Transactions of the Korean Nuclear Society Virtual Autumn Meeting
October 21-22, 2021

Pressure Drop Performances of 3D Printed Debris Filtering Bottom Grid

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1. Introduction

Debris filtering bottom grid (DFBG) is located at the lower most of the nuclear fuel as shown in Fig. 1. It is required to perform in a reactor for not only supporting fuel rods, but also filtering debris. It is made of Inc-718 material and must support the fuel rod with enough force. Thus, it can prevent excessive behavior due to abnormal fuel rod vibration and maintain the fuel rod supporting stably through end of life. In addition, DFBG serves to protect the fuel from foreign materials during operation, so it has internal filter structures to filter debris out. Therefore, to perform above functions, DFBG design with complicated inner structure and longer grid height could be desirable. However, these can lead to an unfavorable design to the nuclear fuel such as longer fuel rod length and higher pressure drop.

To overcome these difficulties, KEPCO Nuclear Fuel (KNF) is considering to adopt 3D printing technology. It is officially called as additive manufacturing (AM) [1]. This technique allows to make desired shape with complex geometries using feed materials, and KNF has chosen powder bed fusion (PBF) process among AM techniques that is totally different from conventional manufacturing. KNF is expecting to accomplish more complex shapes while satisfying functional requirements when building up DFBG with 3D printing.

KNF has tried to make several DFBG candidates that are full size (16x16) of grid array. And to validate design effectiveness, some evaluations were carried out as following items;

- Prototype quality (dimension, shape, roughness)
- Mechanical test (load-deflection, dynamic crush)
- Hydraulic test (pressure drop, debris filtering)

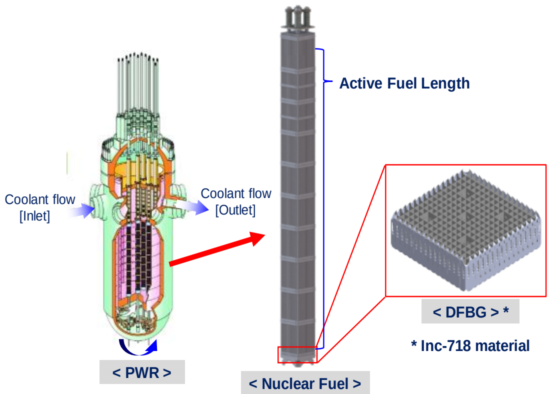
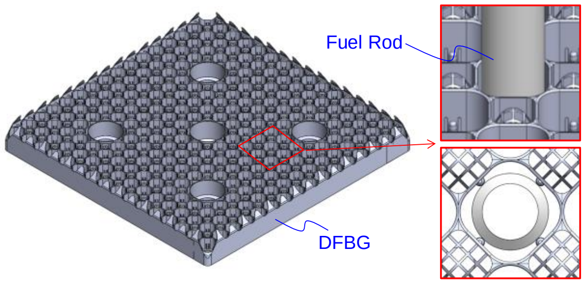


Fig. 1. General configuration of DFBG in a nuclear fuel

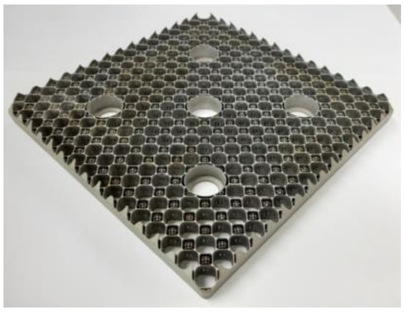
Various debris filtering configurations has been created and performance verification tests were carried out. In this paper, design feature and manufactured qualities of one of them is introduced. Also, results of pressure drop test with two specimens are compared.

2. Design Feature and Manufacturing

Design feature of the DFBG concept is as shown in Fig. 2(a). The structure of the cell is shaped as rhombus that allows the grid wall to be spring-like so that it can make entirely grid elastic and flexible. Also, large and small cells are optimally combined to reduce pressure drop by having a large channel cross-sectional area. A conical mesh-type filtering structure is installed at the top of each small cell to trap foreign materials inside of the mesh. Fig. 2(b) shows the 3D printed DFBG that was built-up with PBF process.



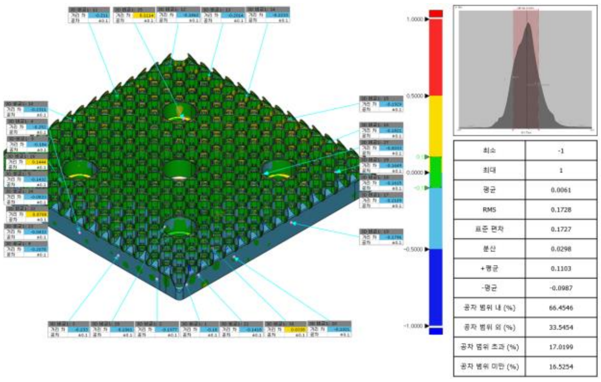
(a) Design feature [2]



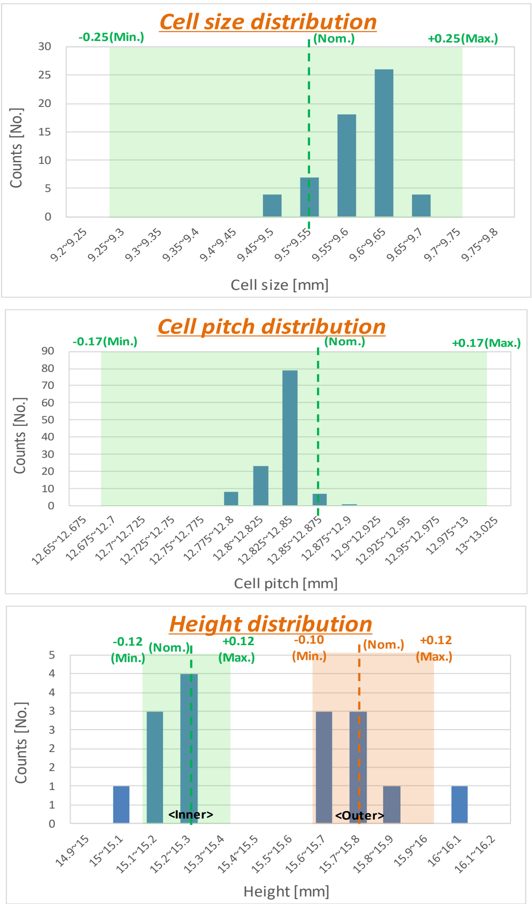
(b) Prototype of DFBG (Inc-718)

Fig. 2. Design feature and 3D printed DFBG through PBF process

Dimensions of 3D printed DFBG were measured using non-contact 3D scanner equipment. Measurement items include grid width, strap thickness, cell size, cell pitch and the size of debris filtration passage, etc. Inspection results are summarized as shown in Fig. 3. Overall dimensions and qualities are acceptable. Surface roughness is one of important factors in terms of coolant flow resistance. The surface roughness was observed within Ra 5 ㎛ in case of the outer surface shown in Fig. 4.



(a) Dimensional measurement deviation variance



(b) Distribution of the dimension data

Fig. 3. Results of dimensional measurement of 3D printed DFBG

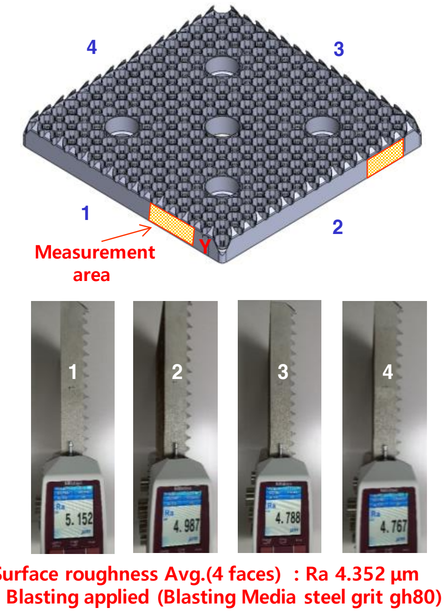


Fig. 4. Roughness of 3D printed DFBG outer surface

3. Pressure Drop

3.1 Prediction

Minimizing pressure drop is one of the main goals on designing nuclear fuel assembly. Factors that directly affect the pressure drop characteristics include the channel cross-sectional area of the flow, wetted perimeter of the flow, the height of the grid strap, and the surface roughness, etc.

The prediction of pressure drop in a non-circular shape can be obtained after deriving equation (1) using the Bernoulli and Darcy-Weissbach's equation. Two designs were compared. One is 3D printed DFBG and the other is commercial DFBG. Assuming that the operation conditions are the same, the converted pressure drop characteristics for one cell can simply calculated. Table I shows comparison of the predicted pressure drop. It indicates surface roughness is dominated to the pressure drop. If the value of roughness is same, reduction of pressure drop of 3D printed DFBG is better by mitigation of loss head. For accurate prediction, it is required to be measured of the friction coefficient from the research, which is planned to be carried out in the future. In addition, surface roughness improving methods are being studied at the same time.

Table I: Comparison of the predicted pressure drop

Items	Commercial DFBG	3DP DFBG
Flow sectional area (in^2)	0.210	0.209
Height of the grid (in)	1.922	0.600
Hydraulic radius R_h (in)	0.106	0.103
Pressure drop*	λ·4.533	λ·1.456

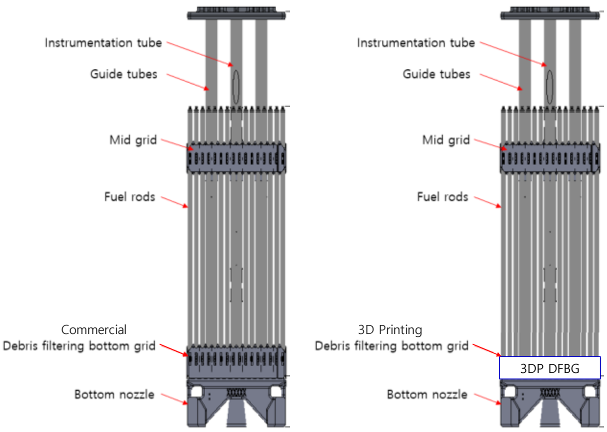
* λ × geometric characteristics

$$\Delta P = \gamma \cdot \lambda \cdot \frac{L}{4R_h} \cdot \frac{V^2}{2g} \quad (1)$$

where, P = pressure drop,
γ = specific gravity
λ = coefficient of friction
L = vertical height of grid
R_h = hydraulic radius
V = velocity of fluid
g = acceleration of gravity

3.2 Pressure Drop Test

For verification of the pressure drop characteristics, tests were performed. Fig. 5 shows schematic of the test assemblies for pressure drop that are installed in the coolant circulation closed loop. The nominal in-core velocity of coolant in a pressurized water reactor is approximately 5 m/s. The range of flow velocity was applied 4~6 m/s that are commonly considered to range from 85 % to 115 % of the nominal flow velocity. Measurement range was set from the base of bottom nozzle to above of the DFBG, and all components except the DFBG are the same with each other.



<Commercial DFBG> <3DP DFBG>

Fig. 5. Schematic of the test assembly for pressure drop

Fig. 6 and Table II show the result of the two pressure drop test results. From the test results, it is shown that the pressure drop characteristics of 3D printed DFBG is reduced at about 16~18% in the test flow rate compared to that of commercial one. It can be understood that main reason is affected to mitigate loss head by lower grid height.

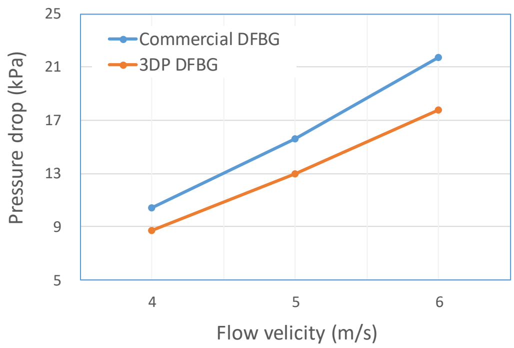


Fig. 6. Comparison of two pressure drop test results

Table II: Summary of the pressure drop test results

Flow velocity (m/s)	Commercial DFBG (A)	3DP DFBG (B)	Reduction rate (B/A-1) (%)
4	10.44	8.73	16.3
5	15.57	12.98	16.6
6	21.71	17.75	18.2

4. Conclusions

From the study, it can be clearly seen that the 3D printed DFBG has more advantages regarding pressure drop reduction, since 3D printing technique can make complex geometries while the height and flow blockage area are improved compared to that of commercial.

Thus, it is concluded that the 3D printing method could be helpful to enhance fuel performance and build industry reliability. In the future, KNF plans to continue to carry out design complementation and modify, build-up 3D products and out-of-pile tests through feedback.

ACKNOWLEDGEMENTS

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea government(MOTIE) (20201510100030, Development of manufacturing technology of nuclear fuel assembly supporting structures and safety class 1 valve items based on 3D printing and standardizations)

REFERENCES

[1] ISO/ASTM52900-15, “Standard Terminology for Additive Manufacturing – General Principles – Terminology”, 2015

[2] Patent No. 10-2020-0109027, “Inconel spacer grid of a nuclear fuel assembly”, 2020.08.28