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A Study on the Stiffness Variation of Hybrid Composite Material Reinforcing Pneumatic Tubes

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Abstract

Pneumatic tube type structures have been studied extensively in the field of soft robotics. These pneumatic tube structures have advantages in terms of ease of use as well as being able to control structure stiffness through pneumatic control so that it is widely used in everyday life. However, few studies have investigated the material properties of pneumatic tube type structures such as the variation of stiffness by pneumatic control. The purpose of this study is to analysis the mechanical properties variation of the composite materials reinforced with pneumatic tubes which pneumatic pressure are varied. By using the finite element code, the performance changes of the hybrid composite materials according to parameters in relation to the performance of the existing composite material such as pneumatic tube diameter and arrangement interval of tube are analyzed. The effects of parameter variations on the material stiffness of the composite materials reinforced with pneumatic tubes are investigated through numerical study.

Keywords: pneumatic tube, hybrid composite, stiffness control.

1 Introduction

The pneumatic tube type structure is mainly utilized in the field of soft robots due to the feature that various changes can be made according to the external situation of the structure. In addition, pneumatic tube-type structures are widely used in everyday life such as life tubes and automobile airbags, because safety and mobility for collision can be easily secured. In addition to these advantages, the pneumatic control of the tube has the feature that it can directly control the stiffness of the structure and has an advantage that the pneumatic control is relatively easy to control the stiffness.

There are not many examples of pneumatic tube structures that can control the rigidity of materials by pneumatic control, which is the main goal of this study. Studies related to the pneumatic tube type studied in the field of medical robots have been conducted to construct a structural force of the form that appears in the human body by controlling the contraction and tension of the muscle using a tube-shaped structure [1-5]. On the other hand, studies on stiffness control are mainly carried out using smart materials. For several decades, there have been great efforts to develop smart, self-sensing and controlling materials that can adapt their material properties to changing environmental conditions [6-10]. Studies are underway to adjust the material properties while maintaining the shape of the structure constant by giving external stimuli such as temperature change, constant electrical stimulation, and pressure in a certain environment [11, 12].

In this study, the change of mechanical material properties according to the change of pneumatic pressure is analyzed in the composite materials reinforced with pneumatic tube. The analysis of the characteristics of the material will be carried out by using the finite element method (FE code) for the change of the bending stiffness according to the parameters such as the diameter of the pneumatic tube and the arrangement interval of the tubes. The effects of parameter variations on the material stiffness of the composite materials reinforced with pneumatic tube are investigated through numerical studies. The final results can be applied to endoscopes and catheters applied to human body, and it will be a way to solve control and safety for various fields such as human body assisted robots.

2 Methods

In the present study, we try to control the material properties of the material as desired by controlling the stiffness in the state where air pressure acts. The structure to be analyzed is a beam-like structure, in which the interior of the structure is drilled in the form of a tube. The shape of this structure is shown in Figure 1 and Figure 2. Figure 1 is a beam structure with a tube structure inside and Figure 2 is a structure in which a single structure of beam shape is stacked several times, and the inside of the stacked composite structure is uniformly tube-shaped. One end of each structure is fixed, and a distribution load is applied to the free end in a state in which the internal pressure acts, so as to grasp the stress applied to the structure.

Modeling consists of four cases. The first case in a single structure is change the diameter of the tube. Refer to Table 1 for the diameter of the tube that made the change at this time. Refer to Table 2 for conditions of change in internal pressure in FE analysis. The second case is simulated by changing the material properties of the material. The mechanical properties considered are density, Young's modulus, and Poisson's ratio. The diameter of the tube in the composite structure and the distance between the tubes were varied. The property value 1 of Table 3 was applied to the composite structure constantly. Refer to Table 1 for the tube conditions inside the structure applied in the analysis process and Table 2 for the internal pressure when analyzing the composite structure. Unlike a single structure, a composite structure has a plurality of tube-shaped holes therein.

In order to consider the effect of the stress generated by the internal pressure, the analysis was divided into two stages. Pressure was applied to the inner tube shape of the structure according to Table 2 to take into account the internal pressure generated in the structure. The stress generated by the internal pressure was defined as the pre-stress type, and the next step analysis was performed. In the second step, constraint is applied to all node points on one end surface, and 0.007N is assigned to the upper surface of the opposite free end. This is to confirm the result of the tip deflection at the end after performing the structural analysis.

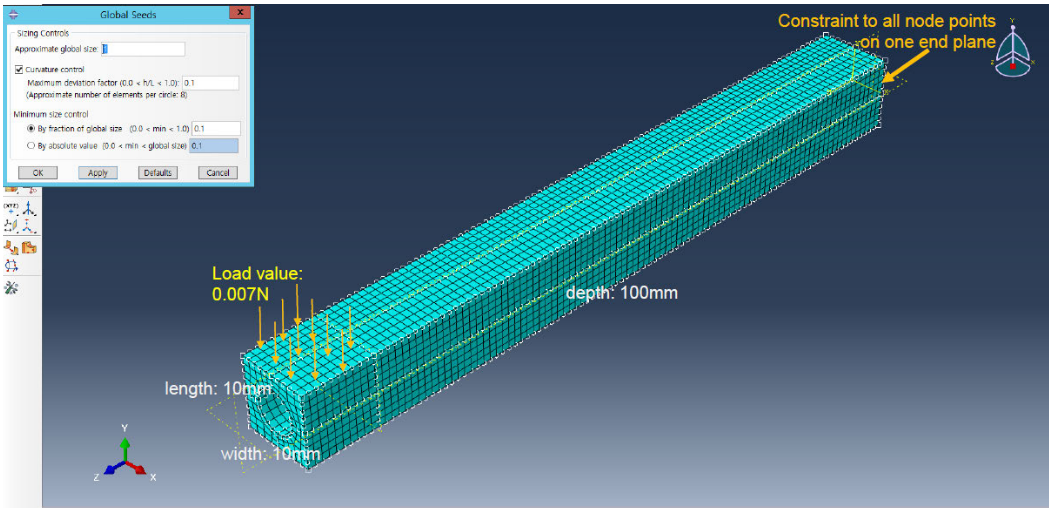

Figure 1: Single structure used in simulation

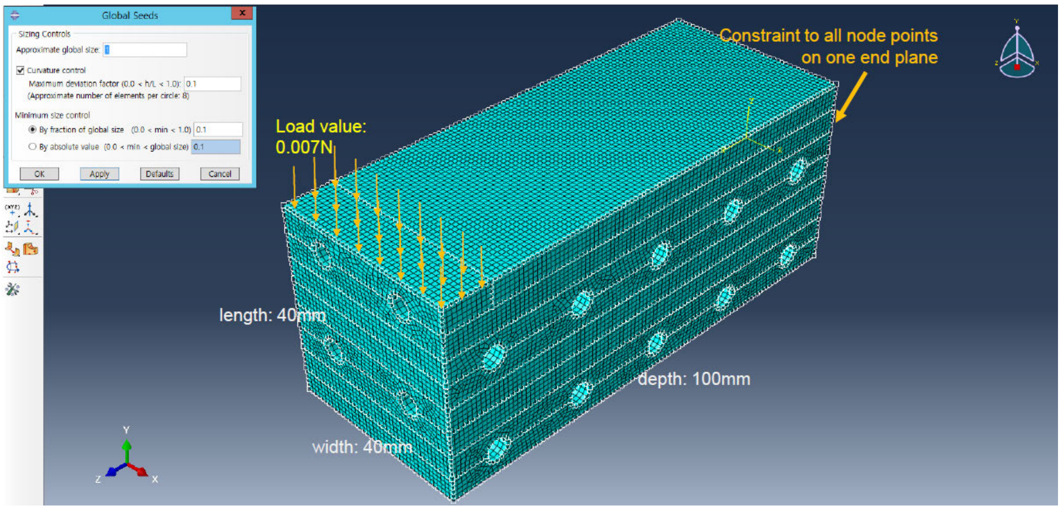

Figure 2: Composite structure in which tube structures are arranged

Diameter of tube structure (mm)	2	2.5	3
Distance between the tubes (mm) (only used in composite structures)	10	13.4	20

Table 1 : Tube conditions applied in structural analysis

Internal pressure applied in a single structure (Pa)	0	0.12	0.6	1.2
Internal pressure applied in a composite structure (Pa)	0	$1.2*10^{-4}$	$0.6*10^{-3}$	$1.2*10^{-3}$

Table 2 : Pressure condition applied in structural analysis

	Density (g/cc)	*Young's Modulus(MPa)*	*Poisson's ratio*
Property Value 1	2.2	496	0.46
Property Value 2	3.0	800	0.38
Property Value 3	3.8	1100	0.3

Table 3 : Property values considered in model

3 Results

The results for a single structure are shown in Figure 3 and Figure 4. In all cases, it was confirmed that as the magnitude of the withstand pressure increases, the value of deflection at the free end decreases. As a result, it can be seen that as the internal pressure increases, the bending stiffness increases.

Let us look at each. Figure 3, it can be seen that when the inner pressure is 0 Pa, as the diameter of the tube increases the value of deflection gets increase. However, as the magnitude of the internal pressure increases, the y-axis on the Figure 3 deflection decreases. It can be seen as the diameter gets decrease, the width gets decrease. Also, it is considered that the inner diameter increase and the inner pressure increase, the more the bending stiffness is affected. The reversal phenomenon occurs when the internal pressure of 0.12 Pa is applied, which can be seen as a phenomenon caused by the sectional area of the structure being changed by the diameter of the tube. When the cross sectional area decreases, the bending stiffness tends to decrease. As the diameter increases, the deflection increases.

Figure 4 showed similar results. When the inner pressure is 0 Pa, the Young's modulus decrease, the deflection increase. As the inner pressure increases, the value of deflection on the y-axis of Figure 4 decreases. As the Young's modulus becomes decrease, the rate of change of the value of deflection becomes increase.

The results for the composite structure are shown in Figure 5 and Figure 6. In the composite structure, it was confirmed that the value of deflection at the free end decreases as the inner pressure increases. This shows that the composite structure also get more affection to the load while the inner pressure increase and the bending stiffness decrease.

Figure 5, it can be seen that when the inner pressure is 0 Pa, the diameter increase, the value of deflection increase. However, as the magnitude of the internal pressure increases, the value of deflection decreases. Although it is not shown in this study, it is presumed that if the magnitude of the internal pressure is increased, the reversal phenomenon may occur in a certain section as in a single structure. Figure 6 is the result for the distance between tubes. The increase the gap between the tubes, the rate of deflection of the free ends increase. This result also shows that if the influence of the internal pressure is increased, the reversal phenomenon will occur at a certain interval.

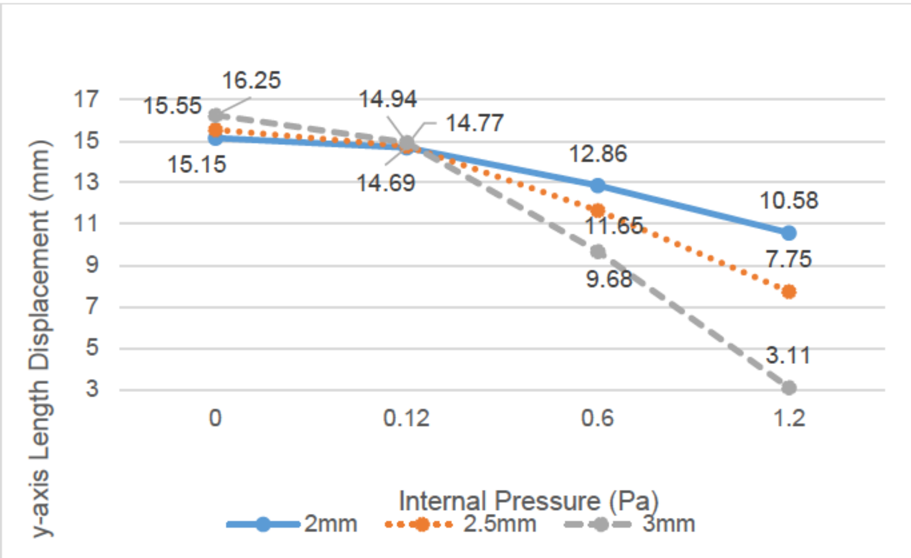

Figure 3 : Simulation result of diameter variation in single structure

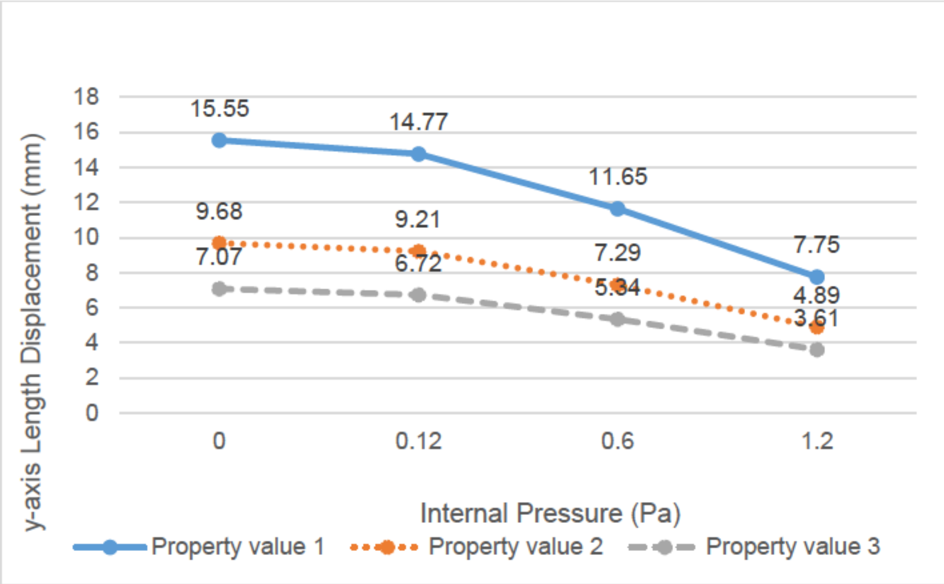

Figure 4 : Simulation result in single structure when property value changes

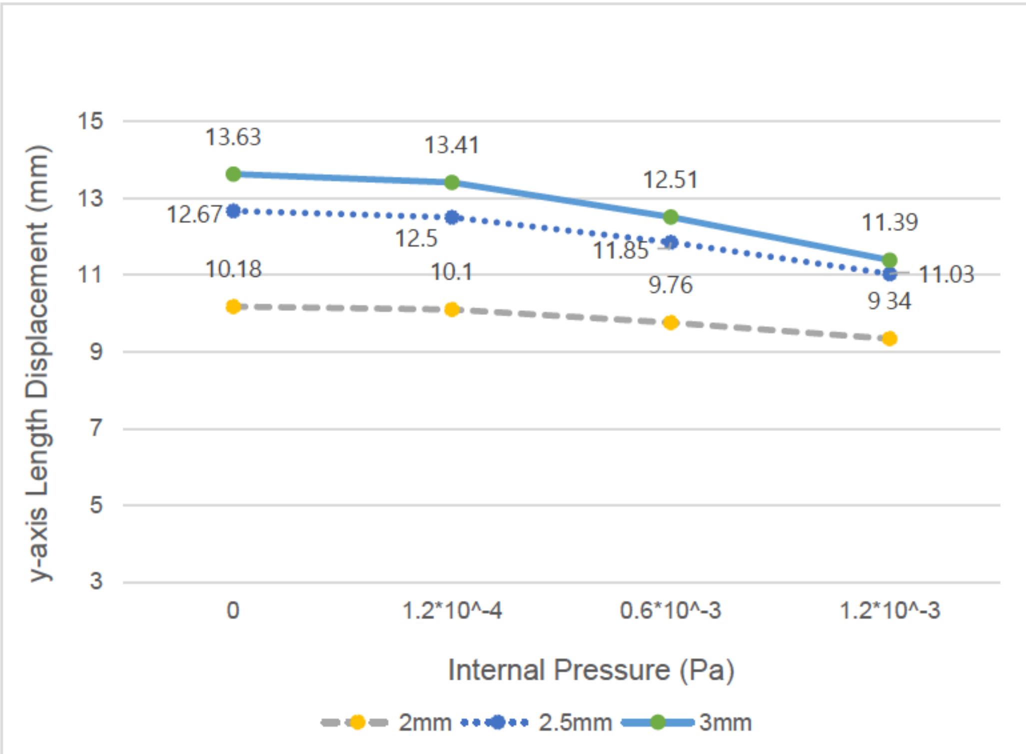

Figure 5 Simulation result of composite type structure with different tube diameter

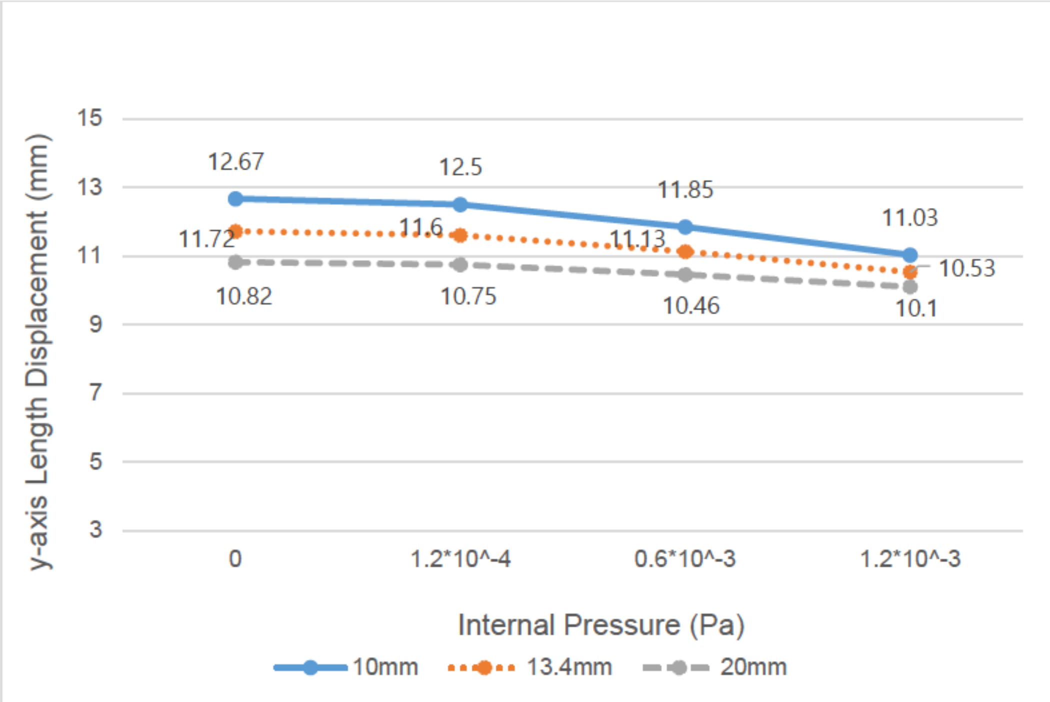

Figure 6 : Result of composite type structure with different tube spacing while constant diameter

4 Conclusions and Contributions

In this study, changes in material properties were analyzed by checking the stiffness change of the material according to the pressure change of the structural model. For the analysis, the structures were modeled in the form of single tube structures and multiple tube insert composite structures, and the tip deflection of beam structure with the increase of inner tube pressure under the constant loading condition was obtained through the finite element analysis. From the derived results, it can be seen that the amount of tip deflection of the beam structure under the constant loading condition decreases as the internal pressure increases. This result shows that the rigidity of the structure increases as the pressure applied to the tube inserted inside the structure increases.

From the results of this paper, we can control the rigidity of the structure by controlling the pressure acting inside the structure. This has the advantage that the stiffness of the structure can be changed as needed only by controlling the pressure resistance without changing the material or the shape of the structure. In addition, the use of hydraulic or pneumatic makes it safer for endoscopy or catheter insertion. In order to improve control precision, future research will attempt to analyze the numerical relationship between parameters that affect stiffness and stiffness characteristics depending on the type of structure.

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