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Additive manufacture of nuclear fuel supports and valve items

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1. Introduction

Additive manufacturing (AM) can be described as the process of joining or adding materials with the primary objective of making objects from three-dimensional (3D) model data using the layer-by-layer principle [1]. Over the last several decades, periodic reviews summarizing the progress and outcomes of additive manufacturing have been published [2-5]. A sizeable number of these papers have focused on the roles that various processing technologies can play in the engineering of a product designed for a specific purpose [6-8]. Applications are found even in industries where the safety is extremely required such as automobiles, railways, and aviation. The number of components that can be produced using additive manufacturing is increasing continuously. Meanwhile, there is also an effort to apply additive manufacture to nuclear industry parts. The components that are required to be produced in a timely manner are adequate for additive manufacturing, because there is a limitation in mass production. The parts of excellent design that cannot be produced by the existing manufacturing process are also adequate for additive manufacture.

In Korea, the Korea Atomic Energy Research Institute (KAERI) is focusing on the application of additive manufacturing to the nuclear industry with various additive manufacturing, nuclear parts specialists. The target material is the flow plate and support grid that fixes the bottom of the nuclear fuel assembly. Also, the multi-purpose valve of less than 3 inches in size is under consideration.

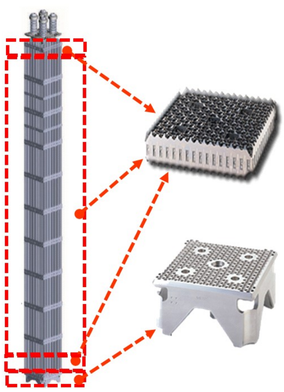

Fig. 1. Selected items for additive manufacture, nuclear fuel support grids and flow plate

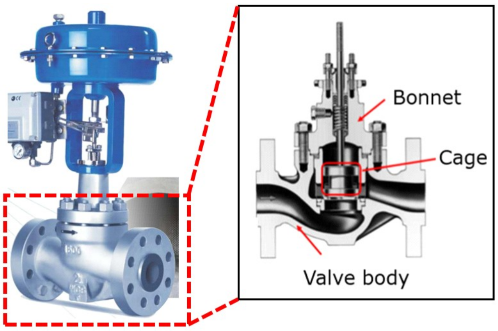

Fig. 2. Selected items for additive manufacture. Body, bonnet, cage parts for nuclear safety class 1 3-in. valve.

Nuclear fuel supports fix the fuel rods to be arranged at regular intervals and to withstand vibrations and shocks in the reactor. Nickel alloys are used for the upper and lower support grids, and zirconium alloys are used for the intermediate support grids. Currently, each material is rolled into a plate, cross-assembled, and spot-welded to form a support grid, which is vulnerable to excessive vibration and impact. However, it is expected that the mechanical stability of the parts will be greatly improved if it is possible to make the integrated manufacturing without spot welding by the additive manufacture method.

This study also deals with the manufacture of nuclear safety class 1 3-in valves. Not all of the valve items shown in Fig. 2 are fabricated by additive manufacture, but only those parts that are most vulnerable to fabricating by conventional casting and machining are selected. The bottom part of the valve is composed of body, bonnet and cage parts. After assembling each additively manufactured parts, it is aimed to complete parts satisfying performance requirements such as flow test.

This research is aimed at the commercialization, standardization and certification of additively manufactured nuclear components. This is the stage where basic arrangements are carried out for the fields of nuclear fuel support and valve parts. The contents of the proceedings to date are summarized as follows.

2. Methods and Results

2.1 Nuclear fuel supports

Fig. 3. Nuclear fuel support grids (Inconel 718, PBF)

Parts of Inconel 718 material corresponding to the upper and lower support grids of the fuel support were fabricated by powder bed fusion (PBF) method. Only some of the parts (1/25 part of the total) were fabricated. Specimens were subjected to the post-heat treatment suitable for the Inconel 718 parts in accordance with the existing support grating design used. In Fig. 3, the leftmost part is manufactured by conventional method, the rightmost part is manufactured by PBF method, and the middle part is the specimen after heat treatment. The mechanical strength of the product was stronger or similar than that of ordinary parts, and the shape of the product was relatively insignificant. However, there remains a need to provide a method to reinforce the elasticity of the spring device supporting the fuel, and to solve the surface roughness problem which may affect the flow of the cooling fluid and hinder the corrosion characteristics.

2.2 Control valves

Fig. 4. Body, bonnet, cage parts for nuclear safety class 1 3-in. valve. (SUS 316, BJ aided casting)

Valve items were fabricated by binder jetting (BJ) method among additive manufacture methods. In the direct energy deposition (DED) or PBF method, which is widely used as a metal additive manufacture method, it is difficult to realize a bending part of a valve item. Therefore, at present, the most feasible solution is to adopt the method of pouring the castings into the mold after BJ additive manufacture of the mold. This can be said to be almost the same as the existing casting method, but it is advantageous in that the design can be realized by the additive manufacturing, and the manufacturing and machining can be minimized.

Fig. 3. Cv value test line

In order to verify the structural stability in the body, a comparative evaluation of the allowable stress according to the maximum stress point was carried out and the sufficient mechanical strength was secured. In order to carry out the Cv test for the existing original valve, a test line for the control valve 3inch was built. For this purpose, additional pressure transmitter, temperature transmitter, and pressure gauge are also available for the test equipment. It is evaluated whether the flow rate is excessively increased or decreased according to the additive manufacturing design error. Also, it was evaluated whether the bending tube of the valve can withstand the flow rate change.

3. Conclusions

Significant progress has been made in the further development of techniques intrinsic to additive manufacturing, but some of the challenges that remain to be accomplished. It is needed to overcome the several limitations of metal additive manufacturing and to increase the applicability to nuclear power products and foster them as a new growth industry.

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