

Polymer, Process and Design Elements of a Balloon Expandable Bioabsorbable Drug Eluting Stent

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Statement of Purpose: Balloon expandable stents depend on ductile materials that allow the stent structure to deploy and remain open following balloon deflation. The ideal material will have low yield strength, high elastic modulus, and high elongation to failure. These properties will enable a stent design with low recoil and high radial stiffness. Today's balloon expandable stents are made from metal alloys that have been finely tuned to meet design requirements. There are several challenges to design a polymeric balloon expandable stent due to lower modulus compared to metals, and time-temperature dependencies on stent recoil and radial stiffness. This study summarizes the polymer, process and design elements of a fully bioabsorbable drug eluting stent.

Methods: Poly (lactide-co-glycolide) [PLGA] 85/15 used in this study was obtained from Purac with an inherent viscosity (IV) ranging from 2.2 to 2.4 dl/g. Poly (caprolactone-co-glycolide) copolymer was used in conjunction with PLGA 85/15 to provide ductility for balloon expandable stent designs. Barium sulfate, obtained from Sachtleben Corporation, was used as a radiopaque (RO) agent. Stock solutions of PLGA 85/15 with different amount of poly (caprolactone-co-glycolide) copolymer were prepared in 1,4-dioxane. Desired amount of barium sulfate and sirolimus were added to the solutions. The solution was loaded in a syringe and dispensed on a rotating PTFE-coated mandrel (OD = 0.04", length = 14") contained in a dioxane-rich environment. The coated mandrel was dried at an elevated temperature, e.g., 60-70°C in an oven flushed with nitrogen. The solvent level in the tubular structure was about 7% by weight. The tube was removed from the mandrel and supercritical carbon dioxide extraction method was used to remove residual solvent to below detectable limits. Average tube thickness was 200 µm. The tubes were cut using excimer laser into desired stent designs. Stent performance was determined by measuring the radial stiffness and recoil values.

Results:

Material Properties: A test method was developed to determine the mechanical properties of the tubes. Tensile testing to failure showed typical necking and drawing of the tubing material associated with strain localization within a relatively narrow band of material. A high resolution optical strain measurement system was developed for measuring the failure strain within the necked region. This method provided a material strain limit of about 50% that was used as an input to the design process.

Stent Design: Figure 1 shows a 3x18mm stent pattern for fabrication from the drug containing PLGA tubes. It is a closed-cell design consisting of radially expandable columns connected by axial connectors. Each column consists of struts arranged in a zigzag pattern with radial arcs connecting them. The apex of each radial arc has an axial connector extending to the apex of an arc in the

neighboring column, making a closed-cell pattern. The cells are relatively small and the column density is relatively high to compensate for the low modulus of elasticity of polymers relative to that of metals. The design consists of hinges in which strains are localized to induce local material drawing. The double hinge arrangement allows for a stiffer and stronger expanded stent, and a higher stiffness-to-strain ratio can be achieved. The accumulation of permanent strains in the hinges during expansion is necessary to enable the stent to remain open after balloon deflation and removal. Figure 2 shows a stent containing barium sulfate and sirolimus after expansion. The material within the hinge has experienced straining well beyond the yield point.

Stent Properties: Characterization of the elastic recoil of a polymeric stent following balloon deflation is of particular interest due to the time-temperature dependence of the material response. Recoil measurements were taken at t=0 and at various time points up to two weeks with the stent stored at 37°C in water between measurements. Stent recoil reached a plateau of about 11% by two weeks as shown in Figure 3. The expanded stent's radial stiffness and radial strength are important attributes for clinical efficacy. Figure 4 shows a plot of radial pressure versus percent diameter reduction obtained from radial compression testing of a bioabsorbable drug eluting stent sample in comparison to BX Velocity[®] bare metal stent. It should be noted that the work (i.e., area under the given curve) required to reduce the diameter of the bioabsorbable stent by 10% is higher than that for the bare metal stent.

Conclusions: A drug containing fully bioabsorbable drug eluting stent has been developed. Bench top testing has shown that the balloon expandable stents have acceptable recoil and radial stiffness values. These stents have drug eluting capacity higher than current drug eluting stents and could be a promising next generation treatment option to treat peripheral artery diseases.

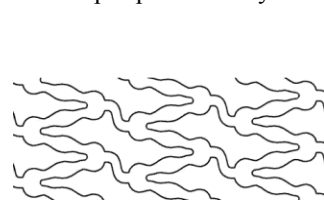


Figure 1. Stent Design

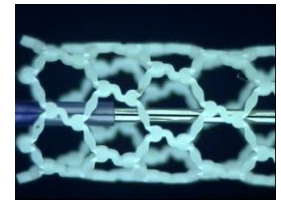


Figure 2. Bioabsorbable Stent

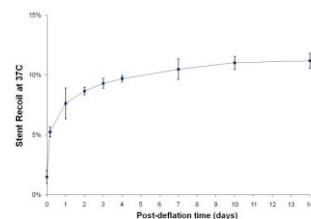


Figure 3. Stent Recoil

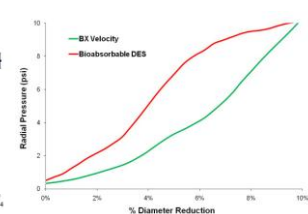


Figure 4. Stent Radial Stiffness