Effect of Hf, Ce on microstructure and mechanical properties of L-DED processed AISI 316L

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ABSTRACT

In this study, AISI 316L powder was mechanically mixed with Fe-10Hf or Fe-10Ce (wt.%) powders to achieve final alloy compositions 0.1 wt.% Hf and Ce, respectively. Samples were fabricated using L-DED, and the effects of Hf and Ce additions on the microstructures and mechanical properties were investigated.

KEY WORDS

Additive manufacturing, Laser direct energy deposition, AISI 316L

1. INTRODUCTION

Laser direct energy deposition (L-DED) process is one of the metal additive manufacturing (AM) processes that produces 3D components that involves the use of a high-power laser to melt and fuse metal powder directly into a substrate.[1] On the other hand, AISI 316L is an austenitic stainless steel that has good corrosion resistance and mechanical properties.[2] In traditional ferrous casting processes, Hf and Ce are known as grain refining elements that enhance mechanical properties by acting as nucleation sites. This occurs through the formation of fine oxides during solidification.[3] This study investigates the resulting changes in microstructure and mechanical properties by adding small amounts of grain-refining elemental powders to prealloyed powders.

2. EXPERIMENTAL METHOD

Manufacturing parameters and chemical composition of substrate and powder used in this study are shown in Table 1 and 2. Schematic of the observed surface of the manufacture samples and scanning strategies are shown in Fig.1. In this study, the L-DED process was conducted using MX-Lab (InssTek Inc., Korea), with Ytterbium Fiber Laser with a maximum output power of 500 W and a laser spot size of 0.3 mm. SEM, XRD and EBSD analysis for microstructure, and tensile test for mechanical properties were done.

Table 1: Manufacturing parameters

Manufacturing parameters	
Scan speed (mm/min)	600
Laser power (W)	200
Powder feed rate (g/min)	1.4
Hatch space (mm)	0.3
Layer thickness (mm)	0.15
Dwell time (sec)	3.5

Table 2: Chemical composition of substrate and powder

Powder	Fe	Cr	Ni	Mo	Hf	Ce
AISI 316L	Bal.	17	10	2	-	-
Fe-10Hf	Bal.	-	-	-	10	-
Fe-10Ce	Bal.	-	-	-	-	10
Substrate (S45C)	Bal.	0.25	0.25	-	-	-

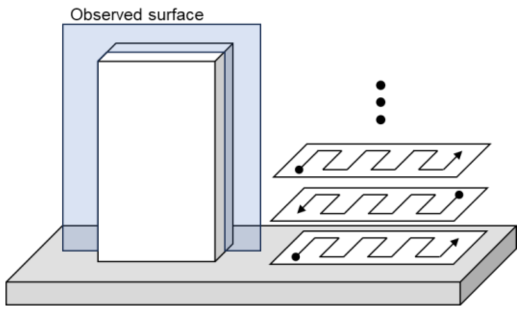

Fig.l: Schematic of scanning strategies

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Microstructure

SEM images of 316L, Hf0.1 and Ce0.1 were shown in Fig.2. The grain size was significantly reduced in both Hf0.1 and Ce0.1 samples, with Ce0.1 exhibiting finer grains than Hf0.1. HfO or CeO particles were not observed in SEM analysis. However, it shows that nanosized oxides may have formed during the process, inhibiting grain growth and contributing to the observed grain refinement.

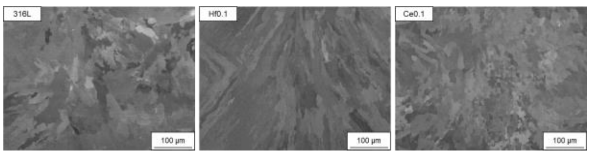

Fig.2: SEM image (grain) of 316L, Hf0.1 and Ce0.1.

Hf0.1 sample exhibited an increased cell structure size and a dendritic structure at the bead boundaries. In contrast, Ce0.1 sample showed an irregular morphology with smaller cell structures compared to Hf0.1. The addition of Hf is expected to reduce the cooling rate, while the addition of Ce increased it. The minimal addition of Hf and Ce significantly influenced the cell structure of the deposited material, which is expected to have a notable impact on its mechanical properties.

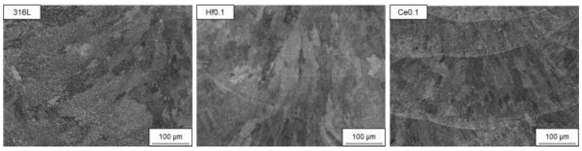

Fig.3: SEM image (cell structure) of 316L, Hf0.1 and Ce0.1.

Also, primary BCC δ-ferrite was partially observed, consistent with the known behavior of L-DED processed AISI 316L, where rapid cooling induces the formation of δ-ferrite.[4] In Hf0.1 sample, the size of δ-ferrite remained relatively unchanged, whereas Ce0.1 sample exhibited a significant reduction in both the fraction and size of δ-ferrite. The addition of Ce effectively reduces the size and amount of δ-ferrite, resulting in a substantial decrease in γ/δ boundary area, which is expected to influence the mechanical properties.

3.2 Mechanical properties

Fig.4 shows strain-stress graph of 316L, Hf0.1 and Ce0.1 In the case of Hf0.1, yield strength decreased while elongation increased. The reduction in grain size contributed to the improvement in elongation; however, the increase in cell structure size likely led to the decline in yield strength. In the case of Ce0.1, yield strength showed no significant change, but both ultimate tensile strength (UTS) and elongation exhibited substantial increases. The significant refinement of both grain size and cell structure size greatly enhanced elongation, while the reduction in γ/δ boundary area offset any improvement in yield strength.

These results indicate that the addition of trace amounts of Hf and Ce, followed by mechanical mixing and L-DED processing, leads to notable changes in both microstructure and mechanical properties.

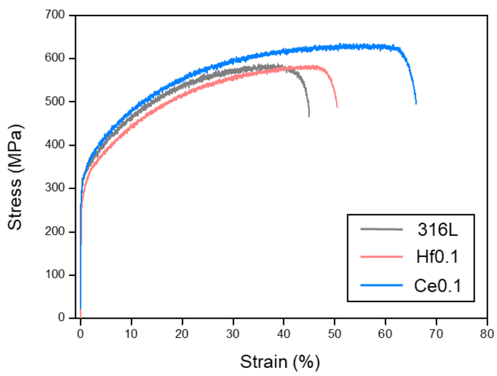

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Fig.4: Strain-stress graph of 316L, Hf0.1 and Ce0.1

4. SUMMARY

In this study, pre-alloyed AISI 316L powder was mechanically mixed with Fe-10Hf and Fe-10Ce (wt.%) powders to achieve final alloy composition containing 0.1 wt.% Hf and Ce, respectively. Samples were manufactured using L-DED process, and the effects of Hf and Ce additions on microstructural and mechanical properties were analyzed. Grain refinement was observed in both Hf0.1 and Ce0.1 specimens. However, in the case of Hf0.1, increased cooling rates led to a coarser cell structure, resulting in improved elongation but reduced strength. In the case of Ce0.1, both the grain and cell structure sizes were significantly reduced, leading to a substantial increase in elongation. However, due to a decrease in γ/δ boundary interfacial area, the strengthening effect was offset, yielding no significant difference in yield strength compared to the 316L. This work shows that even minimal additions of Hf and Ce with mechanical mixing at L-DED process, can result in significant changes to microstructure and mechanical properties.

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