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Mathematical Filtering of TPMS Structure for Enhanced Flow Characteristics

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TPMS (triply periodic minimum surface) refers to a periodic surface that extends infinitely through three independent axes, represented by trigonometric functions and with an zero average curvature. Recently, additive manufacturing studies have shown increased interest in TPMS due to its self-supporting characteristics and the infinite series of periodic surfaces that are possible when using TPMS. In earlier work, a functionally graded type of TPMS that involves changing the size of the unit cell or the solid volume of the TPMS or mixing TPMS cell structures was suggested. The present study suggests an explicit filtering method for the design of functional TPMS in which functionally graded TPMS outcomes can be designed without changing the basic TPMS structures. A local explicit filtering method using a non-linear sigmoid function creates a sign distance field in three-dimensional space and enables the design of the functional TPMS through arithmetic calculations with the sign distance field of the TPMS. The sigmoid function used with explicit filtering method has two independent parameters and enables the user to create different sign distance fields by changing each of these parameters. The design of the functional TPMS was confirmed by applying the explicit filtering method to a Gyroid, a TPMS structure. To compare the pressure drop of the TPMS fluid channel when applying the explicit filtering method, functional TPMS flow channels and the original flow channel without the explicit filtering method were manufactured by additive manufacturing and compared in experiments.

1. Introduction (Times New Roman 10pt)

Additive manufacturing has developed to a level that can be used in actual industries, and is currently used in high-tech industries like aerospace and medical engineering. In a high value-added industry, the demand for research of additive manufacturing is increasing. Triply Periodic Minimal Surface(TPMS) is a self-supported structure and has a characteristic that can perfectly separate into two space based on the surface of TPMS, so it has been actively studied as lattice structure. This study suggests a design method that can transform a TPMS structure using mathematical function to be used efficiently in actual industry. Through a arithmetic calculations with the mathematic function using sigmoid function and TPMS function, it can be transformed as much as desired degree and position.

2. Functionally Graded TPMS Design

2.1 Explicit Filtering Function using SDFs

TPMS is a zero average curvature that separates the space into two different space and has a periodicity through three independent axes. Recent studies have shown interest in making functionally graded TPMS method with changing porosity or cell size or mixing TPMS structures. In this study, a Gyroid is used among the TPMS structures and the equation of Gyroid is represented in equation 1.

$$f(x) = \frac{1}{1+e^{-x}} \tag{1}$$

A explicit filtering function designed the functionally graded TPMS structure by giving nonlinearity to the TPMS structure using the sigmoid function. The explicit filtering proposed in this study made it possible to design a implicit modeling by creating a signed distance field of space and performing arithmetic calculations with the TPMS signed distance field by adjusting the desired position and value. The used sigmoid function is defined in equation 2, and Fig.1 shows the signed distance field of the basic TPMS and the functionally graded TPMS designed with the explicit filtering function. The filtering function was applied to both edge areas of TPMS.

$$\Phi(x,y,z) = \sin(x) * \cos(y) + \sin(y) * \cos(z) + \sin(z) * \cos(x) \quad (2)$$

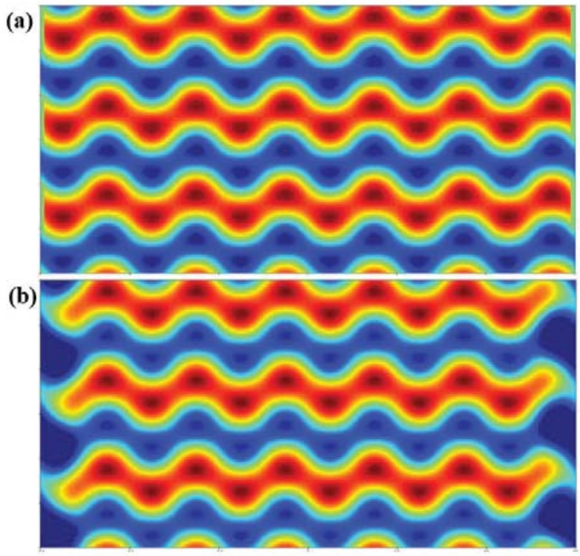

Fig. 1 Contour graph of signed distance field (a) original TPMS without filtering (b) filtered TPMS

2.2 Design and Result of Experiment

The functional TPMS flow channel with explicit filter applied for the experiment was designed, and the unit cell was designed with 10 mm and the size of the TPMS flow channel was designed with 60×30×30 [mm]. Fig. 2 showed the two types of TPMS flow channel.

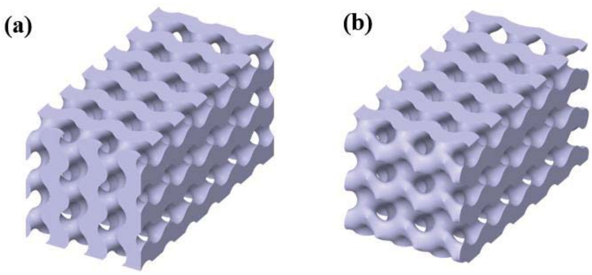

Fig. 2 Isometric of TPMS fluid flow channel (a) Original, (b) Filtered

To compare the effect of explicit filtering techniques on pressure drop in inlet and outlet flow channels, two types of TPMS flow channel, original TPMS flow channel without applying explicit filter and filtered TPMS flow channel, were designed and tested. The flow channels were manufactured with DLP 3D printer. The experiment compared the pressure drop in 2-14 L/min with installing a differential pressure gauge between inlet and outlet of the flow channel. The result of the experiment is showed in Fig. 3. the pressure drop of the filtered TPMS channel is lower than the original TPMS channel. In 5 L/min each pressure drop are 4.03 kPa and 3.30 kPa, showing a significant result of about 18.1%, and as the flow rate increased, the pressure drop was larger.

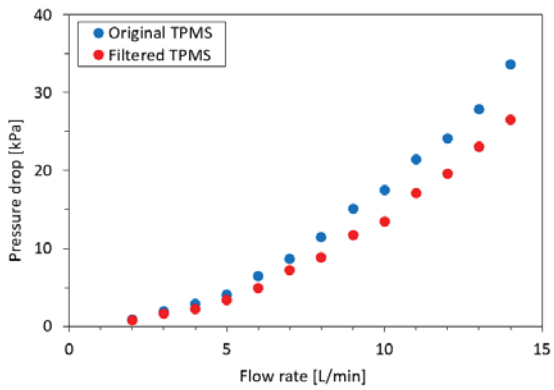

Fig. 3 Comparison of pressure drop with original TPMS and filtered TPMS

3. Conclusions

This study is proposed a new method designing a functionally graded TPMS. The functional TPMS is designed through arithmetic calculations of TPMS signed distance fields using sigmoid functions. Flow channels were manufactured and the effect was confirmed through pressure drop to confirm the performance of the functional TPMS. Filtering applied to the inlet and outlet creates a slope at the inlet and outlet, reducing the pressure drop by reducing the resistance when the flow enters the channel. Mathematical explicit filtering functions can create various designs by adjusting the position and value desired by the designer.

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