POLYMERIC FOAMS MODELLING BASED ON MICROSCOPIC CELL GEOMETRY FOR LIGHT SANDWICH STRUCTURE APPLICATION TO HELICOPTER BLADE IMPACT

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Abstract

In this paper, a strategy for the modelling of the mechanical behaviour of polymeric foams is developped at the scale of the microstructure. The basic idea relies on the idealization of the microstructure by a network of perturbed truncated octahedron cells. Each cell is modelled with beams elements in agreement with micrograph observations. Moreover, an elastoplastic mechanical behaviour is applied to the beams to deal with buckling of the edges. The strategy is evaluated on examples of compressive and shearing tests.

1 Introduction

As presented in figure 1, an helicopter blade is basically a box beam made of a metal leading edge for protection, a unidirectional glass fibers/epoxy resin roving dealing with the centrifugal loads, carbon fibers/epoxy resin woven fabric skins for aerodynamic shape, carbon fibers/epoxy resin woven fabric stiffeners for torsion and a polymeric foam core for skins stabilization.

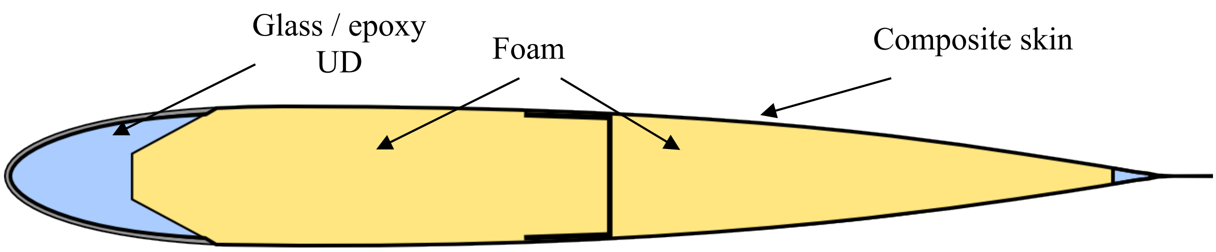

Figure 1. Scheme of a helicopter blade section

During their whole life, helicopter blades can be subjected to various kind of impacts characterized by:

- the relative velocity of impact, up to 150 m.s^{-1} (rotation of the rotor)
- the angle: frontal (0°) or oblique (up to 90°) impact
- the nature of the impactor: ice, wreckage...

When such an event arises, complex degradation phenomena can lead to the failure of the structure, one of them being the failure of the polymeric foam core stabilizing the skins of the blade [1].
Section cuts made on impacted blades have shown that the foam core could fail both in compression behind the roving, and in traction / shear at the skin / foam interface.
As a result, engineers designing helicopter blades need tools to understand and predict the failure of the foam, so as to identify the critical parameters to improve its resistance.

2 Experimental study

2.1 Material and testing methods

The study was carried out on Rohacell 51A (aeronautical grade) foam. This material is an open cell foam (Figure 2) *i.e.* the cells are made of edges with virtually no walls.

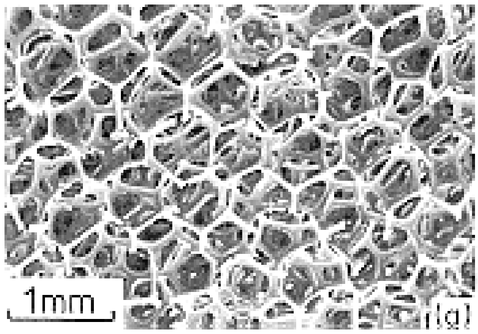

Figure 2. Microscopy of an open cell foam [2]

Three different quasistatic tests were performed on Rohacell specimens (Figure 3):

- compression tests on cylinders (height 10mm and radius 10mm)
- shear tests on “quad bloc” specimen
- indentation tests on cylinders (height 10mm and radius 10mm) by a 20 mm steel ball

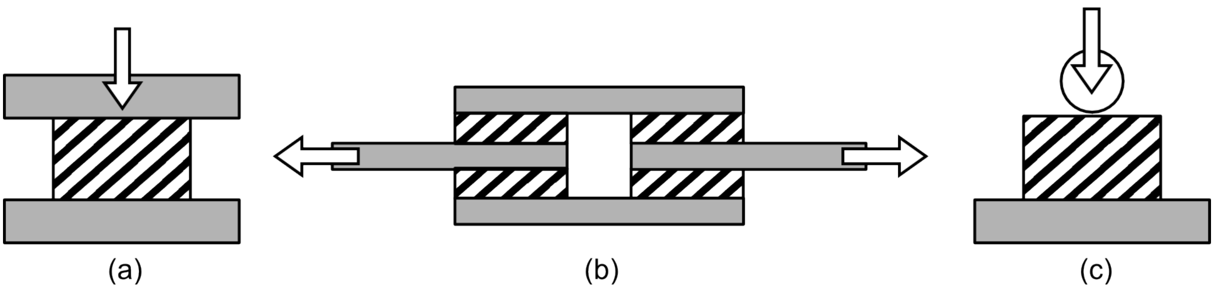

Figure 3. (a) Compression test (b) “Quad-bloc” shear test (c) Indentation test

All the tests were performed on an Instron tensile / compression quasistatic machine equipped with a 10 kN load cell.

2.2 Compression tests

Three main steps can be identified from the stress / strain curve of these compression tests presented in Figure 5:

- a linear elastic part for a total strain ε < 3 %
- a plateau for a total strain 3 % < ε < 50 % (the stress is virtually constant)
- a densification part for a total strain ε > 50 % (the stress increases exponentially due to material accumulation)

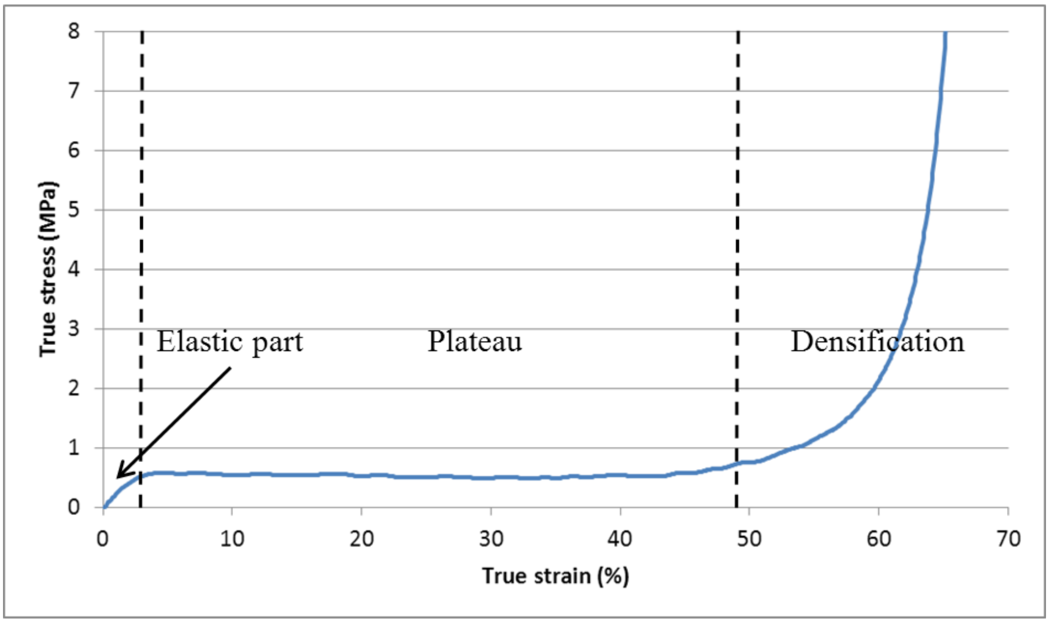

Figure 5. Stress / strain curve for a crushing test on Rohacell 51 A specimen

First observations on experimental compressive tests on Rohacell 51A specimens have shown that during the crushing of the foam, local buckling initiates at one face of the specimen and leads to the complete collapse of the sample as the compression goes on (Figure 4).

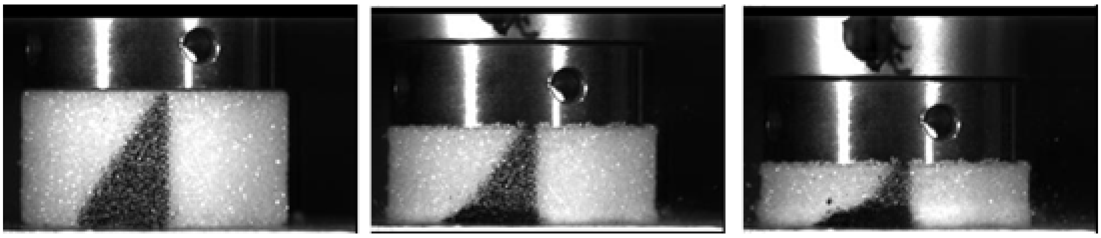

Figure 4. Illustration of local buckling during the crushing of a Rohacell 51A specimen

Section cuts of specimen crushed at different thicknesses and observed with a scanning electron microscope allowed understanding the microscopic phenomena leading to this macroscopic behavior.

During the elastic part, the edges of the foam bend. The plateau phase corresponds to the progressive collapsing of cells edges by elastic buckling and finally the densification phase appears when the cells are totally crushed and thus the edges enter in contact. The behavior of the foam at this stage is similar to the behavior of the constitutive material of the foam.

2.3 Shear tests

One of the stress / strain curves obtained during a shear test on Rohacell 51A is given in Figure 6. It highlights a slightly non linear elastic behaviour at the begining followed by a decreasing stress corresponding to failure. Actually, once reached a given strain (around 0,03 on the curve given) the edges of the constitutive cells of the foam start to break under tensile loading at the border of the specimens. A crack then propagates through the bloc. The residual stress is mainly due to the friction between the to slips of the crack.

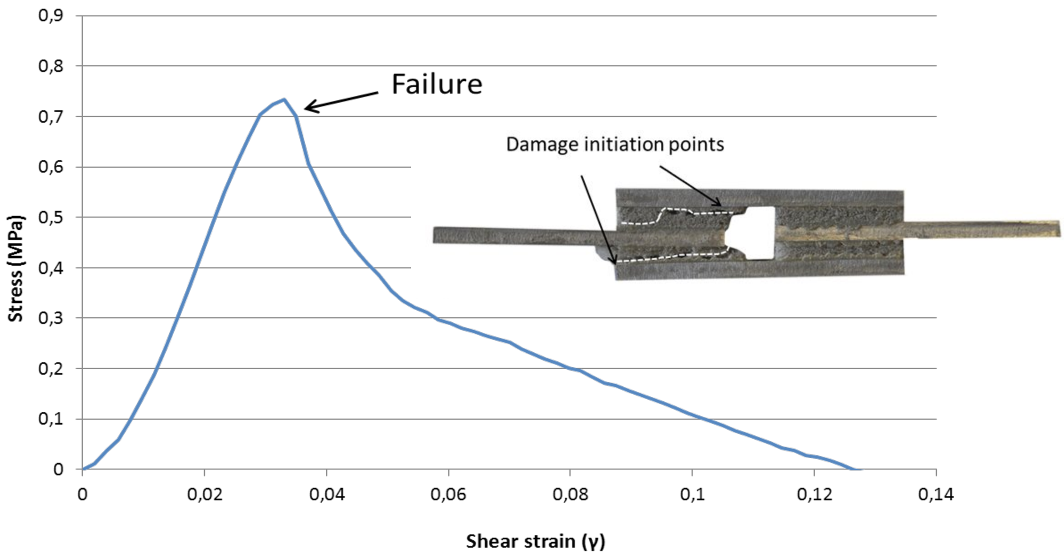

Figure 6. Stress / strain curve for a shear test on a Rohacell 51 A specimen

2.4 Indentation tests

Figure 7 illustrates the damage mechanisms occurring during indentation tests with a permanent deformation under the indenter and a densified zone deeper in the material.

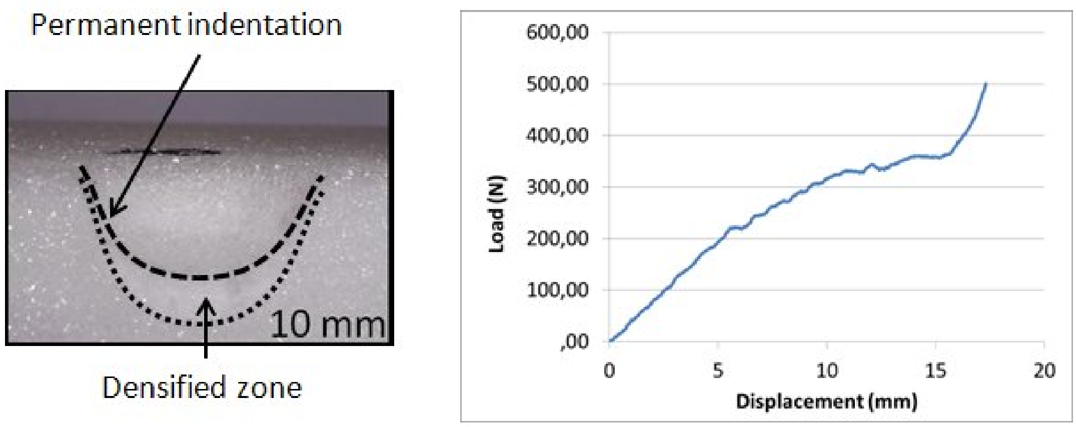

Figure 7. Indentation and densified zone in indented Rohacell 51A specimen

In these last tests, the response of the specimen is driven by a competition between the pure compressive behaviour (under the indentor) and the pure shear behaviour (at the surface).

2.5 Conclusions from the experimental study

It has been showed by the experiments that the behavior of Rohacell 51A is driven by two local phenomena: the local buckling of the edges which leads to the complete collapse of the cells and local brittle failure of the edge in tension (when shear occurs).

2 Numerical study

So as to represent the microscopic failure modes, it has been chosen to model the foam at the scale of the cell. The calculations are made with the explicit finite element code RADIOSS.

2.1 Choice of a reference solid

The first step for our model is to choose a cell geometry that can pave the space. It has been shown notably by Gibson and Ashby [3] that there is no regular polyhedron (Platonic solid) that can pave the 3D space, except cubes and tetrahedron, which does not fit the spherical shape of our foam cell.

However, authors like Bourret *et al.* [4] proposed to distort the pentagonal faces of a regular dodecahedron to allow it to mesh the space.

The possibility to use non-regular polyhedron to pave a given space has been investigated, notably by Thomson [5,6], who proved that a tetrakaidecahedron (or truncated octahedron), could mesh the space while having a unique edge size. Laroussi [6] showed that this solid is representative of foam cells, which has been verified by micrographies on Rohacell specimens (Figure 8).

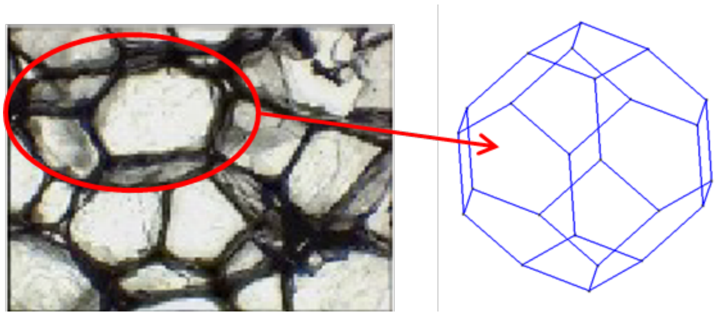

Figure 8. Microscopic observation of Rohacell 51 A and a tetrakaidecahedron

The lengths and the sections of the edges has been measured on numerous cell micrographies and a statistical study performed on the collected data in order to feed a Gauss distribution law. The results are given in Table 1.

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	Length (mm)	**Area (mm²)**
Average value	0.14	$3.0e^{-4}$
Standard deviation	0.049	$1.5e^{-4}$

Table 1. Statistical data on geometrical specificities of Rohacell 51A

2.2 Construction of a virtual specimen

From these data, virtual specimen are generated from a reference cell in three steps (Figure 9):

- the cell is duplicated until it fills a given space (Figure 9 a)
- the mesh is disrupted according to the Gaussian distribution (Figure 9 b and Table 1)
- the disrupted mesh is s to the shaped of the virtual specimen (Figure 9 c)

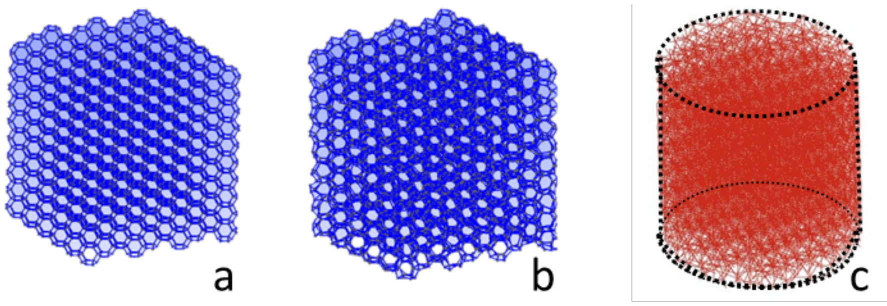

Figure 9. Virtual specimen creation

2.3 Choice of the constitutive material

The edges are modeled using beams in order to allow their bending. In terms of material behavior, the bars of the cells are attributed an elastoplastic behavior in compression in order to mimic the buckling of the edges of the cells. In tension, the elastoplastic behavior is associated with a simple brittle failure criterion to deal with failure.

Calculation made with trusses proved that rotation at the intersection nodes allowed by beams was compulsory to transmit forces and moments into the model.

The section of the beams is calculated to equivalence the mass of the specimen to the sum of all the masses of the beams of the model. Density, Young modulus and tensile failure strain are given by the material properties of the constitutive polymer of the foam (Table 2). The plastic yield strength is given by the elastic buckling limit of the beam for a bi-rotulated boundary condition.

	Constitutive material	**Rohacell 51A**
Density (kg.m^{-3})	1200	51
Young Modulus (MPa)	3200	15
Plastic yield stress (MPa)	30	-
Tensile failure strain (%)	3	-

Table 2. Material characteristics for PMI [7]

2.4 Numerical simulations

Results from a compression calculation performed on a 10 mm high, 10 mm radius specimen are presented in Figure 10. A good correlation is achieved on the whole response of the specimen. Moreover, the failure is, as observed in experiments, the consequence of the buckling of the edges (plastification in the model) which initiates in a thin layer and then propagates to the whole block of foam.

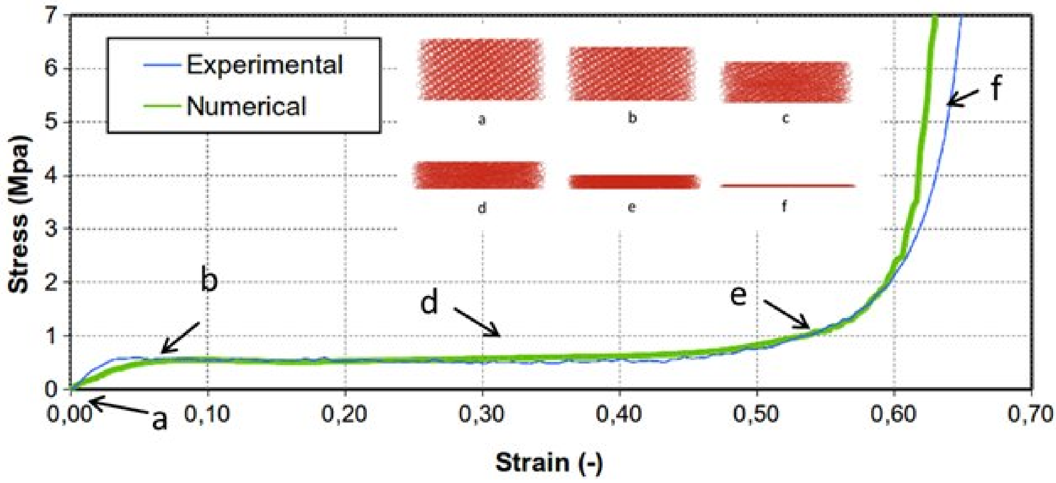

Figure 10. Stress / strain curve for model and experimental results and visualization of the model

In what concerns shear now, a stress versus strain curve is plotted on Figure 11. for a block specimen of dimensions 5x20x20mm of Rohacell 51A foam. As for compression load case, the model is in good agreement with the experimental results on both qualitative - failure modes - and quantitative aspects. As expected, the model highlights the drawback of this specimens: its corners loaded in tension.

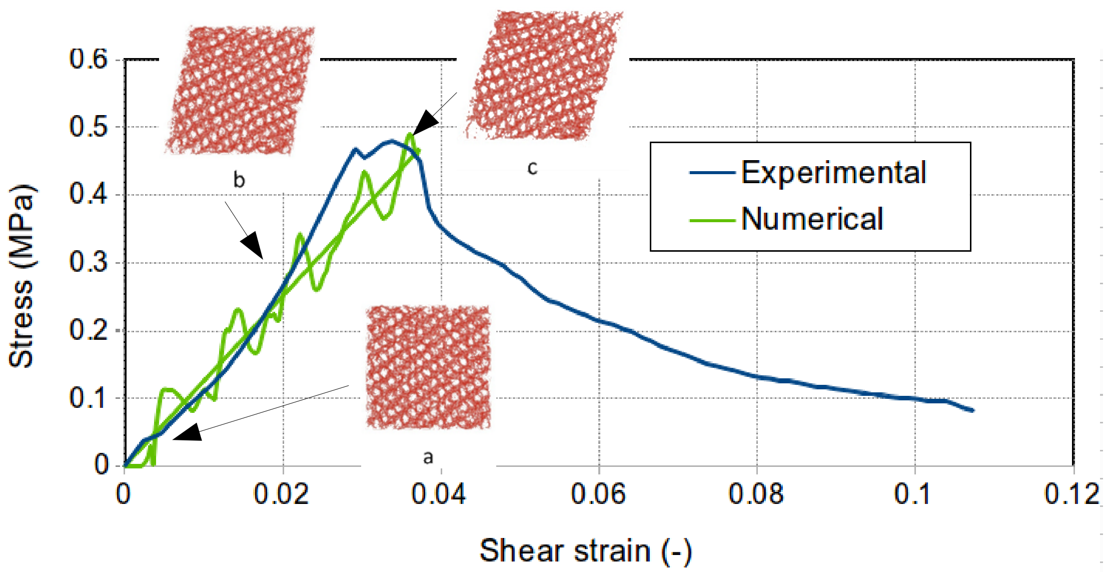

Figure 11. Stress / strain curve for model and experimental results and visualization of the model

Last, Figure 12. presents the accumulation of material under the indentor and the tensile edge breakage on the perimeter of the indentor obtained for a feasability calculation.

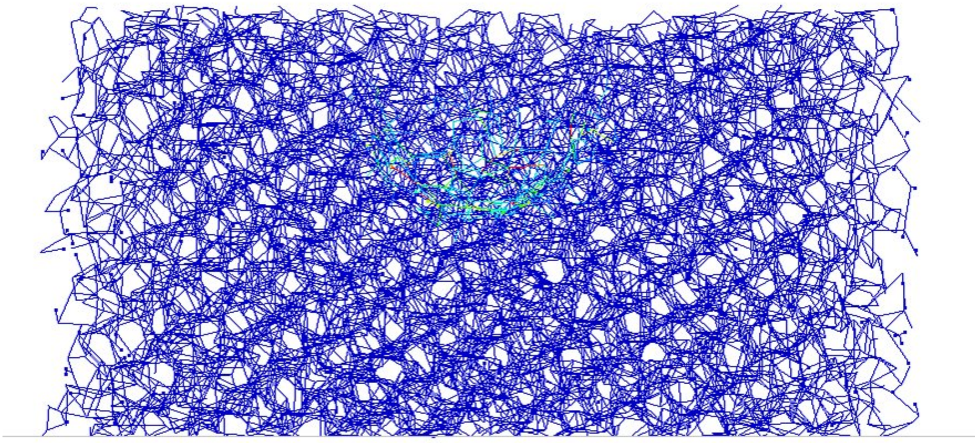

Figure 12. Failure kinematics of a specimen under indentation - feasability model

3 Conclusion

In this paper a microscropic approch has been proposed for the modelling of open cells polymeric foams. At this scale, four major phenomena have been identified: the elastoplastic mechanical behaviour of the polymeric material, the buckling, the brittle failure in tension and the contact of edges of the cells. These four phenomena have appeared to be sufficient to explain the failure scenari of whole blocks of foam under various macroscopic loadings.
The model based on this observations has given satisfactory results for compressive, shearing and indentation simulations. The chronologies of the failures of the specimens have been well represented and
Now, the possibility to make a change in the size of the cells without loss of physical meaning seems to be the major prospects of this work.

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