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Investigation of Bauschinger effect in thermo-plastic polymers for biodegradable stents

Abstract: The Bauschinger effect is a phenomenon metals show as a result of plastic deformation. After a primary plastic deformation the yield strength in the opposite loading direction decreases. The aim of this study is to investigate if there is a phenomenon similar to Bauschinger effect in thermoplastic polymers for stent application that would influence the mechanical properties of these biodegradable implants. Combined uniaxial tensile with subsequent compression tests as well as conventional compression tests without prior tensile loading were performed using biodegradable polymers for stent application (PLLA and a PLLA based blend). Comparing the results of compression tests with prior tensile loading to the compression-only tests a decrease in compressive strength can be observed for both of the tested materials. The conclusion of the performed experiments is that there is a phenomenon similar to Bauschinger effect not only in metallic materials but also in the examined thermoplastic polymers. The observed reduction of compressive strength as a consequence of prior tensile loading can influence the mechanical behaviour, e.g. the radial strength, of polymeric stents after sustaining a complex load history due to crimping and expansion.

Keywords: Bauschinger effect, thermoplastic polymers, load history, tensile/compression test, biodegradable stents.

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1 Introduction

The Bauschinger effect was discovered by Johann Bauschinger in 1886 and refers to a property metals show as a result of plastic deformation. Plastic pre-strain decreases yield strength for deformations in the opposite loading direction. For example, a prior tensile deformation results in a reduction of yield strength for subsequent compressive loading (see **Figure 1**) [1].

For metals the basic mechanism of the Bauschinger effect is the obstruction of dislocations at barriers that produce local back stresses for reversed direction of loading [2].

Senden el al. [3] already showed a phenomenon similar to Bauschinger effect, which was basically described for metals, in polycarbonates. The aim of the present study is to investigate if there is such a phenomenon also for thermoplastic polymers used for stent application. Such effect would influence the mechanical properties of these biodegradable implants, because stents undergo a load history with different tensile and compressive loading states during their processing due to crimping, expansion and arterial loading.

To investigate the influence of plastic deformation on the yield strength in the opposite loading direction combined uniaxial tensile tests with subsequent compression tests as well as conventional compression tests without prior tensile loading were performed using biodegradable polymers for stent application. If there is a difference between the compressive stress-strain curves with and without prior tensile loading, a phenomenon similar to Bauschinger effect will be proved in polymeric stent materials.

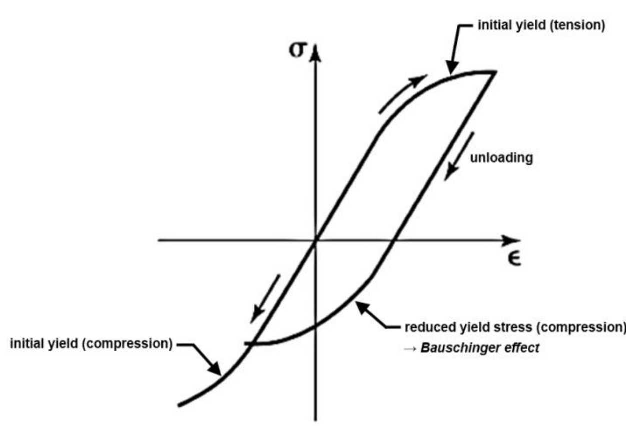

Figure 1: Bauschinger effect

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2 Materials and methods

The combined uniaxial tensile/compression tests and compression tests without prior loading for the investigation of Bauschinger effect were conducted with two biodegradable thermoplastic polymers used in stent applications: poly(L-lactic acid) (PLLA) and a PLLA based blend [4, 5]. The cylindrical specimens were fabricated by melt extrusion using a HAAKE MiniLab II (Thermo Fisher Scientific, Karlsruhe, Germany) with two different extrusion dies that lead to resulting diameters of 2,76±0,20 mm (combined tension/compression) and 1,50±0,02 mm (compression only). The specimen length for tensile and compression testing was 60 mm and 3 mm, respectively.

The material tests were performed using a universal testing machine Zwick/Roell BZ 2.5/TN1S (Zwick GmbH & Co. KG, Ulm, Germany) with a 500 N load cell. According to stent application testing temperature was kept at 37°C.

For tensile testing, special notched jaws were used to ensure uniform load transmission (**Figure 3A**). To position and stabilize the compression specimens a specially built sample holder with round cavities (diameter = 1.5 mm, depth = 0.1 mm, see **Figure 3B**) was used. The testing parameters are summarized in **Table 1**.

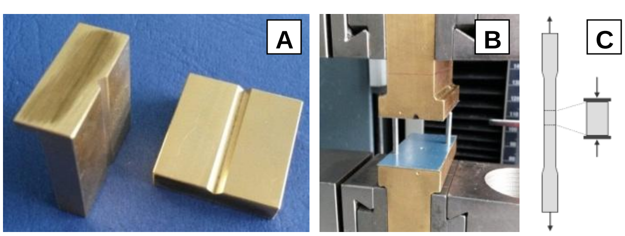

Figure 2: A) Notched jaws for tensile testing, B) sample holder for compression testing and C) procedure for combined tensile/compression tests

From the necked region of the deformed tensile test specimens sections with a length of 3 mm were cut out for subsequent compression testing according to the test method for compression-only tests (see **Figure 3C**).

Table 1: Testing parameters for tensile and compression testing

Test method	Testing temperature [°C]	Initial gauge length [mm]	Testing speed [mm/min]
Tension	37	10	10
Compression	37	3	0.5

Additionally tensile tests with subsequent unloading were executed to identify the transition from the unloading curve to the compression curve.

3 Results

In **Figure 2** the resulting stress-strain curves for the compression tests without and with prior tensile loading for both tested polymeric stent materials are shown (mean value curves for n=5). In both cases the stresses are higher for the specimens without prior plastic deformation. The offset is higher for the blend compared to pure PLLA.

The values for the initial yield stress are listed in **Table 2**. Stress-strain curves for the combined tensile/compression test including the unloading curve after tensile testing are shown in **Figure 4**.

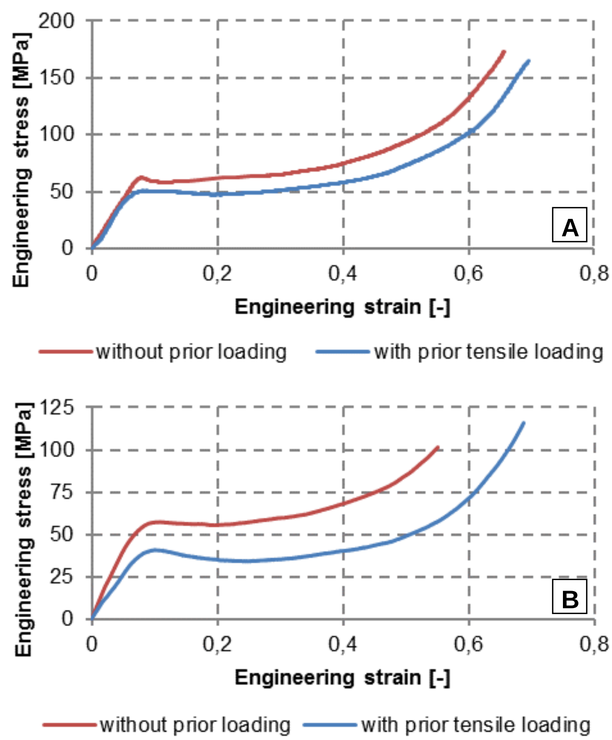

Figure 3: Stress-strain curves for compression tests without and with prior tensile loading for A) PLLA and B) a PLLA based blend**Figure 1:** Reduction of compressive yield stress due to

Table 2: Yield stresses for compression tests with and without prior tensile loading for the tested polymers

Polymer	Yield stress without prior loading [MPa]	Yield stress with prior tensile loading [MPa]
PLLA	65,23±5,37	51,70±5,47
PLLA based blend	59,80±3,76	41,69±5,50

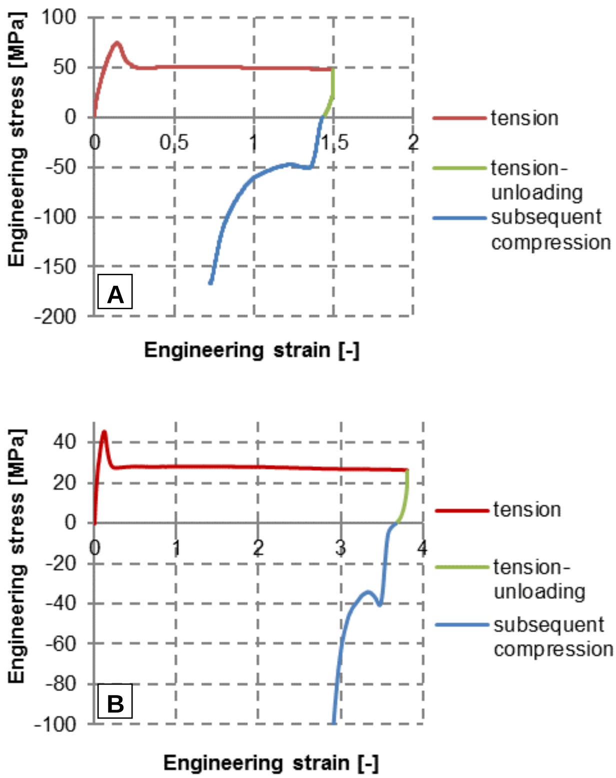

Figure 1: Stress-strain curves for combined tensile/compression tests (tension – unloading – compression) for A) PLLA and B) the PLLA based blend

The graphs for PLLA and the PLLA based blend show a similar curve progression. Because of the gentle slope at the beginning of the compression curve a smooth transition between unloading and compression curve results.

4 Conclusion

To investigate if there is a phenomenon similar to Bauschinger effect in thermoplastic polymers used as material for biodegradable stents combined uniaxial tensile tests with subsequent compression tests as well as conventional compression tests without prior tensile loading were performed. It became apparent that there is a considerable influence of plastic deformation during tensile loading on the yield strength in subsequent compression testing. The initial yield stress reduces by 20% and 30% for PLLA and the PLLA based blend, respectively.

Comparable to the results for polycarbonates of Senden et al. [3] a phenomenon similar to Bauschinger effect can also be demonstrated in biodegradable thermoplastic polymers for stent application. The reduction of yield strength due to plastic pre-strain in the opposite loading direction most likely influences the mechanical properties of biodegradable polymeric stents, e.g. their radial strength, after sustaining a complex load history due to crimping and expansion.

Author's Statement

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