Analysis of the cyclic load-unload-reload tests of VALMEX aged fabric.

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ABSTRACT: The paper presents mechanical response of the VALMEX fabric during the cyclic loading-unloading and reloading experiments. Two types of the aged material used for nearly 20 years as the roofing of the Forest Opera in Sopot (Poland) have been tested. The results have been separately obtained for the warp and fill directions. The comparative analysis has revealed that the material aged in service is more durable in the fill direction, but less durable in the warp direction. It has been also shown, that the material aged in service has kept its high strength properties and could be longer used in the real structure.

1 INTRODUCTION

The VALMEX fabric FR 1000 Hallen type III Universal analyzed in this study has been produced by a German company Mehler Texnologies in the early nineties of the 20th century (POLNAM 1989). Two different sorts of the same fabric have been examined. The first one has been used for 20 years as the canopy of the Forest Opera in Sopot (throughout the paper called the USED material). During operation the USED VALMEX material underwent at least 20 cycles of stretching and unstretching, as used only in summer periods, to be put down for winter (Fig. 1).

Figure 1. Putting down the roofing structure of the Forest Opera in Sopot (Poland) before winter season (Dziennik Bałtycki 2007).

Additionally, the material was exposed to environmental influences. It has confidently underwent ageing, in both weathering and mechanical aspects. The second analyzed kind of the VALMEX fabric is the material from the same production part as the USED one, but it was kept as a spare fabric to repair the roof if necessary (called the NOT USED material). It was stored at a constant temperature, without light access in building basement, hidden from unfavorable weather conditions. It is assumed that it has endured only natural, non-mechanical ageing process - the only acting factor were passing time and presence of oxygen.

The main aim of this study is to evaluate the influence of the service ageing on cyclic response of the VALMEX fabric and to assess if it could be used for longer than 20-year period. Therefore, the cyclic load-unload and reload tests have been performed to compare the USED and NOT USED material performance under variable loading conditions.

2 EXPERIMENTS

The strength machine Zwick Z020 with the video-extensometer has been used for the testing. The width of a specimen has been 50±0.5 mm, while the grip separation has been set to 200±0.5 mm. The load-unload-reload tensile cyclic tests of the USED and NOT USED VALMEX samples have been conducted with the constant strain rate of 0.001 1/s in all experiment phases. In each subsequent cycle the peak strain level has been increased by 1.5% of the total strain increment, until the rupture of the specimen. The relaxation periods of 10 s only have been realized each time the phase has changed. The recorded values of force, elongation and time have been used to calculate the overall material response in the form of stress-strain curves. For both kinds of the VALMEX fabric and for each thread direction 4 specimens have been tested.

The example results of the stress-strain curves for the VALMEX fabric are presented in Figure 2. The response for the warp direction is more repeatable and the discrepancies between the USED and NOT USED samples quite small in comparison to differences observed for the fill direction. The results of a single typical test is given here due to its complex form and to the fact that the rest of the test results converge, expressing common tendencies.

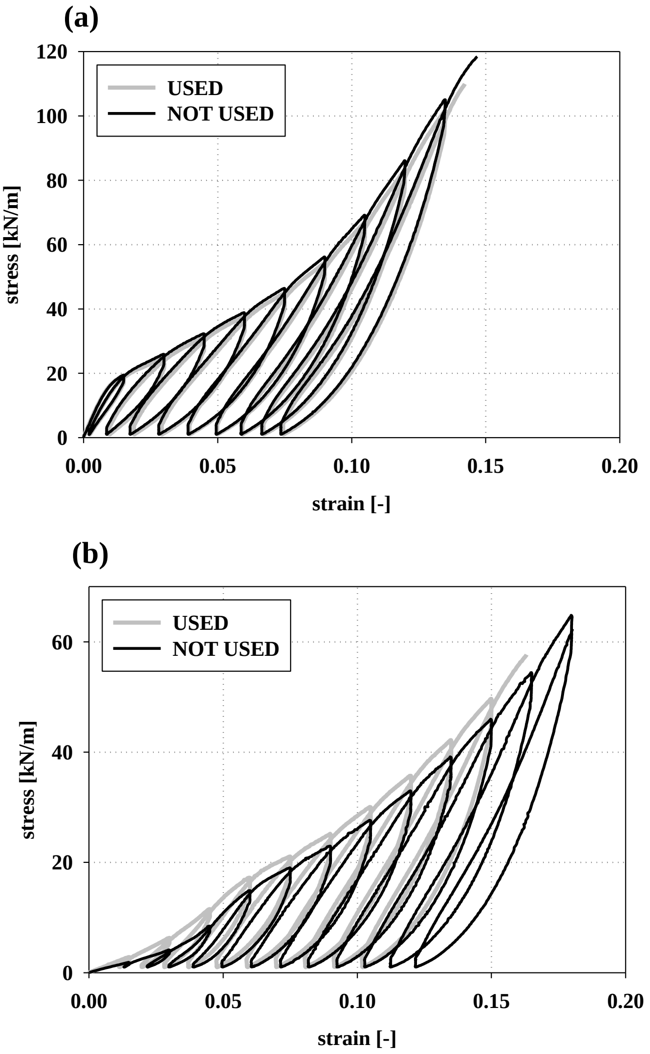

Figure 2. Results of load-unload-reload tensile cyclic tests for the warp (a) and fill (b) direction of the USED and NOT USED VALMEX fabric.

3 ANALYSIS OF CYCLIC TESTS

In the procedure proposed here, each unloading and then successive reloading cycle has been separately approximated by a linear function $f(x) = a \cdot x + b$. Inclination a representing the longitudinal stiffness modulus of the achieved lines are denoted, then, as E_{DOWN} and E_{UPP} for the unloading and reloading phase, respectively. Short relaxation periods between each loading phase have been omitted in the identification process. This methodology is presented for several cycles in Figures 3a, 3b for the warp and fill direction, respectively. The results from both unloading and reloading stages are very similar, thus the value of longitudinal stiffness modulus for every cycle has been calculated as the mean value E_{MEAN} of the E_{DOWN} and E_{UPP}. Figures 4a, 4b show the mean values E_{MEAN} for each cycle for the warp and fill directions, respectively.

The procedure has been executed for all of the cycles, for the USED and NOT USED VALMEX samples, for the warp and fill direction. The achieved results gathered in the form of tables can be found in Żerdzicki (2015).

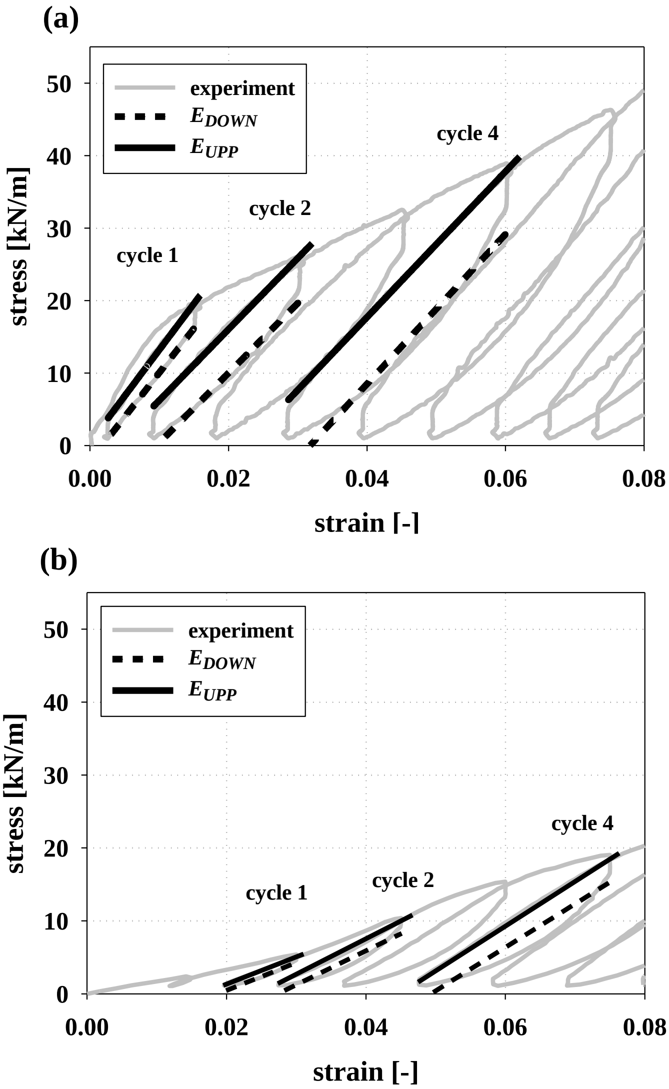

Figure 3. Methodology of elastic modulus identification in each load-unload cycle for the warp (a) and fill (b) direction

It has been assumed that the loading loop consists of the unloading and then reloading stage. Due to that fact, the cycle number "0" refers to the very first loading phase that does not have any preceding unloading part (Fig. 4). Comparing the NOT USED and USED material the differences are not largely pronounced. The greatest discrepancy is detected for the "0" cycle, which for the warp direction corresponds to the immediate elastic modulus and for the fill direction for the stiffness of the coating made of PVC (Kłosowski et al. 2017).

Another reflection of a Figure 4 study concerns a number of cycles that each type of VALMEX has experienced and the evolution of the related longitudinal stiffness moduli. In the case of the warp direction the NOT USED samples are a bit more robust, while for the fill direction the results are opposite. Remember that the USED material underwent about 20 long-time cycles of stretching and unstretching during installation repeated every year of its usage.

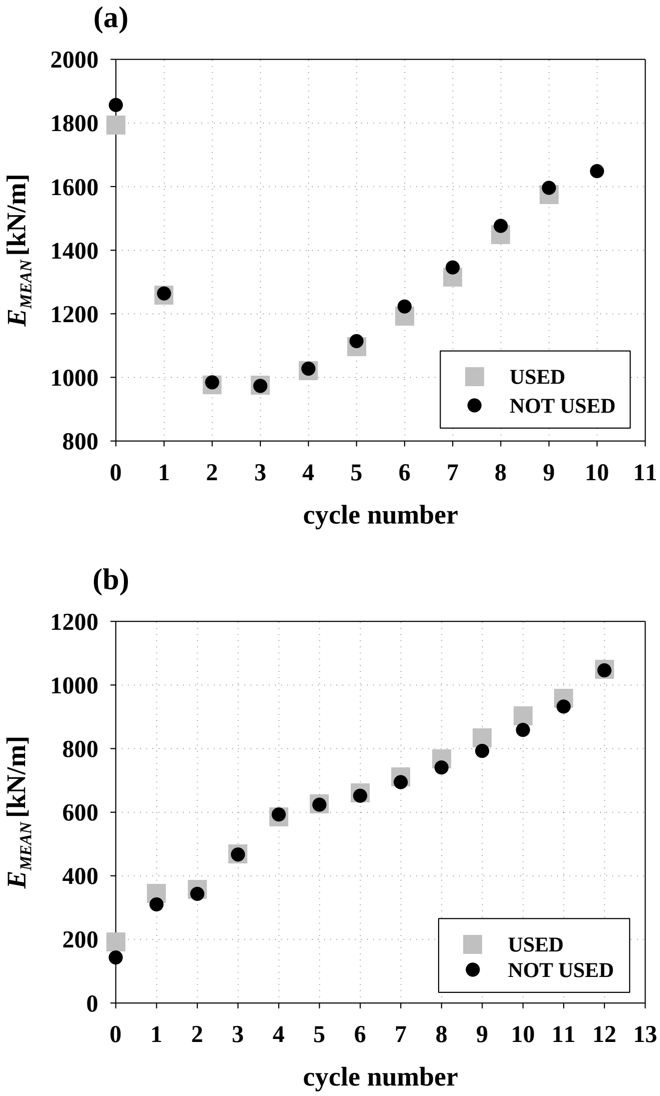

Figure 4. Comparison between the mean values of the longitudinal stiffness E_{MEAN} for the warp (a) and fill (b) direction of the NOT USED and USED VALMEX fabric.

Additionally, the warp direction is the main working direction, characterized by higher strength properties and lower elongations ranges. These properties come from the pretension during manufacturing process resulting in the straight threads in the warp direction. In the fill direction the threads are not tensioned, they are interspersed between the warp threads (Fig. 5).

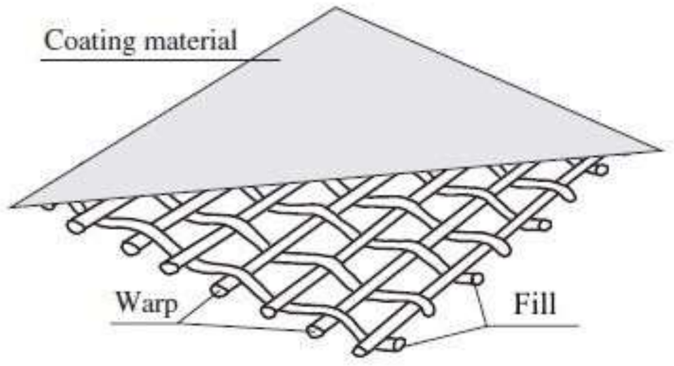

Figure 5. Composition of the coated technical fabric with orthogonal threads of warp and fill (Ambroziak 2015).

Therefore, it has been concluded that the material in the warp direction has gained its ultimate elongation limit and the longitudinal stiffness modulus has started to decrease gradually (damage has occurred – gray squares below black dots in Figure 4a). For that reason the USED fabric has endured one cycle less that the NOT USED one. At the same time, material in the fill direction has been tensioned with equal number of cycles, however to the lower stress level than in the warp direction. It has resulted in hardening of the material (gray squares above black dots in Figure 4b), but still far from its elongation limit. Therefore, it can be concluded that damage has not occurred yet. Thus, both VALMEX types for the fill direction have experienced the same amount of cycles. The last investigated phenomenon, is the overall behavior of the material. In the warp direction, for both materials types, the longitudinal stiffness modulus has first decreased rapidly and then has begun to grow from the fourth cycle (Fig. 4a). In the meantime, in the fill direction the material has exhibited an increasing trend from the first cycle, additionally with several distinct phases of almost linear growth (Fig. 4b).

4 CONCLUSIONS

The presented cyclic tests have proven good VALMEX fabric performance even after 20 years of in service and natural ageing, for both orthogonal material directions. It has been observed, that probably due to the pretension of threads in the warp direction of the material during manufacturing, the USED material for the warp direction showed a lower damage strength than the NOT USED one, while for the fill direction this effect is opposite.

The load-unload cyclic tests are commonly performed to estimate of the damage influence on elastic properties of a material. It is one of the indirect methods for damage measurement (Lemaitre 1996). The results obtained here can be used for the damage analysis of the VALMEX fabric, thus will be investigated in the further research.

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