AFRL-ML-WP-TR-2000-4062

COMPOSITE MATERIALS FOR ADVANCED GLOBAL MOBILITY CONCEPTS

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APRIL 2000

INTERIM REPORT FOR 09/15/98-09/14/1999

PUBLIC RELEASE; DISTRIBUTION UNLIMITED

MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7734

REPORT DOCUMENTATION PAGE

1. REPORT DATE (DD-MM-YYYY) 01-04-2000	**2. REPORT TYPE** Interim Report	**3. DATES COVERED (FROM - TO)** 15-09-1998 to 14-09-1999

4. TITLE AND SUBTITLE Composite Materials for Advanced Global Mobility Concepts Unclassified	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Han, K. K. ; Anderson, D. P. ;	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME AND ADDRESS University of Dayton Research Institute 300 College Park Avenue Dayton , OH 45469-0168	**8. PERFORMING ORGANIZATION REPORT NUMBER** UDR-TR-1999-00100
9. SPONSORING/MONITORING AGENCY NAME AND ADDRESS Materials and Manufacturing Directorate Air Force Research Laboratory Air Force Materiel Command Wright-Patterson AFB , OH 45433-7334	**10. SPONSOR/MONITOR'S ACRONYM(S)** AFRL/MLBC
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-ML-WP-TR-2000-4062

12. DISTRIBUTION/AVAILABILITY STATEMENT
A
PUBLIC RELEASE

Materials and Manufacturing Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson AFB , OH 45433-7334

13. SUPPLEMENTARY NOTES

14. ABSTRACT

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finite-element analysis; graphitic foams; mechanical properties; porosity; processing

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT** Public Release	**18. NUMBER OF PAGES** 14	**19a. NAME OF RESPONSIBLE PERSON** Fenster, Lynn lfenster@dtic.mil
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified			**19b. TELEPHONE NUMBER** **International Area Code** **Area Code Telephone Number** 703 767-9007 **DSN** 427-9007

NOTICE

This technical report has been reviewed and is approved for publication.

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Materials and Manufacturing Directorate

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. AGENCY USE ONLY (Leave blank)	**2. REPORT DATE** April 2000	**3. REPORT TYPE AND DATES COVERED** Interim Report for 09/15/98 - 09/14/99

4. TITLE AND SUBTITLE

COMPOSITE MATERIALS FOR ADVANCED GLOBAL MOBILITY CONCEPTS

5. FUNDING NUMBERS

C: F33615-95-D-5029
PE: 61102
PR: 4347
TA: 34
WU: 10

6. AUTHOR(S)

K. KEN HAN AND D. P. ANDERSON

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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DAYTON, OH 45469-0168

8. PERFORMING ORGANIZATION REPORT NUMBER

UDR-TR-1999-00100

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Materials and Manufacturing Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7334
POC: L. SCOTT THEIBERT, AFRL/MLBC, 937-255-9070

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

AFRL-ML-WP-TR-2000-4062

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APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

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15. NUMBER OF PAGES

14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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FOREWORD

This report was prepred by the University of Dayton Research Institute under Air Force Contract No. F33615-95-D-5029, Delivery Order No. 0006. The work was administered under the direction of the Nonmetallic Materials Division, Materials and Manufacturing Directorate, Air Force Research Laboratory, Air Force Materiel Command, with Dr. James R. McCoy (AFRL/MLBC) as Project Engineer.

This report was submitted in December 1999 and covers work conducted from 15 September 1998 through 14 September 1999.

1. INTRODUCTION

The extraordinary mechanical properties of carbon fibers are attributed to the preferred orientation of graphite crystallites with the fiber axis. This crystallite orientation is achieved through alignment of the precursor molecules by fluid forces in the capillary spinnerets, followed by conversion to graphite in various thermal treatment steps. Via mechanical placement of the fibers, advanced composites exploit the fiber properties by incorporating them as a disconnected reinforcing network in a solid matrix phase.

A novel form of carbon consisting of an open-celled foam has been produced in our laboratory for the last several years. While processing and testing of these foams has continued, there is still a need to accurately model the processing and property development. Earlier work on the process modeling suggested that the maximum amount of shearing, and hence the maximum amount of alignment of the graphitic structure, resulted at high degrees of porosity *[1]*. Other characterization work showed that the foam structure can be modeled as tetrahedral struts *[2]*.

For the model used in the current work, the vertices of a tetrahedron are defined as the center points for spherical bubbles. The faces of the tetrahedron then become the center points of the struts connecting to the next strut in the foam. By keeping the volume of the solid left behind constant as the spheres expand into the tetrahedron, the final shape is obtained. While this specific geometry is known to not be volume filling, it does represent the observed strut juncture (or node) morphology and produces solids similar to other models which are space filling.

The growth of the model foam structure can be seen in Figure 1. Note the foam changes from a closed-cell form to an open-celled foam at the 77 percent level. One can also

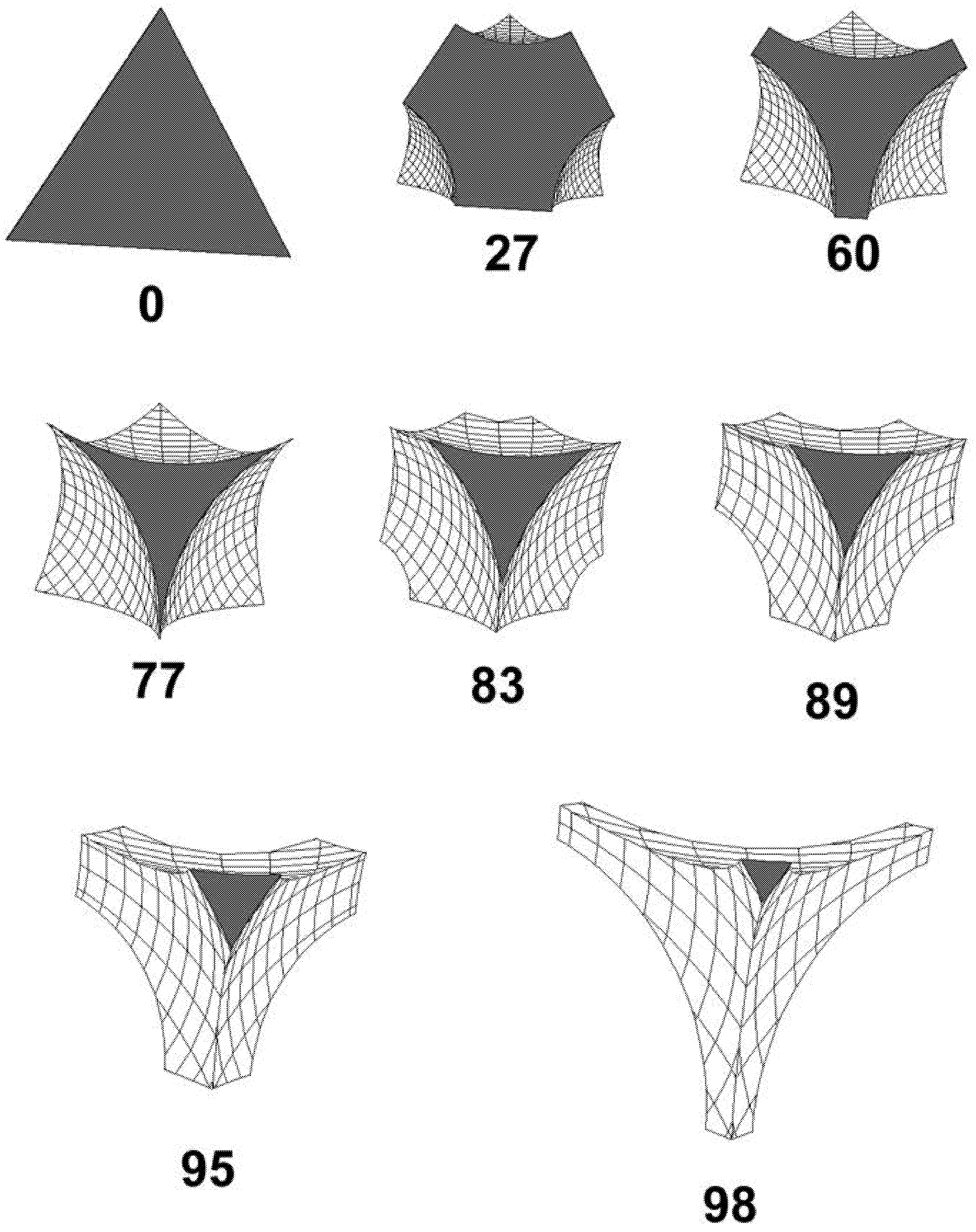

Figure 1. A Series of Tetrahedral Strut Sections Left behind as Spherical Bubbles Grow at the Tetrahedron Vertices. Note the numbers under the strut sections refer to the foam porosity level.

see the significant changes in the bubble surface area at high degrees of porosity corresponding to the high strain levels predicted in earlier work and shown in Figure 2.

While the previous studies were useful in predicting observed bubble morphology and the strain at the center of the growing strut, they could not predict the strains in all locations. They were also of no use in modeling the mechanical behavior of the strut. It was this last limitation which inspired the current work which has occupied the last year of this effort.

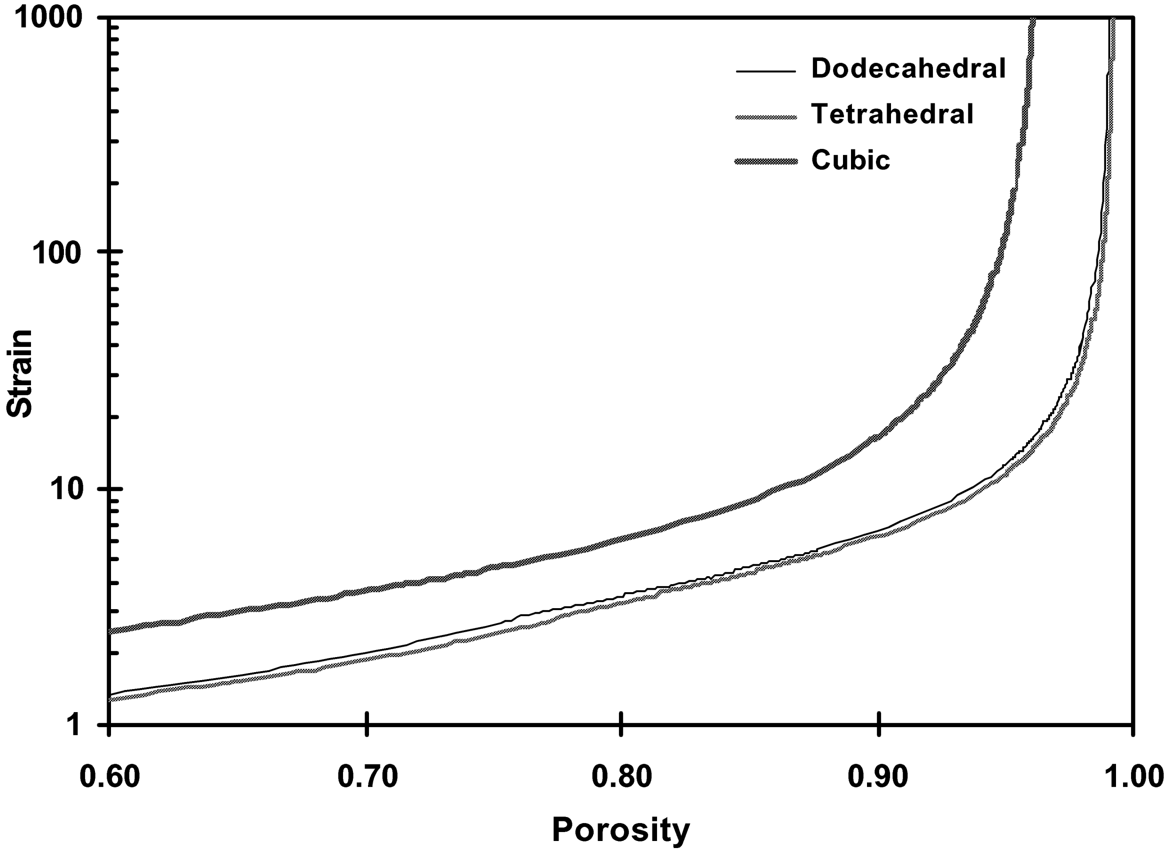

Figure 2. Strain Prediction at the Strut Centers of the Tetrahedral (and other Models) Strut Growth.

2. MICROMECHANICS ANALYSIS WITH FEM FOR CARBON FOAM

Considerable effort has been required to generate the mesh needed to perform the finite-element (FE) analysis for carbon foam. For the method developed in-house, a computer code to generate 3-D meshes for carbon foam was developed. The current software, such as PATRAN, IDEAS, etc., was not able to generate meshes for the carbon foam because of the complex shape of the foam. In developing the code, the voids in the foam were assumed as uniform sizes with spherical shapes. The representative volume element (RVE) was considered as a tetrahedron. The region of the mesh generation is the solid part of the foam, that is, the residual volume from the tetrahedron when the four spheres grow at its four vertexes. Therefore, the region of mesh generated is enclosed with four planes originally with a triangle shape and four partial spheres. Figure 3 shows the mesh generation region.

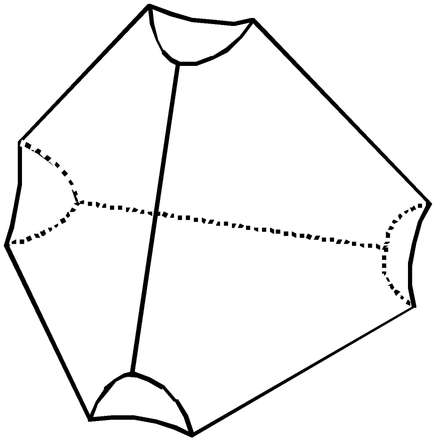

Figure 3. RVE of Foam.

During manufacturing of the carbon foam, when temperature, pressure and the time to release the pressure change, the void sizes will also change according to experimental results and process analysis. Therefore, the RVE shape and size will also change to reflect the bubble growth changes (Figure 4).

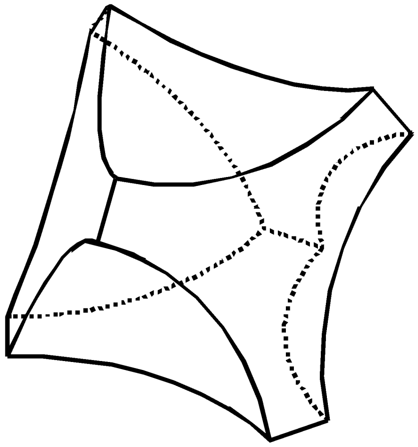

Figure 4. RVE with Bigger Void Size.

In the last case analyzed to date, the four spheres are tangent with each other, and the porosity of foam is at the point of changing from closed cell to open cell. In this case four planes and partial spheres construct the lateral sides of the region. One plane is taken as the bottom, and partial sphere is taken as the top of the region (Figure 5).

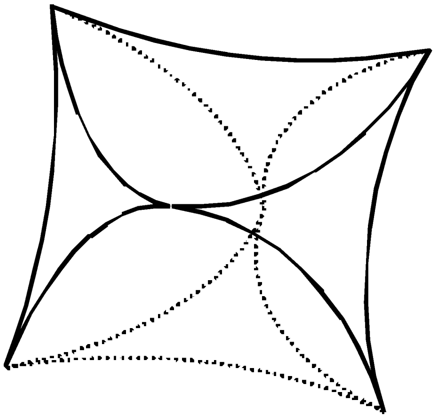

Figure 5. RVE Shape at the Border between Closed- and Open-Celled Morphology.

To implement boundary conditions on the curves of the region, 3-D hexahedron isoparametric elements are generated in the region. According to the geometry, the whole region is divided into six subdivisions. In each subdivision, two-layer elements will be generated. In this way only a few elements are needed to implement the boundary conditions on the complex curves. The computer code to generate 3-D meshes for carbon foam with the porosity shown in Figure 5 was completed. In an RVE 12 isoparametric elements with 95 nodes were generated. Figure 6 shows the elements and nodes. Figure 7 shows the RVE shape that was plotted with MatLab using the finite element data generated from the code. The code for the mesh generation in other cases will be finished soon.

The results shown in this report are limited and do not reflect the enormous effort required for mesh generation. Analysis based on the meshes produced will be much more useful and the data are apparently easily obtained.

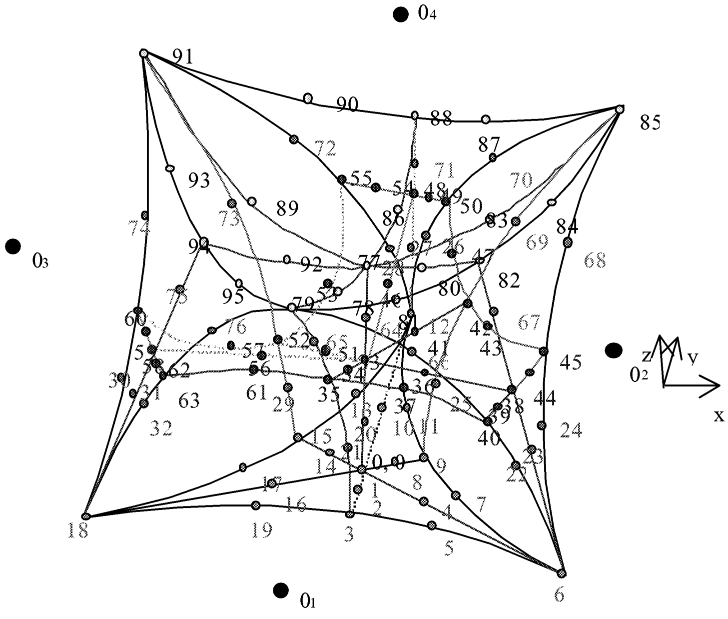

Figure 6. Nodes and Elements in an RVE at the Maximum Porosity of Carbon Foam.

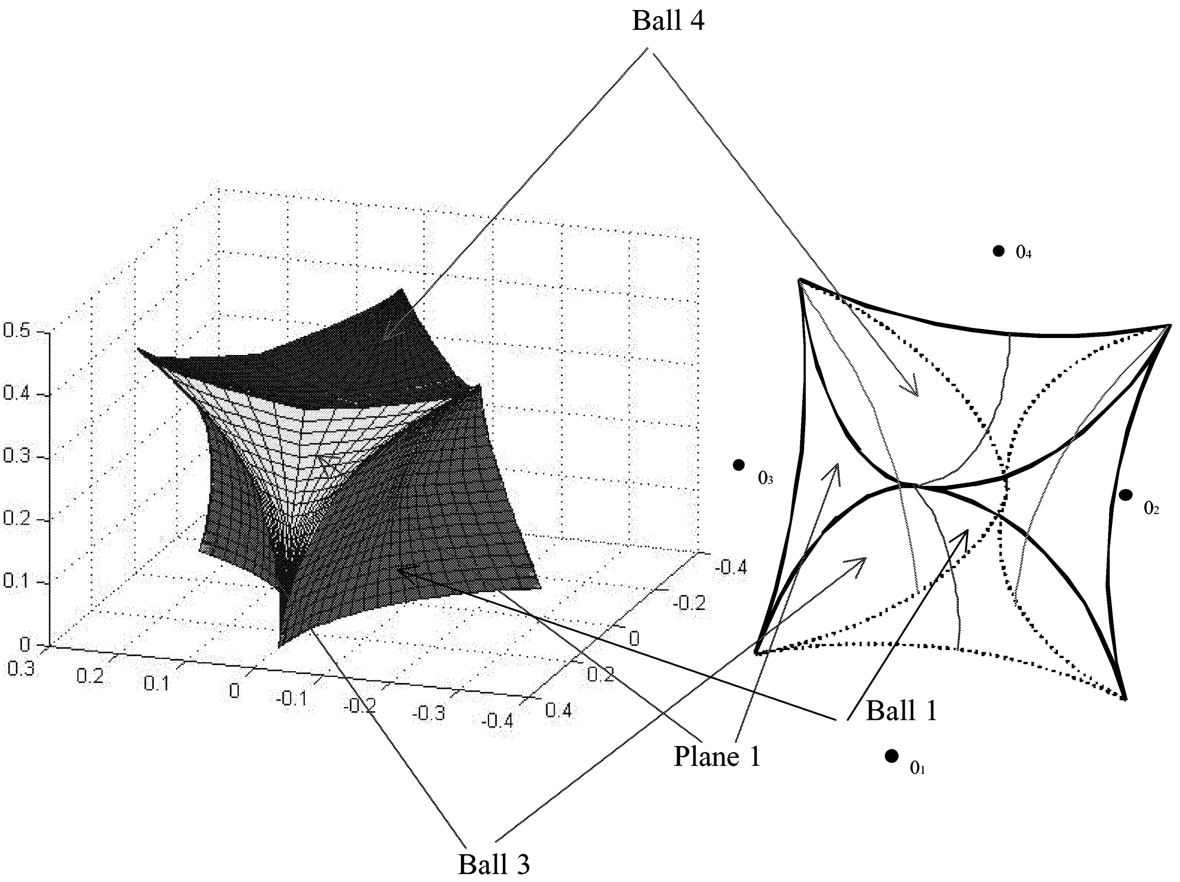

Figure 7. RVE Generated with Data from the Developed Code.

3. CONCLUSIONS

The state-of-the-art commercial software packages for FE mesh generation were found to be inadequate to handle the complex geometry of the growing foam morphology. A model of the foam, based on spherical bubbles growing at the vertices of a tetrahedron and the faces of the tetrahedron forming the midplane of the struts, was used. The in-house programming effort generated the meshes for FE of the combination of changing flat and curved surfaces for some of the models. Additional mesh models representing other levels of porosity are currently being produced.

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