International Journal of Mechanical Sciences 92 (2015) 90–97

Contents lists available at ScienceDirect

International Journal of Mechanical Sciences

journal homepage: www.elsevier.com/locate/ijmecsci

Analysis of mechanical properties of wire mesh for mesh reflectors by fractal mechanics

Tuanjie Li*, Jie Jiang, Tingting Shen, Zuowei Wang

School of Electromechanical Engineering, Xidian University, P.O. Box 188, Xi'an 710071, China

ARTICLE INFO

Article history:
Received 8 September 2014
Received in revised form
19 October 2014
Accepted 1 November 2014
Available online 15 December 2014

Keywords:
Wire mesh
Fractal mechanics
Orthotropic
Self-similarity
Fractal characteristics
Mesh reflector

ABSTRACT

The knitted wire mesh is often used as a reflecting surface of large deployable antennas. Because different wire meshes have different electrical properties, it is very important and necessary to research the analysis method of mechanical properties of wire meshes. The mechanical analysis of the wire mesh is very difficult because of the complex structure and the nonlinear size effect. This paper has put forward a fractal mechanics method for the wire mesh to derive the stiffness of mesh reflectors in modeling of mechanics applications. First, the fractal characteristics of the knitted wire mesh are revealed according to the fractal geometry theory. Then, the elastic performance parameters of the small-scale wire mesh are obtained in the form of the orthotropic plane stress structure by the finite element method. For the fractal structure of the wire mesh, the stiffness matrix of the large-scale wire mesh is completely determined by the elastic parameters of the small-scale wire mesh. The two-bar tricot mesh is used as examples to illustrate the method of the fractal mechanics analysis of wire meshes for mesh reflectors.

1. Introduction

Deployable mesh reflectors have broad application areas such as satellite communications, remote sensing, deep space explorations, and earth observations, etc. These reflectors often use knitted wire meshes to reflect electromagnetic waves. The application of the mesh surface provides a deployable capability which is very attractive from launch constraints for spacecraft requiring large antennas, such as TDRSS and Galileo spacecraft. These mesh surfaces are typically constructed from gold-plated molybdenum wires which are woven in a particular pattern. The ultimate performance of these antennas greatly depends on how well the mesh surface performs as a good reflecting surface at operational frequencies.

Space mesh reflectors are made of the metallic mesh which should meet some requirements of the mechanical property, the microwave electrical property, the collapsible and wrinkle resistance properties, the anti-bulking property and the light transmission property. Many factors affect microwave electrical properties of the wire mesh, such as material properties and weave structures. Mesh materials include stainless steel, the molybdenum and tungsten with the gold-plated or nickel-plated surface [1]. The different weaving structures have different mechanics properties which decide on its electrical properties [2]. It is very important and necessary to research the method for analyzing mechanics properties of different weaving structures.

To the author's knowledge, few researches have been done for the wire mesh which is an important part of deployable mesh reflectors. Due to the wire mesh structure with millions of tiny holes per square meter, it is impossible to establish the flexible multi-body dynamic model. Thus, the analysis of mechanics properties of the wire mesh structure faces huge challenges. The bi-axial tensile test indicated the mechanics of the woven wire mesh structure has the strongly orthotropic characteristics [3]. Then it is essential to determine orthotropic elastic parameters of the wire mesh structure. For the orthotropic composite structures, two-dimensional orthotropic material parameters were identified based on the boundary element method [4,5]. Referencing to the composite parameter identification technique, this paper develops the mechanics equivalent method for the wire mesh to obtain equivalent elastic parameters of the plane orthotropic stress structure. The stiffness matrix of the large-scale wire mesh is completely expressed as the function of elastic parameters of the small-scale wire mesh based on fractal mechanics.

The wire mesh structure is a self-similar fractal which is geometrically stable in the sense that, when generated by a recursive copying process that starts from a basic building block, their final image depends only on the recursive generation process rather than the shape of the original building block. Self-similarity is one of fractal basic characteristics. The self-similar fractal can be divided into two categories: the strictly self-similar fractal and the approximately self-similar fractal. The strictly self-similar fractal is that the

---

* Corresponding author. Tel.: +86 29 88202470; fax: +86 29 88203040.
E-mail address: tjli888@126.com (T. Li).

http://dx.doi.org/10.1016/j.ijmecsci.2014.11.023
0020-7403/

generated graphics are according to the certain mathematical law, such as, the Koch curve and the Sierpinski carpet. Different from the strictly self-similar fractal, the approximately self-similar fractal is a statistical self-similarity or approximate self-similarity fractal. Each part and the whole of the fractal structures in nature, such as rivers, coastline, trees and clouds, have the self-similarity. This kind of the self-similarity is the statistical self-similarity not the mathematically strict self-similarity. The approximately self-similar fractal is abstracted from a lot of statistics. In general, the perimeter–area model in the fractal geometry is used to describe the irregular geometric features of the self-similar objects. When the logarithms of the perimeter and area of many small structural elements forming the structure are linear, this structure is regarded as an approximate fractal structure.

At present, the fractal theory has been widely used in the fields of mathematics, physics, chemistry, mechanics, and computer science, etc. Oshmyan et al. studied the elastic properties of two-dimensional continuous composites of fractal structures and calculated the effective elastic modulus of Sierpinski-like carpets [6]. But they did not involve the size effect of elastic properties. Epstein and Sniatycki used an extended form of the principle of virtual work to define the concept of the generalized force and stress, and introduced an appropriate integration based on the Hausdorff measure, and applied it to the numerical formulation of stiffness matrices of some common fractals [7]. Epstein and Adeeb presented a method to derive the stiffness of self-similar elastic fractals based on the structural mechanics principle and a physically motivated similarity criterion [8]. Adeeb and Epstein [9] showed that for the elastic structures, the stiffness form of fractals depends on generation processes rather than on numerical values of stiffness coefficients of the building block, as long as it is isotropic. Up to now, the research on the fractal mechanics of the wire mesh has not been described.

This paper begins with the fractal characteristics analysis of the wire mesh structure, and presents a method to identify the equivalent elastic parameters of the small-scale wire mesh based on the finite element method. Then, the mapping relation of mechanics between the wire mesh structure and the Sierpiński carpet is established. The stiffness matrix of the wire mesh structure is derived from the fractal mechanics analysis and equivalent elastic parameters. Finally, elastic parameters and stiffness matrix of the two-bar tricot mesh are identified and derived to illustrate the feasibility of the fractal mechanics method for the wire mesh of mesh reflectors.

2. Wire mesh structure

Large deployable antennas often use the knitted wire mesh as the reflecting surface. The wire mesh of reflectors is made of two or three wires of tungsten or molybdenum to twist together. The overcoat covering each micro-wire is made of gold lay over an intermediate layer of the nickel. Fig. 1 gives an expanded view of the mesh sample [10]. This paper takes the two-bar tricot wire mesh [11] as an example. The knitting pattern and simulation model are shown in Fig. 2.

3. Analysis of fractal characteristics of wire mesh structure

3.1. Fractal characteristics of wire mesh structure

Based on the perimeter–area model of the fractal geometry [12], the perimeter and area of slit islands constituting the fractal structure satisfy the power law [12]

$$P_{SI} \sim A_{SI}^{c/2} \tag{1}$$

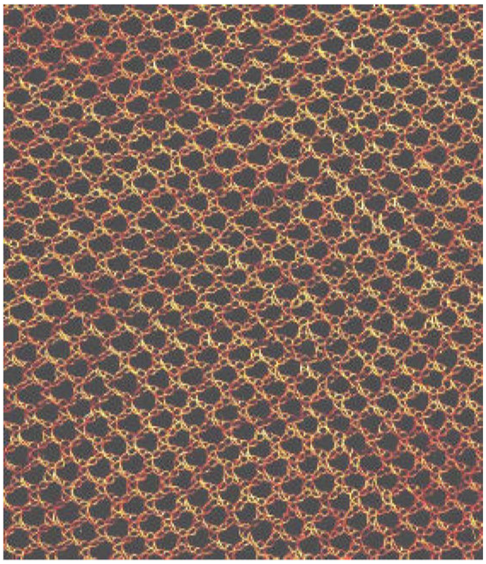

Fig. 1. Expanded view of mesh sample [10].

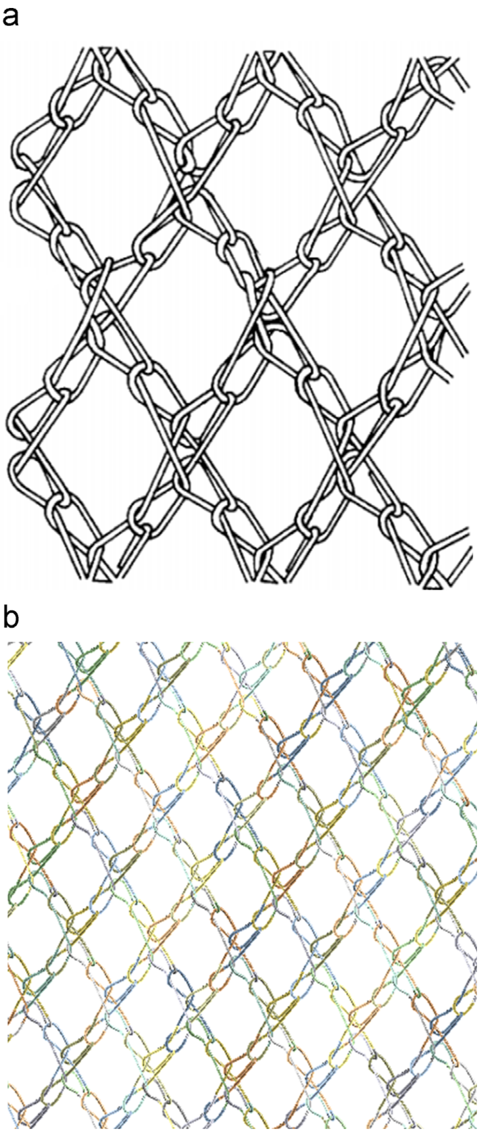

Fig. 2. Two-bar tricot mesh. (a) Two-bar tricot [11]; (b) Simulation model.