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Mechanical behavior of polymeric membrane: comparison between PDMS and PMMA for micro fluidic application

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Abstract

The list of polymers is long each it presents very interesting mechanical advantages. In this paper we interest more especially to two polymers extensively used in the MEMS and more especially in micro-valve actuators, the PDMS and PMMA. Our goal is to study the mechanical behavior of the two polymeric membrane subjected to equal pressure could drag deformation. We have simulate the mechanical behavior by hyper elastic model of Neo-Hookean and linear elastic in order to compare between the two materials in view of amplitude deformation on one hand, and on the other hand we present the numerical conditions thus (the effect of the step, thickness, number of mesh) in order to optimize the dimensionality of the membrane

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Keywords: MEMS, elastomeric, PDMS, PMMA, deformation

1. Introduction

A commercial manufacturers of microfluidic devices see many benefits in employing plastics that include reduced cost and simplified manufacturing procedures, particularly when compared to glass and silicon. An additional benefit that is extremely attractive is the wide range of available plastic materials which allows the manufacturer to choose materials' properties suitable for their specific application.

In the literature much work relating to polymer microfluidic devices has been reported, including microfluidic devices fabricated from a range of polymers. Microfluidic systems fabricated using polydimethylsiloxane (PDMS) have been reported by [1,2,3]. While Locascio *et al.* [4] and Lee Gwo-Bin *et al.* [5] have reported fabrication of microfluidic devices on polymethylmethacrylate (PMMA).

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Polydimethylsiloxane (PDMS) has been the mainstay for rapid prototyping in the academic microfluidics community, because of its low cost, robustness and straightforward fabrication, which are particularly advantageous in the exploratory stages of research. In addition to the simplicity of manipulation, the PDM S has the following properties: it is a hyperelastic polymer; it can undergo very big distortions therefore without deteriorating [6]. It is biocompatible and non porous to the liquids. The PDMS is the main support for the manufacture of fluidic Microsystems. The PDMS used in our work is silgel 612 [7]. In spite of the advantages presented by the use of the PDMS in micro fluidics, a certain number of materials plastic are associated, have been used in answer to the evoked previously difficulties. It is the case of the PMMA. This polymer is spilled enough in MEMS technology, different production methods can be used for the realization of the micro fluidics devices. The composites studied PMMA reinforced to the shock by particles of elastomeric of polybutadiene [8]. In this paper, polymer such as PMMA is compared to PDMS for which magnitudes of deformation, the mechanical behavior of these polymers are studied using hyperelastic and linear model.

In order to optimize the dimensionality of the membrane and to compare between the two materials to equal pressure, we present the effect of membrane thickness and pressure values. This modeling permits to establish the relations between the geometric features of the micro fluidics system and the applied pressure.

2. Material Behavior

In this section we provide a behavior equation of PDMS and PMMA materiel. The modeling is separated in two parts: the hyper elastic model and linear model.

2.1 Neo-Hookean model

A hyperelastic or Green elastic material[9] is a type of constitutive model for ideally elastic material for which the stress-strain relationship derives from a strain energy density function. The hyperelastic material is a special case of a Cauchy elastic material.

An hyperelastic material has a nonlinear behaviour, which means that its deformation is not directly proportional to load applied. An elastic material is hyperelastic if there is a scalar function, denoted by $W=W(\epsilon)$, such that:

$$S = \frac{\partial W}{\partial \epsilon} = 2\frac{\partial W}{\partial C} \qquad (1)$$

Where S is the second Piola Kirchhoff stress tensor, ϵ is the Green strain tensor C is the Cauchy Green strain tensor. The strain energy function of hyperelastic constitutive models such as Neo-Hookean and Mooney-Revlin are expressed as a function of strain invariants, the Neo-Hookean model is obtained:

$$W = \frac{1}{2}G(I_1 - 3) + \frac{1}{2}K(J - 1)^2 \qquad (2)$$

Where:

the strain invariant: $I_1=\mathrm{tr}C$ and $J=\det(F)$

F is the deformation tensor.

$C=F^T F$ and the Green strain tensor: $\epsilon = \frac{1}{2}(C - I)$

The Cauchy stress tensor can be expressed as [10]:

$$\sigma = \frac{1}{J} FSF^T \quad (3)$$

The shear modulus G and the bulk modulus K of the hyper elastic material are defined by the following relations:

$$G = \frac{E}{2(1+\nu)} \quad (4)$$

$$K = \frac{E}{3(1-2\nu)} \quad (5)$$

Where E is Young's modulus and ν is t Poisson's ratio.

2.2 Hook's relation (Linear elastic model)

The most general way to represent a linear relation between the stress tensor σ_{ij} and the strain tensor ϵ_{kl} is given by Hooke's law.

$$\sigma_{ij} = C_{ijkl}\epsilon_{kl} \quad (6)$$

Where σ_{ij}components of the Cauchy stress tensor are ϵ_{kl} are components of the strain tensor and C_{ijkl} is called the elastic constants tensor of fourth order.
The stress-strain relation for an isotropic linear elastic material can be written as

$$\sigma_{ij} = 3K\left(\frac{1}{3}\epsilon_{kk}\delta_{ij}\right) + 2G\left(\epsilon_{ij} - \frac{1}{3}\epsilon_{kk}\delta_{ij}\right) \quad (7)$$

Where δ_{ij} is the Kronecker Delta
Under small strain the deformation of PMMA and PDMS membrane are very little. We can use the linear model for the first order approximation.

3. Simulation

The modeling by finite element is commonly used to calculate the deformation of structure in Microsystems, because of its capacity to simulate the system in two and three dimensions. A three dimensional constitutive model of circular elastomeric membrane has been used for simulation in our study, the FE model of the active structure and boundary conditions are shown in figure.1.
In goal to optimize the response of magnitude deformation, we have to optimize the calculation time when we have to minimize the number of mesh. In our study the chosen time is for errors less than 10%.

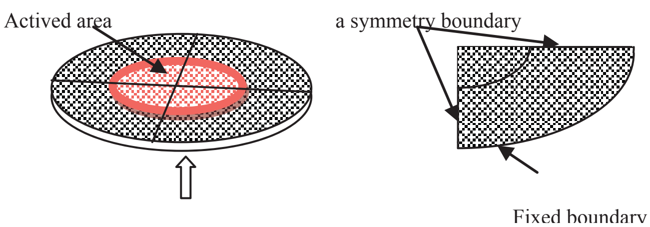

Fig. 1. Model of elastomeric membrane and boundary conditions

4. Discussions

To characterize the mechanical behaviour of material, the deformation of PDMS and PMMA under applied pressure is shown in Fig.2.

In goal to compare between the two models NH and LE, the simulation results for vertical displacement on the surface of PDMS and PMMA membrane are obtained and shown in Fig.3. The Figures show that the results obtained for the tow models are similar at small loading.

To study the response of elastic material under various values of applied pressure and to compare between the PDMS and PMMA in term of maximum deformation, the simulated results are presented in Fig.4. As shown in figure, the maximum of vertical displacement increase with increasing applied pressure for the two materials.

In particular the results show that the PDMS membrane has a large deformation compared with PMMA membrane at same conditions.

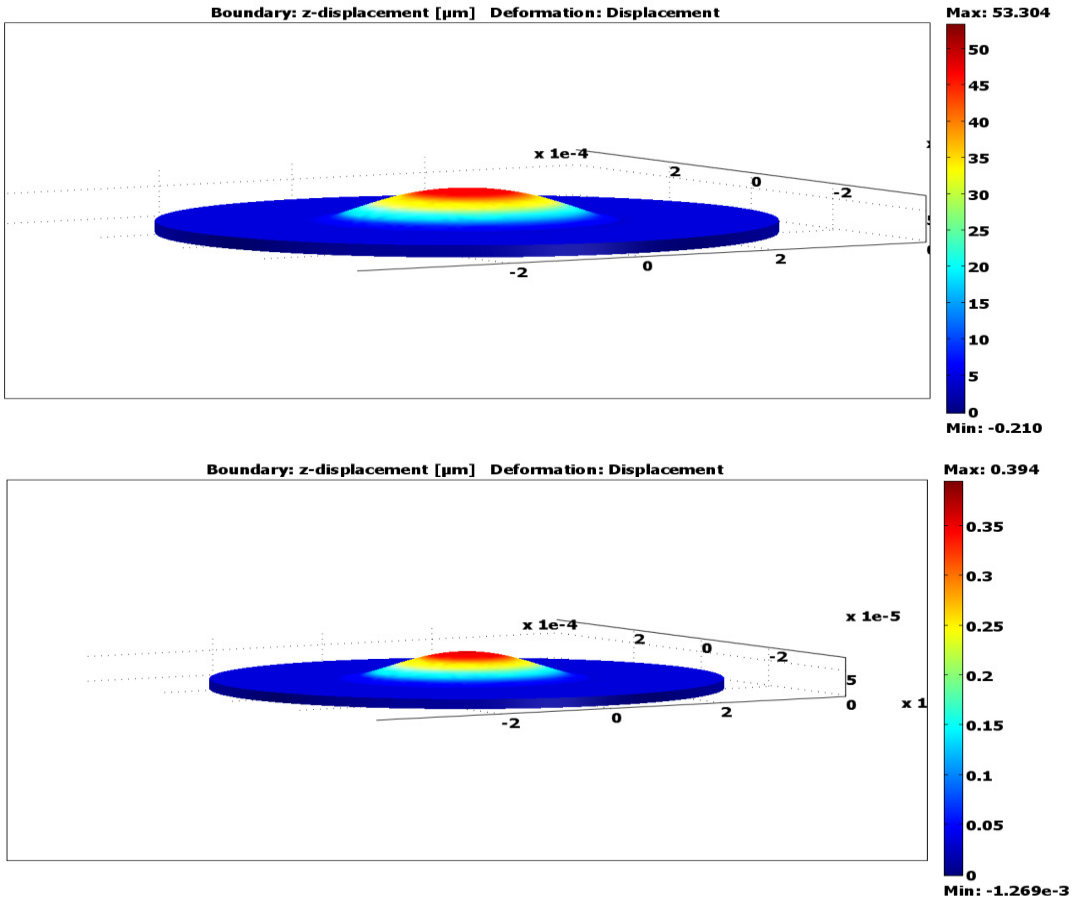

Fig. 2. (a) deformation of PDMS membrane; (b) deformation of PMMA membrane induced by applied pressure

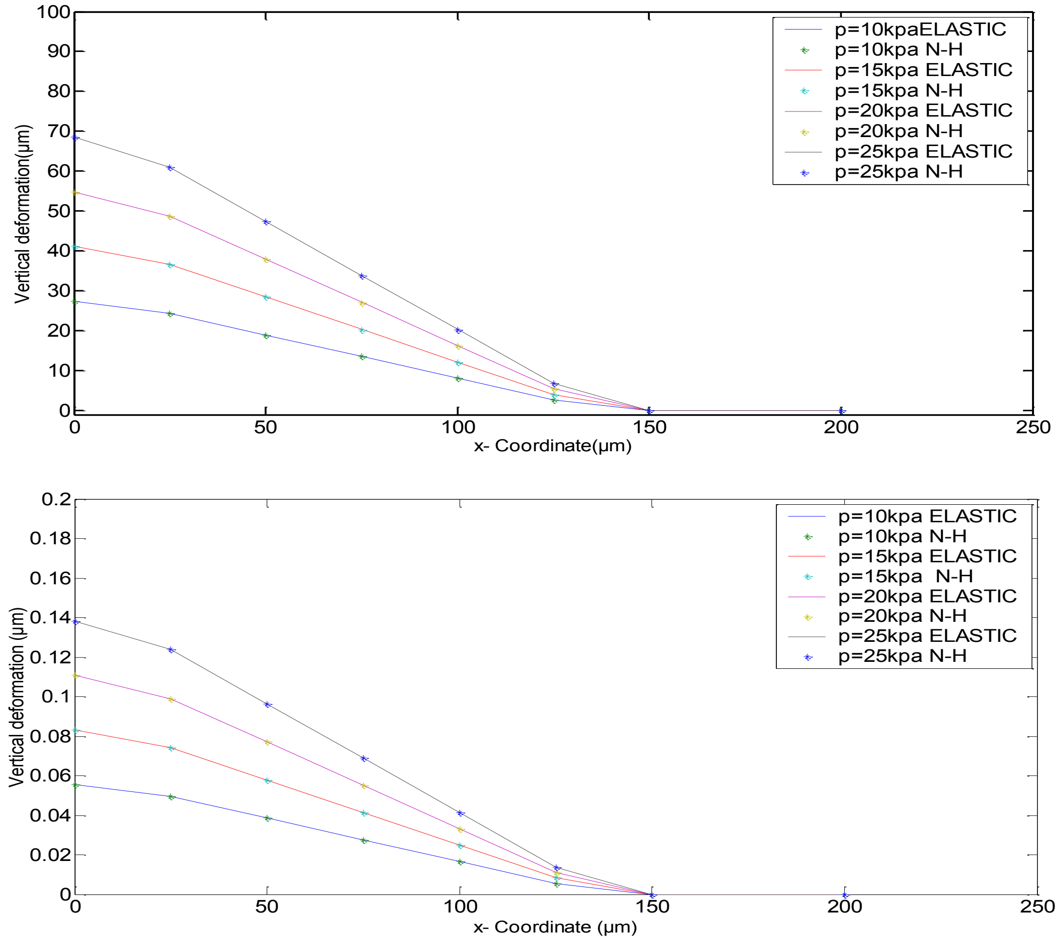

Fig.3. (a) vertical displacement on surface of PDMS membrane; (b) vertical displacement on surface of PMMA membrane at different pressure

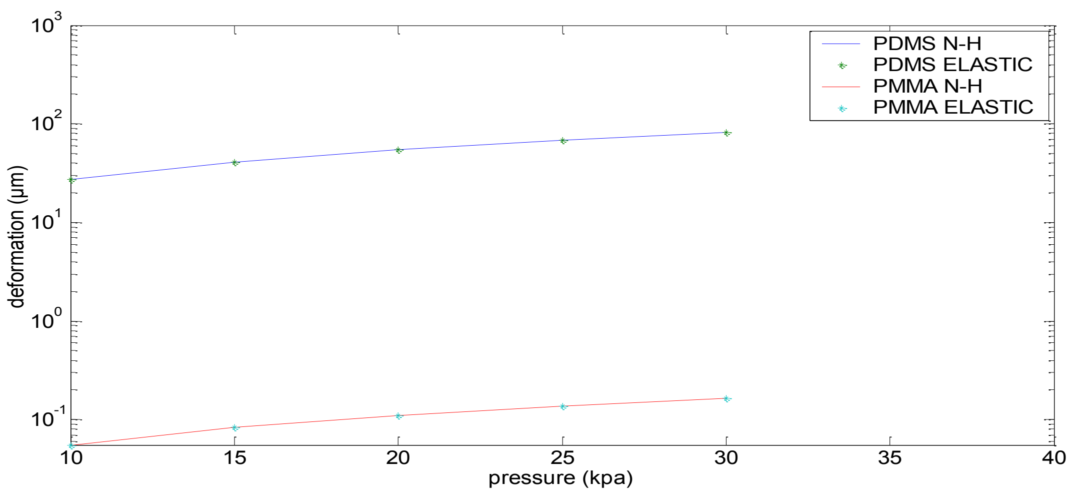

Fig. 4. maximum of vertical displacement on surface of PDMS and PMMA membrane at different pressure

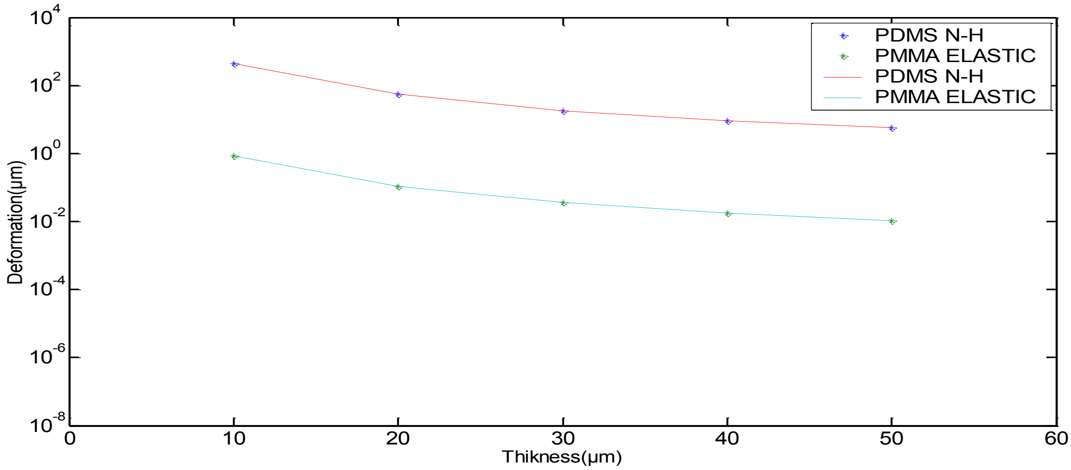

Fig. 5. maximum of vertical displacement on surface of PDMS and PMMA membrane at different thickness

To look the influence of the dimensions membrane on the rigidity of the system, we simulate the relation between deformation and exercised pressure by including the membrane thickness variation (Fig.5). the analysis of this curve show that the membrane deformation decrease with increasing thickness. So to obtain a larger deformation at smaller pressure, adds us interested to decrease the membrane thickness.

4. Conclusion

In this paper we presented two mechanical models (NH and Linear elastic model) to describe the behavior of PDMS and PMMA membrane. We have showed that the similar results are obtained for the two models under small loading. In this case we can replace the complicate hyperelastic model by the simple elastic model for small loading.

The comparison between the PDMS and PMMA membrane deformation are studied at different values of pressure and thickness. The results obtained by FE modelling show that the deformation increase with pressure and reversely decrease with increasing thickness.

The miniaturization in the MEMS is a requirement, thus we always try to decrease the thickness of the membrane, this stage is positive but it will be limited by the rigidity of the system.

The PDMS is better than PMMA in term of maximum deformation, this special characteristic it can be used in microfluidic us active membrane especially us active microvalves with mechanical moving parts, despite the advantages of PDMS rapid prototyping for microfluidics technology, this material suffers from a serious drawback in that it swells in most organic solvents [11].The swelling of PDMS-based devices makes it impossible for organic solvents to flow inside the microchannels.

The PMMA is an elastomer with little deformation in comparison with the PDMS, this property can be used for the construction of canalization of microvalve when the rigidity is required.

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