Delivering the Nuclear Promise
Top Innovative Practice

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Additively Manufactured Thimble Plugging Device at Byron Unit 1

2021 Top Innovative Practice Winner

Exelon, working with Westinghouse Electric Co., installed the world's first 3D printed core component, a thimble plugging device, into a commercial nuclear reactor, Exelon Corp.'s Byron Unit 1 in the spring of 2020. The use of additive manufacturing has been limited in nuclear fuel applications; however, incorporating the swiftly evolving technology can clearly enable many benefits such as advanced fuel component designs, reducing costs, accelerating timelines, simplifying supply chains, enhancing safety and increasing performance.

Innovation

Additive manufacturing (AM) technology is based on the principle of creating 3D objects layer by layer and has experienced rapid growth in a wide variety of industries in recent years. The use of AM has primarily been limited in nuclear fuel applications. However, incorporating the swiftly evolving technology can clearly enable many benefits such as advanced fuel component designs, reducing costs, accelerating timelines, simplifying supply chains, enhancing safety, and increasing performance [1, 2]. With insertion into Byron Unit 1 reactor core in March 2020, the AM thimble plugging device (TPD) was the world's first 3D printed core component to be inserted into a commercial nuclear reactor.

With no nuclear industry direct in-reactor irradiation experience with AM materials when the project began, AM tensile specimens were irradiated in a test reactor (including 316L Stainless Steel and Alloy 718 nickel super alloy) and were later removed and tested in the hot cell at the Westinghouse Churchill facility. By combining the standard test methodologies of tensile testing with state-of-the-art Digital Image Correlation technology, the team effectively characterized additively manufactured 316L Stainless Steel. The results were compared against conventional wrought materials thereby successfully demonstrating that AM materials yield similar material behavior properties to cast or wrought materials of the same alloy. Along with additional testing, such as corrosion testing and dye penetrant testing, this test program enabled the use of AM materials in nuclear applications. The NRC observed some of this testing and provided favorable feedback of the state-of-the-art material characterization efforts undertaken. In addition, members from Westinghouse and Exelon met with the NRC and walked them through all aspects of the AM TPD from design and development, to testing, qualification, process control, licensing, etc., to ensure that the NRC was aware of the implementation of this new technology.

The TPD was chosen as the first component for this proof-of-principle initiative based on the following benefits:

- The TPD was chosen as it is a simple component and because of its location in the fuel assembly guide thimble tubes, it provided a safe opportunity to demonstrate a first application of the AM process with little/minimal risk.
- With the complexity of the TPD design, its requirements, and common 316L stainless steel material, there were many enhanced learning aspects of limitations and opportunities of the AM process
- Form, fit, and function of the component would not be altered from its conventionally produced counterpart, as proven with significant mechanical testing (bending, compression, tensile, joint strength, and fatigue)
- The design of "growing" AM thimble plugs on an existing conventionally manufactured TPD base plate, using the latest Laser Powder Bed Fusion technology provided a learning opportunity of a hybrid part (i.e., a part fabricated using both additive and conventional technologies)
- Additional learning was enabled through requirements to establish the necessary supply chain, develop a controlled process, demonstrate manufacturability of the design, and complete confirmatory testing of an AM produced component.

Safety

Exelon and Westinghouse performed the design, manufacturing, testing, delivery, and installation with zero safety events. Safety was a primary factor in the decision-making process to select a thimble plugging device for a first-time application of AM technology. The TPD was selected due to the minimal impact on the plant in the unlikely event of a failure. Should an AM thimble plug detach from the base plate mount, the AM thimble plug would be wholly contained within the fuel assembly guide thimble tubes for the useful life of the fuel assembly, resulting in no significant detrimental impacts to reactor operation, no compromise to any safety criteria or production of any loose debris. Additionally, by utilizing similar materials with low cobalt content, ALARA goals would continue to be maintained.

Cost Savings

The AM TPD design simplified the rodlet design by eliminating the attachment of the individual threaded rodlets and the associated crimp nuts (that required manual assembly) to the TPD baseplate. This AM project demonstrated how AM technology has the potential to greatly simplify the number of parts and processes required for manufacturing fuel components and other components used in nuclear facilities.

Productivity/Efficiency

The number of parts for a TPD was greatly reduced using AM. The supply chain was also simplified since many individual parts were no longer needed for the hybrid AM design. The ability to rapidly prototype was proven with this project by being able to adjust 3D models and print prototypes in one day rather than relying on a supply chain that would take months to produce and deliver prototype parts. This project also demonstrated that less raw material (powder) was consumed during 3D printing versus conventional fabrication methods due to the net shape printing aspect with no conventional machining required.

Transferability

The greatest benefit of this successful project is to enable further use of AM in other in-reactor applications. Further in-reactor experience will help reduce industry and NRC concerns regarding the use of this technology.

Westinghouse has multiple programs currently underway in many different areas from enhancing fuel assembly debris filtering, thin-walled structures (such as spacer grids), tooling used in manufacturing, and the fabrication of spare/replacement parts. These examples/opportunities of what can be achieved using AM are considerably better understood as a direct result of this AM TPD project (see References [3] and [4] for a summary of the current state-of-the-art). More and more opportunities to use AM are beginning to arise from producing advanced fuel products to fabricating replacement parts much more cost effectively and with reduced lead times [5]. In conclusion, the AM TPD project has offered a great launching pad for many future opportunities for the use of the AM technology in the commercial nuclear field.

Team Members

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References

[1] – *Advanced Nuclear Technology: Additive Manufacturing Roadmap for the Nuclear Power Industry – Metal Alloy AM Technologies.* EPRI, Palo Alto, CA: 2020. Product ID #3002018276.
[2] – *Additive Manufacturing Roadmap for the Nuclear Power Industry: Metal Alloy AM Technologies*. EPRI, Palo Alto, CA: 2021. Product ID #3002022977.
[3] – *Quick Insight Brief: Laser Powder Bed Fusion – Additive Manufacturing*. EPRI, Palo Alto, CA: 2020. Product ID #3002019762.
[4] – *Quick Insight Brief: Directed Energy Deposition-Additive Manufacturing*. EPRI, Palo Alto, CA: 2020. Product ID #3002019764.
[5] – *Quick Insight Brief: Additive Manufacturing to Support Spare and Replacement Parts*. EPRI, Palo Alto, CA: 2020. Product ID #3002019767.

Figure 1 - Additively Manufactured Thimble Plugging Device

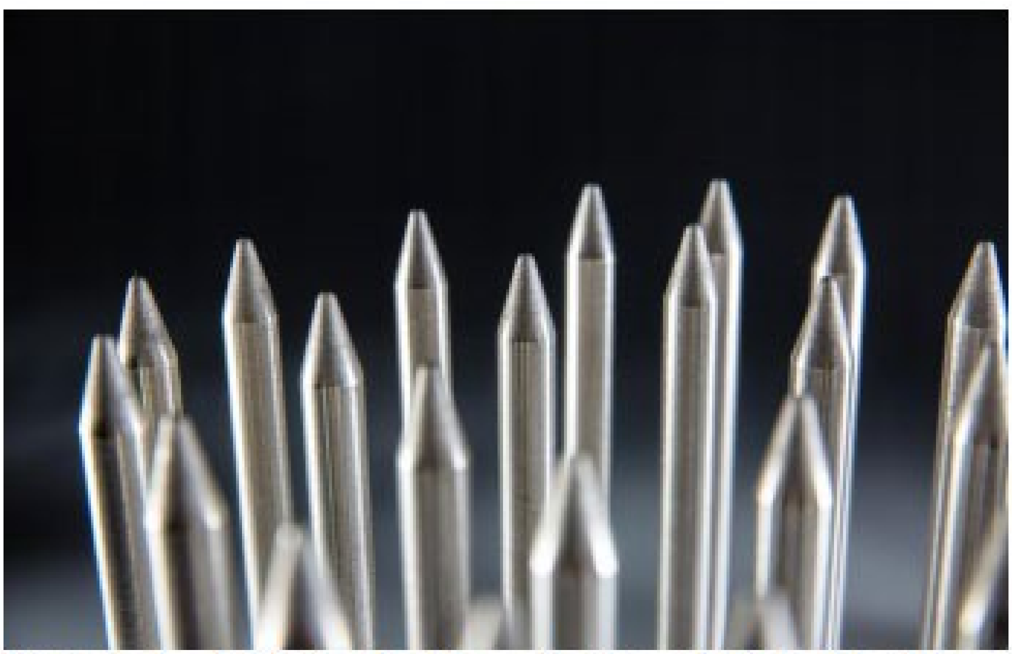

Figure 2 - Additively Manufactured Thimble Plugs