POLYMERIC CORONARY STENTING: NUMERICAL EVALUATION OF PLLA STRAIN-RATE DEPENDENCE AND COMPARISON BETWEEN IMPLICIT AND EXPLICIT METHODS

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INTRODUCTION

Coronary arteries affected by **atherosclerosis** are commonly treated with **stents**. The drawbacks induced by bare metal and drug eluting stents have led to the progressive adoption of alternative stent materials such as **biodegradable polymers**. Poly-L-Lactide Acid (**PLLA**) is of particular interest as stent material, as it shows a strong and stiff behavior, and a mechanical support to the vessel comparable to that of metallic devices [1,2]. However, the viscous characteristic of the polymer might be a computational issue, particularly with Explicit finite element solvers where the usual strategy consists on acting on the **mass scaling** by modifying the value of the **target time increment (TTI)**.

The aim of this work is to numerically investigate the **strain-rate dependence of PLLA** and to compare the results obtained with an **Implicit solver** to those produced by an **Explicit** one at the variation of the TTI.

MATERIALS AND METHODS

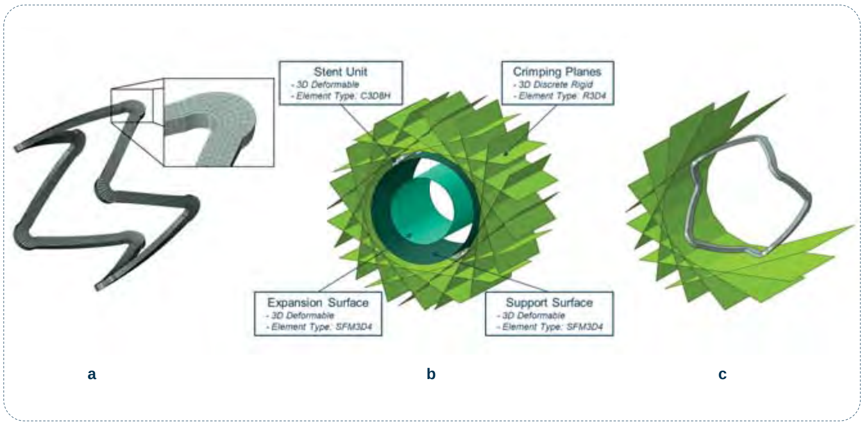

Fig. 1 – a) Stent unit and mesh detail; b) Initial configuration of the unstressed system; c) Detail of the circumferential positions of the crimping planes.

A finite element analysis was performed by studying an ideal **stent unit** (Fig. 1,a) with geometrical dimensions comparable with those of coronary stents. The stent unit was made of an elastic-plastic material whose plastic behavior was implemented according to **Johnson-Cook plasticity model** to reproduce PLLA performance. Two numerical simulations were carried out using **ABAQUS® / Dynamic Implicit**, each one made of five steps to properly reproduce the surgical stenting procedure (Fig. 2).

A **Realistic** simulation and an **Accelerated** one were implemented to evaluate the influence of PLLA strain-rate dependence on the simulations results.

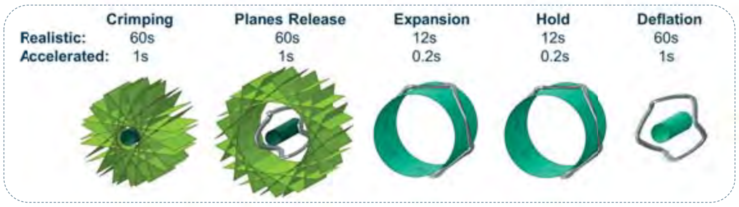

Fig. 2 – Visualization of the five simulation's steps with definition of each step time for both the realistic and accelerated case.

The comparison between **Implicit** and **Explicit** solvers was focused on the influence of the **TTI** on the simulations results. Thus, both for realistic and accelerated cases, **free crimping** simulations were performed to evaluate the accuracy of the Explicit solver with respect to the Implicit one.

RESULTS

PLLA STRAIN-RATE DEPENDENCE: IMPLICIT SIMULATIONS RESULTS

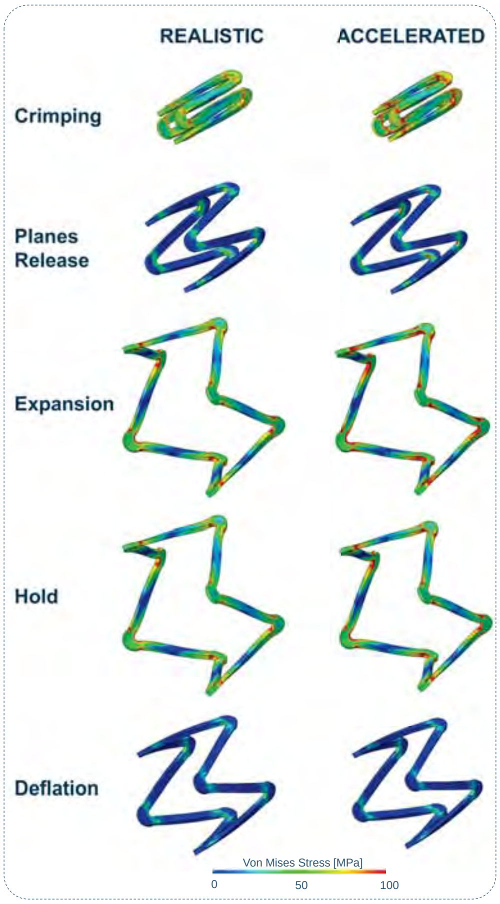

Fig. 3 – Comparison between **realistic** and **accelerated** Implicit simulations through the visualization of color maps of **Von Mises Stress [MPa]** at the end of each step.

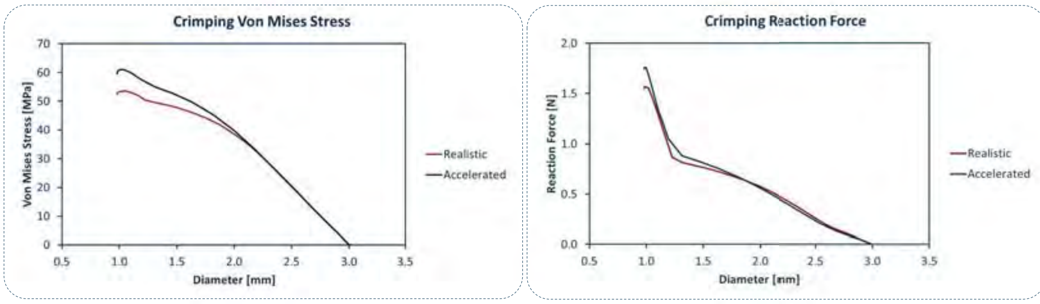

Fig. 4 – Comparison of the crimping step between realistic and accelerated Implicit simulations in terms of mean **Von Mises stress [MPa]** computed on stent unit vertex (left) and **crimping Reaction Force [N]** quantified on the crimping planes (right).

EXPLICIT SIMULATIONS: INFLUENCE OF TARGET TIME INCREMENT (TTI)

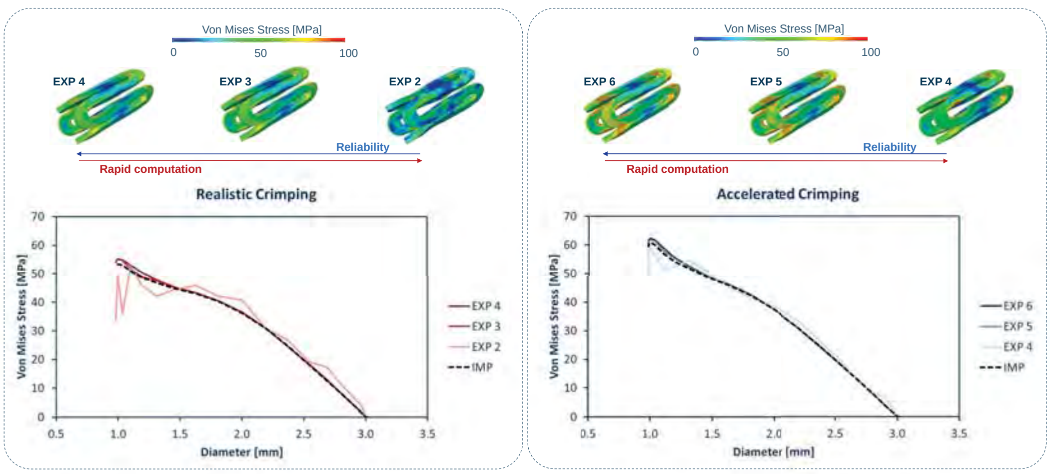

Fig. 5 – **Realistic crimping:** comparison of the realistic Explicit results obtained with TTI equal to 10^{-4} (EXP 4), 10^{-3} (EXP 3) and 10^{-2} (EXP 2) with the Implicit result (IMP). **Accelerated crimping:** comparison of the accelerated Explicit results obtained with TTI equal to 10^{-6} (EXP 6), 10^{-5} (EXP 5) and 10^{-4} (EXP 4) with the Implicit result (IMP). In both cases the mean Von Mises Stress [MPa] computed on stent unit vertex was considered.

CONCLUSIONS

The difference in output values between Realistic and Accelerated cases resulted as a direct consequence of PLLA's **viscous behavior**. Hence, **realistic step times should be imposed** to obtain reliable results, in particular when analyzing the coronary stent design. Indeed, the viscosity is only related to the plastic field in the Johnson-Cook material model. Thus, strain-rate dependence would be more evident with a stent design more prone to work beyond elastic deformations. The analysis of the Explicit simulations demonstrated that acting on the mass scaling by imposing high values of TTI could lead to drastic **computational time decrease** but also to **lower outputs reliability**. In addition, the comparison between Realistic and Accelerated cases highlighted that the TTI ensuring a good compromise between required computational costs and realistic results is strictly dependent on the imposed step time. Referring to the Realistic case, a **TTI value of 10^{-3}** was individuated as sufficiently small to produce comparable results to the Implicit case in reasonable computational time.

References: [1] A.C. Bobel and P. E. McHugh. Cardiovascular Engineering and Technology. 2017. [2] R. G. Pauck et al. Medical Engineering & Physiscs 37. 2015; 7-12.

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