APPLICATION OF THE MODIFIED LOCATI METHOD TO DETERMINE THE DURABILITY OF A COMPOSTABLE POLYMER

Domen Šeruga(*), Marko Nagode, Jernej Klemenc
University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia
(*)Email: domen.seruga@fs.uni-lj.si

ABSTRACT
Compostable polymer materials are becoming more common as industries and consumers aim to minimise their impact on the environment. Here, a compostable polymer material NatureFlex™ has been tested using a modified Locati method to determine the durability at the target number of cycles to failure. The specimens were prepared from a 45 µm foil and placed into the test rig. Current results show a higher durability in the transverse direction at the target 100000 load cycles.

Keywords: durability, Locati method, step test, compostable polymer, NatureFlex, fatigue.

INTRODUCTION
Compostable polymer materials have recently gained attention as industries and consumers aim to minimise their impact on the environment (Patane et al., 2018, Patane et al., 2019, Rudnik 2008). Although there is a limited number of these materials used commercially, they will become more common in the future (McKeen 2017). Usually, studies regarding packaging films focus on suitability for maintaining fresh-cut quality of food or involve testing of shelf-life duration (e.g. Patane et al., 2018, Patane et al., 2019). However, an increased importance of renewable resources for raw materials and their recyclability/compostability are also introducing the use of agro-based natural materials in other applications, e.g. automotive interiors (Kamath et al. 2005, Medina 2006). Hence other material properties for compostable polymer materials will inevitably become more required, e.g. the load-bearing capacity and the durability.

In this study, the durability of a compostable polymer material NatureFlex™ NVS with the thickness of 45 µm has been tested. NatureFlex™ NVS is a sustainable packaging film, based on the cellulose - the most abundant organic compound on earth (Rudnik 2008). It has been specifically formulated to offer improved stiffness under chill cabinet conditions and a controlled level of moisture permeability (Futamura 2019). A modified Locati testing has been applied to determine the durability at the target number of cycles to failure. This type of testing is usually required for validations of prototypes during the R&D process of mechanical components when their load-bearing capacity is tested at a target number of load cycles (Locati 1955, Zhang et al. 2003, Klemenc 2015).

METHOD
The modified Locati method is based on the description of the durability curve by the Basquin equation:

\[ S = \frac{E}{2\pi \times \beta \times t} \]

where:

- \( S \) is the stress at failure,
- \( E \) is Young's modulus,
- \( \beta \) is the fatigue stress exponent,
- \( t \) is the thickness of the specimen.
\[
\log(\sigma) = A + B \log(N) \tag{1}
\]
and the Palmgren-Miner damage accumulation rule:

\[
D = \sum_{i=1}^{k} \frac{n_i}{N_i} \tag{2}
\]

where \(\sigma, N, A, B, D, n_i\) and \(k\) represent the loading stress for the given dynamic ratio, the number of cycles to failure, the intercept of the durability curve, the slope of the durability curve, the accumulated fatigue damage, the number of load cycles at load level \(i\) and the load level at which the failure occurred, respectively (Locati 1955, Zhang et al. 2003, Klemenc 2015). The load is applied in load-cycle blocks whereas its level increases in each consecutive load-cycle block until rupture of the specimen is detected. The advantage of the method is the determination of the durability at the target number of cycles to failure without prior knowledge of the slope of the durability curve. If a proper test plan is considered, various slopes of the durability curve intersect at the target number of cycles to failure and hence the result becomes independent from the slope of the durability curve (Zhang et al. 2003, Klemenc 2015). The proper test plan involves the determination of the initial load level, the lengths of load-cycle blocks and the load increment in each consecutive load-cycle block (Klemenc 2015). It is solved by an optimisation procedure, here the Downhill Simplex method has been used (Šeruga and Nagode 2019). Optimal determination of the test plan ensures that the intersection of durability curves with various slopes, denoted as the best-fit point, leaves a trace during the loading as close as possible to the vertical line going through the target number of cycles to failure (Klemenc 2015).

RESULTS AND DISCUSSION

Specimens were cut from a 45 \(\mu\)m foil in the “as-received” condition without any additional processing, Figure 1a. In order to decrease the force measurement error, six layers of the foil were bonded, taped and inserted between the top and the bottom grips of the test rig for dynamic mechanical tests, Figure 1b.
Next, the static stress-displacement curves in both transverse and longitudinal directions have been determined which then provided the connection between the stresses and the displacements of the specimens during loading. Figure 2.

![Static stress-displacement curves](image)

**Fig. 2** - Static stress-displacement curves for: (a) transverse and (b) longitudinal direction of loading

Finally, the modified Locati test plan was initiated at the loading frequency of 5 Hz and the stress signal was calculated from the force and displacement measurements, Figure 3.

![Stress signal](image)

**Fig. 3** - (a) The recorded stress signal during transverse loading of specimen Nr. 3 and (b) the recorded stress signal during longitudinal loading of specimen Nr. 3

The tests were carried out on a 25-kN MTS hydraulic testing machine. A built-in LVDT was utilised to measure the displacement. The force was measured using a 25-kN tensile-compressive load cell that is integrated into the test rig. Two step load histories were considered during the study, one in the transverse and the other one in the longitudinal direction. Experimental results of the durability testing are given in Figure 4.

The determination of the static stress-displacement properties demonstrates a higher strength of the NatureFlex™ NVS with the thickness of 45 µm in the longitudinal direction (Figure 2). The ruptures of the specimens were recorded at around 70 MPa in the transverse direction (Figure 2a) whereas the stress at rupture under longitudinal loading occurred at around 120 MPa (Figure 2b).
The comparison of the shapes of the static curves shows a more ductile behaviour of the material in the transverse direction. During the cyclic loading however, the results of this study show that the durability of the NatureFlex™ NVS at 100000 cycles is around 40 MPa in the transverse direction and around 30 MPa in the longitudinal direction, Figure 4). This can be explained as the consequence of higher ductility of the material in the transverse direction, hence the initiation and the propagation of the fatigue damage is inhibited. On the contrary, the fatigue damage is more pronounced in the longitudinal direction, supposedly due to a lower ductility of the material and therefore a higher susceptibility to cracks or microcracks.

Although a high caution was taken during the preparation of the specimens, cracks could have been introduced during this procedure which would then affect the durability of the specimens. A source of uncertainty is introduced due to the measurement of low absolute force values on the tensile-compressive load cell which can be seen as the fluctuations of the stress signals of about 5 MPa in Figure 3. This uncertainty could be diminished by the application of a load cell with a lower nominal measurement value. Furthermore, the viscoelastic effects of the material have not been considered during the optimisation of the test plan although the stress relaxation is evident in both loading directions in Figure 3. The drawbacks arisen during this study can be addressed in the future investigations.

CONCLUSIONS

The modified Locati method has been applied to the durability determination of a compostable polymer NatureFlex™ NVS. The specimens have been prepared from 45 µm foil and tested on a 25-kN MTS hydraulic testing machine according to the optimised test plan. Whilst further validation is required, the results suggest that the durability of the NatureFlex™ NVS specimens under the above conditions is higher in the transverse direction as opposed to the higher static load-bearing capacity of the material in the longitudinal direction.
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REFERENCES


