Transactions of the Korean Nuclear Society Virtual spring Meeting
May 13-14, 2021

Phase Evolution in Cobalt-Chromium Alloy Prepared by Direct Energy Deposition Method

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1. Introduction

Cobalt alloys have been widely used since early 1990's as cobalt-chromium-tungsten, or cobalt-chromium-molybdenum ternary alloys due to their good magnetic properties, corrosion resistance, wear resistance, and high temperature strength [1]. These properties are attributed to the crystallographic structure of cobalt; the solid solution strengthening effect from the alloying elements such as chromium, tungsten, and molybdenum; and the precipitation hardening by carbides.

Nuclear power industry in Korea is facing to share its portion with the various renewable energy scheme, and shall be impelled to the better maneuverability along with the higher performance. In this regard the nuclear power industry needs to be prepared with the load-following operation option instead of the present base-load one. The relevant hardware components of the CRDM (control rod drive mechanism) in relation with the operation modes shall be better prepared with the improvement in the component materials as well as in the design. For the nuclear power plants to be operated in the load-following mode CRDM may have to move much more frequently than in base-load one, and the contact area of the control rod and the latch arm shall be more wear resistant.

Cobalt alloys are prime candidate materials of resistance to wear at high temperature. Hard facing of wear resistant cobalt alloy on the substrate of gripper latch arm of CRDM in the load-following operation is the one having been applied in the advanced countries (Fig. 1), damage on even the wear resistant cobalt alloy hard facing layer is still reported though.

In this study Stellite 6™ alloy powders was deposited on the austenitic stainless steel plate by the direct energy deposition (DED) method of an additive manufacturing (AM) process. The phase evolution was examined with TALOS F200X S/TEM (scanning transmission electron microscope), focusing especially on the cobalt phases rather than the precipitates.

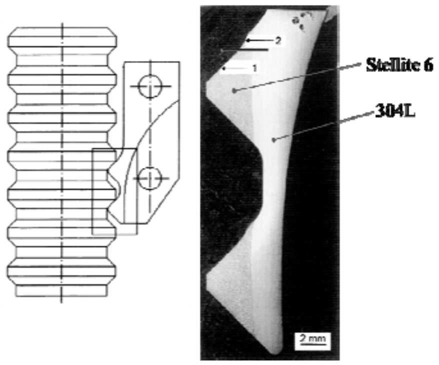

Fig. 1. Schematic diagram showing the contact area between the drive rod and the gripper latch arm; micrograph of a latch arm revealing worn area of hard-faced alloy [2].

2. Experiment and Result

Stellite 6™ alloy powders with the diameter of 50 to 100 μm range were additively deposited by DED method on 20 mm thick Type 304L stainless steel base plate. For the DED AM process ytterbium fiber laser was used. The laser power was about 800 W, and the beam traverse speed was 850 mm/min. To estimate the effects of temperature gradient to the microstructure during the AM building process, the base plate was held at room temperature for the one specimen, and at 300°C for the other. The chemical composition of cobalt-base Stellite 6 alloy powders is shown in Table I.

Table I: Chemical composition of Stellte 6™ cobalt-base alloy

Co	Cr	W	C	Ni	Mo	Si
Bal.	29.70	4.64	1.12	2.23	0.18	1.20

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 base plate, and the next layers of another five mm of height were deposited alternately in perpendicular direction to the previous

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

Fig. 2. Shows a dendrite arm of matrix cobalt phase (gamma) with thin disk shape of epsilon cobalt phase embedded (indexed with diffraction pattern). Atomic number contrast in HAADF mode (Fig. 2 b) more clearly delineate the thin epsilon phase indicating the enrichment of heavier element such as tungsten.

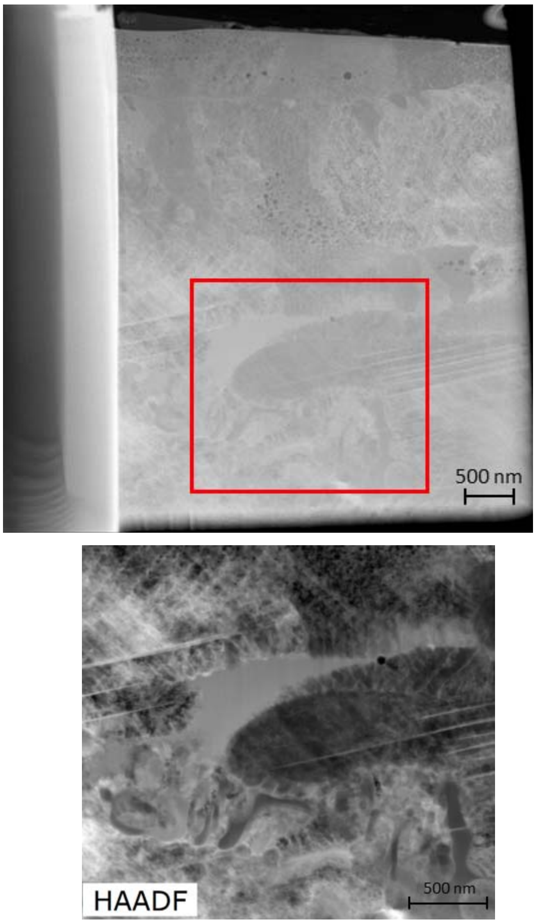

Fig. 2. STEM micrograph of dendritic arm of AM Stellite 6™ alloy on 304L stainless steel base plate, demonstrating the gamma cobalt (globular shape) and epsilon cobalt (disk shape) : (a) BF (Bright Field) (b) HAADF (High Angle Angular Dark Field)

To examine the individual phase within the AM Stellite 6 specimen, elemental mapping was carried out in STEM. Figure 3 illustrate the distribution map of cobalt, chromium, tungsten and iron atom, respectively. The depletion of cobalt and iron atoms together with the enrichment of chromium atoms are well demonstrated for the specific phase, while tungsten atoms appear to evenly distributed rather than expressly partitioning within the specific phase.
However, any partitioning of a specific atom for the disk shaped epsilon phase is not disclosed through the elemental mapping because of the spatial resolution of the technique. Some more detail examination of the crystallographic analyses as well as the in-depth chemical analysis would be helpful for the further investigation.

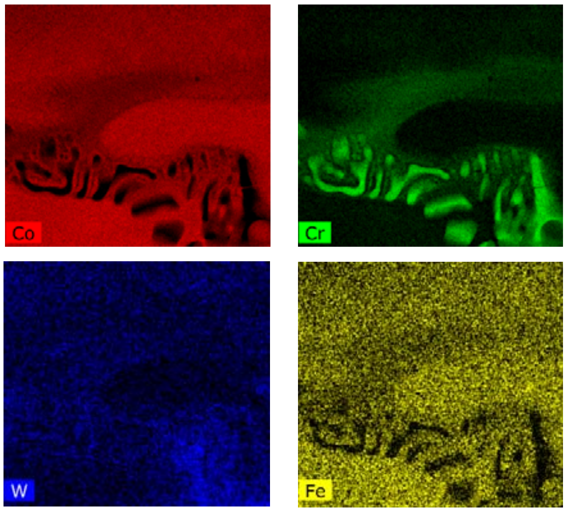

Fig. 3. STEM elemental mapping showing the distribution of Co, Cr, W and Fe atoms in the matrix phase of additively manufactured Stellite 6 specimen

3. Summary

By direct energy deposition additive manufacturing technology wear resistant cobalt-base Stellite 6™ alloy powders was deposited on Type 304L stainless steel base plate at room temperature and 300°C, respectively. By using scanning transmission electron microscope thin disk shaped epsilon cobalt phase as well as fcc cobalt phase was observed. And the cobalt phases were identified with the elemental mapping method in addition to the selected area electron diffraction.

Acknowledgements

Additively manufactured samples in this study were prepared through the support from INSSTEK, Daejeon, Korea.

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