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Geometrical and Structural parameters Investigation of an Inclined Air Pillow for Soft Pneumatic Actuator

Basem Ragab [a], Saber Abd Raboo [a], Mahmoud Elsamanty [a, b]

[a] Department of Mechanical Engineering, Benha University, Egypt

[b] Mechatronics and Robotics Department, School of Innovative Design, Egypt-Japan University for Science and Technology

Abstract. Soft actuators have recently been gaining popularity in the field of robotics because of their higher flexibility, lightweight, low cost, and simplicity of fabrication. The traditional rigid grippers have been used widely in industrial applications for a long time. However, when the conventional rigid grippers are used, the grabbing object's shape must be considered when designing the gripper surface. As a result, the gripper can only hold a limited number of things and occasionally a unique object. In this paper, a novel SPAs geometrical parameter is developed by studying the influence of the change of the chamber wall thickness, base thickness, and the chamber angle on the SPA work envelope when applying a wide range of positive pressure on the inner surfaces of spas. The soft pneumatic actuator (SPA's) models with large and small thickness ratios are compared by using FEM. The simulation using the finite element method demonstrates that decreasing the wall thickness ratio of the model provides a greater bending angle than the model with a higher wall thickness ratio at the same input pressure. Also, for the change of the chamber angle at an angle equal to zero, the SPAs provide a bending angle only, but when the chamber angle increases, the SPAs provide bending and twisting together. The proposed models still maintain the air surface area inside the actuator. Furthermore, it was observed that when compared to the other models, the lower wall thickness ratio model has the greatest effect on the bending and twisting angles. Finally, an increase in the deformation was observed by 60% and 44.5% of bending and twisting together due to change of the SPA's wall thickness.

Keywords: Soft robotics**,** Soft pneumatic actuator, hyperplastic material.

1. INTRODUCTION

Soft robotics is a new research area that looks to nature to reduce the complexity needed for systems to interact safely with their environments. Unlike conventional robots, which are typically used for repetitive tasks with high precision, also they can be difficult to use outside of controlled environments such as factories due to the difficulties that arise with environmental uncertainty. Another significant possible constraint is the risky relationship between humans and robots. In factories, rigid robots are typically built to move quickly or generate high torques, which can be harmful when close to humans or other fragile objects. Soft robots, in comparison to rigid robots, use soft materials like silicone rubber that can deform while dealing with unfamiliar environments .

Moreover, soft robotics seeks to prepare robots for the unpredictable requirements of such circumstances by endowing them with capabilities depending on their bodies' material properties and anatomy rather than control systems. Consequently, soft robotics and tissue engineering can be combined to build hybrid systems for medical applications [1]. These robots are different from the traditional robots in that they are made of hard materials, and compliance is accomplished with variable stiffness actuators and compliant control to allow continuous movement and equal force distribution. Additionally, soft robots are significantly less expensive than rigid robots. Finally, because of their scalability, soft robots are perfect. Compared to rigid robots, any change in the shape or size of a soft robot can be performed much more quickly and cheaply .[2]

Soft-robotic systems can use morphological computation to adapt to and deal with the environment in ways that rigid systems find difficult or impossible. At multiple levels, soft robots have the potential to provide a connection between the living and artificial systems. Researchers have drawn inspiration from worms, elephant trunks, snakes, octopus arms, jellyfish and when developing concepts of locomotion. The researchers are investigating new soft actuator models for robots that grip, manipulate, or even walk [3][4]. Typically, soft robots have two categories of soft actuators: smart actuators (made of electroactive polymers, shape-memory alloy, electrorheological fluids, and magnetorheological elastomers). The second category is hydraulic and pneumatic actuators. During the last decade, many innovative soft robot designs for locomotion, swimming [5], and manipulation have been reported [6]. Pneumatic soft grippers have three or four identical pneumatic actuators (or fingers) with multiple air chambers inside the actuator structures. These pneumatic actuators are usually made of soft materials such as silicone rubber or other elastomers [39]. When a soft actuator is pressurized by the supply air, the embedded air chambers inflate, which leads to the bending of the actuator. Hyperelastic soft sensors are used to stretch with finger elongation. Contact pressures measured by the soft sensors are used in force-feedback control for which either the joint angles or the link lengths are adjusted [40]

Consequently, a variety of designs of the pneumatic network (pneu-net) actuators and soft pneumatic actuator (SPAs) are distinguished by their dual connected chambers and their function as networks [7];[8]. As the pneu-net actuators are pressurized, their chambers are swollen, and the pneu-nets achieve the extension motion. Also, it is found that there is a linear relationship between the bending angle and the input pressure. It might aid in predicting the prestressed actuator's pressurized action [9]. A new SPA is inspired from the segmented structure of earthworms', this type of actuators uses a novel structure of freer bottom to eliminate the bottom constraint and improve the actuator's bending capacity .[10]

Particle jamming can help improve the gripper's performance in various ways [13]. Pneu-net actuators are designed to reach unique target trajectories for specific applications, and the sensitivity of nine parameters to actuator bending deformation has been investigated. We can notice that the influence of the chamber and middle-layer width parameters on the actuators bending performance are more critical than those of other parameters [11][12]. Recently, the area of soft robotics has become increasingly relevant due to their characteristics: (a) they are safe for human interaction; (b) they are also affordable to be manufactured; (c) they are easy and simple to be fabricated; (d) they are theoretically simpler to actuate and operate; and (e) they have a minimal footprint [14][9]. Soft pneumatic networks (pneu-net) and soft pneumatic actuator (SPA), which have been recommended for biomedical applications and soft robots due to their ingrained safety and compliance, with the development of soft materials, bending and extension motions are now possible [15]. Several pneumatic artificial muscle-powered prosthetic hands have also been demonstrated [16]. On the other hand, soft robotics in general, and bio-inspired soft robots in particular, do not work well with one-dimensional motion. soft pneumatic actuators and other Pneumatic balloon actuator [17] ;[18]

Traditionally, silicone rubbers are the primary source material used in the fabrication of soft robots because of their excellent soft quality and low cost; Silicone rubber is also a perfect biocompatible material used in medical applications [19]. However, the soft property makes designing and building a robust, multifunctional soft gripper challenging. flexible and highly deformable materials such as rubbers, polyurethane plastics, silicone, and elastrators are used to build soft robotics [20][21]. FEM simulations were performed to confirm the first design theory, and the simulations were run for a plain-shaped chamber. Based on the simulation results, we used 3D printed molds to create a hybrid gripper that incorporates both soft material and rigid parts to overcome the drawbacks of the conventional SPAs without reducing the compliances [22][23].

Two hyper-elastic silicones were used to make the actuators. (Elastosil M4601 has elasticity's bulk modulus of 262 kPa, and translucent soft silicone has a bulk modulus of 48 kPa. Another significant contribution of this research is the suggestion of a thin, flexible metal embedded in the geometry of the actuators, not only to provide the length-restricting effect required for bending but also to keep the actuators from bending under their weight in their neutral states when no input pressure is applied [24]

SCP actuator was fabricated using a nylon 6,6 multifilament material to realize the lightweight and high actuation performance of the soft gripper, which can produce a greater output force than that of the traditional single filament material. Experiments verified that the soft gripper could grasp objects with different shapes approximately 3.5 times its own weight, which is useful in soft robotic applications with low weight and large output force requirements .[38]

An experimental rig was designed to test the fabricated soft pneumatic actuator (SPA) samples embedded with the flex sensor under various operating conditions. This involves setting the initial orientation of the actuator as well as regulating the pressure and period of the input pneumatic supply [25]. The soft actuator is driven and controlled by a pneumatic power system with on-off solenoid valves. To determine the relation between pneumatic pressure and bending angle of the actuator, system identification that is based on the test data is applied in the system identification MATLAB software toolbox [26]. We built a modular volumetric control system for actuating a wide range of soft fluidic actuators. The system comprises interchangeable cylinder pump units that can be swapped out or added to as required based on the application [27]. A large compressor with a high flow rate was not necessary to produce a large grasping force or fast actuation, allowing it to be used in teleoperated systems without any complex control algorithms [22]. Molding is a popular method for fabricating soft actuators in laboratories. While the twisting and bending movements of pneu-net actuators have been indicated in previous studies, there is still a need for further research into how the chamber angle affects this motion [30]. However, as commercial elastomers and additive manufacturing technologies have been developed, the problem will be resolved in the future [32][28]

3D printing method has been introduced in the soft pneumatic actuators (SPA's) manufacturing method a new technique by using two types of TPU 3D printing filament [31]. First, an included network of channels was created for a finger that spiraled in a helix when actuated. An oblique chamber can be used by a pneu-net actuator to produce coupled bending and twisting motions [32][34]. While the twisting and bending movements of pneu-net actuators have been indicated in previous studies, there is still a need for further research into how this motion is affected by the chamber angle [24][35].

We present a novel, tendon-driven soft robotic gripper with active contact force feedback control, which leverages the passive compliance of the gripper to allow the gentle harvesting of berries. The versatile gripper can generate a desired force as low as 0.5 N with a mean error of 0.046 N [41]. Two different thermoplastics materials are printed together to form a relatively hard backbone and a relatively soft airtight actuation bellows. The implementation of positive layer jamming will be described, along with the additive manufacturing techniques used to produce the gripper and the test results of the final design [42] ;[43]

Consequently, standard rehabilitation devices have physical restrictions that prevent patients from performing ADL or task-oriented rehabilitation activities. Because of their complex structures and mechanisms, these devices are often costly to produce. Rigid therapy robots have a higher risk of causing accidents when used. These limitations in conventional devices prompted the developments of soft robotic devices [44]. Many soft pneumatic actuators (SPAs) have been widely used in rehabilitation devices because of their advantages [45]. Grasping tests revealed that grippers made of softer materials are more energy effective for grasping but have a lower overall grasping weight than those made of harder materials. The gripper made of DS10 can withstand a pressure of 20 kPa [46]. Since soft robotics is suitable for gripping biological creatures. However, it does not work directly to gripped objects because of the properties of soft material. Soft actuators (SPAs) could be used with underwater robotics systems.[47]

This study discusses the design, simulation, and fabrication of a soft pneumatic actuators. In this paper, we present a new pneu-net actuator design that can generate bending and twisting motions together by adjusting the chamber angle. The characteristics of this actuator are studied to show its effect of changing various parameters on the structure of the crop things with irregular shapes. The fabrication process is similar to that of other pneu-net actuators, using a simple molding system. A pneu-net is fabricated using silicone rubber. Finite element analysis (FEA) for the silicon rubber material can be used to predict the motions of actuators with different chamber angles. Based on the finite element analysis (FEA), The actuator's chamber angles can be adjusted to produce a large variety of deformations, Also, the actuator wall thickness can be adjusted to withstand the inner pressure to produce more deformation. We manufacture actuators with various oblique chambers to check the development and progress, and then we run a series of experiments on the chosen actuators to validate the models. finally, checking the various actuators with different oblique chambers on grasping objectives with different sizes and shapes. This test shows that the manufactured actuator can achieve more stable gripping with a large effective area and more adaptation to various geometric features of target objects. Finally, we demonstrate how simulations and experiments based on our design approach could be used to direct the design of actuators for a broader range of applications

2. DESIGN AND MODELING

2.1 Inclined air pillow parameters

The soft pneumatic actuator (Pneu-Net) which described in this paper is consists of channels arranged in a row. The major difference between the pneumatic actuator presented in this study and usual Pneu-Nets is the chamber arrangement. Common PneuNets consist mainly of a set of chambers with a zero-inclination angle. This type of actuators can only generate circular bending motion in two dimensions. In this paper, a new structure has been produced, composed of a series of angled chambers to generate both twisting and bending motions together in three- dimensions by changing the chamber angle of the soft actuator, which have more flexibility and degrees of freedom. The chambers with angles are designed parallel to each other at a particular degree. The wall thickness and the base thickness is a variable in this case, the width and height of the actuator is kept constant The Soft Pneumatic actuator in this study has various geometrical parameters. The air pillows dimensions are categorized by the number of air pillows (N), wall thickness (t_1), base thickness (t_2), total length (L) of pneu-net, air pillow height (h), We also define the chamber angle of the actuator as , as shown in table 1.

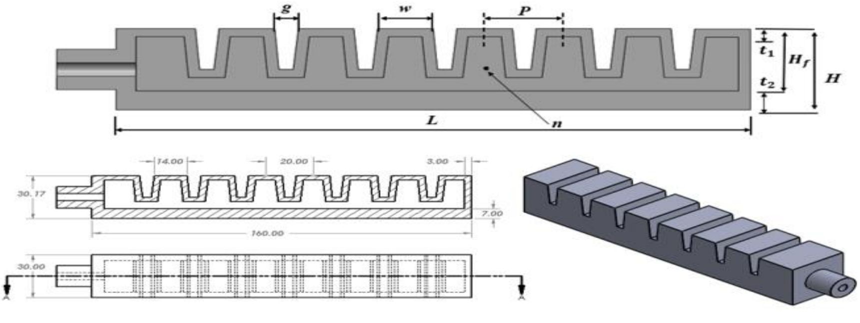


FIG 1. 3D model and schematic diagrams for Soft pneumatic actuator.

TABLE 1. Variables used in the simulation process

Parameters	Value
t_1	3,4,5,6
t_2	6,7,8,9
H	30
H_f	18
P	20
W	14
γ	0,30
Pressure	10 to 90 KPa
width	30
Length	160

The inflation direction is perpendicular to the oblique chambers of the actuator, producing coupled bending and twisting motions in 3D. When the orientation of chambers in the design is perpendicular to the actuator long edge, it means that the angle (γ) equals 0 degrees. As the actuators are pressurized, the deformation will become more difficult as the value of angle γ changes. When the soft pneumatic actuator is internally pressurized, this makes the thinner inside walls of the chambers inflated. The proposed Pneu-net is investigated at different angles(γ) from $0° \ to \ 30°$. The actuator is designed using CAD software. Selecting these range of values depend on the benchmark that has been done in simulation for some models to make sure that these values is really the effective values to for using in case of the material is silicon rubber.

For the Pneu-net actuator in this study, various geometrical parameters as illustrated in Figure.1 affect the actuator's efficiency and behavior. And a great number of actuators with a variety of capabilities are produced by different combinations of these parameters. There has been a lot of research into how specific parameters affect actuator efficiencies, such as chamber height, wall thickness, and the total actuator length. In this paper, we concentrate on some parameter that has not been exploited before.

3. SIMULATION

3.1 Hyper-Elastic Material Identification

The Soft pneumatic actuator model is fabricated with silicone rubber material, and a conventional molding method is used in the fabrication process. One type of soft material that can be used in molding is silicone rubber. However, the anisotropic property of the material is important to identify most of its characteristics. So, a standard tension specimen was prepared, as shown in table 2, and uniaxial tests were carried out to a molded silicone rubber material ISO 37 standard. The test is carried out using a universal test machine of Lloyd instruments. Test samples were molded to determine the material properties, as shown in figure.2.

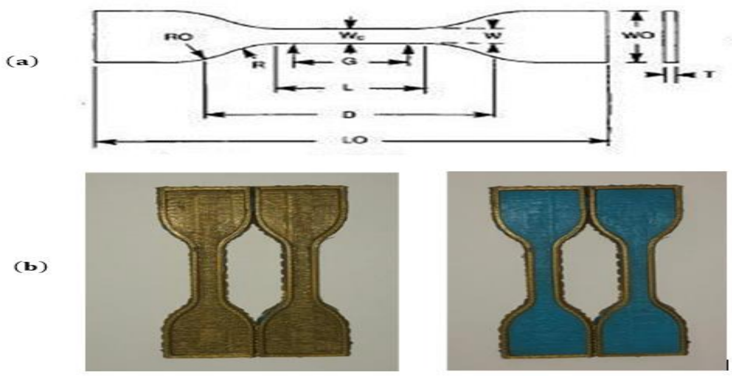


FIG 2. (a) geometry of the specimen used in the test according to ISO 37 standard [36], (b)specimens used in test.

TABLE 2. dimensions of the specimen of the tension test.

Dimension	Parameter (mm)
W – Width of narrow section	6
L – Length of narrow section	33
W0 – Width of overall	25
L0 - Length of overall	115
G – Gauge length	25
D – Distance between grips	80
R – Radius of fillet	14
R0 – Outer radius	25
T - Thickness	4

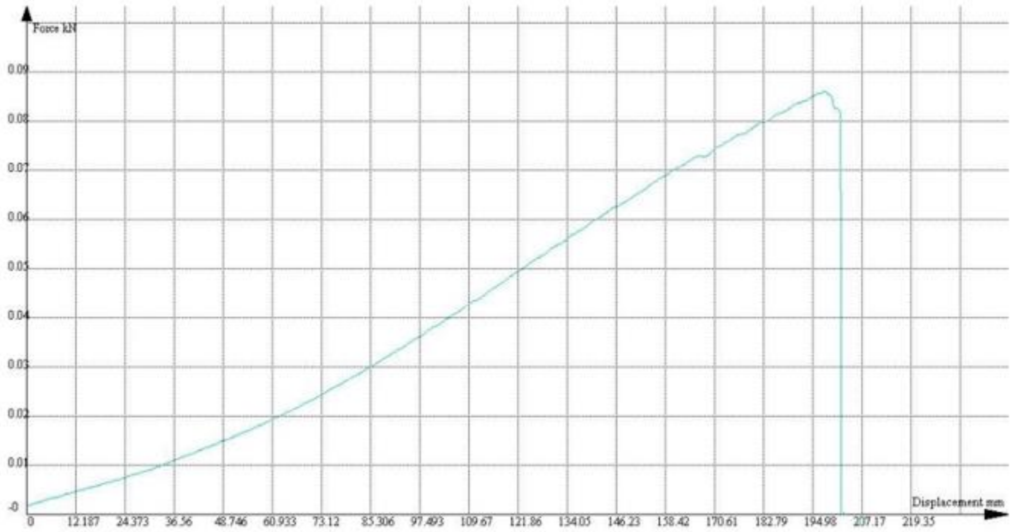


FIG 3. data based on the universal test

TABLE 3. the properties of silicone rubber [37].

Density	1100kg/ $\mathbf{m^3}$
Young's modulus	0.05G*P*a
Poisson's ratio	0.33
Bulk Modulus	1.6 G*P*a
Shear Modulus	0.02 G*P*a
Tensile Strength, Yield	0.0448 - 145 MPa
Tensile Strength, Ultimate	0.138 - 165 MPa
Elongation as Yield	900 %
Elongation at Break	5.00 - 1450 %
Toughness	0.7 MPa.m$^{1/2}$

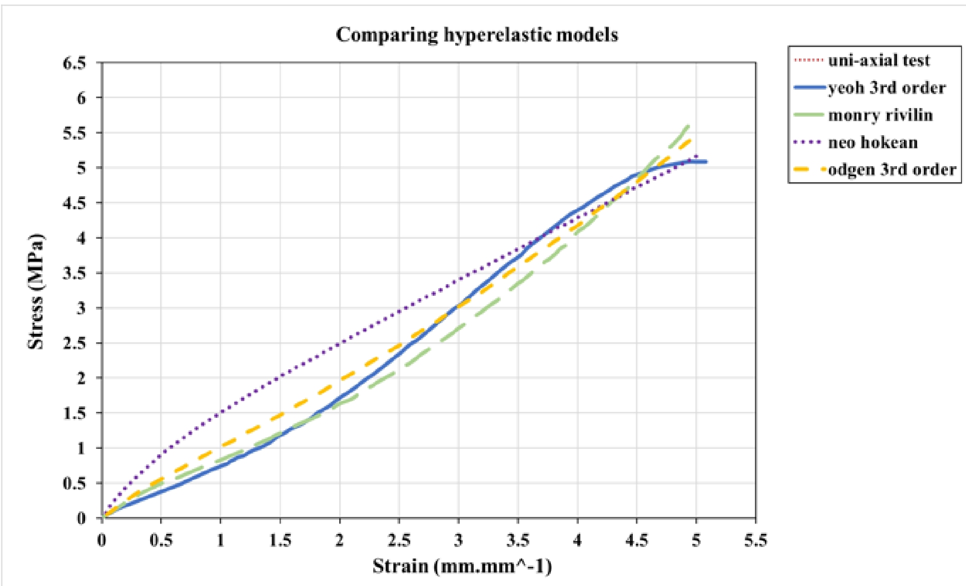


FIG 4. uniaxial test fitted with several hyperplastic models (Ogden, Mooney–Rivlin, polynomial models, and Yeoh) with ANSYS.

The test data was documented as shown in figure.3. and the stress-strain relationship was quite similar for each test sample.

The average data from the uniaxial test were fitted with several hyperplastic models (Ogden, Mooney–Rivlin, polynomial models, and Yeoh) with ANSYS as shown in figure.4. The material properties of the silicone rubber are shown in table 3.

The final Stress-Strain curve which produced after making curve fitting for the data as shown in figure.5. Moreover, the data which have been generated is used for Hyper-elastic material in FEA analysis. Based on results from theoretical model data and experimental test data, the silicone rubber's stress-strain curve was developed. Each specimen's test nominal stress-strain data is fitted in ANSYS using the Yeoh model. Additional fitting methods are carried out in order to overcome the issue of excessive deformation and convergence that this model still exhibits. The coefficients of the model are finally determined as C10 = 0.17225, C20 = 0.10772 and C30 = - 0.00013921

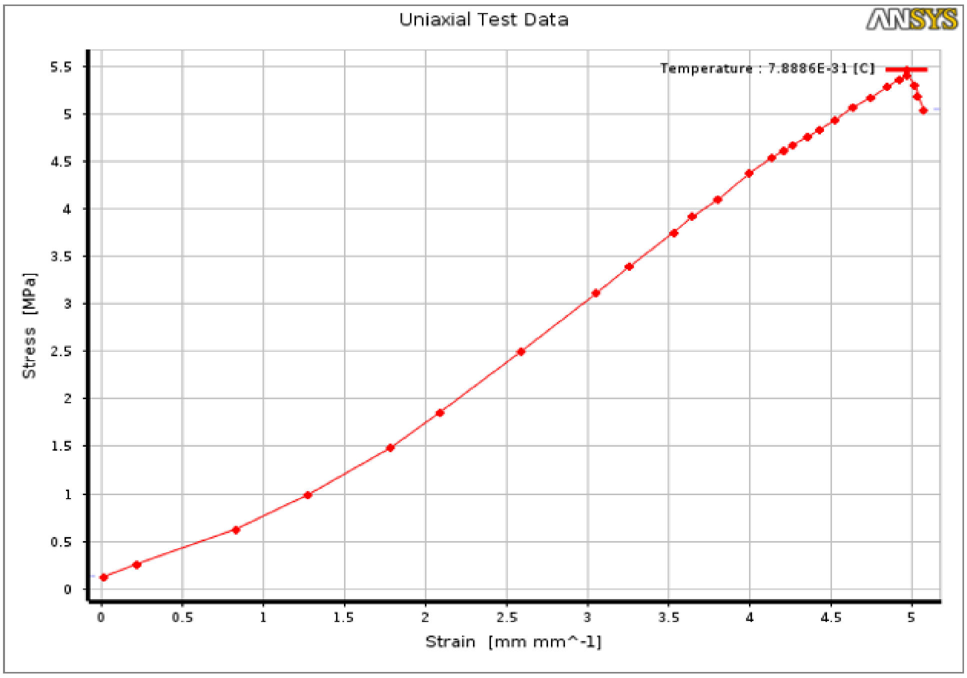
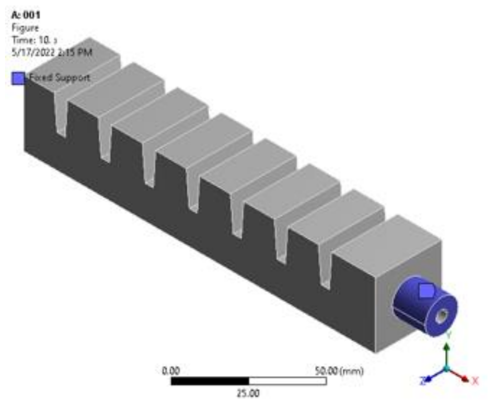


FIG 5. The stress-strain curve for the silicone rubber.

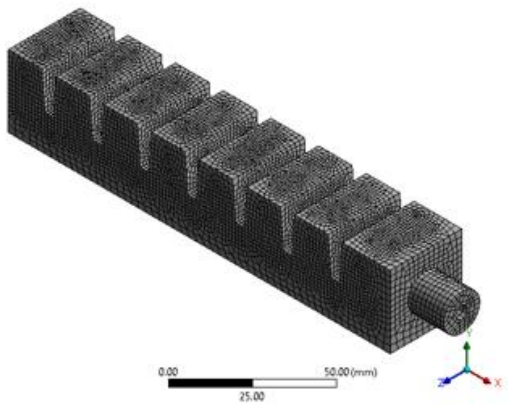
3.2 SIMULATION (Finite element method)

The finite element method (FEM) is a computational technique. A large number of different engineering systems have been analyzed and optimized by using the finite element method. After Solidworks created the soft pneumatic actuator model, it was imported into FEM software to solve it. In this study, a finite element model has been employed to predict the pneumatic actuator performance, test the effects of main parameters, and ensure that the model's structure has been optimized.

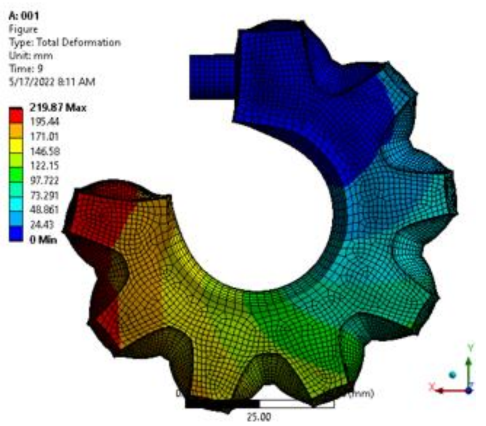
As silicone rubber is a hyper-elastic material, we should ensure that the effects of large deformation have been considered and activated in the FEM. The helical Pneu-net actuator has been fixed at one end and then actuated by pressure in the inner channel, as shown in figure.6 (a). A tetrahedron with quadratic order has been selected for the mesh elements. Benchmark has been conducted for the mesh elements, as shown in figure.6 (b). The size of each element has been selected to be (1:2 mm). This mesh size has been chosen after many different tries with different mesh sizes between (1:5), and we found that at this mesh size, the solution has converged. Finally, the actuator was pressurized, as shown in figure.6(c).



(a) fix the model from one end



(b)Mesh benckmark



(c) solving the model

FIG 6. The basic configuration of a SPA. (a) basic model when fixed at one end.; (b) Schematic diagram of meshing in ANSYS; and (c) when it is activated pneumatically.

4. Effect of geometrical parameters

4.1 Effect of chamber wall thickness.

Wall thickness t_1 is very critical parameters and has a great effect on the deformation and bending angle of the soft actuators. The wall thickness has been changed from 3mm to 6 mm by step 1mm to study the change on the bending angle and the deformation to see the effect of this change in order to know the suitable wall thickness, which leads to the best deformation. figure.7, show how the change of the wall thickness can affect the bending angle of the soft actuators. it is noticed that the bending angle and deformation of the SPAs illustrates a linear relationship between pressure and chamber thickness for different values. There is an Inverse relationship between the bending angle of the soft actuators and the chamber wall thickness. Higher deformation resistance and greater pressure carrying ability are produced by higher thickness than by lower thickness. However, the soft actuator flexibility A significant portion of the actuator's flexibility is reduced in this case, and the actuator bending angle becomes smaller. When the actuators pressure bearing capacity and stiffness are maintained. So, the SPA's wall thickness should be small as possible to improve the deformation and the bending angle and also to make the actuators weight lighter.so from the Figure.8, wall thickness is set as t1=3mm.

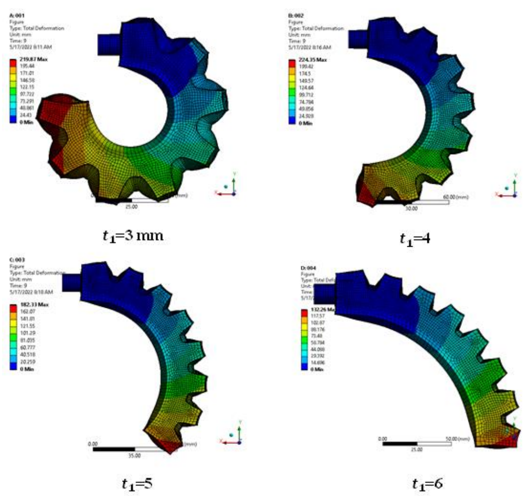
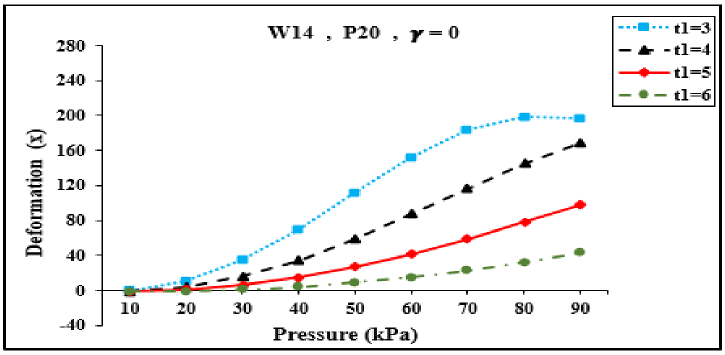


FIG 7. simulation results of the soft actuator due to the increase of the pressure of 90 kPa at different wall thicknesses (t_1=3, t_1=4, t_1=5, t_1=6 mm).

Figure.8, show the effect of the wall thickness on and the deformation in the x,y, and the actuator bending angle. As shown in Figure8, the deformation in the x-axis and y-axis decreases with the increasing chamber wall thickness due to the pressure increase from 10 to 90 kPa. This indicates that the bending angle and deformation of the actuator increase when the wall thickness is 3mm and decrease at a wall thickness of 6mm.also on the bending angle of the actuator. As shown in figure the bending angle of the actuator shows a linear relationship with pressure for different chamber thickness. Bending angle of the actuator is inversely proportional to chamber thickness. Higher thickness leads to better deformation resistance and larger pressure carrying capacity. However, the actuator is less flexible and the bending angle decreases. When the stiffness and pressure bearing capacity of the actuator are maintained, the section thickness should be as small as possible to reduce weight and improve bending ability. As shown in figure.8, section wall thickness is set as t1 = 3mm.

(a)



(b)

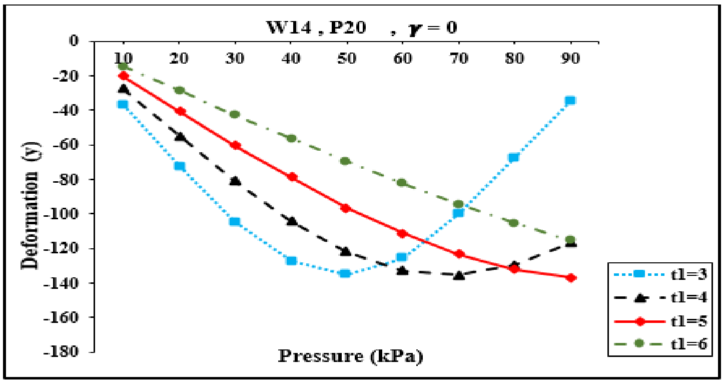
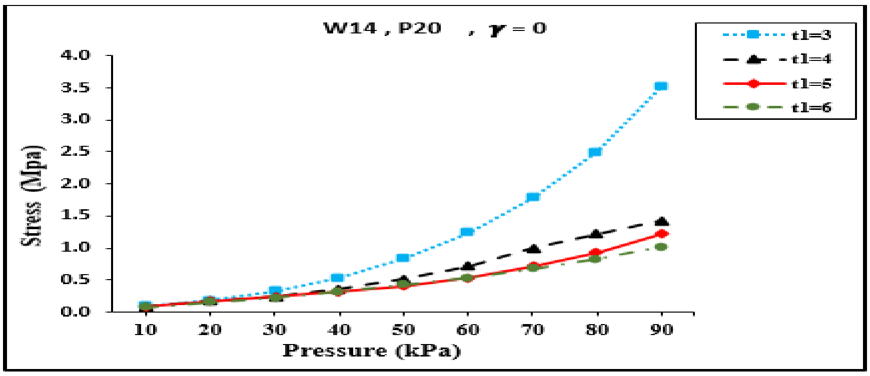


FIG8. results of influence parameters (a) deformation in x axis and (b) deformation in y axis due to the applied pressure ranged from 10 to 90 kPa at $\gamma = 0°$ and variable wall thickness (t_1= 3, t_1= 4, t_1=5, t_1= 6 mm).

Figure.9, show the effect of the wall thickness on the stress and strain of the actuator. As shown in Figure.9, the stress and strain decrease with the chamber wall thickness increase due to the pressure increase from 10 to 90 kPa. This indicates that the stress and strain of the actuator increase when the wall thickness is 3mm and decrease at a wall thickness of 6mm.

(a)



(b)

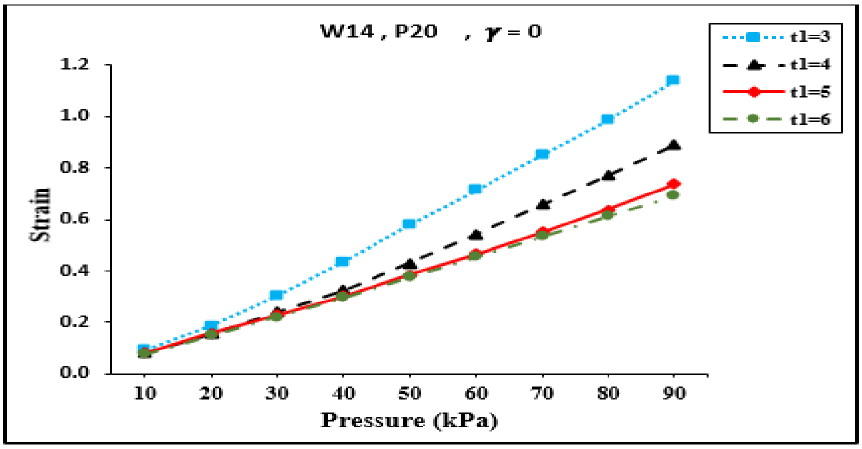


FIG9. results of influence parameters. (a) Stress and (b) strain due to the applied pressure at $\gamma = 0°$ and variable wall thickness (t_1= 3, t_1= 4, t_1= 5, t_1= 6 mm).

4.2 Effect of the chamber angle

Chamber angle γ is a critical parameter and has a great effect on the actuator's trajectory. So, all the parameters in this case are kept constant and the chamber angle only parameter that can be changed varies from $0°$ *to* $30°$ to determine its effect on the deformation of the soft actuator. we investigate the effect of the range of the angles. As the chamber angle (γ) increases, the soft actuator moves an extra distance along the x-axis. The helix's loops become more separated horizontally, the SPA's moves less distance in the y-direction, and the radius of each chamber loop of the actuator becomes smaller. Therefore, as with the chamber angle increase, the pitch length of the actuator becomes larger than in the case of a small angle, and the bending radius of the chamber becomes smaller, as shown in figure.10. The actuator tip motion is recorded, and indicated. Finally, the tipping point of the actuator moves to the farthest remote position along the x-axis, and then the actuator returns to make a circular shape.

In Figure.11, the chamber angle changes from 0 to 30 degrees. With the increase of the chamber angle at variable pressure from 10 to 90 kPa, the deformation on the x-axis decreases with increasing the chamber angle as shown in figure.11(a) and the deformation in the y-axis increases with the increase of the chamber angle as illustrated in figure.11(b). The deformation in the z-axis has been noted in this case, and the actuator starts to twist as shown in figure.11(c). In the case of angle 0 degrees, the actuator makes a bending angle only, but in the case of increasing the angle up to 30 degrees, we noticed that the chamber starts to make bending and twisting angles together.

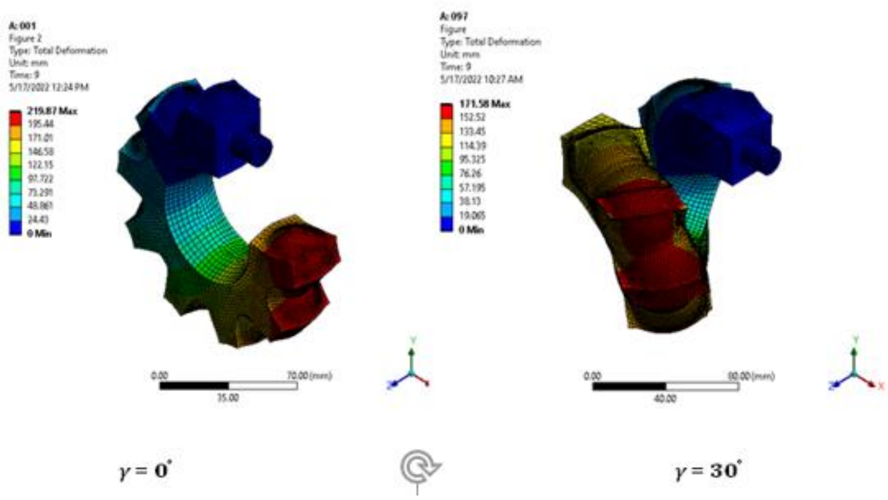


FIG10. simulation results of the SPA's due to the increase of the pressure of 90 kPa at chamber angle ($\gamma = 0^{\circ}$, $\gamma = 30^{\circ}$).

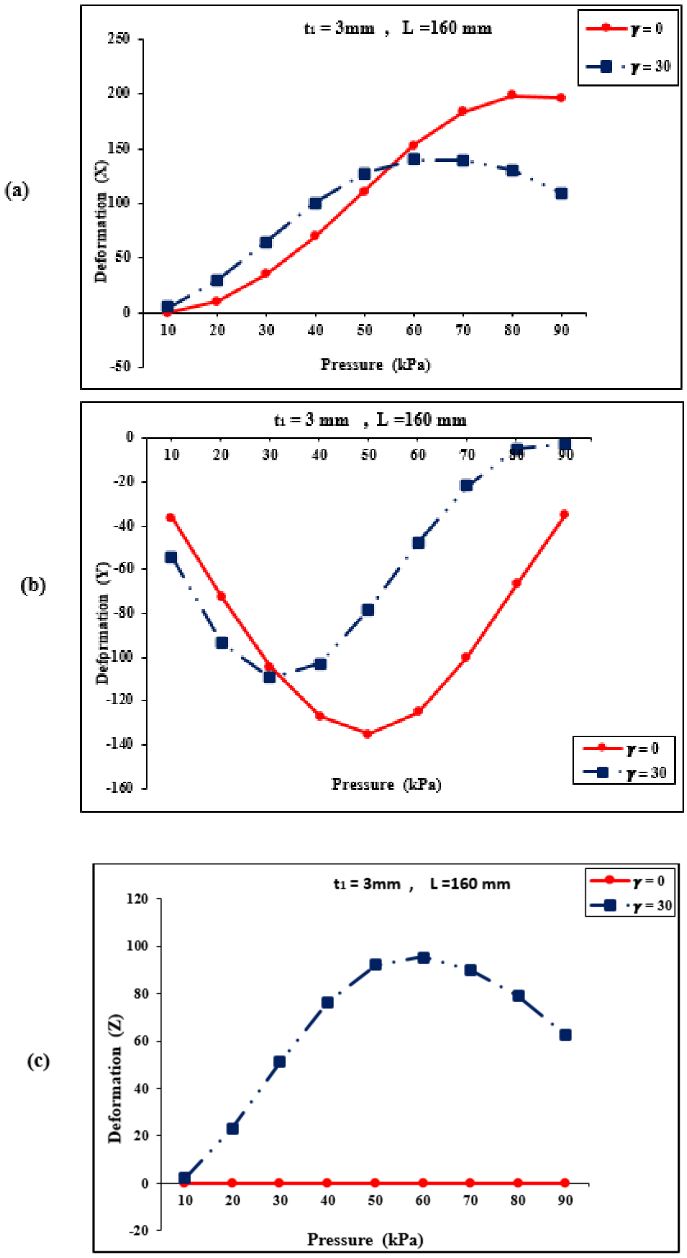


FIG 2. FEA results of cumulative deformation images(a) deformation in x axis and (b) deformation in y axis(c) deformation in z axis to show the effect of applied pressure on variables γ SPAs (γ = 0°, γ = 30°).

4.3 Effect of base thickness.

base thickness t_2 is investigated in this study to show its effect on the deformation and bending angle of the soft actuators. The base thickness has been changed from 6mm to 9 mm by step 1mm to study the change on the bending angle and the deformation to see the effect of this change in order to know the suitable base thickness which leads to the best deformation. figure.12, illustrates that when $t_2 =$ 6mm and with the increase of the pressure the deformation is being similar to the deformation when $t_2 =$ 9mm with a very little change. Also, it is noticed that the bending angle of the actuator has a very minor change. If the base thickness become smaller than 6mm, it leads to low bottom stiffness and There is no longer a pure bending deformation produced by the SPA's. Furthermore, as long as the pressure is higher than 90 kPa, the simulation's results does not converge. While for base thickness 7mm and 8mm, the deformation and the bending angle of the soft actuators have a linear relationship with the pressure, and when increasing the base thickness bigger than 9mm the deformation and the bending angle decreases.so, from the figure.12, the base thickness of the actuator is set as t_2=7mm to verify the flexibility of the SPA's and ensure a linear relationship between bending angle with pressure.

Figure.13 shows the influence of the plate thickness on bending angle of the actuator. It indicates that when t_2= 6 mm, minor plate thickness leads to insufficient bottom stiffness, and the actuator no longer shows a pure bending deformation because of the plane deformation of the plate. Moreover, while the pressure exceeds 90kPa, the simulation result does not converge. While for t_2= 7 mm and t_2= 8mm, bending angle of the actuators has a linear relationship with pressure, and with the increase of plate thickness to t_2= 9, bending angle of the actuator drops. In order to keep a linear relationship between bending angle with pressure and to ensure the softness of the actuator, thickness of the plate is set as t_2= 7 mm.

Figure.13 show the effect of the base thickness t_2 on the deformation in x,y directions and the bending angle of the actuator. As shown in figure.13, the deformation in x-axis, y-axis has Very little effect with the increasing of the chamber base thickness due to the increase of the pressure from 10 to 90 kPa.for the increase in base thickness from 6mm to 9 mm, the deformation in x-axis has small effect as shown in figure.13 (a). Also, the deformation in the y-axis has a small effect, as shown in figure.13 (b). This indicates that the bending angle and deformation of the actuator do not change significantly, and this variable does not have a significant effect on the bending angle and deformation.

Figure.14 indicates the influence of the chamber base thickness on the stress and strain of the actuator. As shown in figure.14 (a), the stress does not change significantly and the strain has very little effect. As shown in figure.14 (b), the chamber base thickness increased due to the increase of the pressure from 10 to 90 kPa. This indicates that the stress and strain do not change significantly, and this variable does not significantly affect the stress and strain.

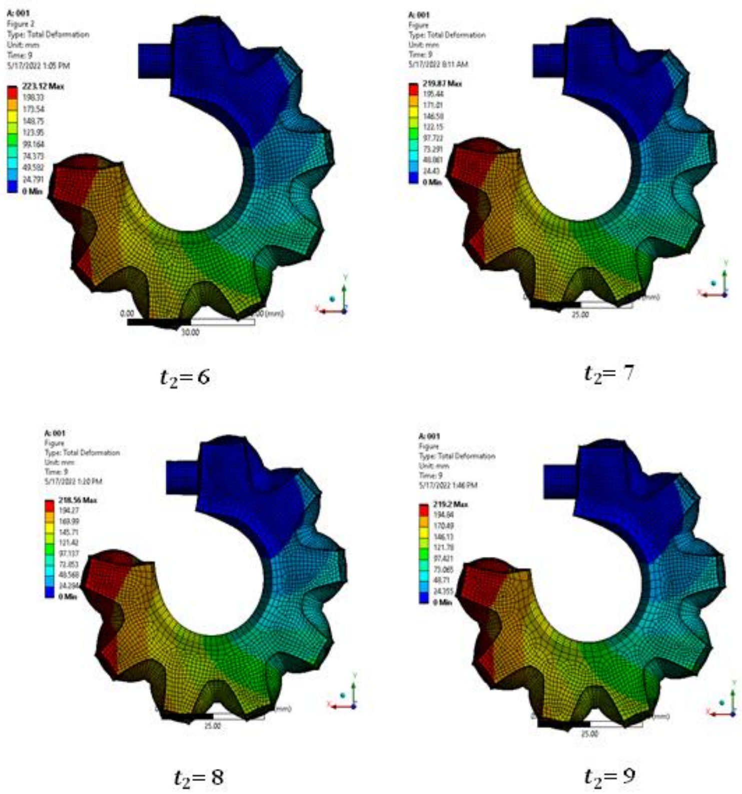


FIG 3. simulation results of the soft actuator due to the increase of the pressure of 90 kPa at different base thicknesses (t_2= 6, t_2= 7, t_2= 8, t_2= 9 mm).

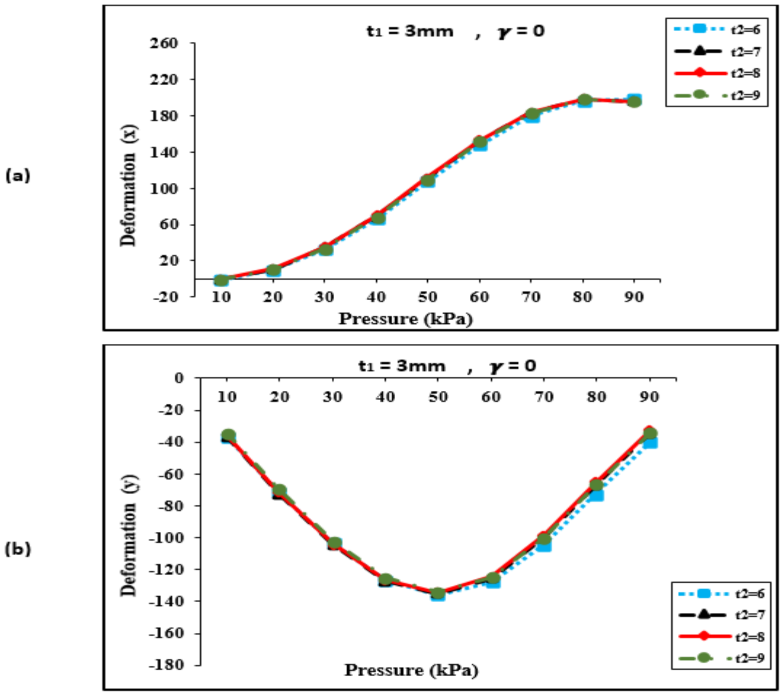


FIG 4. results of influence parameters (a) deformation in x axis and (b) deformation in y axis due to the applied pressure at $\gamma = 0°$ and variable base thickness (t_2= 6, t_2= 7, t_2= 8, t_2= 9 mm).

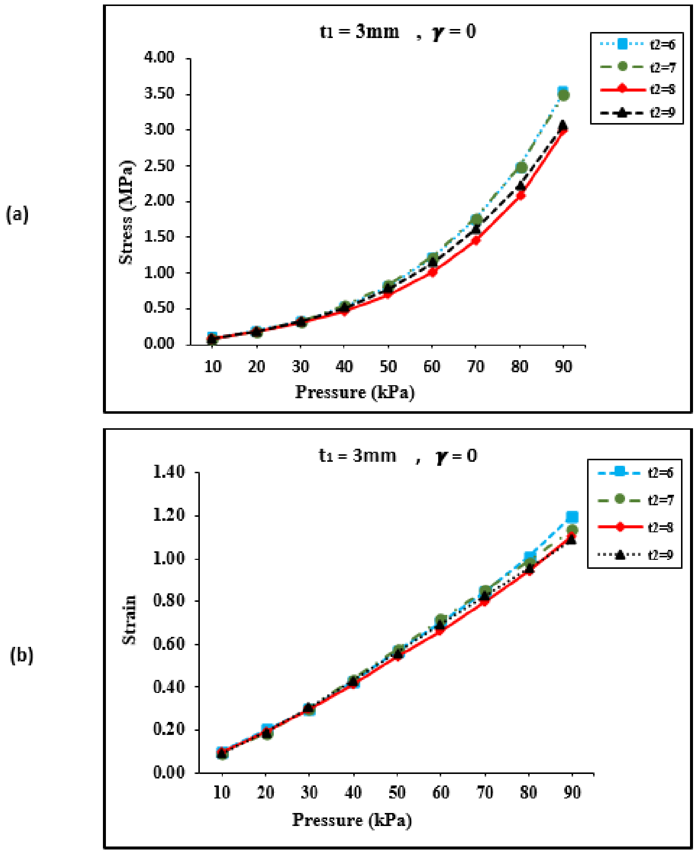


FIG 5. FEA results of accumulated deformation images to show the effect of applied pressure on the variable's bottom thickness (t_2=6, t_2=7, t_2=8, t_2=9 mm).

5. Conclusion

This paper proposes a new soft pneumatic actuator (SPA's) with large bending angles and deformation. Through simulation using finite-element method (FEM), it is indicated that the soft pneumatic actuator has dramatically improved its deformation and the bending angle has become bigger. The most efficiency of the grasping for the SPA in case of the bigger bending angle. Also, investigate a novel structure of pne-net that can produce a twisting and bending motion together in a wide range by adjusting the geometrical parameter such as wall thickness, base thickness and the chamber angle. The effect of this geometrical parameter on the deformation of the actuator is analyzed in detail in this study. In simulation, the deformation and bending angle have been calculated for each actuator at various pressure. Simulation results illustrate that the wall thickness is acritical parameter. As the wall thickness of the chamber increases, the deformation decreases and the bending capacity decreases. Also, when the chamber angle increases, the actuator begins to make twisting angle. we noticed that when the base thickness increases, we noticed that there a Little slight change occurs. The newly developed actuator significantly improves the bending angle. However, there are still some parameters to be studied and some problems to overcome. The actuator Stiffness is insufficient, and Potential solutions to these defects include particle strengthening and materials with variable stiffness. An interesting problem to further investigate is how to plan the grasping method and path to realize a reliable grasp for objects with different shapes and dimensions. Finally, an increase in the deformation was observed by 60% and 44.5% of bending and twisting together due to change of the SPA's wall thickness and the chamber angle. In the future, we'll attempt to create an analytical model for this form of the actuator and utilize it to create new designs for actuators that follow the appropriate trajectories. Our future work will also concentrate on this issue since combining chambers with varying chamber angles in a single actuator would result in more motion forms for different application demands.

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