behaviour with TTS method

For testing the creep behaviour with the TTS method, the samples were tested by a three point bending test in a DMA (dynamic-mechanical analysis) testing machine (DMA Q800, TA Instruments) with a constant force of 5 MPa. The sample specifications are 60×10×3 mm. The bearing distance is 50 mm. The short creep tests of 30 min are from 40 °C to 130 °C (T_G of the resin is 146 °C) in steps of 10 °C. The so several short creep tests at different temperatures are superposed to a master curve at the reference temperature of 50 °C using the Williams-Landel-Ferry (WLF) equation [6], where a_T is the shift factor, T is temperature, T_{ref} is reference temperature and C_1 and C_2 are the WLF-constants.

$$\log a_T = (C_1*(T-T_{ref})) / (C_2+(T-T_{ref})) \quad (2)$$

The resulting master curve is fitted with equation (1) and extrapolated to 10^5 h.

3. Results

3.1 Flexural properties

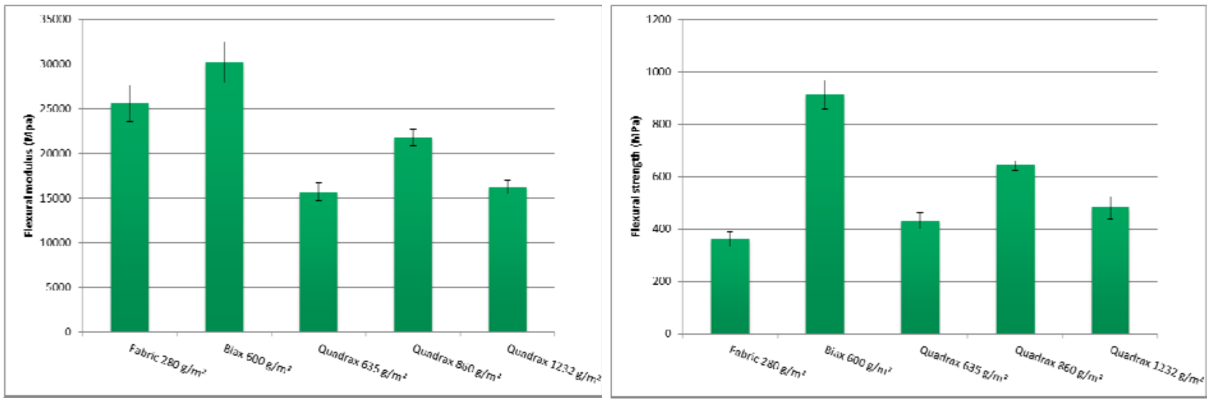

Figure 1. Flexural properties of laminates with different glass fibre textile reinforcement

The flexural modulus and the flexural strength of the non crimp fibre textile and the reference woven fabric are shown in figure 1. It can be seen that the biax 600 g/m² has the highest flexural modulus and strength, whereby the modulus is about 18 % and the strength is about 150 % higher than that of the woven fabric. The fabric shows the second highest flexural modulus, but the lowest flexural strength. As expected the quadraxial textiles have a lower flexural modulus, because in these samples only 25 % of the fibres are aligned in the direction of stress. On the contrary 50 % of the fibres in the samples of the woven fabric and the biaxial non crimp fibre textile are in the direction of stress. The ranking of the non crimp fibre textiles is the same in the flexural strength as in the flexural modulus.

3.2 Creep behaviour with real time method

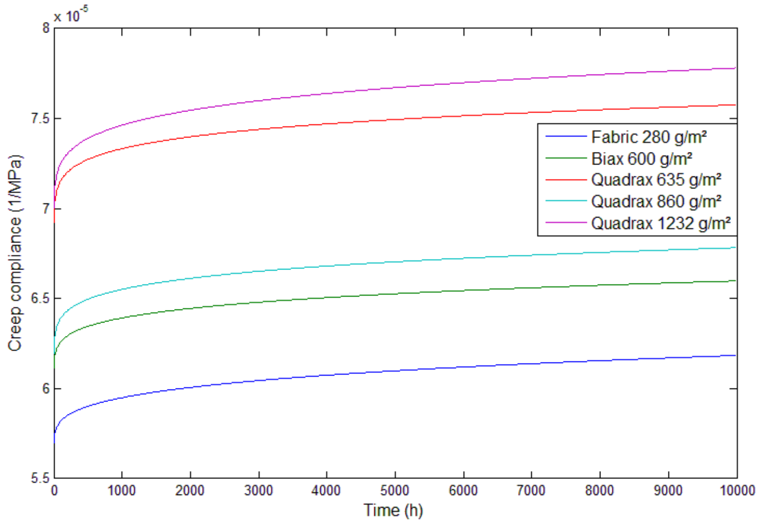

Figure 2. Creep behaviour of laminates with different glass fibre textile reinforcement, measured with real time method

Loading the sample with a constant stress, the strain increases with time reaching a plateau value. According to the creep behaviour of the different glass fibre textile reinforcements shown in figure 2, the creep compliance reacts oppositional to the flexural modulus. The sample with the highest flexural modulus shows the lowest creep compliance over time, except the woven fabric 280 g/m². It features the lowest creep compliance, but showed the second highest flexural modulus. Compared to the creep compliance of a SMC sample (converge to 2*10^(-4) 1/MPa) all tested glass fibre textile reinforcements have a distinct lower creep compliance in the range of one power.

3.3 Creep behaviour with TTS method

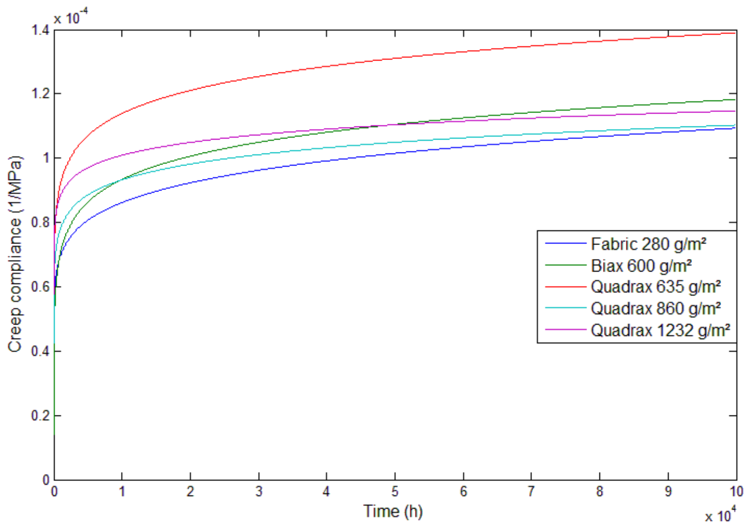

Figure 3. Creep behaviour of laminates with different glass fibre textile reinforcement, measured with TTS method

Measuring the creep behaviour with the TTS method in the DMA, it showed slightly different results for the creep compliance of the different glass fibre textile reinforcements compared to the real time method (se figure 3). There is a bigger difference in the gradient of the different curves, which might be mainly due to the small discrepancies in the thickness and fibre volume content of the sample plates, which are having a higher influence on the experiments in the DMA due to the smaller sample size. But the tendency of the curves stays the same as in the real time experiment, the woven fabric 280 g/m² having the lowest creep compliance and the non crimp fibre textiles having a marginal higher one.

3.4 Comparison of creep behaviour measured with real time and TTS method

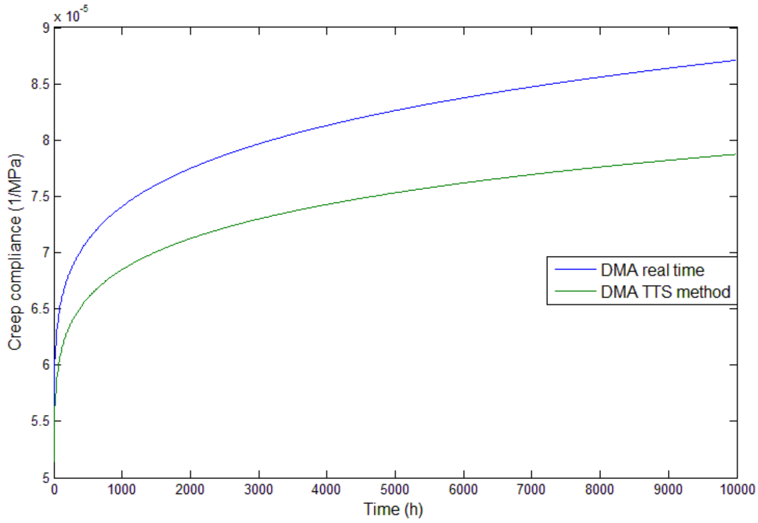

Figure 4. Comparison of creep behaviour measured with real time and TTS method by means of samples with HP-B600E-10 reinforcement; reference temperature 40 °C

For validating the usage of the TTS method for predicting the long term creep behaviour a comparison between a real time experiment and the TTS method in the DMA was made. The two curves in figure 4 show a high congruency, differing less than 1*10^(-5) 1/MPa. Further experiments demonstrated that the temperature and the sample specifications have a high influence on the results of the creep compliance, especially if results by different testing machines are to be compared. Here it is essential that all dimensions of the samples are up and down scaled with the same factor.

4. Discussion

The flexural properties as well as the creep behaviour of different non crimp glass fibre textiles were tested in comparison to the currently used fabric for the RTM flange fabrication. Compared to samples made of SMC, all materials used in this study have higher flexural properties and a much better creep behaviour. So in general all tested non crimp fibre textiles are a great alternative to the SMC material. Thereby the biaxial textile with an area weight of 600 g/m² shows both a higher flexural modulus and flexural strength due to the complete stretched fibres in the textile. However, in terms of the creep behaviour the woven fabric 280 g/m² still has the lowest creep compliance curve and therefore the best creep properties, which determine the maintenance interval and the operating costs of the part. But taking into account the easier handling, the high potential of production cost savings and the very low flexural strength of the woven fabric, the biax 600 g/m² seems to be the best alternative for the fabrication of loose flanges in RTM technique. Nonetheless the flange itself is not a straight sample but a circular ring. That is why the fibre orientation into stress direction needs to be taken into account to make a final decision concerning the material optimisation in terms of a biaxial or quadraxial non crimp fibre reinforcement.

The creep behaviour was tested both in a real time experiment and with the TTS method. Hereby the TTS method is a way to gain the results of a long term experiment through time temperature superposition in a short amount of time. Experiments show that a high congruency can be achieved, if the geometrical dimensions of the samples are the same. If the TTS method is done on another machine than the long term creep tests, an exact down scaling to the smaller samples in the DMA is absolutely necessary. Another important factor is the temperature, accelerating the creep process with higher temperatures. The reference temperature of the TTS method needs to match the temperature of the long term creep test, otherwise the results are not comparable.

5. Conclusion and outlook

Using resin transfer moulding for the fabrication of flange elements a reduced creep compliance is achieved, realising a higher fibre volume content and an anisotropic load appropriate design of the part. However the prior used fabric 280 g/m², possessing a preferable low creep compliance, is very difficult to handle and causes severe production costs due to the low area weight. Different non crimp glass fibre textiles with high area weight have been tested. The main results of this study can be summarized as follows:

- Considering the easy handling, the high area weight, the high mechanical properties and the just slightly higher creep compliance all non crimp fibre textiles are a good alternative compared to the fabric 280 g/m².
- Considering the highest flexural modulus and flexural strength the biaxial non crimp glass fibre textile with an area weight of 600 g/m² is the best material optimisation for the flange. Nonetheless the load appropriate fibre orientation still needs to be taken into account.
- The TTS method was investigated as an accelerated test method for the long term creep behaviour of GFRP material, which shows to be a feasible alternative way of testing the creep behaviour, if the correct geometrical dimensions and reference temperature are used.

The next steps to complete this research are the fabrication of flanges with the chosen non crimp glass fibre textiles. These flanges then need to be tested regarding the mechanical properties and the creep behaviour in a buckle test.

References

[1] L. Josch. *Langzeitverhalten von glasfaserverstärkten Kunststoffbauteilen am Beispiel von Losflanschen*. Dissertation TU Clausthal, Clausthal-Zellerfeld, 2010.
[2] D. Gross, W. Hauger, W. Schnell, P. Wriggers. *Technische Mechanik: Band 4: Hydromechanik, Elemente der Höheren Mechanik, Numerische Methoden*. Springer Verlag, Berlin Heidelberg, 2007.
[3] T. A. Osswald, J. P. Hernández-Ortiz. *Polymer processing: modeling and simulation*. Hanser Verlag, München, 2006.
[4] R. S. Lakes. *Viscoelastic Solids*. CRC Press, 1998.

[5] DIN EN ISO 14125. *Fiber reinforced plastic composites – Determination of flexural properties.*
[6] M. L. Williams, R. F. Landel, J. D. Ferry. The Temperature Dependence of Relaxation Mechanisms in Amorphous Polymers and Other Glass-forming Liquids. *Journal of the American Chemical Society*, 77(14):3701-3707, 1955.