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DOES THE STRESS-STRAIN BEHAVIOUR OF PTFE-COATED GLASS FIBRE FABRICS DEPEND ON THE LOAD HISTORY?

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Summary. It is known that PTFE-coated glass fibre fabrics show a mechanical saturation behaviour under repetitive monotonous loads [1]. That means that the stress-strain behaviour changes from load cycle to load cycle. This behaviour is convergent so that stiffness values strive towards asymptote values. However, when using these fabrics in membrane structures they are subjected to various natural load histories which lead to biaxial stresses with different stress ratios in different orders. The question arises whether loads of different orders lead to a different material response. If so, stiffness parameters would not be global but would have to be given dependent on the order of loads.

In the research presented here, load histories with different orders of stress ratios are investigated in biaxial tensile tests. The impact on the stress-strain response of a PTFE-coated glass fibre fabric is evaluated. The results reveal to what extent the mechanical saturation behaviour depends on a previous load history. They indicate that in stress ratio 1:1 and 2:1 the stress-strain response mainly of fill direction is dependent on the previous load history even after multiple repeated load cycles in these stress ratios. The stress-strain paths in the other stress ratios 1:2, 1:0 and 0:1 behaved independently of previous loadings.

1 INTRODUCTION

In recent investigations it could be shown that coated woven fabrics for architectural applications show a saturation in their stress-strain behaviour under multiple repetitive loads [1, 2]. This behaviour is convergent, the main parameters describing a stress-strain path approach asymptote values. These parameters are namely strain at maximum load, intensity of nonlinearity and irreversible strain after unloading.

In membrane structures, different stress ratios could apply at one specific local point in the surface under different loadings, e. g. different occurring strass ratios under wind pressure compared to under wind suction. Does this have to be considered in the constitutive model of the material? When looking at typical biaxial test protocols for evaluation of material parameters like in EN 17117-1 [3] or MSAJ/M-02-1995 [4], which use a predefined order of investigated stress ratios, the question arises whether the recorded data would be the same if the order of stress ratios would be changed. In other words: Is the stress-strain behaviour under a specific stress ratio independent of the previous load history of the sample? If so, the deviated stiffness parameters could be understood as “global” material parameters. If not, the impact of different load histories must be considered in testing and in the evaluation of these tests as well as in the design of membrane structures.

Obviously, the biaxial load protocols of EN 17117-1 and MSAJ/M-02-1995 were constructed assuming a load history dependency. They initially apply load cycles under stress ratio 1:1 in order to eliminate initial slack in the yarns. Between the other four tested stress ratios 2:1, 1:2, 1:0 and 0:1 they also apply three load cycles under stress ratio 1:1 with the objective to bring the fabric back to the state it had after the inital three 1:1 load cycles. This would not be required in case the material response in an investigated stress ratio would be independent after one or some more load cycles in this very stress ratio.

For PVC-coated polyester fabrics, this question has already been addressed by e. g. van Craenenbroeck et al. [5] and Galliot & Luchsinger [6] by comparing recorded stress-strain paths in biaxial tests under different loading situations to each other. van Craenenbroeck et al. found small effects of load history variations on the stress-strain behaviour which were assessed as not relevant for the computational model. Neither Galliot & Luchsinger found significant impacts in their tests.

For PTFE-coated glass fibre fabrics such investigations are not known. This paper presents a first rough investigation into load history dependencies of one woven glass-PTFE fabric.

2 EXPERIMENTAL TESTS

The tested material is an architectural glass-PTFE fabric type II according to FprCEN/TS 19102 [7] named B18039 by Verseidag Indutex GmbH, Krefeld, Germany. It is a plain weave woven fabric. Three plane biaxial tests were performed using a testing machine conform to EN 17117-1. For each test, a different test protocol was established considering the five different stress ratios used in EN 17117-1 or MSAJ/M-02-1995.

The main feature of these test protocols was that they were constructed with different orders of stress ratios. Considering the mechanical saturation behaviour of coated textiles [1, 2], 50 load cycles were scheduled in each stress ratio. Right after the 50th load cycle a hold time of 0.5 h on zero stress was foreseen and another 51st load cycle was scheduled before the next load block with 50 load cycles of the next stress ratio was applied. This gave the possibility to check whether reverse creep has an influence on the stress-strain behaviour and the load history dependency.

The monoaxial stress ratios 1:0 and 0:1 were placed at the end of the test protocol. On the contrary, the biaxial stress ratios were placed at the beginning with changing order. Herewith, stress-strain paths were recorded for the biaxial stress ratios without a previous load history when they were the starting stress ratio or with a previous load history from one or two other biaxial stress ratios when they are at position two or three.

For instance, in the first stress protocol in Figure 1, stress ratio 1:1 is the beginning one and thus the stress-strain behaviour was not affected by other previous stress ratios in the load history. In the second load protocol, stress ratio 1:1 is placed at the third position with 2:1 and 1:2 as previous stress ratios. In the third test protocol, 1:1 is placed at the second position and has only 1:2 as previous stress ratio.

The monoaxial stress ratios have different previous load histories because of the varied order of the biaxial stress ratios before.

The load rate was chosen very high with 1 kN/m/s in order to keep the tests reasonably short with 50 load cycles for each biaxial stress ratio and hold times in between. The testing machine was challenged at the high speed to hit the forces precisely at all times; this can be seen in Figure 1 by the slightly zig-zag course of the maximum forces in the load blocks. Despite the high speed, each test took ca. 5 hours. The three tests were coded DFG011217, DFG010218 and DFG020218.

Because in none of the three tests the monoaxial stress ratios are available without load history, two additional cyclic monoaxial tests were performed (DFG1917 & DFG 5917). They just contained 50 load cycles in warp or fill, respectively, with the same load rate as in the biaxial tests.

Figure 1: Three different load protocols for three tests, shown as realized by the testing machine

3 EVALUATION

In order to detect load history dependencies in the stress-strain behaviour, the last stress-strain paths before the hold time (load cycle 50) of each load block were extracted, normalized and compared to each other as shown below. Possible dependencies were checked for each stress ratio separately.

Figure 2 shows the recorded stress-strain response for stress ratio 1:1. The shown paths are a little trembling due to the very high load rate. Nevertheless, Figure 2 shows paths for three situations: (a) without previous load history (black), (b) with previously applied stress ratios 2:1 and 1:2 (blue) and (c) with previously applied stress ratio 1:2 (green). For this comparison, always the 50th load of each stress ratio block was extracted from the full recorded data.

In both warp and fill directions considerably different stress-strain path are observed for “without previous load history” on the one hand and “with previous load history” on the other hand. For fill direction, a strong stiffening is detected while warp shows a medium softening. Looking at the strong differences in fill direction, it can be assumed that the previous high loading of the fill yarns in stress ratio 1:2 has straightened the formerly crimped yarns within the weave. As they are straightened before the loadings in stress ratio 1:1 were applied, they behave stiffer now. The additional predominant loading in warp in stress ratio 2:1 slightly reduces this effect as can be seen from the stress-strain path laying slightly right of the path with only predominant fill loading in the previous event 1:2. In warp direction, the response tends to be softer with 2:1 and 1:2 as previous loadings. This effect may be a result from the fact that the warp yarns get more crimped while fill yarns straighten under predominant fill load in 1:2.

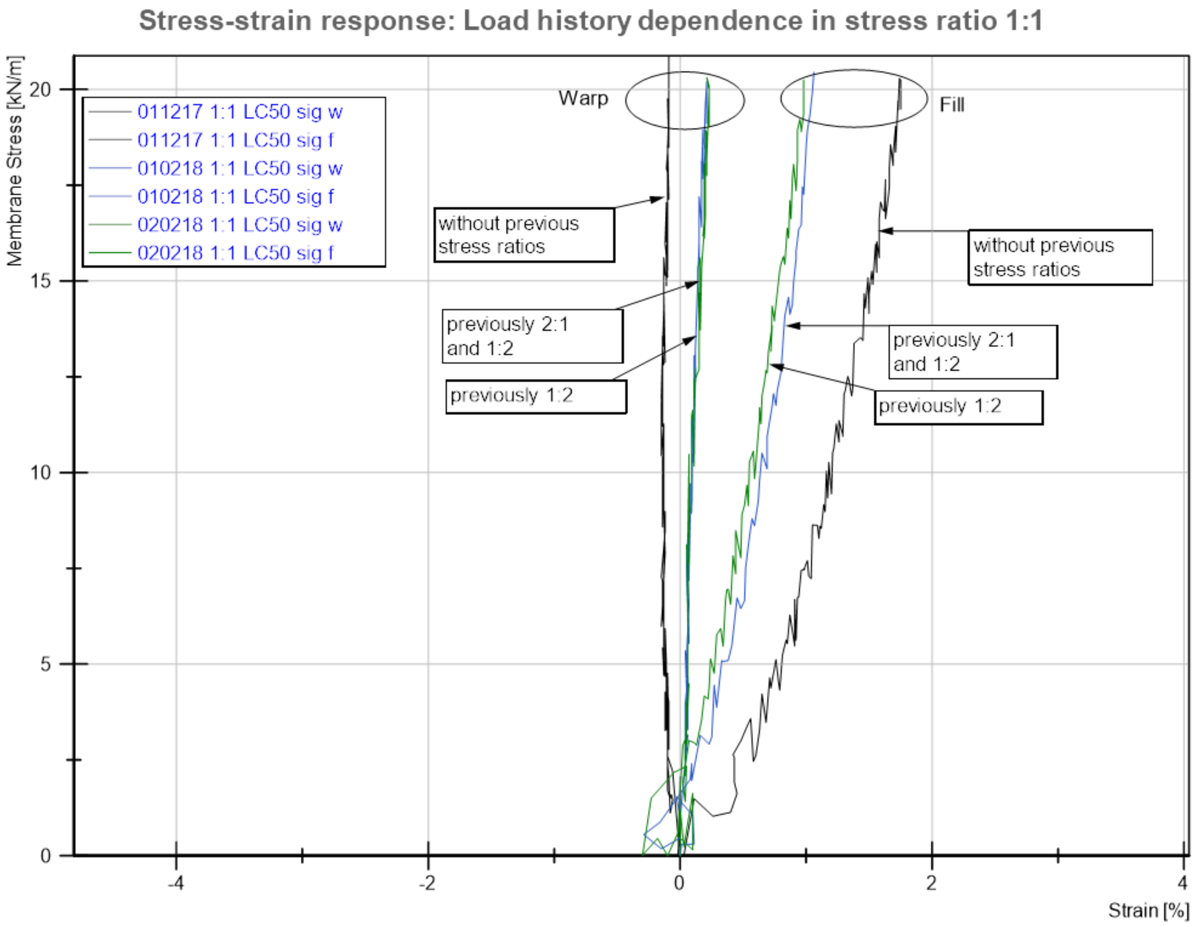

Figure 2: Stress-strain response in stress ratio 1:1

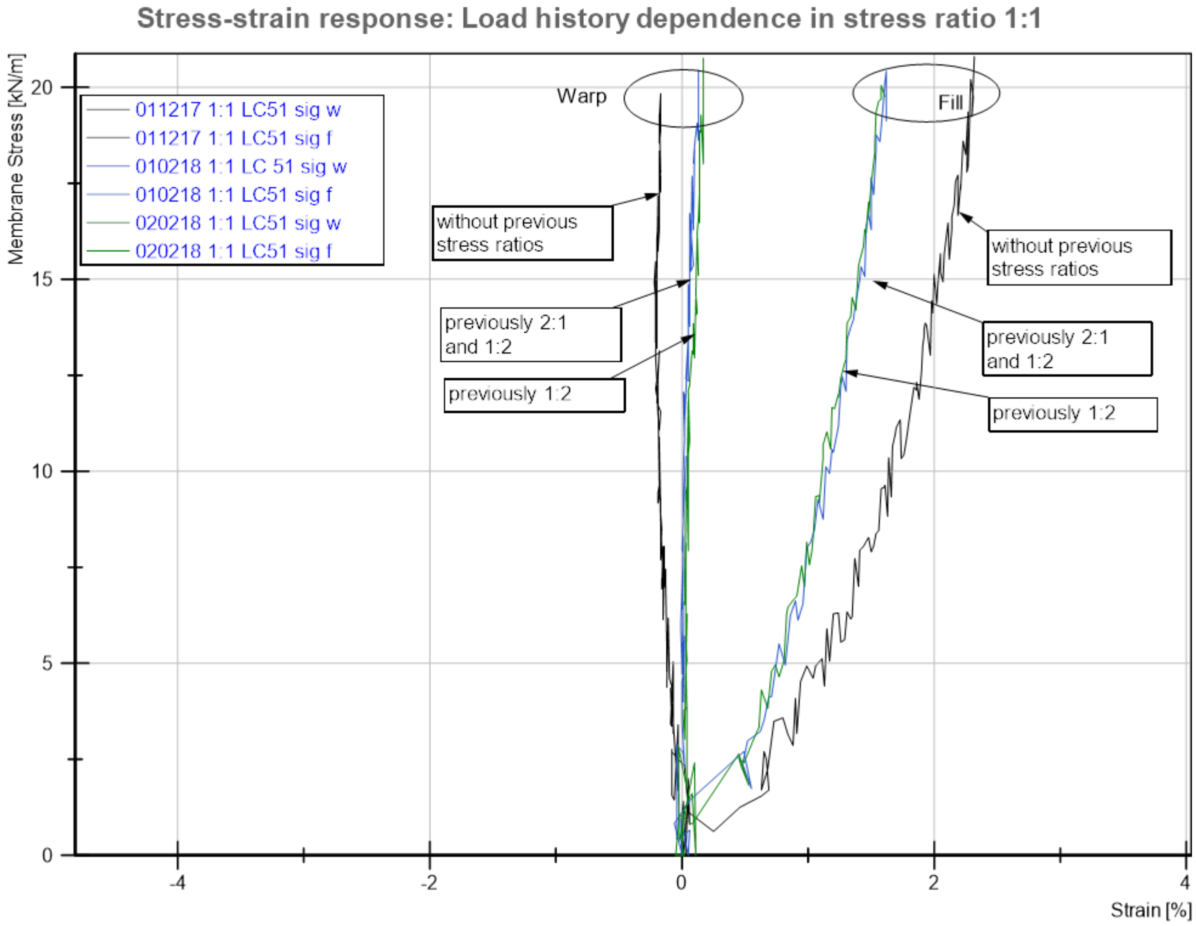

Figure 3: Stress-strain response in stress ratio 1:1 after the hold time on zero stress

The stress-strain paths in load cycle 51, i. e. right after the hold time of 0.5 h on zero stress, see Figure 3, show basically the same material behaviour. Apparently, reverse creep has the same softening impact on all the stress-strain paths and thus does not influence the load history dependencies. In the following, only the behaviour before the hold time, i. e. in load cycle 50, is analysed.

In stress ratio 2:1, different responses are recognized with previous stress ratios than without, see Figure 4. Again, this effect is stronger in fill direction and again remarkably higher stiffness in fill and slightly less stiffness in warp were found. The high number of load cycles with high fill stresses in the combination with previous stress ratios 1:2 and 1:1 amplifies the straightening effect of the yarns, which can be observed in the slightly stiffer stress-strain path with « previously 1:2 and 1:1 » compared to the stress-strain path with only « previously 1:1 ».

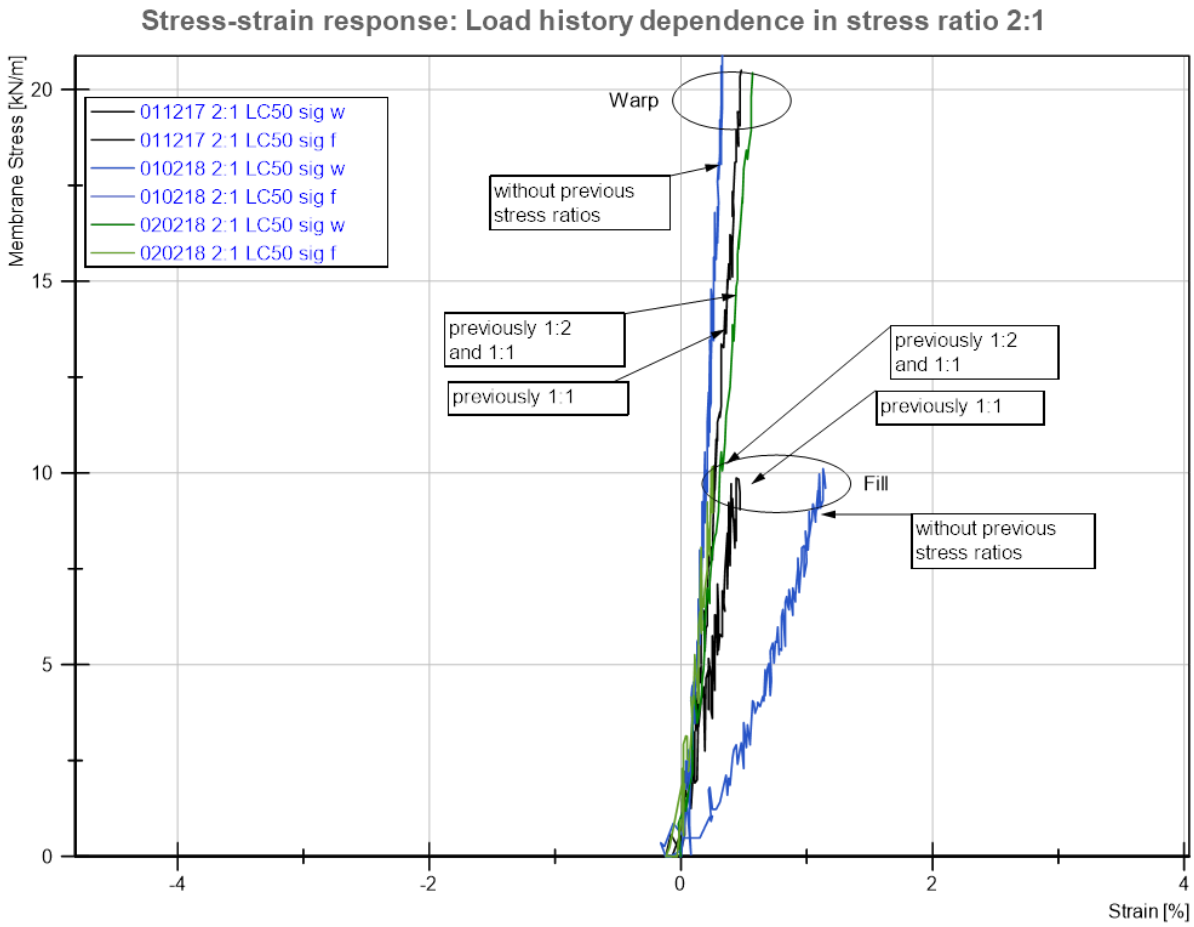

Figure 4: Stress-strain response in stress ratio 2:1

Looking at stress ratio 1:2, Figure 5 reveals no load history dependency. The recorded stress-strain paths are fairly the same with and without the investigated previous load events. The same can be observed for the monoaxial stress ratios 1:0 and 0:1, see Figure 6 and Figure 7. The found differences in fill direction under stress ratio 1:0 are small and would only slightly change the Poisson's ratio. Moreover, in the monoaxial stress ratios the data are compared to additional test data from separate pure monoaxial tensile tests. It can be seen from the latter that the behaviour without any previous stress ratios is the same (again with the exception of small differences in the transverse contraction in fill under 1:0). Assumably, the yarn straightening effect of loading only one weave direction is so strong that it is able to overwrite any previous yarn geometry. Basically, the slight differences in fill direction can be explained by the fact that if the fill yarns had been straightened before by some prehistory, then subsequent monoaxial straightening of the warp yarns can pull more crimp into the fill yarns as if they were already crimped. This becomes visible in the diagram in Figure 6 by comparably higher transverse contraction.

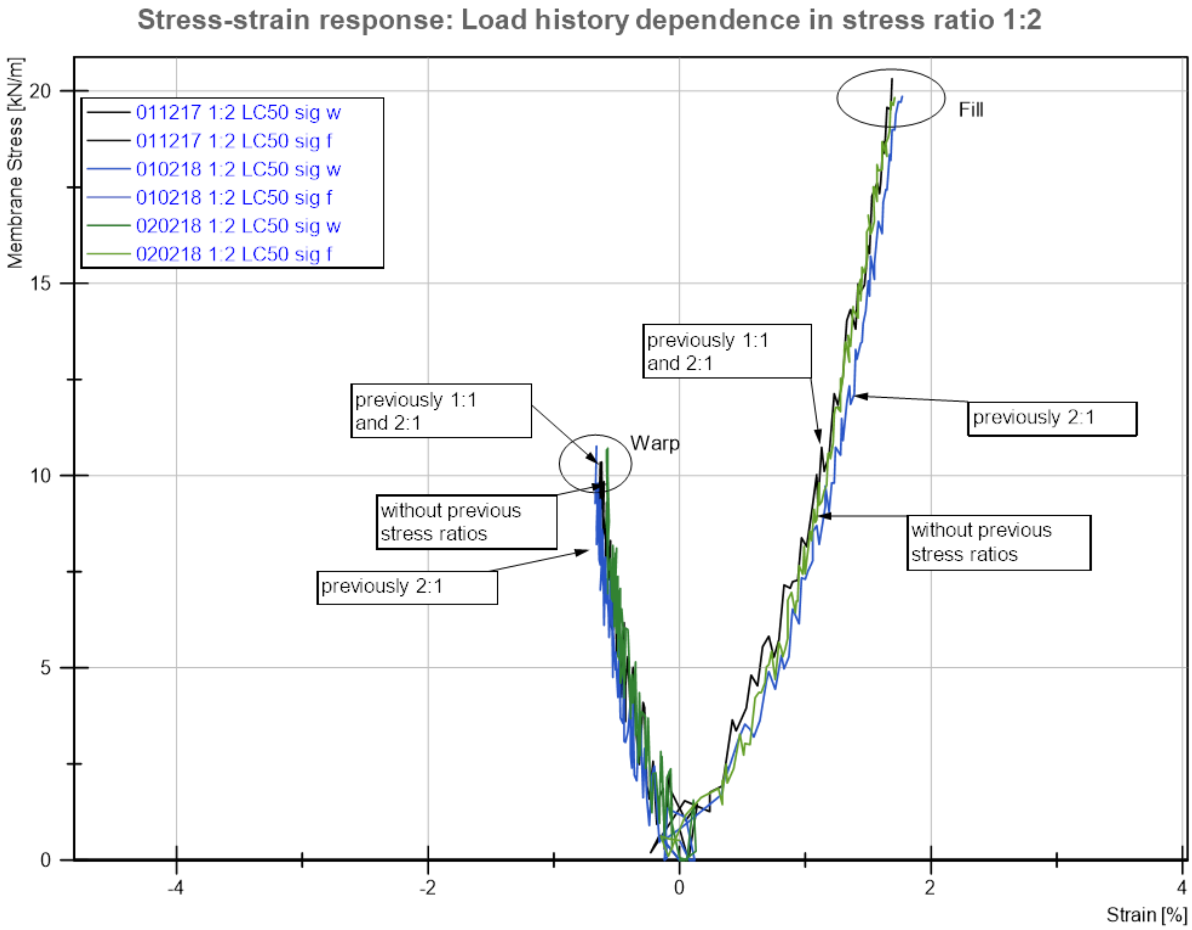

Figure 5: Stress-strain response in stress ratio 1:2

Overall, it can be stated for the investigated glass-PTFE fabric that in many loading situations a previous load history can be eliminated by load cycling. Similar to saturation tests, it is just a question of how many load cycles are required to do so. However, the results indicate that a previous load history cannot be neglected in the stress ratios 1:1 and also 2:1, at least not in fill direction.

It seems that because fill yarns have a high initial crimp, predominant loading in fill direction as in 1:2 and 0:1 has a high potential of mechanical conditioning of the material, i.e. bringing the material to a state inevitably connected with these stress ratios. Of course, this works only after a sufficient number of load cycles. On the contrary, a high warp stress has less potential for mechanical conditioning. A sufficient potential to overwrite a previous load history during predominant warp stressing was only observed in the monoaxial stress ratio 1:0. More generally speaking: A load history can only be eliminated by sufficiently predominant stress in one weave direction.

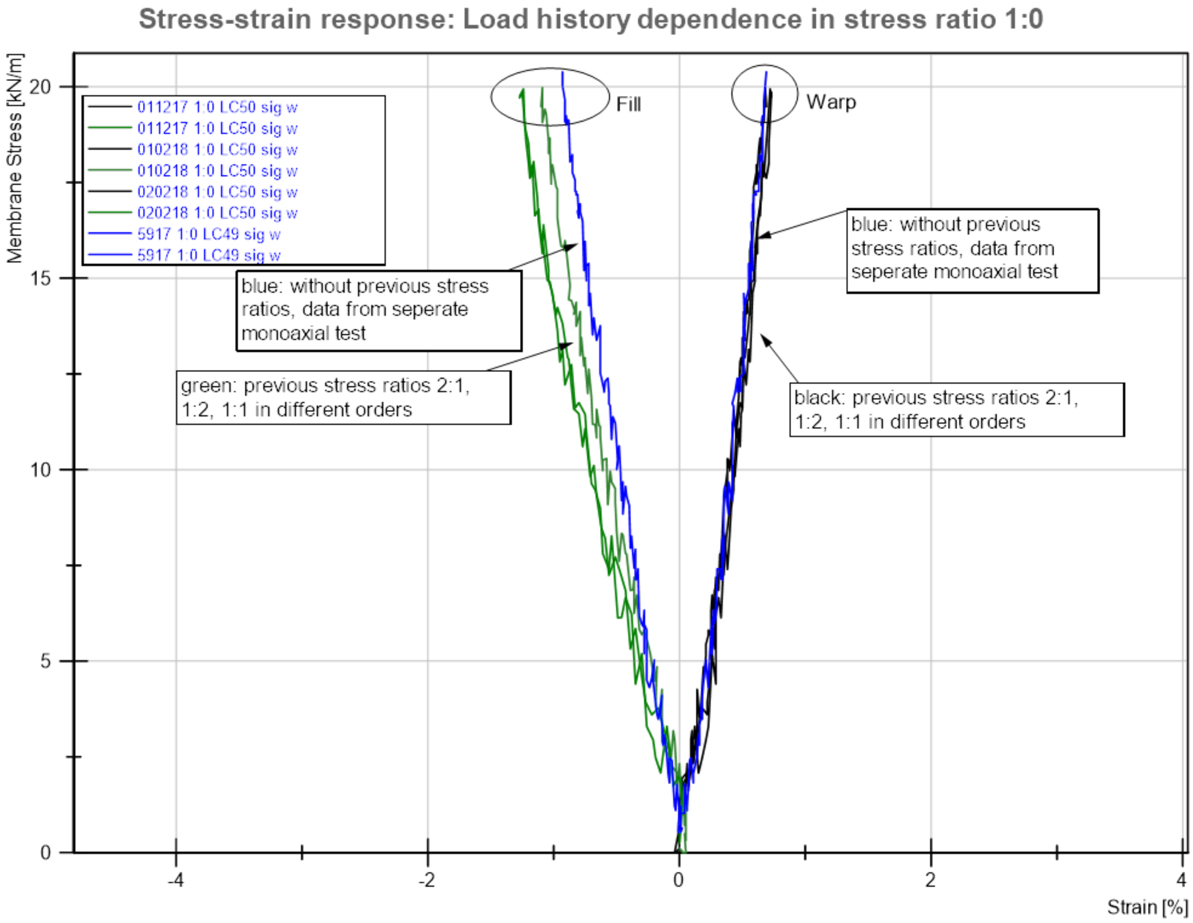

Figure 6: Stress-strain response in stress ratio 1:0

4 CONCLUSIONS & OUTLOOK

The present paper gives a first insight of whether the stress-strain behaviour of architectural PTFE-coated glass fibre fabrics is dependent on a previous load history. As an example, one glass-PTFE fabric was investigated with three different biaxial load histories including the usually used five stress ratios for biaxial testing. The differences between the load protocols were the order of applied stress ratios. In each stress ratio 50 load cycles were applied to check if an impact of a previous load history on the stress-strain response could be overwritten by repeating a new load many times.

To investigate the influence of different load histories for each stress ratio, the last load cycle was extracted from the recorded data. The extracted paths were compared to each other. It was observed that the stress-strain behaviour was independent of previous loadings in the monoaxial stress ratios 1:0 and 0:1 as well as in the biaxial stress ratio 1:2. In other words, in these stress ratios a weave geometry could be established that (with sufficient load cycles) is inevitably associated with this stress relationship. On the contrary, load cycling in stress ratios 1:1 and 2:1 was not able to eliminate a previous load history completely, particularly in fill direction. More generally speaking – with regard to the investigated fabric: A load history can only be eliminated by sufficiently predominant stress in one weave direction. How much predominance is sufficient is different in warp and fill direction. Predominant fill stress has the higher potential to overwrite previous load incidents than predominant warp stress. In an even stress state, i.e. 1:1, the probability to overwrite a previous load history is the lowest.

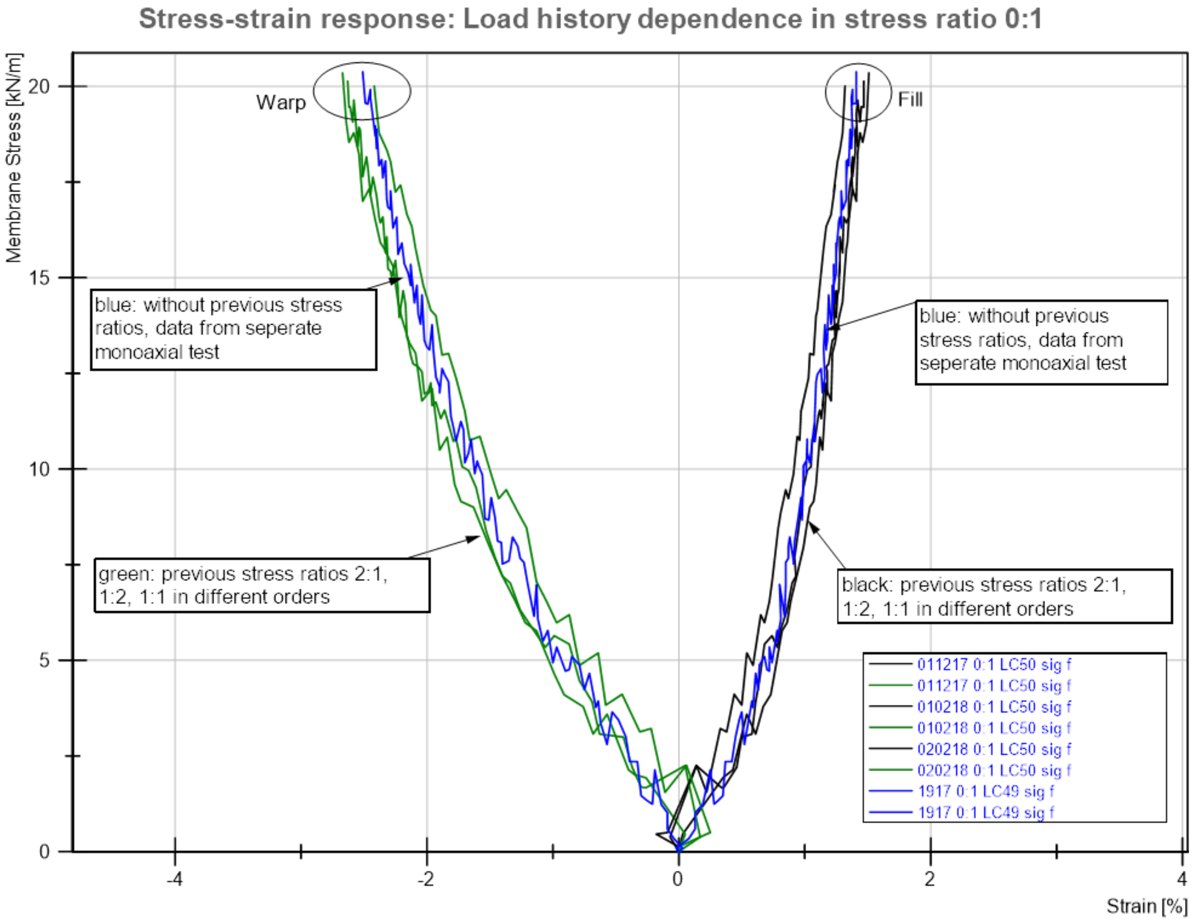

Figure 7: Stress-strain response in stress ratio 0:1

Future investigations will be carried out to check the load history dependency for differentiated properties of the stress-strain paths like intensity of nonlinearity, strain at maximum load or irreversible strain after unloading. They will include the saturated state in their considerations and analyse if the behaviour changes with lower load rates which would enable viscoelastic effects to fade away. Furthermore, in cases where a previous load history can be overwritten, it would be of interest how many load cycles are required to do so. Finally, the impact of load history dependencies on the material parameters has to be assessed. If this impact is significant, it should be considered in future biaxial load protocols.

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