Dynamic Impact Characteristic of an Additively Manufactured Debris Filtering Bottom Grid

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1. Introduction

Additive manufacturing, also called as three-dimensional printing, is a technology that build objects by adding many layers of material, whether the material is usually plastic and metal. Over the past few years, KEPCO NF has been putting efforts to seek feasibility of adopting this technology for the manufacturing of nuclear fuel components including the spacer grids. Especially, additive manufacturing of the spacer grid theoretically can enable design freedom to the designer and provide robust products by breaking away from the conventional sheet metal working, followed by assembling and welding the intersecting points as shown in Fig. 1.

In case a spacer grid is subjected to an excessive load during shipping, handling, manufacturing and operating, the spacer grid carries out crucial roles such as protecting the fuel from impact and maintaining mechanical integrity. For this reason, the spacer grid design requires to have superior capabilities. A prototype of debris filtering bottom grid (DFBG) was designed and manufactured using additive manufacturing technology, and dynamic impact test was performed to investigate the dynamic impact characteristics. Finally, the result was compared with the test result of conventional spacer grid.

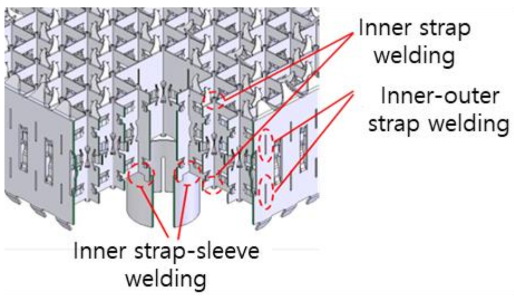


Fig. 1. Conventional manufacturing of Spacer Grid

2. Test Specimens

2.1 Conventional Spacer Grid

KEPCO NF's HIPER16 top grid was selected in order to perform a comparison test. Conventional top grid is fabricated using Inconel 718 inner and outer straps which has spring, dimple and slot by sheet metal work. After fixing the straps as assembled in the jig, each cross section is connected by brazing filler metal. The welding strength is strong but the constrained area does not cover entire cross-sectional line of the straps.

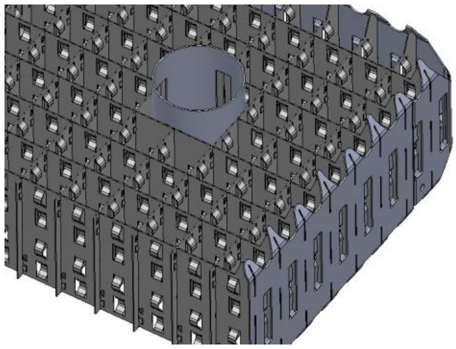


Fig. 2. Cross Sectional View of HIPER16 Top Grid Assembly

2.2 Additively Manufactured Spacer Grid

KEPCO NF has introduced a new design concept of DFBG which has not only advanced debris filtering features but integrated design and diamond shaped cells to reinforce the mechanical strength along with increased elasticity. Unlike the conventional spacer grids, all cross-sectional lines are connected and there are no windows behind the spring or dimples, therefore the load-bearing area increases drastically even though the overall height is decreased[1].

The specimen was manufactured through SLM280HL powder bed fusion 3D printer, using Inconel 718 powder as feedstock. Stress relief thermal treatment was applied in order to remove the residual stress in the specimen, however no other heat treatment such as age hardening was applied. The specimen was overall bead blasted after printing.

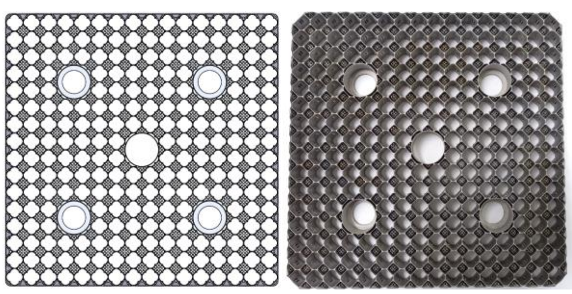


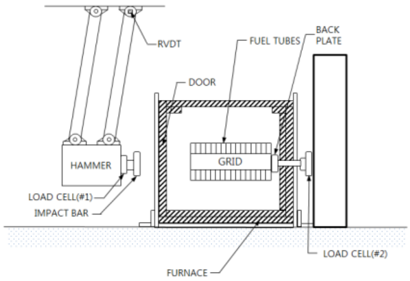
Fig. 3. 3D model (left) and actual printed (right) DFBG prototype

3. Dynamic Impact Test

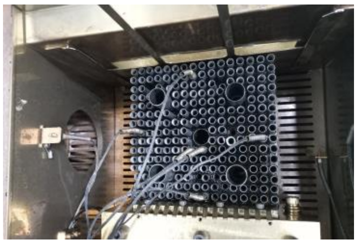
3.1 Test Outline

KEPCO NF's dynamic impact test equipment was used to apply impact to the spacer grid specimen. The equipment consists of hammer, load cell and high temperature furnace. The hammer connected to the pendulum applies an impact to one side of the specimen which is fixed in the opposite side. The weight of the hammer is equivalent to the weight of the fuel rods within one span supported by the spacer grid. The impact velocity of the hammer can be calculated using the energy conservation law and the initial test angle of the pendulum. Through the impact test, the impact load on the spacer grid was measured according to the impact velocity of the hammer.

One 3D printed DFBG and one HIPER16 top grid was prepared, and short fuel rod cladding and guide tubes were inserted in each cell of the grid. Temperature of the furnace was raised up to 600°F in order to simulate the reactor condition, and the specimens were impacted by the hammer until buckling occurs while increasing the pendulum drop angle.



(a) Schematic of the dynamic impact test equipment



(b) Installation of specimen in the high temperature furnace

Fig. 4. Dynamic impact test equipment

3.2 Test Result

Figure 5, Figure 6, and Table 1 compare the two test results which are converted to relative values; where impact force is the measured value using the load cell, stiffness is derived from simple harmonic oscillator equation, and impact energy is calculated with the pendulum angle (impact velocity) and hammer weight. Dynamic crush strength for HIPER16 top grid was clearly determined at the maximum impact force before buckling. However, 3D printed DFBG did not show any sign of buckling while the pendulum angle reached maximum which the equipment can handle.

The test result shows that dynamic crush strength of additively manufactured DFBG is approximately 5 times bigger than HIPER16 top grid, and stiffness of the DFBG is approximately 40% smaller than HIPER16 top grid. Actual crush strength of the DFBG can be even more increased because buckling has not occurred during the test. Although detail design is different to each other, DFBG can be considered to be weak in terms of impact because the strap height is about 0.7 times smaller than the HIPER16 top grid. But from the test, it can be concluded that increased load-bearing area due to integrated design actually dominates the crush strength. Moreover, additively manufactured grid can be superior compared with the current grid in terms of seismic integrity. This is because the impact strength, stiffness and seismic factor of the dynamic crush test data are main inputs regarding fuel seismic performance calculation of the nuclear fuel.

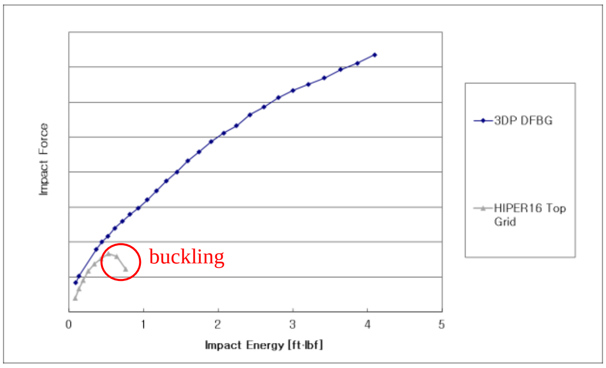


Fig. 5. Dynamic crush test result (crush strength)

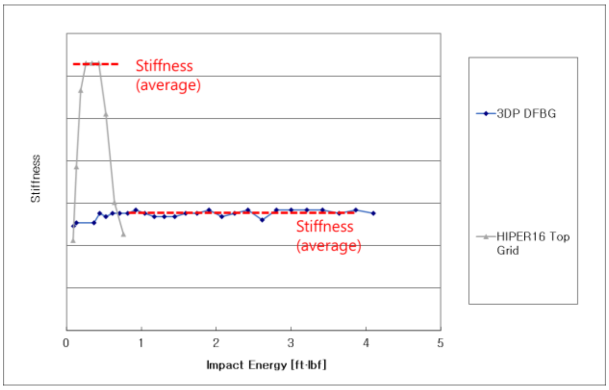


Fig. 6. Dynamic crush test result (stiffness)

Table 1: Comparison of dynamic crush test result

Items	HIPER16 TG	3DP DFBG
Rel. Crush strength	0.22	1.0*
Rel. Stiffness	1.76	1.0

** No buckling occurred: Maximum impact during test*

4. Conclusion

Dynamic impact test was conducted on additively manufactured DFBG and conventionally manufactured HIPER16 top grid of Inconel 718, with simulated fuel rods and guide tubes inserted in the high temperature furnace. From the test result, it is believed that the DFBG designed and manufactured in consideration of additive manufacturing has significantly higher strength and lower stiffness, consequently suggests direction as an ideal approach for a new concept grid design. Thus, it is concluded that the additive manufacturing technology could be helpful to improve dynamic impact characteristics of the spacer grid and seismic performance of the fuel assembly.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Patent No. 10-2020-0109027, "Inconel spacer grid of a nuclear fuel assembly", 2020.08.28