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Numerical Modeling to Determine the Mechanical Behavior of Polyurethane Foams

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ABSTRACT: The objective of this paper is to establish a numerical model for a Representative Volume Element (RVE) and perform calculations by using the finite element method (Abaqus) to determine the static behavior of polyurethane foams. The influence of the porosity, size, shape and aperture of bubbles on the static behavior of polyurethane foams was taken into account in this study. This model was validated by comparing the analytical results with the simulation results using Abaqus software for the static behavior in compression. We will use this model to homogenize a macroscopic volume of foam and obtain an equivalent homogeneous solid.

Keywords: Foam, Material, Cellular, Modelling, Simulation

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I. INTRODUCTION

Polyurethane foams are widely used to manufacture soundproofing parts of car. It is important to study their mechanical behavior to improve their acoustic performance. The behavior of the foams depends on the polyurethane material, the porosity of foam, and form of bubbles in opened cell foams. Tension, compression and impact properties of a polyurethane foam have been measured as a function of foam density. Significant differences in the behavior of the foam were observed depending on the mode of testing. The power-law relationship for the modulus was the same for both tension and compression testing because of the elastic compliance of the cellular structure of the foam using a simple geometric model. For closed-cell cellular materials, they exhibit several interesting properties but these properties are very difficult to simulate and understand. This problem is mostly due to the highly complex organization of the cells and to their very fine walls.

Several studies have focused on the microstructure of the walls and its influence on mechanical properties [1-6]. X-ray tomography is used to create the model 3D and non-destructive visualization of the studied materials at the scale of their cellular microstructure. The simulations have been done on the same structure with 3D elements with a depth chosen equal to the thickness in order to represent beams with square sections and use cubic elements [1]. The initial microstructure and local deformation mechanisms of a polyurethane foam during a compression test are investigated by means of X-ray micro-tomography. The validation of the modelling procedure is performed in relation to the macroscopic mechanical response as well as to the local deformation mechanisms observed during the experiments [2-3].

This paper describes a procedure to produce the RVE model in Abaqus software. The proposed model has thearchitecture of closed-cell cellular solids as seen in tomography. The method is enriched by the fact that the thickness value of each element is measured in the tomographic image.

II. PRESENT THE MODEL IN ABAQUS

2.1. Spherical cellule model

A previous observation by electron microscope for the foam section presented a quasi-closed cell structure. The average diameter of a cell is 100 µm and the walls are very thin in the adjacent area [7]. The geometrical parameters of the model are diameter D and inter-cell distance as shown in Fig. 1. Model of spherical cellule is presented in Fig. 1 and values used for the parametric studies in this model are given in Table 1.

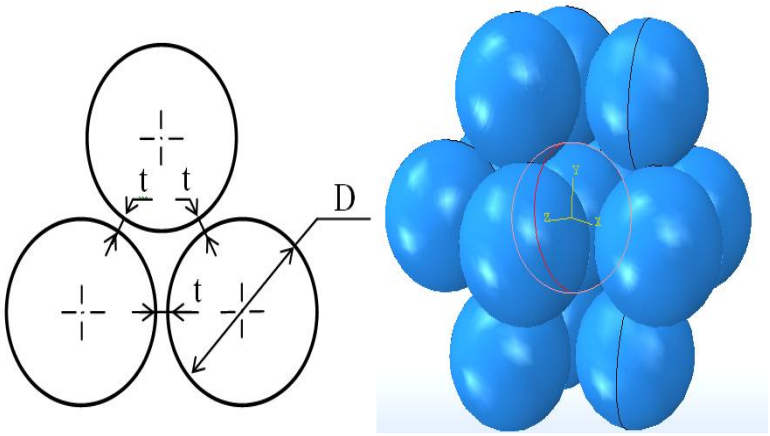

Fig 1. Dimension (left)and arrangement (right)of spherical cells

Table 1.The parameters of spherical model

Model number	D (mm)	t (mm)	Model number	D (mm)	t (mm)
N^{01}	0.08	0.0800	N^{13}	0.10	0.0100
N^{02}	0.08	0.0500	N^{14}	0.10	0.0050
N^{03}	0.08	0.0300	N^{15}	0.10	0.0010
N^{04}	0.08	0.0200	N^{16}	0.10	0.0005
N^{05}	0.08	0.0100	N^{17}	0.12	0.0800
N^{06}	0.08	0.0050	N^{18}	0.12	0.0500
N^{07}	0.08	0.0010	N^{19}	0.12	0.0300
N^{08}	0.08	0.0005	N^{20}	0.12	0.0200
N^{09}	0.10	0.0800	N^{21}	0.12	0.0100
N^{10}	0.10	0.0500	N^{22}	0.12	0.0050
N^{11}	0.10	0.0300	N^{23}	0.12	0.0010
N^{12}	0.10	0.0200	N^{24}	0.12	0.0005

2.2 Elliptic cellule model

2.1.1 Case 1: b=2a, c=a

This case is shown in Fig. 2. The values used for the parametric studies are shown in Table 2

Table 2.The parameters of elliptic model

Model number	b =2a (mm)	a =c (mm)	t (mm)	Model number	b =2a (mm)	a =c (mm)	t (mm)
N^{25}	0.20	0.10	0.0800	N^{30}	0.20	0.10	0.0010
N^{26}	0.20	0.10	0.0400	N^{31}	0.16	0.08	0.0010
N^{27}	0.40	0.20	0.0500	N^{32}	0.30	0.15	0.0010
N^{28}	0.40	0.20	0.0300	N^{33}	0.10	0.05	0.0010
N^{29}	0.30	0.15	0.0100				

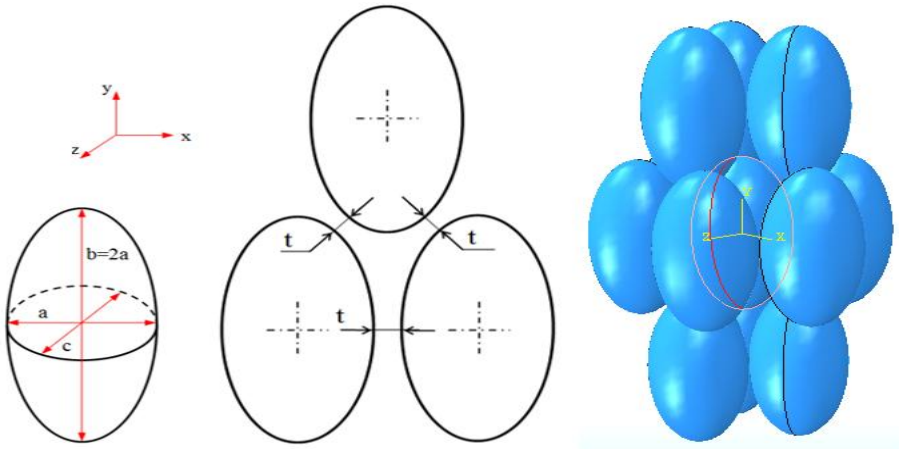

Fig 2. Dimension (left)and arrangement (right)of elliptic cells

2.1.2 Case 2 : a =2b=2c

This case is shown in Fig. 3. The values used for the parametric studies as shown in Table 3

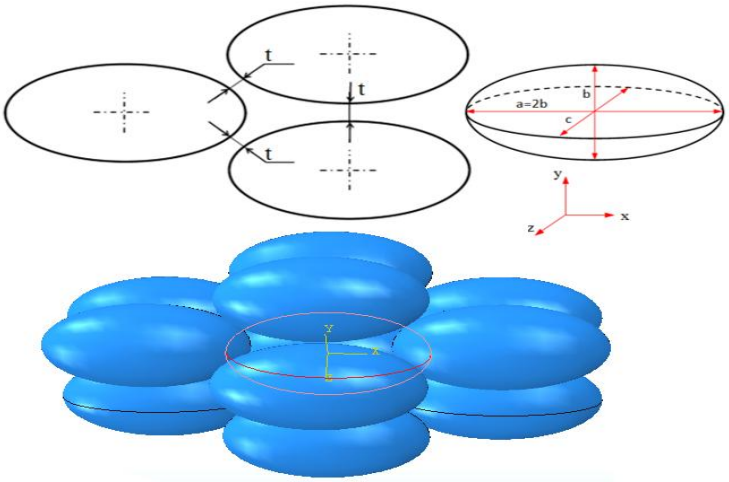

Fig 3. Dimension (left)and arrangement (right)of elliptic cells

Table3.The parameters of elliptic model

Model number	b =2a (mm)	a =c (mm)	t (mm)	Model number	b =2a (mm)	a =c (mm)	t (mm)
N^{34}	0.20	0.10	0.0800	N^{39}	0.20	0.10	0.0010
N^{35}	0.20	0.10	0.0400	N^{40}	0.16	0.08	0.0010
N^{36}	0.40	0.20	0.0500	N^{41}	0.30	0.15	0.0010
N^{37}	0.40	0.20	0.0300	N^{42}	0.10	0.05	0.0010
N^{38}	0.30	0.15	0.0100				

III. THE REPRESENTATIVE VOLUME ELEMENT AND PROPETIES OF MATERIALS

From forms of cells defined above, we constructed RVE by repeating patterns periodically in three directions of space. We note that, this RVE must be large enough to represent the foam but small enough comparing to the size of the entire Polyurethane foam. The Fig.4 shows the dimensions of RVE (0.5 x 0.5 x 0.5 mm^3).

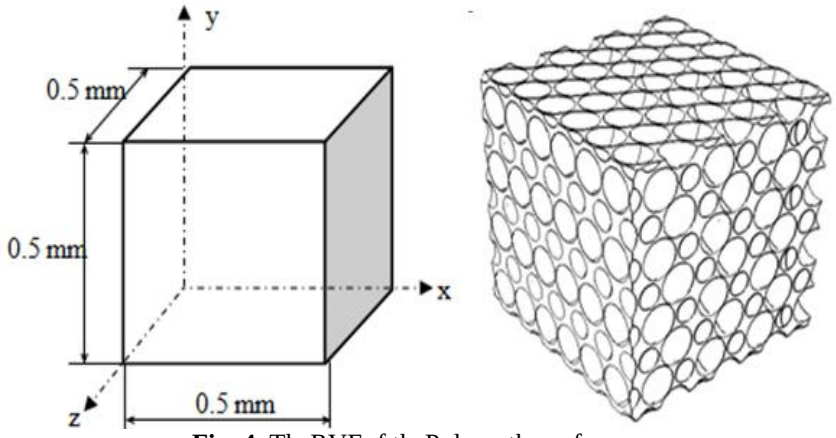

Fig. 4. TheRVEof thePolyurethane foam

The mechanical properties of walls of polyurethane foams are resumed in Table 4 [2].

Table4.Mechanical properties of polyurethane foam

Mechanical properties	Symbol	Polyurethane	Unity
Modulus of elasticity	E_s	1600	MPa
Coefficient of Poisson	ν	0.38	
Limit of elasticity	σ_e	40	MPa

IV. RESULTS AND DISCUSSION

The distribution of von Mises stresses for RVE in Abaqus as shown Fig. 5. From the simulations of the compression test on the RVE, we determined their equivalent Young's modulus by using Hooke's law. The stress is calculated from the reaction force *F* after the numerical simulation and the applied surface

S = l^2 = $(0.5)^2$ = 0.25 mm^2. The deformation is calculated from the imposed displacement u=0.005 mm. The results obtained for the spherical model and elliptical model are given in Table 5 and Table 6.

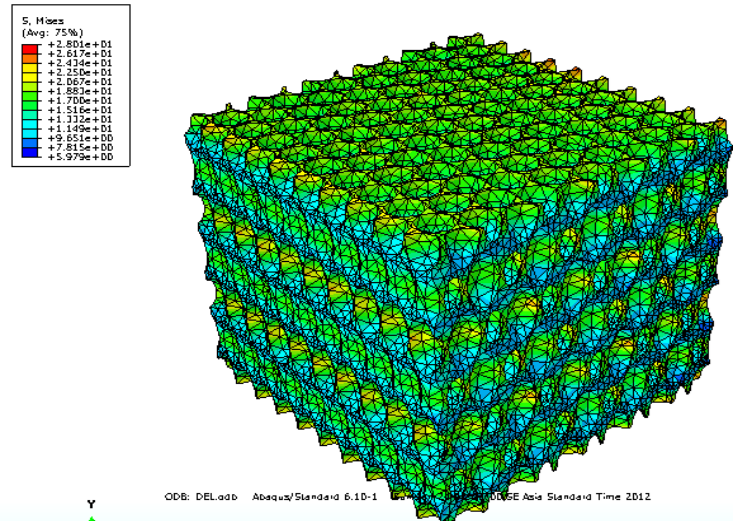

Fig.5. Von Mises stresses for the RVE

For the spherical model, Young's modulus decreases non-linearly and monotonously, depending on the porosity of the RVE. Cell size has no influence on the module (Fig. 6a). For elliptical models, Young's modulus decreases in a non-linear to a value porosity approximately 0.7, then appears to increase. This phenomenon is not practical; it may be due to a problem of meshing between cells. Indeed, when the porosity increases the space between the cells decreases and there is no element in this space (Fig. 6b).

Table 5. Young's modulus versus porosity for the spherical model

RVE Model	Porosity	E_f (MPa)	RVE Model	Porosity	E_f (MPa)
N^{01}	0.1120	1286.4120	N^{13}	0.6064	0388.1616
N^{02}	0.2224	1032.9640	N^{14}	0.6664	0307.1304
N^{03}	0.3192	0832.5680	N^{15}	0.7224	0221.2512
N^{04}	0.4264	0643.0880	N^{16}	0.7312	0211.8604
N^{05}	0.5416	0446.2920	N^{17}	0.0880	1345.0320
N^{06}	0.6344	0333.0628	N^{18}	0.1840	1101.5840
N^{07}	0.7192	0235.0304	N^{19}	0.2704	0925.0000
N^{08}	0.7312	0221.1576	N^{20}	0.3808	0739.3760
N^{09}	0.1600	1167.5760	N^{21}	0.5304	0506.4320
N^{10}	0.2392	0976.7360	N^{22}	0.6152	0365.7952
N^{11}	0.3664	0739.3160	N^{23}	0.7024	0255.2956
N^{12}	0.4848	0540.7280	N^{24}	0.7152	0238.7244

An extensive study of micromechanical models of cellular material is presented by Gibson and Ashby [7], a relation has been proposed to determine Young's modulus as a function of porosity for the simple geometry of cells. They expressed the elastic modulus for closed cell foam as follows:

$$\frac{E_f}{E_s} = \phi^2 \left(\frac{\rho_f}{\rho_s} \right)^2 + (1-\phi) \left(\frac{\rho_f}{\rho_s} \right) + \frac{\rho_0 (1-2\nu_f)}{E_s (1-\rho_f / \rho_s)}$$

where$E$ represents the modulus of elasticity, ρ is the density and ϕ is the fraction of the solid contained in the cell edges, the indices f refers to foam and s to the solid, $\nu_f$is the Poisson coefficient of the foam. The low initial pressure of the gas ρ_0 (in our case, the atmospheric pressure), makes the third term of the equation negligible.

Table 6. Young's modulus versus porosity for the elliptic model

RVE Model	Porosity	E_f (MPa)	RVE Model	Porosity	E_f (MPa)
N^{25}	0.1360	1216.7320	N^{34}	0.1360	1212.1240
N^{26}	0.2528	0943.3600	N^{35}	0.2528	0798.2800
N^{27}	0.3480	0750.2880	N^{36}	0.3480	0754.5480
N^{28}	0.4856	0533.2560	N^{37}	0.4856	0482.1680
N^{29}	0.5312	0481.5480	N^{38}	0.5312	0457.3520
N^{30}	0.6528	0317.1308	N^{39}	0.6528	0252.4768
N^{31}	0.6712	0320.6024	N^{40}	0.6816	0237.8600

N^{32}	0.6824	0307.3392	N^{41}	0.6824	0236.4420
N^{33}	0.7976	0387.8376	N^{42}	0.7976	0361.0880

To validate proposed model, we have compared the numerical results with analytical results, as shown in Fig 7. We note that the simulation of Abaqus gives the results very close to the analytical results for the spherical models respectively (Fig. 7a). The comparison demonstrates that the modeling and numerical simulation for these models are quite effective for the prediction of the mechanical behavior of such materials. It can be used to homogenize a macroscopic volume of foam and obtain an equivalent homogeneous solid. We also found that the relative difference between the numerical model and analytical model is less than 30% for Young's modulus of elasticity and porosity (Fig. 7b). This difference is due to the geometric form of the model (ellipse) used in the simulation which is quite different from the geometric of the model (cubic and tetrakaidecahedral) in the analysis. This difference also suggests a study to modify the analytical equation to introduce a parameter that takes into account the geometric shape of the cell.

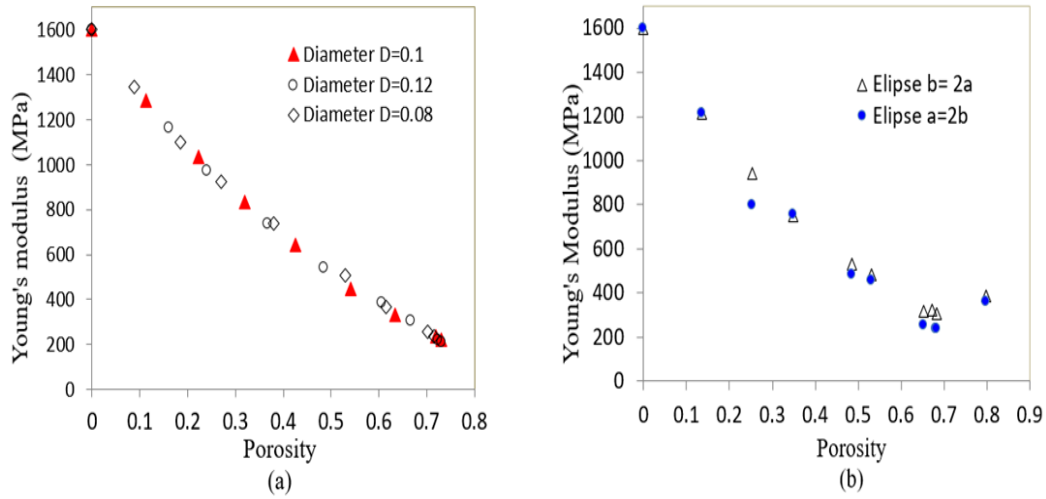

Fig.6. The relations between the Young's Modulus and the Porosityfor
(a) the spherical model, (b)the elliptic model

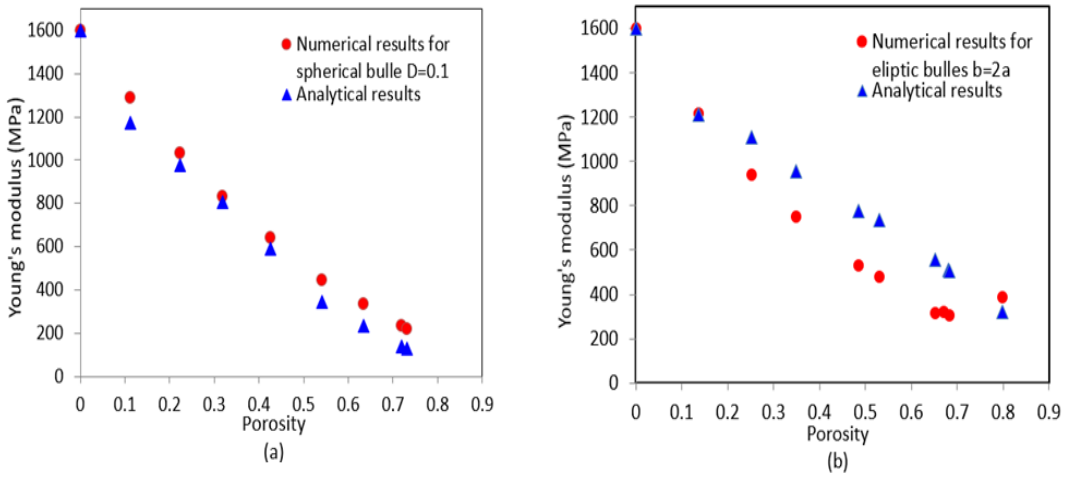

Fig.7. Comparison of numerical results with analytical resultsfor (a) the spherical model, (b)the elliptic model

V. CONCLUSION

In this article, we have proposed a method of modeling and numerical simulation for the model RVE of Polyurethane foams. The comparison of the results obtained by the Abaqus 3D simulations and by the analysis has proved the precision and effectivity of the present model. The present model allows us to predict the mechanical behavior of Polyurethane foams without carrying out the X-ray tomography. It will be used to homogenize a macroscopic volume of foam and obtain an equivalent homogeneous solid.

REFERENCES

[1] Eric Maire, Arnaud Fazekasb, Luc Salvo, X-ray tomography applied to the characterization of cellular materials. Related finite element modeling problems,Composites Science and Technology 63, 2003, 2431–2443.

[2] S.Youssef, E. Maire, Finite element modelling of the actual structure of cellular materials determined by X-ray tomography, Acta Materialia 53, 2005, 719–730.

[3] O. Caty, E. Maire, Modeling the properties of closed-cell cellular materials from tomography images using finite shell elements,ActaMaterialia 56, 2008, 5524–5534.

[4] N.J. Mills, Finite Element Models for the viscoelasticity of open-cell polyurethane foam,Cellular Polymers, 25 (5), 2006, 293-316.

[5] Conor Briody, Dr. Barry Duignan, Characterization, material modelling and simulation of flexible polyurethane foam, International conference on materials, tribology, recycling, 2011, 23-36.

[6] Liying Zhang, Manish Gurao, King H. Yang, Material characterization and computer model simulation of low-density polyurethane foam used in a rodent traumatic brain injury model, Journal of Neuroscience Methods 198, 2011, 93–98.

[7] L.J.Gibson, M.F. Ashby,Cellular Solids, Structure and properties (Cambridge University Press, Cambridge, 1997).

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