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Strengthening of Zircaloy-4 using Oxide Particles by Laser Beam Treatment

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1. Introduction

Accident tolerant fuel (ATF) cladding is being developed globally after the Fukushima accident with the demands for the nuclear fuel having higher safety at normal operation conditions as well as even in a severe accident conditions. Korea Atomic Energy Research Institute (KAERI) is one of the leading organizations for developing ATF claddings [1]. One concept is to form an oxidation-resistant layer on Zr cladding surface. The other is to increase high-temperature mechanical strength of Zr tube. The oxide dispersion strengthened (ODS) zirconium was proposed to increase the strength of the Zr-based alloy up to high temperatures [2]. The ODS treatment on the Zr surface layer was successfully performed using a laser beam scanning (LBS) process, as shown in Fig. 1 [2]. In this study, the effect of oxide materials (Y_2O_3, CeO_2) used for the ODS treatment on the tensile strength was investigated.

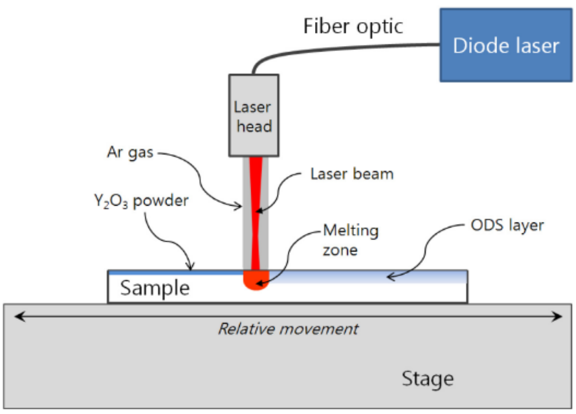

Fig. 1. Schematic illustration of ODS treatment using a laser beam scanning [2].

2. Methods and Results

A Zircaloy-4 (Zr-1.5Sn-0.2Fe-0.1Cr) alloy sheet with 2 mm in thickness was used as a substrate. Oxide powders of Y_2O_3 (99.9%, 1 μm, Alfa Aesar, USA) and CeO_2 (99.9%, 70-105 nm, Alfa Aesar, USA) was purchased, and coated on Zircaloy-4 sheet with the thickness of 10–55 μm. Oxide coating was prepared using a water-based slurry containing a polyvinyl alcohol (3 wt% to oxide powders) as a bonder. The slurry was coated on Zircaloy-4 plate by a doctor blade, and dried in an oven at 80C for 30 min. The coated Zircaloy-4 samples were laser beam scanned by a continuous wave diode laser with a maximum powder of 250 W (PF-1500F, HBL Co, Korea). Beam diameter was 260 μm. Hatching distance was set as 0.2 mm to overlap the laser affected zones. Schematic illustration of LBS was shown in Fig. 1. To prevent oxidation during the LBS, Ar gas was continuously blew onto the melting zone through a laser nozzle.

Fig. 2 shows the microstructures of the ODS (Y_2O_3) treated samples. Laser induced ODS alloying layer was observed at the surface with dark contrasts. Below the ODS layer, the heat affected zone was observed about 300 μm in thickness. As the coating thickness was increased from 10 μm to 30 μm and 55 μm, the thickness of ODS treated layer was increased from 41 μm to 180 μm and 205 μm at 180 W, and from 87 μm to 192 μm and 230 μm at 200 W respectively. Fig. 3 shows the microstructures of the ODS (CeO_2) treated samples. The formation of ODS alloying layer and heat affected zone was similar to the case of Y_2O_3 coating. However, the ODS layer was irregular in thickness. The average thickness was 45 μm (180W) and 100 μm

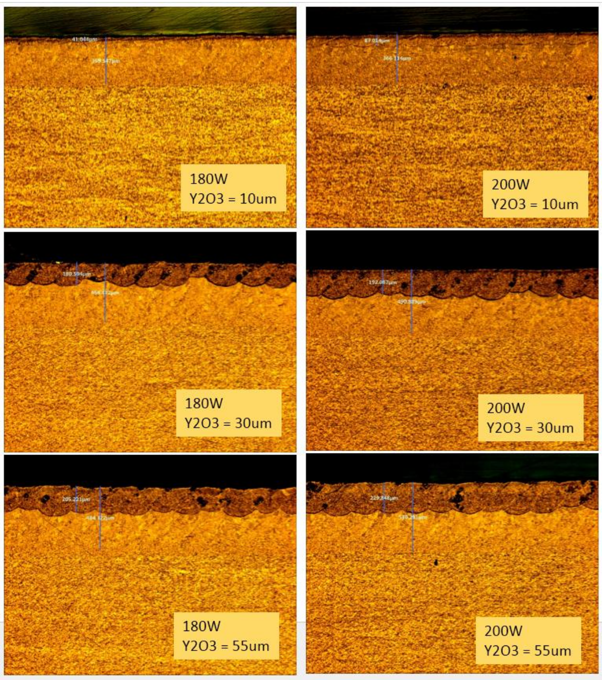

Fig. 2. Cross-sectional microstructures of ODS Zircaloy-4 samples with respect to the laser beam powder and coating thickness of Y_2O_3.

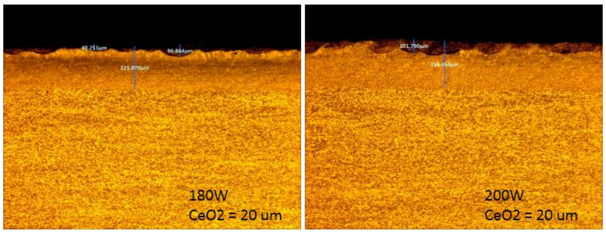

Fig. 3. Cross-sectional microstructures of ODS Zircaloy-4 samples with respect to the laser beam powder and coating thickness of CeO_2.

(200 W) for the 20 μm CeO_2 coated Zircaloy-4 samples. The density of oxide particles in ODS alloying layer was higher in the case of CeO_2 than in the case of Y_2O_3.

Fig. 3 shows the tensile stress to strain curves for the fabricated samples. For the tensile test, small-sized specimens with the cross-sectional dimensions of 2 mm × 4 mm and gage-length of 6 mm were machined by a wire electro-discharge machining. The tensile test was performed at room temperature and 380°C at a displacement rate of 1 mm/min. Fig. 4 shows the appearance of specimens after the tensile test. The brittle fracture of the ODS Zircaloy-4 was observed at

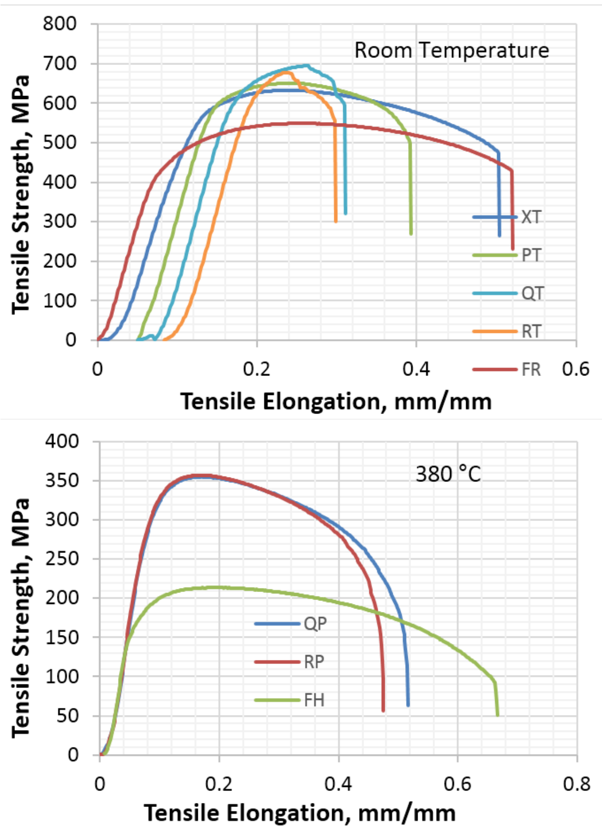

Fig 3. Tensile stress-strain curves for the ODS (Y_2O_3) Zircaloy-4 samples at room temperature and 380℃, with respect to the coating thickness: P=10 μm, Q=30 μm, R=55 μm.

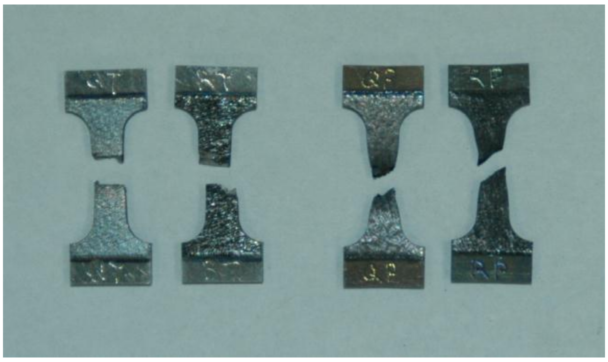

Fig 4. Appearance of tensile specimens after the test at room temperature (left two) and 380℃ (right two) for the ODS (Y_2O_3) Zircaloy-4 samples.

room temperature. However, the high-temperature strength as well as ductility was obtained at elevated temperature of 380℃. Further test at higher temperature (>500℃) will be performed soon. The strength increase by the ODS treatment was caused by the dispersive Y_2O_3 particles and martensite formation on the Zircaloy-4 sheet using an LBS method [2].

3. Conclusions

Oxide particles such as Y_2O_3 and CeO_2 were dispersed homogeneously in a Zircaloy-4 plate surface using an LBS method. From the tensile test at 380℃, the strength of laser ODS alloying on the Zircaloy-4 sheet was increased more than 50% when compared to the initial state of the sheet, although the ODS alloyed layer was less than 20% of the specimen thickness. This technology showed a good opportunity to increase the strength without major changes in the substrates of zirconium-based alloys.

Acknowledgment

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