NUMERICAL MODELING OF AUXETICS IN STRUCTURE STRENGTH

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Abstract

The paper deals with computer simulations of mechanical behaviour of a no-void ideal auxetic isotropic material. Current literature offers wide range of models which resemble the manufactured or natural structures. However, it does not answer the question how a change into auxetic no-void state would affect the continuum effective mechanical properties. Auxetic with the Poisson ratio -0.3 has been compared through typical tests to a classic steel elastic material.

Most of the engineering software cannot precede Poisson ratio below zero. Therefore a unique technique was applied using equation of state to overcome this obstacle. All simulations have been done in elastic regime. For the tensile/ compression tests a 10 mm edge cube was modelled, the bending test used a 5x5x250 mm bar. The loading for initial tests was realized as a kinematic displacement of particular nodes. For bar bending a force was applied in the middle of the beam. The finite element method has been used with explicit time integration algorithm implemented in commercial software with one integration point brick elements.

Specific properties have been observed for each test, for tensile test auxetic showed higher strength while for compression material was weaker. Logically the bending test showed no clear influence of negative Poisson to material strength. Further simulations as a shear or impact tests are planned.

Keywords: *computational mechanics, auxetics, negative Poisson ratio, material engineering*

1. Introduction

Auxetics are materials that have a Negative Poisson's Ratio (NPR). Surprisingly while being stretched they become thicker perpendicular to the applied force. A growing interest in auxetic materials is caused by a possible benefit of their unique behaviour, which may result in enhancement of their toughness, tear resistance, acoustic properties or mechanical strength. It was shown that in nature there are materials with inherent auxetic properties such as special inorganic crystals [1], e.g., silicon dioxide [2], zeolites [1], metals [3] and others. Auxetic behaviour is generated by material internal structure and the deformation mechanism it undergoes while being submitted to external loading. This is a scale-independent property which can be obtained on any level. Therefore, much of the current research effort is focused on producing artificial auxetic materials. So far auxetic foams, has been well investigated and successfully produced and many others like micro porous polymers or composites are being researched. However most of those materials have low density, as it is what allows the hinge-like areas of the auxetic microstructures to flex. This results in low material elasticity modulus which for natural zeolite was measured to be 72 GPa [4] and auxetic foam only 0.21 MPa [5]. Therefore for structure strength it is an obvious advantage in introducing NPR on the lowest possible material scale. Material and chemical scientists are examining various molecules, liquid crystals, polymer chains to achieve this property. Of course the question of introducing an auxetic behaviour in a continuum that does not contain voids is still open. Current literature offers wide range of models which resemble the manufactured or natural structures. However, it does not answer the question how a change into auxetic no-void state would affect the continuum effective mechanical properties. In this paper, the finite element computational method (FEM) is applied to study the deformation and elastic properties of auxetic samples.

2. Constitutive model of the hypothetic auxetic no-void material

Every numerical model requires constitutive relations to be defined. It completes the fundamental laws of nature and characterizes specific properties of the studied material. The ordinary steel material in elastic range was described by isotropic Hook's law where the stress/strain relation is defined by:

$$\sigma_{ij} = \frac{E}{1+\nu}\left[\varepsilon_{ij} + \frac{\nu}{1-2\nu}\varepsilon_{kk}\delta_{ij}\right], \tag{1}$$

where: the Young modulus, E and Poisson's ratio, ν are needed to define. Auxetic material could not be modelled basing on this model due to the software limitation. Therefore the negative Poisson's ratio was introduced with indirect way. A split of the stress tensor into the deviatoric, s_{ij} and pressure, p parts is used:

$$s_{ij} = \sigma_{ij} + p\delta_{ij}\,, \tag{2}$$

$$p \overset{\text{def}}{=} -\frac{1}{3}\sigma_{kk}\,, \tag{3}$$

where the pressure is described by linear equation:

$$p = K\mu\,, \tag{4}$$

and the volume changes are expressed by densities ratio as following:

$$\mu = \frac{\rho}{\rho_0} - 1\,. \tag{5}$$

Finally the constitutive relation for deviatoric stress/strain is given in form:

$$s_{ij} = 2G\varepsilon_{ij}^{d}\,. \tag{6}$$

Assuming values of NPR, and Young modulus the required shear modulus, G and bulk modulus K are calculated with known relationships in theory of elasticity:

$$G = \frac{E}{2(1+\nu)}\,, \tag{7a}$$

$$K = \frac{E}{3(1-2\nu)}\,. \tag{7b}$$

This method lets to avoid much software limitation to input the negative value of the Poisson's ratio.

3. Problem description

Free, basic test has been held each time for identical samples, one for classic elastic material another for auxetic one. Implemented models simulated steel material, typical modulus and steel material parameters were used. For compressive and tensile simulation a cube of 10 mm edge was chosen, one of its walls has been attached to the virtual surface while the opposite one was moved. The test was quasi static and the main goal was to achieve strain stress curves. For the bending test 250 mm long beam with 5 mm edge was chosen and pressed in the middle of it. The modelled beam was simply supported at the ends.

4. Problem solution and analysis of the results

All FEM models were built using brick elements. In case of tensile and compressive test a prescribed motion was defined with the same characteristic for both examples. A total force was than compared for a compression test which result is shown in Fig. 1. An evident difference can be observed, elastic material reaction force is by 15% higher. For a cube tension situation is opposite, hear auxetic material has superior properties what is depicted in Fig. 2. For the beam bending test a pre defined force was applied and increased gradually up to maximum value. Curves in Fig. 3 show that auxetic sample was slightly easier to bend. LS-Dyna software was used to calculate each variant with explicit time integration method. For auxetic material imputing negative Poisson value was not accepted as the software reported error. Therefore a unique technique was used to avoid this limitation. Previously described elastic plastic model does not required Poisson ratio value but the shear modulus and equation o state. The shear modulus was calculated basing on typical elastic modulus and Poisson ratio -0.3 while the linear polynomial equation was attached to the material model, for c1 factor bulk modulus was put.

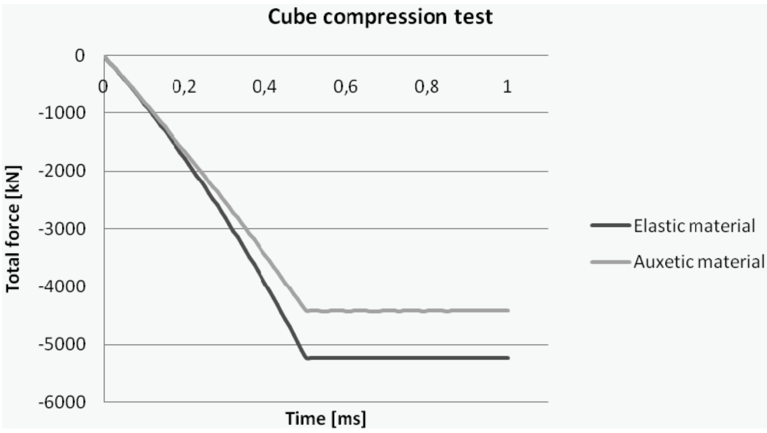

Fig. 1. Compression test force / time curve

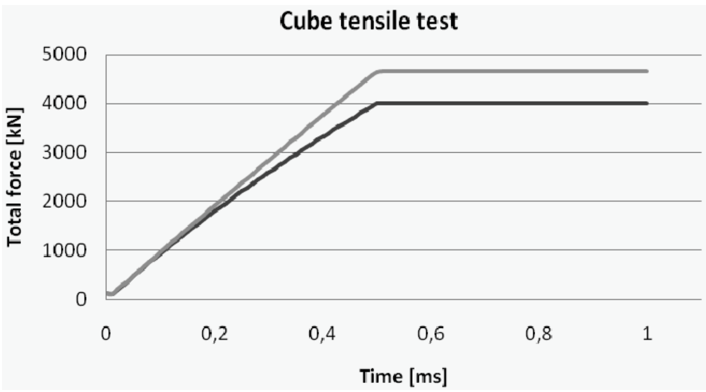

Fig. 2. Tensile test force / time curve

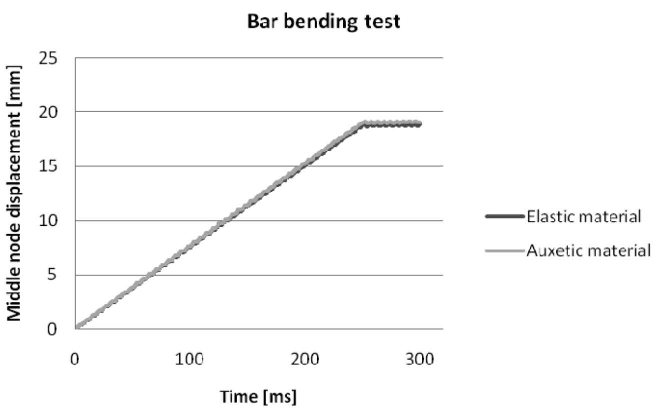

Fig. 3. Bending test deflection / time curve

5. Conclusions

All test has given clear results about auxetic material response under prescribed load or motion. For the compression test auxetic material is clearly easier to press but surprisingly for the reverse direction of the motion material shows advantage. The final bending test gives very similar results, with auxetic material having a slightly lower strength. Concluding analysis which has been held for ideal no void auxetic material showed no clear influence of the negative Poisson ratio on material mechanical properties. Further test including shear test and a response to dynamic load or impact are suggested.

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