

TEXTILE PROSTHESES FOR VASCULAR APPLICATIONS

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Abstract

Strain energy method and Castigliano's theorem were applied for modeling. Agreement between the values of Young's modulus of textile stents derived by the strain energy method to those of the experimental is good. Braid structural parameters, i.e., length and width of each diamond trellis, total number of diamond trellises, length of fabric braided in one carrier rotation, and braid inclination angle are formulated. Load-strain curves were obtained by strip testing of textile stents on Instron. The objective of the empirical model was to formulate, quantify, and predict compression force of textile stents. The empirical model is able to predict the compression force of textile stents from any two of the known manufacturing variables.

Goal

The objective of this project is to develop a new class of implantable endoluminal prosthesis for biomedical applications based on advanced textile technology. The most likely initial application will be in the field of arterial circulation. As a result of this project, applications of textiles in medical technology will be expanded.

Introduction

The current study suggests the application of polyester monofilament braided structures to be used as stents, hence called textile stents. Prototypes of textile stents and bifurcated textile stents were manufactured with textile machinery [1]. Manufacturing variables namely braid angle, braid diameter, and heatset time showed statistically significant effect on the compression force of textile stents [2]. Strong correlation (*adjusted* $R^2 = 0.9999$) was observed between radial and *in vitro* (unidirectional) compressions of textile stents [3]. The objective is to predict the Young's modulus of textile stents by strain energy method. In the current study, strain energy method and Castigliano's theorem [4] were applied for modeling. The equations needed to predict the Young's modulus by strain energy method were divided into three parts: determination of structural geometry, definition of the strain energy function, and equations derived by strain energy method [5, 6]. The strain energy equations were derived from those of the plain weave [7]. Strain energy method is being used by textile researchers to understand various facets of the performance of fiber assemblies [8], fibrous composite materials [9], yarns [10], plain weave fabrics [11], and hybrid fabrics [12]. Previous braid models developed by Heirigs and Schwartz [13] and Zang *et al.* [14] provided useful guidelines in understanding the structure and properties of braids.

Young's Modulus

The Young's modulus of the textile stent was determined by the strain energy method. The resulting equation is

$$E_I = \frac{x^3 (\cos^2 \theta_1) + y^3 (\cos^2 \theta_2)}{\frac{x^3 y^3}{12B} \sin^2 \theta_1 \cos^2 \theta_2}$$

where $x = A_1PA_2$, $y = C_1PC_2$ (Figure 1)
 θ_1, θ_2 : respective braid inclination angles
 B: flexural rigidity of monofilaments

To calculate Young's modulus, flexural rigidity of monofilaments is necessary. Flexural rigidity is calculated by the approach proposed by Ucar [15]. Ten monofilament samples were tested for flexural rigidity. All the necessary calculations were performed with the Maple[®] software. The values of Young's modulus calculated by the strain energy (mechanical) model were compared to those obtained by strip testing (ASTM[®] D 5035-95) of textile stents on the Instron.

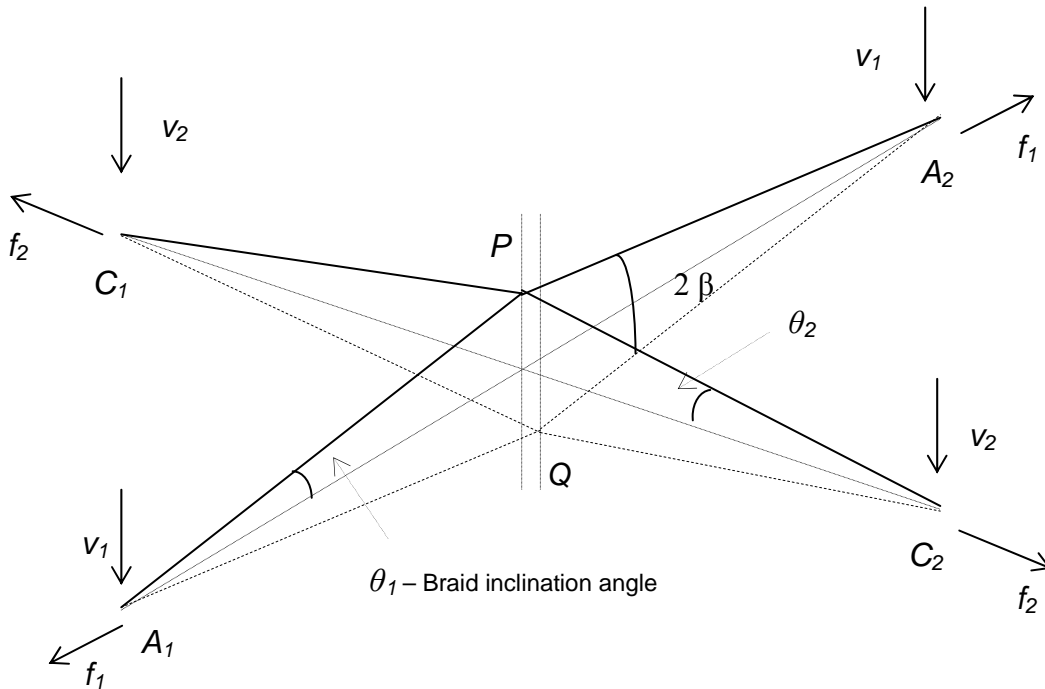


Figure 1 Monofilaments intersection as a unit of the braided structure.

Figure 2 shows the comparison of Young's moduli values. In the Figure, 60° braid angle and 60 minutes heatset textile stents were compared for their Young's modulus. The comparison showed good correlation (adjusted $R^2 = 0.7955$).

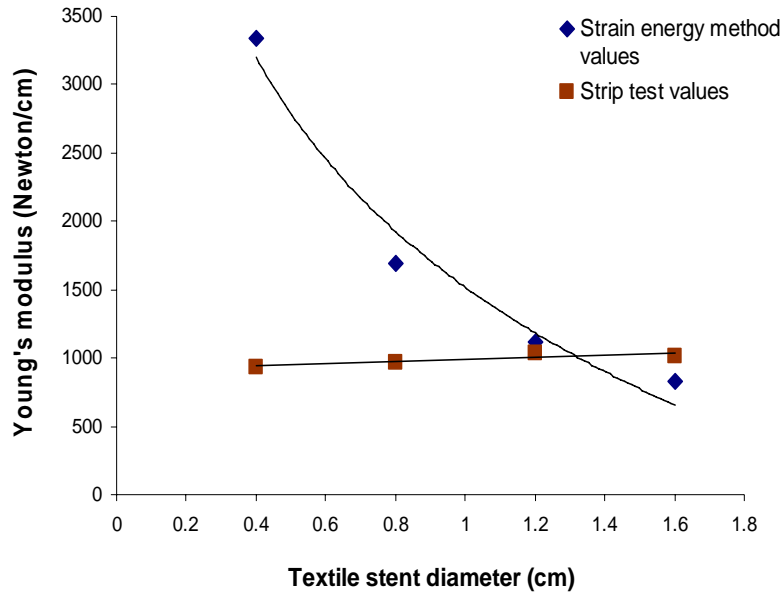


Figure 2 Comparison of Young's moduli

The strain energy (mechanical) model was based on energy stored in the system during deformation. The Young's modulus of textile stents was determined from the geometry of the structure and flexural rigidity of monofilaments. It gave similar values for textile stents of different braid angles. Also, textile stents being compared were heatset, but there was no heatset factor in the strain energy model. It was assumed that monofilaments were rigidly joined at the point of their intersection.

Figure 3 shows the load-strain curves of the textile stents. The initial region of the load-strain curve is defined as 'decrimping strain', where monofilaments were just slipping within the structure. Once the decrimping was over, textile stent started elongating. Higher diameter textile stents showed higher decrimping strain. 'Decrimping strain' was a distinguishing characteristic of the textile stents. Self-expanding textile stents need to be crimped while placing on the catheter.

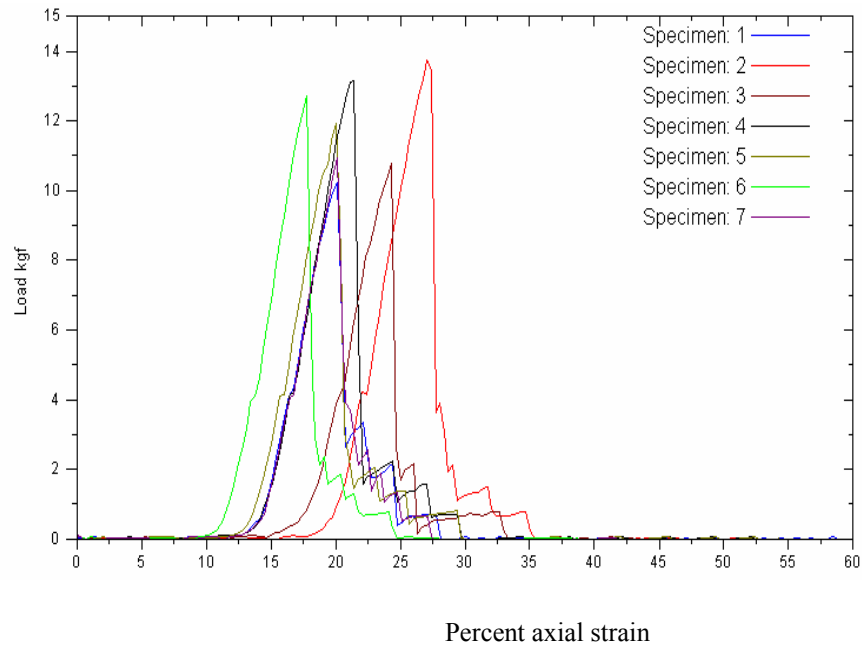


Figure 3. Load-strain curves (4 mm diameter textile stents).

Compression Force

The strain energy (mechanical) model could not quantify compression related parameters. The objective of the empirical model was to formulate, quantify, and predict the compression force of textile stents. The empirical model is able to predict compression force of textile stents from any two of the known manufacturing variables. This can become an innovative approach to formulate, quantify, as well as predict a material property from the available pool of parent data. The parent compression force data used in the empirical model were obtained by the novel compression testing of textile stents on Instron [16]. The compression force of textile stents is plotted against the heatset time in Figure 4.

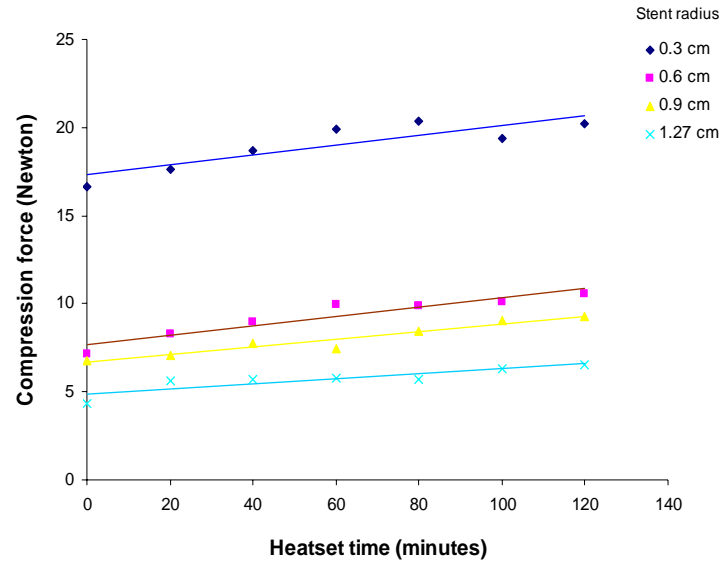


Figure 4. Trends for 60 degree braid angle textile stents.

Conclusions

The strain energy method and Castigliano's theorem were applied for modeling to determine modulus. Agreement between the values of Young's modulus of textile stents derived by the strain energy method to those of the experimental was good (*adjusted R*² = 0.7955). Braid structural parameters, i.e., length and width of each diamond trellis, total number of diamond trellises, length of fabric braided in one carrier rotation, and braid inclination angle were formulated. Load-strain curves were obtained by strip testing of textile stents on Instron. The objective of the empirical model was to formulate, quantify, and predict compression force of textile stents. The empirical model is able to predict compression force of textile stents from any two of the known manufacturing variables.

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Patent Disclosure:

1. Adanur, S., and Irsale, S., “Polymeric Textile Prostheses for Vascular Surgery Applications”, Auburn University Technology Disclosure, 25 July 2005.

Publications:

1. Irsale, S., and Adanur, S., “Modeling Polymeric Textile Stents: Predicting Young’s Modulus and Compression Force” (under preparation).
2. Irsale, S., “Textile Prosthesis for Vascular Applications”, Masters thesis- Auburn University, (2004). <http://graduate.auburn.edu/auetd/>
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Oral Presentations:

1. Irsale, S., “Compression Force Modeling of Braided Textile Stents”, Southeastern Conference on Theoretical and Applied Mechanics (SECTAM), Tuskegee, AL, (August 15, 2004).
2. Irsale, S., “Braided Monofilaments in Vascular Prosthesis”, TechTextil North America, Atlanta, GA, (March 31, 2004).
3. Irsale, S., “Prototype Manufacturing of Textile Stents”, Auburn University Graduate Research Forum, Auburn, AL, (March 4, 2004).
4. Irsale, S., “Textile Prosthesis for Vascular Applications”, Six State Graduate Student Consortium- Florida State University, Tallahassee- FL, (April 15, 2004).

Poster Sessions:

1. Adanur, S., Swagat, I., Warner, S., and Chaikof, E., “Textile Prostheses for Vascular Applications”, National Textile Center 13th Annual Forum, March 20-22, 2005, Raleigh, NC.

Industrial Contacts:

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