ISSN: 2472-3703 DOI: 10.6911/WSRJ.202011_6(11).0022

Research on Controllable Porous Structure based on TPM

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Abstract

In this paper, a design method of porous structure based on three period minimal surface is introduced. The three period minimal surface expressed by implicit function is used as the basic pore unit to construct micro porous structure. The distance function and log-sigmoid function are defined, The parameters such as pore shape, pore size, specific surface area and porosity of the porous element can be effectively controlled, and the performance of the designed porous structure can meet the ideal requirements.

Keywords

Porous structure design, three period minimal surface, effective parametric control.

1. INTRODUCTION

Porous material is a kind of material containing a large number of pores, and the pores are used to meet some or some design requirements to achieve the desired performance index. It has a wide range of applications. At present, most of them are inorganic gas capsules, porous semiconductors, porous metal materials, etc., which have the common characteristics of low density, high porosity and large specific surface area [1, 3]. Porous materials are widely used in mechanical engineering, chemical engineering, biomedical engineering, geological research and energy science due to their special structure.

In the traditional design methods of porous structure model, there are geometric method of constructing solid and reverse method of medical image.

Chean et al. [4] based on the established volume model library, the 3D combination of the model was carried out by parameterization method to realize the construction of porous structure body, and the final porous implant was obtained by Boolean operation with the contour model; Wetter et al. [5] designed the building block type hexahedral porous structure unit by using the method of structural solid geometry, and then formed different forms of porous structure unit by combining the elements; Based on the layered theory, starlya et al. [6] proposed a construction method of element accumulation body, which used the structural entity to construct the micro element, so as to realize the structural body construction of different pore size units in different regions; Sun et al. [7] constructed the porous element library based on the geometric method of structural entity, and characterized the porosity and axial stiffness of the model; Li Limin et al. [8] established a micro porous structure unit model by means of computer-aided design, and converted it into a negative model and a solid model in space to carry out Boolean operation to obtain the three-dimensional porous structure model of the target. Although the above design methods have been widely used in the construction of porous structure model, it can not effectively control and evaluate the structural performance and mechanical parameters of the model, resulting in no reference rules for the model construction process. Based on this, this paper proposes a design method of porous structure based on three period minimal surface. The TPMS expressed by implicit function is used as the

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basic pore unit to construct the micro porous structure. By defining the distance function and log-sigmoid function, the TPMS unit models with different structures are constructed, and the ideal porous structure model is constructed.

2. UNIT DESIGN OF POROUS STRUCTURE

Three dimensional periodic minimal surface [9,12] (TPMS) is a kind of surface which shows periodic changes in three independent directions in three-dimensional space. One of the characteristics of the surface is that the average curvature of any point on the surface is zero. It can extend infinitely periodically in three independent directions. It can approximately simulate and express many physical structures, such as soluble colloids, silicates, etc., and can give a simple mathematical expression for these physical structures. At present, there are many mathematical methods to generate the three-dimensional periodic minimization surface, the periodic surface of parametric TPMS is generally defined as:

$$\phi(\mathrm{r}) = \sum_{k=1}^{k} A_k \cos[2\pi(h_k \bullet r)/\lambda_k + p_k] = C$$

Where r is the position vector in Euclidean space, Ak is the amplitude factor, hk is the kth grid vector in the derivative space, λk is the periodic wavelength, pk is the phase displacement, and C is a constant.

Among the implicit surfaces represented by trigonometric periodic functions, the most common ones are p-surface, d-surface and g-surface [13,15], the expression is as follows:

$$P:\phi(r) = cos(2\pi x) + \cos(2\pi y) + \cos(2\pi z) = 0$$

$$D:\phi(r) = \cos(2\pi x)\cos(2\pi y)\cos(2\pi z) - \sin(2\pi x)\sin(2\pi y)\sin(2\pi z) = 0$$

$$G:\phi(r) = \sin(2\pi x)\cos(2\pi y) + \sin(2\pi y)\cos(2\pi z) + \sin(2\pi z)\cos(2\pi x) = 0$$

In order to obtain more abundant and complex porous structural elements, a function or constant is usually added to the implicit surface function. Taking p-surface as an example, a new p-surface is formed by adding distance constant t into its constructor, then the structural equation can be expressed as follows:

$$\phi(\mathrm{r}) = \cos(2\pi x) + \cos(2\pi y) + \cos(2\pi z) = t$$

The porous structure models with different porosity are obtained by changing the value of distance constant t. the ideal porous element model is finally obtained by adjusting the value of distance constant t. When the value of t is less than a certain value, it will cause discontinuity of the surface and produce cavities; when t is greater than a certain value, it will lead to surface interference. In particular, when t = 0, the surface defined by implicit function is called minimal surface, which means that the surface area reaches the critical value under normal variation, that is, the surface with zero mean curvature. The surface divides its space into two equal parts, so the porosity of porous structure defined by minimal surface is 50%. In the implicit function, by changing the value of constant term t, the volume fraction of solid object defined by the surface can be changed (also known as porosity for periodic structure). As shown in Fig. 1, it shows the structure of p-surface represented by implicit function when the distance constant t is 0.8, 0, - 0.8 in MATLAB.

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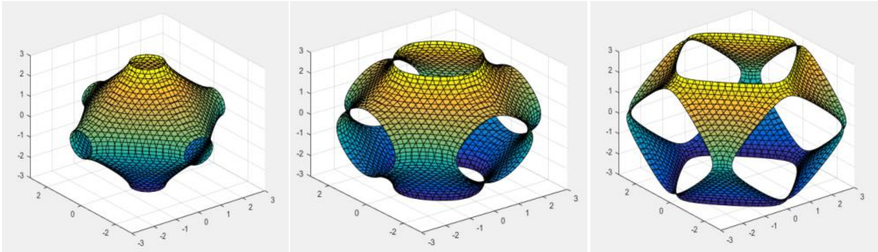

Fig 1. Different structural forms of p-surface represented by implicit function when the distance constant t is 0.8, 0, - 0.8 respectively

In MATLAB software, input P structure, using marching cube algorithm to display TPMS unit, extracting equivalent surface from implicit surface represented by implicit function, so as to extract corresponding STL solid model, and then in Geomagic studio Thicken in studio software, control model size is 50 mm × 50 mm × 50 mm, porosity is 70%, 80%, 90%, through the "accurate surface" command, form CAD entity, export STP format (CAD file format, for model post-processing), STL format (triangle mesh file format, for rapid prototyping printing), as shown in Figure 2.

Fig 2. P structure with 70%, 80% and 90% porosity

3. POROUS STRUCTURE MODELING BASED ON TPMS FUSION

In order to achieve a more ideal porous structure model, different elements need to be spliced together. In this paper, the log-sigmoid function [16, 17] is used for feature fusion of multi-class porous elements in a certain direction. This method is used as a bridge to realize the effective blending of different element structures in a model.

Log sigmoid function: $\mathrm{f}(x,a,c)=\dfrac{1}{1+e^{-a(x-c)}}$

In order to avoid the mutation in the model, the discontinuous change of the structure in the model is realized by adjusting the parameters of the function (a and c in the formula). Suppose there are two kinds of TPMS units φ1 and φ2, φ1 is on the right side of the model and φ2 is on the left side of the model. If the fusion is carried out in the X direction, the starting position is f (x0, y, z) = 0, and the ending position is f (x1, y, z) = 1,the fused surface model can be defined as:

$$\Phi\,(x,y,z)=\frac{1}{1+e^{-a(x-c)}}\phi_1(x,y,z)+(1-\frac{1}{1+e^{-a(x-c)}})\phi_2(x,y,z)$$

Through the construction of continuous function, we can effectively realize the splicing of two TPMS functions. In this paper, let c = 0 in the above formula, and change the gradual change rate by adjusting the value of a. the larger the value of a, the greater the mutation rate of the model. φ1 and φ2 represent two different base surface functions.

In order to verify the effectiveness of the design method, this paper selects two different TPMS elements and uses the log sigmoid function method to construct an ideal porous structure. As shown in Fig. 3, the surface model of P-G structure composed of P-element and g-element and the 3D solid model after surface thickening (a = 2, c= 0 in the fusion formula).

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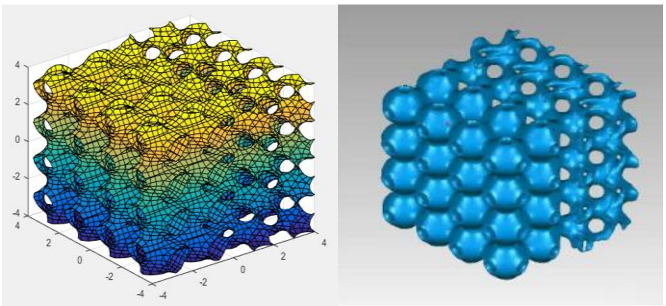

Fig 3. Surface model and solid model of P-G porous structure

4. CONCLUSION

In this paper, based on the TPMS parameterized curved surface, the construction method of porous structure is studied. The TPMS is taken as the basic pore unit, and the TPMS expressed by implicit function is used as the basic pore unit to construct the micro porous structure. By defining the distance function and log-sigmoid function, the TPMS pore units with different structures are constructed by adjusting the model construction parameters, The pore shape, size, linear change rate and other structural characteristics of the porous model are changed to obtain an ideal porous structure model.

REFERENCES

[1] Shi Jianping, Yang Jiquan, Li Jingbo, et al. Modeling of heterogeneous materials and Research on digital droplet injection technology [J]. Journal of Nanjing Normal University (Engineering Technology Edition), 2012,12 (1): 10-14.

[2] Shi Jianping, Yang Jiquan, Wang Xingsong, status and trend of 3D printing technology for multi material parts [J]. Mechanical design and manufacturing process, 2017 (2): 11-17.

[3] Li Feng, Wang Chengtao. Determination of contact angle between articular cartilage and artificial joint materials [D]. Lubrication and sealing, 2009, 34 (8): 1-5.

[4] Luo L,Petit A,Antoniou J,et al.Effect of cobalt and Chromium Ions on MMP-l,TIMP-1,and INF-α gene expression in human U937 macrophages. A role for tyrosine kinases[J].Biomaterials,2005, 26(28):5587-93.4

[5] Rabe M,Verdes D,Seeger S.Understanding protein adsorption Phenomena at solid surfaces[J]. Advances in Colloid & Interface Science,2011,162(1):87-106.

[6] Hao Liang, Dai min, Shuai Lang, et al. Effects of wear products of artificial joint on TNF - α secretion by monocytes [J]. Chinese Journal of tissue engineering, 2007,11 (1): 67-69.

[7] Zheng J,Song W,Huang H,ct al.Protein adsorption and cell Adhesion on polyurethane/Pluronic surface with lotus leaf-like topography[J].Colloids Surf B Biointerfaccs,2010,77(2):234-239.

[8] Liu Wanjun, Li Bingzhe, Cao Yilin, et al. Biomimetic technology of tissue-engineered

[9] Wettergreen M A,Bucklen B S,Starly B,et al.Creation of a Unit block library of architectures for use in Assembled Scaffold engineering [J].Computer-Aided Design,2005, 37(11):1141-1149.

[10] Starly B,Lau W,Bradbury T,ct al.Internal architecture design and free form fabrication of tissue replacement structures[J].Computer-Aided Design,2006,38(2):115-124.

[11] Sun W,Starly B,Nam J,ct al.Bio-CAD modeling and its applications in computer-aided tissue engineering[J]. Computer-Aided Design,2005,37(11):1097-1114.

[12] Xu Jianzhong. Current situation and Prospect of bone tissue engineering products [J]. Journal of the Third Military Medical University, 2008, 30 (13): 1215-1218.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202011_6(11).0022

[13] Effects of Baifeng and internal structure of scaffold on vascularization of porous bioceramic artificial bone in vivo [D]. Fourth Military Medical University, 2007.

[14] Starly B,Lau W,Bradbury T,ct al.Internal architecture design and freeform fabrication of tissue replacement structures[J]. Computer-Aided Design,2006,38(2):115-124.

[15] Cheng Y L,Kikuchi N,Hollister S J.A novel method for biomaterial scaffold internal architecture design to match bone elastic properties with desired porosity [J]. Journal of Biomechanics, 2004, 37(5): 623-636.

[16] Hollister S J,Lin C Y.Computational design of tissue engineering scaffolds[J].Computer Methods in Applied Mechanics & Engineering, 2007, 196(31-32): 2991-2998.

[17] Cheah C M,Chua C K,Leong K F,ct al.Development of a Tissue Engineering Scaffold Structure Library for Rapid Prototyping. Part 1: Investigation and Classification[J].International Journal of Advanced Manufacturing Technology, 2003, 21(4): 291-301.