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An Application of Design for 3D printing to APR1400 Nuclear Fuel Spacer Grid

Seungmin Kim [a], Ihn Namgung [a*]
[a]*KEPCO International Nuclear Graduate School, 658-91 Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan 689-882 South Korea*
[*]*Corresponding author: inamgung@kings.ac.kr*

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1. Introduction

The application of Additive Manufacturing (AM) into the nuclear industry, presents a revolutionary opportunity to enhance the design, fabrication, and performance of nuclear reactor components [1]. Among these components, Spacer grids are essential for maintaining the geometric arrangement of fuels in core, ensuring structural stability, and optimizing heat dispersion and neutron moderation within nuclear reactors. However, to have spacer grids with required structural performance and capabilities to protect fuel rods from various loads, current spacer grid needs to be redesigned [2-5].

Known for its layer-by-layer construction approach of 3D printing, AM offers design flexibility and production advantages over traditional manufacturing methods. This research aims to simulate the AM process for the spacer grid, a critical component of the APR1400 fuel assembly, to understand the complexities of metal layering, heat management, and base removal sequences. This is crucial as spacer grids consists of thin plates that may deform during AM process, it is important to simulate beforehand to find defects and additive process anomalies.

The design of spacer gird should meet and maintain the accurate positioning and spacing of fuel rods, facilitating fluid flow, and mitigating damage from vibrations and all other loads, thereby ensuring the structural integrity of fuel assemblies.

This study examines design for AM of spacer grid and address the challenges of designing complex shapes and enhancing the manufacturing efficiency of nuclear fuel spacer grid. This method could be applied to any other nuclear components. This approach could lead to improvements in productivity, efficiency, and the stability and performance of reactors. The potential of AM to create complex yet structurally improved spacer grids can meet higher safety standard of nuclear fuel in harsher loading conditions [6].

2. Methods and Results

In this section, some of the methods used in the process of simulating the spacer grid model using AM are described. The AM simulation process include spacer grid model for AM, a removal step, a heat treatment step, and compensation model.

2.1 Spacer grid model for AM

The AM analysis process includes the build phase, layering step, cooling step, removal step, and heat treatment step. The purpose of this project is to gain an understanding of AM analysis through the analysis of a basic form of spacer grid, addressing detailed considerations for AM build setup through the Laser Powder Bed Fusion (LPBP) setup. The analysis will utilize tools such as Ansys Workbench Additive and Additive Print, and the results obtained using these tools will be compared.

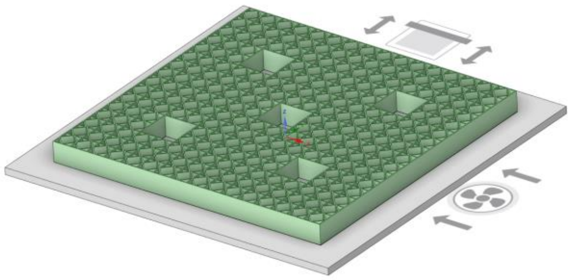

Fig. 1. Setup of spacer grid model for AM simulation

Figure 1 shows the spacer grid model set up for AM simulation. Unlike the spacer grid of the existing APR1400 fuel assembly, diagonal bars have been added. This allows the spacer grid to resist not only square loads but also shear loads. Additionally, it has been designed to not require any support, including base support, for efficient manufacturing.

Table I: Mesh settings for AM simulation

Support action	None
Build material	316 Stainless steel
Mesh method	Voxelizer
Build element size (mm)	1
Base element size (mm)	10

Table 1 shows the mesh settings for the AM simulation. Optimized mesh settings are required for accurate simulation, and in this study, a voxel mesh similar to the layering method was used.

2.2 Removal step

The removal step refers to the process stage where the printed part is removed from the build platform or baseplate. In this simulation, it is used to predict deformations or stresses that may occur when the part model is separated from the baseplate, and the predicted deformations are used to compensate the part model.

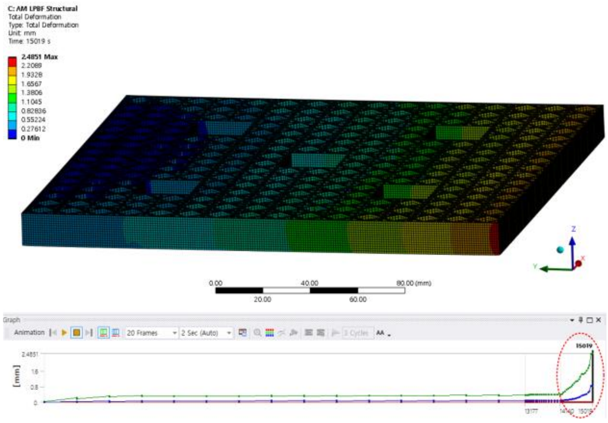

Fig. 2. Total deformation for base removal.

The analysis results showed a maximum deformation of 2.485mm, occurring at the start of the base removal, indicating that the model's deformation appeared during the removal steps.

2.3 Heat treatment step

The heat treatment step is used to alleviate residual stresses accumulated in the component during the printing process, reduce defects such as porosity, and enhance material properties, thereby improving the quality and performance of the final product.

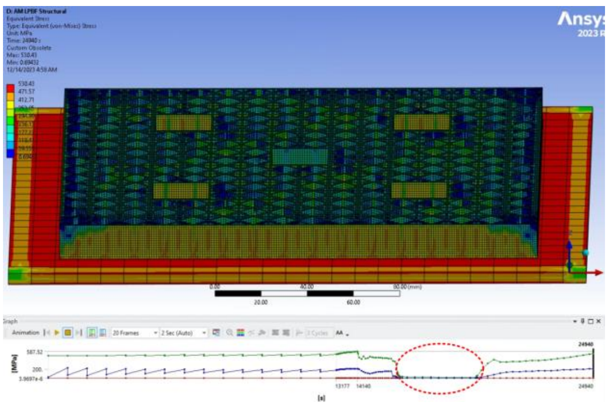

Fig. 3. Equivalent stress for heat treatment.

Figure 3 shows that the heat treatment process alleviates residual stresses up to 587.52 MPa.

2.4 Compensation model

In AM process, the design of compensated models plays a crucial role. It focuses on addressing and mitigating various deformations and inaccuracies that can occur during the printing process. Parts in AM often undergo warping, shrinking, or other forms of deformation due to thermal stresses. A compensated model is specifically designed to counter these issues, ensuring that the final product meets the desired dimensions and specifications.

This compensated model is derived from the results of the removal step simulation. The deformation caused by thermal shrinkage is obtained from the simulation results. Based on these results, the nodal displacement can be reversed to create a compensated model. The figures below illustrate the process of creating a compensated model.

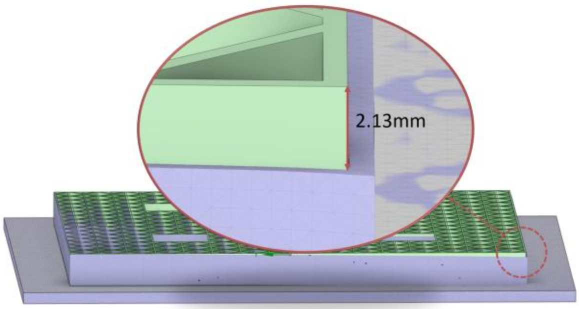

Fig. 4. Comparison between the original model and the compensated model.

Figure 4 shows the comparison with the original spacer grid model, demonstrating that the compensated model accounts for the thermal shrinkage and deformations caused by base removal.

3. Conclusions

This study conducted simulations of the AM process and analyzed and compared the levels of deformation and stress for the additively manufactured spacer grid model. Various tools were used to compare the simulation results, contributing to the accurate prediction of the AM process. Furthermore, based on the analysis results of the part model that underwent deformation during the AM process, a compensation model was designed. The creation of the compensation model was used to address deformation issues related to thermal shrinkage and base removal. This research provided important insights for analyzing more complex models in the future and laid the groundwork for further studies.

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