The general relation between tensile strength and swaging process conditions of the nuclear fuel assembly

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1. Introduction

Recently, many research reactors for civilian uses have successfully converted from highly enriched uranium (HEU) to low enriched uranium (LEU) fuel to decrease the proliferation risks associated with HEU fuel. However, the high-performance research reactors (HPRRs) in the U.S. and Europe still need efforts for developing high-density LEU fuel to secure their performance after conversion.

In this regard, KAERI and SCK CEN have been cooperating on qualifying the performance of the high-density atomized U3Si2 fuel since 2021. The cooperative project has two phases: 1. KIMQI-FUTURE flat-type fuel plate qualification 2. KIMQI-GTA curved-type fuel assembly qualification. As the 2nd phase, KAERI is developing the swaging process, joining curved-type fuel plates to the assembly components called side plates.

In this study, we performed tensile tests for the analysis of the strength of the swaged connections between the fuel plate and the assembly components called side plates, and the relation between tensile strength and swaging process conditions were described.

2. Methods and Results

We designed mock-up specimens for the tensile test of swaged fuel plates, and specimens were prepared with varying swaging process conditions to analyze the general relation between tensile strength and the process variables. For fuel qualification, tensile tests for mock-up specimens shall be performed before and after fuel plate swaging, and the results should fulfill the fuel specifications of tensile strength, 27kgf/cm per unit area. Fabrication of mock-up specimens for the tensile test is described as follows;

2.1 Fabrication of mock-up specimens

As shown in Fig1, insert the mini-size plate (which has the same radius and width but a shorter length than the fuel plate as shown in Fig.2) between two side plates' grooves (fuel assembly components as shown in Fig.3).

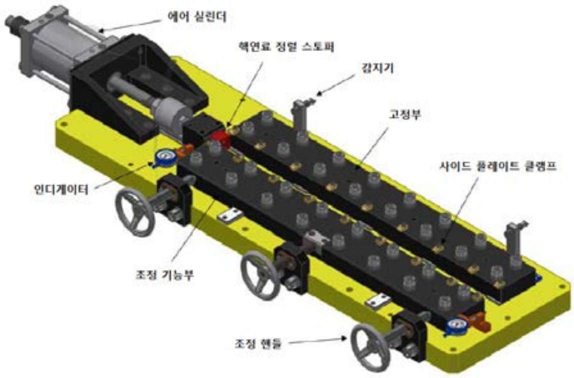

Fig 1. Swaging fixture of the MCT [1]

Fig 2. Mini-size plate

Fig 3. Side plates

Subsequently, the mini-size plate combined with side plates by passing swaging wheels right above the groove of the side plates and deforming grooves to hold the mini-size plate as shown in Fig. 4 and Fig.5.

As the swaging process variables, the swaging depth (the depth of insertion of the swaging wheel into the side plate) and the swaging height (the height from the groove's top slope to the point swaging wheels passing) varied.

Fig 4. Swaging wheels

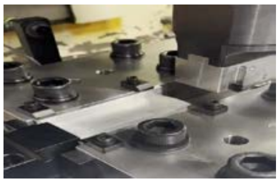

Fig 5. Swaing process

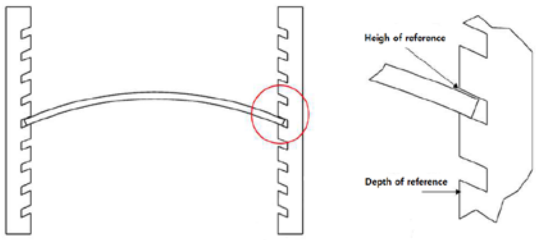

Fig 6. Swaging depth and Swaging height

Final mock-up specimens for tensile tests consist of 24 mini-size plates between side plates as shown in Fig.7.

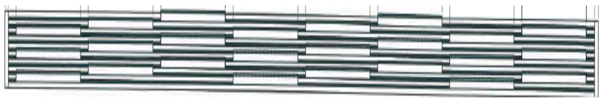

Fig 7. Mock-up specimens

For the tensile test, each mini-size plate was cut into 1 tensile test sample by the cutting wheel and prepared to fit into the fixture of the MTS materials test systems.

2.2 Tensile tests

The fixture of the MTS is designed for holding each sample with parallel alignment during the test as shown in Fig 8. The tests were conducted by pulling the sample at the rate of 2mm/min.

Misalignments were largely avoided by the preliminary verification of equipment and tooling during the test. We measured the maximum load of the tensile strength when the failure occur in the sample, and the swaging strength was calculated by Equation 1.

Swaging strength(N/mm) = F(N) / N(EA) x d(mm) [2] – Eq. 1

Fig 8. Tensile test of mock-up

Where Swaging strength (N/mm) is the strength per unit of mini-plate, F(N) is the maximum load of tensile strength test, N(EA) is the number of mock-ups, and d(mm) is the diameter of mini-plate. The minimum limit of tensile strength is 27(N/mm).

2.3 Analysis of tensile strength changes by swaging conditions

In the 1st test, the swaging height and depth were set to 0.4mm to conduct swaging, respectively. The same tests were performed in at least one mock-up which consists of 24 tensile samples providing further assurance of the integrity of the swaged connections. The results showed that the tensile strength varied from 6.6(N/mm) to a maximum of 30.1(N/mm).

For the 2nd test, the swaging depth changed to 0.5mm while other conditions were the same. In this case, the tensile strength varied from 22.2(N/mm) to 41.6(N/MM). The results showed that the tensile strength of the swaged joint increases quickly once the side plate lip contacts enough with the fuel plate.

The 3rd test was set at 0.6mm for the swaging depth while the swaging height varied from 0mm to 0.4mm. The results were recorded in Table 1, and it showed that ultimately, swaging with high enough depth would produce robust connections between mini-plates and side plates causing it too has higher tensile strength. Furthermore, the strongest tensile strength was achieved at the swaging depth of 0.6mm and the swaging height of 0.3mm.

No.	Press in depth(mm)	Press in height(mm)	Measure value (N/mm)
1	0.6	0.0	76.25
2		0.1	76.5
3		0.2	89.6
4		0.3	**95.3**
5		0.4	55.07

Table 1. Tensile test results of the 3rd test.

3. Conclusions

In this regard, it should be noted that the swaging process conditions such as the swaging height and the swaging depth have an important role to fulfill the tensile strength specifications. For the successful irradiation tests at the BR2, more research should be followed in the future.

REFERENCES

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[2] Kim, K. S., Ryu, J. S., Park, J. H., Cho, Y. G. and Oh, J. H., 2009. Preliminary Thermal Stress Analysis for Plate Type Fuel Assembly, KAERI/TR-3936/2009, Korea Atomic Energy Research Institute, Daejeon.