Chapter 18
Evaluation of a Suitable Material for Soft Actuator Through Experiments and FE Simulations

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ABSTRACT

Soft actuators are generally built to achieve extension, contraction, curling, or bending motions needed for robotic or medical applications. It is prepared with a cylindrical tube, braided with fibers that restrict the radial motion and produce the extension, contraction, or bending. The actuation is achieved through the input of compressed air with a different pressure. The stiffness of the materials controls the magnitude of the actuation. In the present study, Silastic-P1 silicone RTV and multi-wall carbon nanotubes (MWCNT) with reinforced silicone are considered for the evaluation. The dumbbell samples are prepared from both materials as per ASTM D412-06a (ISO 37) standard and their corresponding tensile strength, elongation at break, and tensile modulus are measured. The Ogden nonlinear material constants of respective materials are estimated and used further in the finite element analysis of extension, contraction, and bending soft actuators. It is observed that silicone RTV is better in high strain and fast response, whereas, silicone/MWCNT is better at achieving high actuation.

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INTRODUCTION

The traditional robots exist in the industries are made of metallic parts, motors and fluidic actuators. In contrast, the soft robot uses compliant materials that well suit it for handling soft or fragile materials or unshaped objects. The robot that uses soft material for gripper design is ultimately called as soft robot. It could be applied in medical or industrial applications in order to handle fragile objects like organs, fabrics, papers, vegetables, meat, eggs, etc. The soft actuators are pneumatic actuators that made of polymeric materials. They have been prepared as a key component in soft mechanism in order to directly contact or manipulate the object. Many different kinds of soft actuators have been investigated in the past. The McKibben actuator is the earliest developed pneumatic actuator which used compressed air to expand the rubber tube in the radial directions. It deformed in longitudinal direction when the radial movement of the rubber tube was restricted by knitted fibers H.F. Schulte (1961). The knit angle was the key factor to obtain the extension or contraction motion of the actuator. The rotary type fiber reinforced bending actuator was developed by Noritsugu et al. (2003). Saga (2007) attempted to drive a robot hand with tendon drive with a silicone rubber pneumatic balloon soft actuator. Suzumori et al. (1991) developed a flexible micro actuator that used three fiber-reinforced silicone chambers to achieve bending motion by controlling pressure applied to each cylinder. In most of the actuators Suzumori et al. (1991), Ching-Ping Chou and Hannaford (1996), Smagt et al. (1996), Kawashima (2004) Vanderborght et al. (2006), Hosoda et al. (2008), Wakimoto et al. (2005), Sasaki et al. (2005), Suzumori et al. (2007) in the past, the reinforcement of the rubber tube was used for getting anisotropic elasticity. Suzumori et al. (1994) also attempted to utilize the shape anisotropy instead of fiber reinforcement. He used spoke-shaped rubber components in chambers to restrict the radial motion of the core tube. Ikeuchi et al. (2008) developed a hydraulically operated bellow shaped micro catheter. Wakimoto et al. (2011) developed a rubber actuator using room temperature vulcanized (RTV) silicone rubber for bidirectional curling motion with one air cylinder. Iwata et al. (2011) proved that fiber knitting angle of 23.5° and 66.5° are the best to achieve contraction and extension motions respectively. Ili et al. (2013; 2014) conducted finite element (FE) analysis of three-chamber nylon reinforced soft bending actuator for finger flexion. Agarwal et al. (2016) Ecoflex 00–30, a platinum-catalyzed silicone to prepare the actuator core tube and polyethylene terephthalate (PET) to constraint its motion in the radial direction. They further studied the performance of the actuator through simulations and experiments. Razif et al. (2014) and M. Razif et al. (2014) conducted experiments and simulations on two chambers soft actuator realizing biologically inspired fin for robotic fish. Natividad et al. (2018) developed the pneumatic actuator with fabric inflation modules that are attached to a common flexible but non-inflating plastic spine. They evaluated the static and dynamic performance of their different designs. Ning et al. (2017) developed a single degree of freedom inchworm robot with low cost silicone material and controlled its locomotion by friction hysteresis.

Figure 1 shows components of a bending actuator developed with Silastic-P1 silicone room temperature vulcanization (RTV) rubber. All the above soft actuators attempted in the past used silicone of different grades or silicone RTV to build inner rubber rube of the actuator.

The tensile strength of silicone is generally in the range of 5-10 MPa. The linear actuation of the actuator depends on a few parameters; stiffness and tensile strength of the rubber chamber, fiber knitting angle and tensile strength of the fiber, the shape and the thickness of the actuator. The core tube must exhibit high flexibility and good mechanical strength as well in order to have high performance. On accounting these, Silastic-P1 silicone RTV rubber and multiwall carbon nanotubes (MWCNT) reinforced silicone were considered in this research for the design of inner core rubber chamber. The reason for