# Fundamental Study of Seal Tube Welding for the LVDT Instrumentation

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## 1. Introduction

The irradiation test of Zircaloy-4 tube specimens using the LVDT(Linear Variable Differential Transformer) for the pressure and elongation was planned for the evaluation of a nuclear fuels performance.[1,2] To establish the fabrication process, and for satisfying the requirements of the irradiation test, an laser welding machine using a Fiber laser source was developed, and the preliminary welding experiments for optimizing the process conditions of the specimens of a Zircaloy-4 seal tube to MI cable parts for the LVDT were performed. Seal tube with a 12.12mm diameter and a 0.7mm wall thickness has been used and the optimum conditions of the circumferential welding have also been selected.

This paper describes the experimental results of the laser welds of the specimens of Zircaloy-4 seal tube and the metallographic examinations of the laser welded specimens for various welding conditions for the fuel irradiation test. These investigations satisfied the requirements of the fuel irradiation test using a radiation-resistant LVDT for the pressure and elongation and the laser welds for the specimens of the cladding tubes at the HANARO research reactor.

## 2. Materials and Results

### *2.1 Test Materials*

For the instrumented capsule fabrication of the irradiation test, all the specimens were composed with Zircaloy-4 cladding tubes. For the seal tube parts using a radiation-resistant LVDT [3], the joint configuration of the specimens was also prepared as shown in Fig. 1.

### *2.2 Welding Machine*

The welding machine was designed as shown in Fig. 2 by a Fiber laser with the pulsed type in order to achieve a circumferential welding. Laser welding system is under development and consists of the optical welding head, monitoring vision system, helium gas supply and rotary index. At this welding machine, the laser source for the seal tube welding was also used by a 150 W of average power using the optical fiber transmission.

### *2.3 Examination Procedure*

The macro-sections of Zircaloy-4 specimens were investigated by a metallographic examination to determine the penetration depth of the seal tube to the MI cable part. The welded specimens using the seal tube to MI cable were polished and etched electrically with the following etchant : $H_2O$ 90%, oxalic acid 10% (Vol.%).

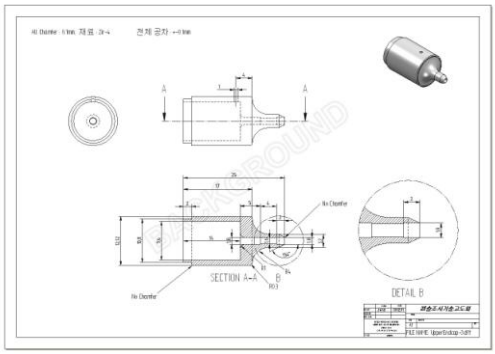


Fig 1. The configuration of the LVDT seal tube specimen.

Fig 2. Photograph of the Fiber laser welder.

### *2.4 Investigation of the seal tube welding*

Table 1 shows welding parameters and laser weldability for both the STS/STS and Zr-4/Ta joints. The primary goal in this experiment is to investigate a proper weld penetration and a soundness in the weld joint of a metal combination for a seal tube welding. The metals which have high melting points such as STS/STS and Zr-4/Ta made by a laser power of 50 W approximately, revealed an partial penetration such as the wide cross-section. However, the dissimilar metal combinations such as Zr-4/STS made at a laser power of 45 W showed an over-

fused penetration such as a burn-through. From the primary welding experiment, it is found that STS/STS and Zr-4/Ta joints show similar penetration depths and bead widths. In a secondary experiment to secure a verification of the weld specimens by the Fiber laser, it is also concluded that the sound welds are of a partial penetration and good bead appearance. The STS/STS and Zr-4/Ta joints having a 154° inclined angle as shown in Fig. 1 is the most desirable design for a seal tube welding. As a result of examining the characteristics on penetration depth of the STS/STS and Zr-4/Ta welding by a fiber laser was appeared, it was found that the optimum parameters of the circumferential welding would be at least 50 W of base average power and 10 ms of a pulse width to be welded.

Table 1. Weld parameters and laser weldabilities of combination metals.

| Cladding metals | Laser power(W) | Pulse width(ms) | Welding speed(rpm) | Laser weldability |
|---|---|---|---|---|
| STS316L x STS316L | 30% (45W) | 10 | 2 | Satisfactory |
| Zircaloy-4 x Ta | 35% (53W) | 10 | 2 | Satisfactory |
| Zircaloy-4 x STS316L | 30% (45W) | 10 | 2 | Brittle |

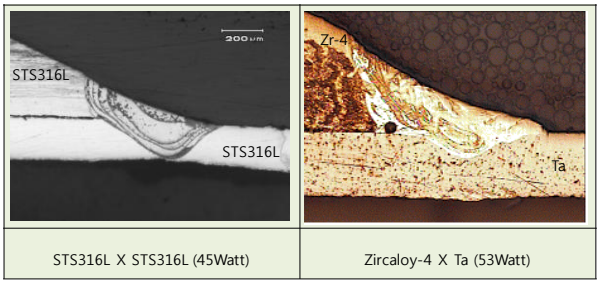


Fig. 3. Macro-sections of the STS/STS and Zr-4/Ta welded specimen.

*2.5 Welds inspection by a micro X-ray radiography*

To find the weld defects and to confirm the soundness of the weld joints, micro-focus X-ray radiography was conducted. Even though a little problem is expected for a welding the same metals, dissimilar binary metal combinations such as STS/STS and Zr-4/Ta joints require laser power to obtain sound welds. Fig. 4 shows two parallel lines in the middle of a tube corresponding to the lines of the temperature sensors. A sound weld is confirmed by an X-ray transmitted image for the STS/STS and Zr-4/Ta joints, in which the MI cable is not damaged by the laser source in a short time while welding. In order to obtain a sound weld between a seal tube and a MI cable based on the experimental results, metallographic examination and X-ray radiography of the welds, it can be suggested that a laser power of 50 W and a welding speed of 2 rpm are the optimized welding parameters for the joint configuration in Fig. 1.

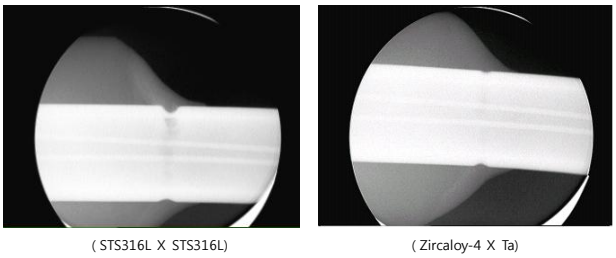


Fig. 4. RT images of the STS/STS and Zr-4/Ta welded specimens.

## 3. Conclusion

This study was carried out the weld parameters and to select the suitable metal combination for a joining of a seal tube to a MI cable for a fuel irradiation test. A Fiber laser welder with a 150 W pulsed and 50 um SI optical fiber transmission was set up to weld a seal tube to a MI cable for the LVDT instrumentation. In the laser welding experiment, a joint of a dissimilar binary metal combination of Zr-4/Ta was suitable for a seal tube to MI cable joining in terms of the sound welds. Based on this fundamental experiment, instrumented capsule fabrications with the LVDT will be provided for the fuel irradiation test at the HANARO research reactor.

## Acknowledgements

This work was supported by the Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST).

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