Additive Manufacturing for Wear Resistant Component in Nuclear Reactor

Jinsung Jang[a], Min Ha Shin[a,b], Do-Hyang Kim[b], Ji Hoon Kang [a], Chang Hee Han[a], Junhyun Kwon[a]

[a] *Advanced Materials Development Group, Korea Atomic Energy Research Institute*
989-111 Daedeok-daero, Yuseong-gu, Daejeon, 34057 Korea
[b] *Department of Materials Science & Engineering, Yonsei University*
50 Yonsei-ro, Seodaemun-gu, Seoul, 03722 Korea

[*]Corresponding author: jjang@kaeri.re.kr

1. Introduction

As the long-term national energy supply scheme is being rather drastically changed, the operation mode of the nuclear power plants as well as the construction plan for the future nuclear power plants in the country may need to be adjusted accordingly. When various energy resources other than nuclear energy such as renewable ones become momentous in energy mix, the nuclear power plants need to be more prepared with the load-following operation option instead of the base-load one because those other electricity sources would be a kind of intermittent in nature.

For the nuclear power plants to be operated in the load-following mode the relevant components may need to be improved in their characteristics on top of the enhanced core monitoring system able to evaluate the local power density distribution more precisely and quickly [1]. Control rod drive mechanism (CRDM) may have to move much more frequently in the load-following operation mode, and consequently the contact area of the control rod and the latch arm shall have to be more wear resistant. Hard martensitic stainless steel is one candidate material for the control rod, and the contact area of the latch arms may be hard-faced with wear resistant cobalt-base alloy such as Stellite 6™ (Fig. 1.).

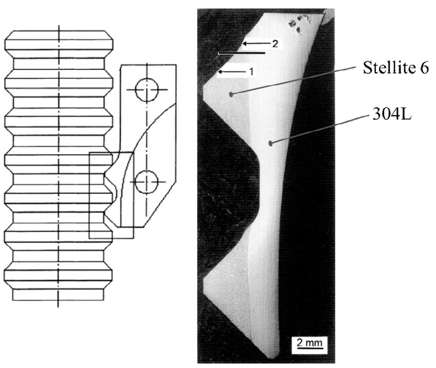

Fig. 1. Schematic diagram showing the contact area between the drive rod and the gripper latch arm; micrograph of a latch arm revealing worn area of hard-faced alloy [2].

In this study additive manufacturing (AM) technology instead of the conventional hard-facing technology is considered to obtain the finer grain structure of matrix phase and the more uniformly distributed carbides. And it is expected to obtain the better maneuverable microstructure, and consequently the better wear resistance. Using direct energy deposition (DED) AM technology, three different cobalt-base alloy powders were deposited on stainless steel base plates, respectively. The evolution of the microstructure, including the characteristics of grain growth and grain boundary, grain size distribution, and pore formation was investigated. Also mechanical properties such as micro hardness and wear properties of cobalt-base AM layer are evaluated and compared with those from the conventionally hard-faced ones.

2. Experiment and Result

Three kinds of cobalt-base alloy powders were additively deposited by DED method on 20 mm thick Type 304L stainless steel base plates, respectively. To estimate the effects of temperature gradient during the AM process, the stainless steel base plates were held at room temperature and 300°C, respectively. Cobalt-base alloy powders were 50-125 micron in diameter, and the chemical compositions of three alloy powders are shown in Table I.

Table I: Chemical composition of cobalt-base alloys

	Cr	W	C	Ni	Mo	Si
Stellite 6	29.70	4.64	1.12	2.23	0.18	1.20
Stellite 21†	28.00	0.20	0.35	0.5	6.00	1.00
Stellite 25	19.94	15.4	0.06	10.5	0.01	0.11

† *in practice ASTM F75 alloy that is similar with Stellite 21*

For the DED AM process ytterbium fiber laser was used. The laser power was 600-980 W, and the beam traverse speed was about 850 mm/min (14.1 mm/sec). For the first several layers up to five mm of height, AM processing was carried out in one direction parallel to the rolling direction of the stainless steel base plate, and the next layers of another five mm of height were alternately deposited in perpendicular direction to the

™ *Stellite is a registered trade mark of Kennametal Inc.*

previous deposition direction. Each AM deposition layer corresponded around 450 micron in height.

Inverse Pole Figure (IPF) maps from electron backscattered diffraction (EBSD) on the cross section of the deposited AM Stellite 6 layers are demonstrated in Fig. 2. Melt droplets are clearly delineated within which relatively coarse columnar grains are revealed, and the austenitic stainless steel base plate reveals its fine equiaxed grains.

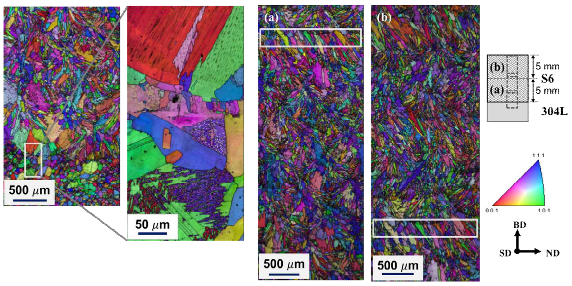

Fig. 2. EBSD map of AM Stellite 6 alloy on 304L stainless steel base plate, demonstrating the structure, size distribution and the orientation of the grains.

Grain size distribution, grain morphology and pore formation were observed by using SEM/EBSD; and dendritic growth of alpha cobalt phase with lamellar structure of M_7C_3 carbide within the inter-dendritic region were also identified by using SEM/TEM/EDS.

Microhardness of the AM Stellite 6 layer was measured, and is compared with that from the hard-faced one in Fig. 3. Even with the same cobalt-base Stellite 6 alloy deposition in both cases, an obvious enhancement of the microhardness values is made clear for the AM case.

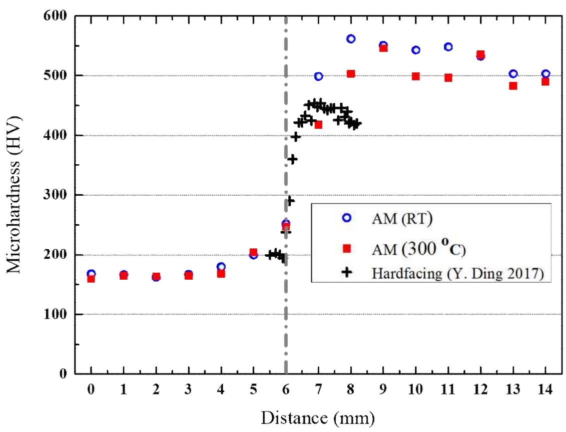

Fig. 3. Microhardness of AM cobalt-base Stellite 6 deposition layer compared with that of hard-faced one [3].

Although the practical performance of the relevant components shall be evaluated together with the environmental effect such as corrosion (i.e. through tribocorrosion test), better wear resistance of the AM Stellite 6 layers could be expected from this hardness test result when compared with that from the hard-faced one.

3. Summary

By DED AM technology three kinds of cobalt-base alloy powders were deposited on Type 304L stainless steel base plate at room temperature and 300°C, respectively. Various microfeatures of the deposited AM Stellite 6 layers were investigated by using electron microscopes. AM Stellite 6 layer showed the higher microhardness values than the laser hard-faced one, helping expect that AM technology could produce better wear performance than the conventional hard-facing technology even with the same wear resistant depositing material.

Acknowledgements

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