Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

Spacer Grid Lateral Crush Strength depending on Welding Methods

Joo-Young Ryu*, Han-Gil Woo, Nam-Gyu Park, Seung-Jae Lee
KEPCO Nuclear Fuel Co., 242, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: jyryu@knfc.co.kr*

1. Introduction

A spacer grid is an important component of the nuclear fuel assembly which has a mechanical function to support and protect the fuel rod by absorbing the impact force, and it also has a thermal hydraulic function to enhance the coolant heat transfer capability. Spacer grid maintains the gap between the fuel rods and enables the fuel rod to cool down by providing coolant flow path.

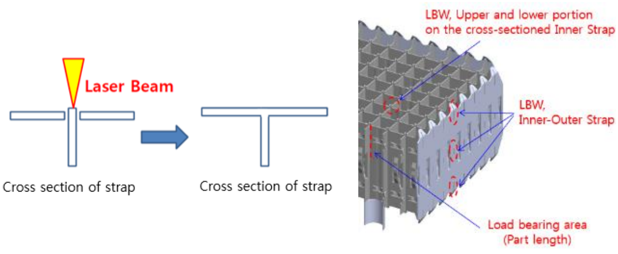
However, when the nuclear fuel is subjected to an unwanted excessive load during shipping, handling, manufacturing and operating, it could lead to fuel failure such as spacer grid buckling and cladding tube deformation. The maximum limiting load acting on the spacer grid is the lateral impact load during seismic/LOCA accidents. For this reason, in order to ensure the seismic performance and mechanical integrity of the fuel, spacer grid design is required to withstand the lateral impact load and maintain high strength throughout the lifetime of operation[1, 2].

One of the factors that determine the spacer grid strength is welding method. KEPCO NF (KNF) usually uses laser beam welding and brazing when manufacturing the spacer grids. This study is to investigate the crush strength variations of the same designed grids utilizing two different welding methods. KNF has simulated and tested to study this effect and the results are compared and discussed.

2. Grid Welding

2.1 Laser Beam Welding

Laser beam welding (LBW) is a method of melting using concentrated heat source to the base material with high density laser light energy. KNF uses Nd-YAG laser welding to melt and weld the cross-sectioned area on the upper and lower portion of the straps during fabrication of the grid assembly. The welding strength is strong but the constrained area is short.

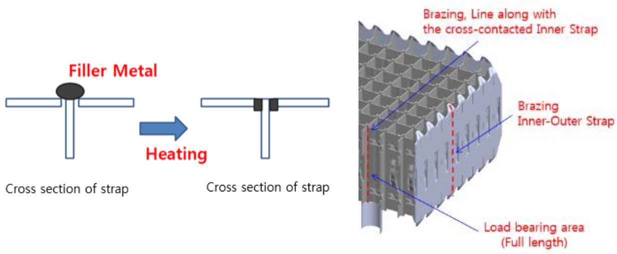


(a) LBW process concept (b) Grid ass'y fabrication
Fig. 1. LBW process for grid assembly

Figure 1 shows LBW process and its application for the grid assembly.

2.2 Brazing

Brazing is a welding; only the brazing material is melted and bonded without melting the base material by using a non-ferrous metal or base metal alloy which has a melting point lower than that of the base material. For brazing, the spacer grid is filled with filler material at each line along with the cross-contacted area after loaded into the brazing vacuum furnace. The bonded strength is weaker than LBW but the entire length of the strap cross section is welded. Figure 2 shows brazing process and its application for the grid assembly.

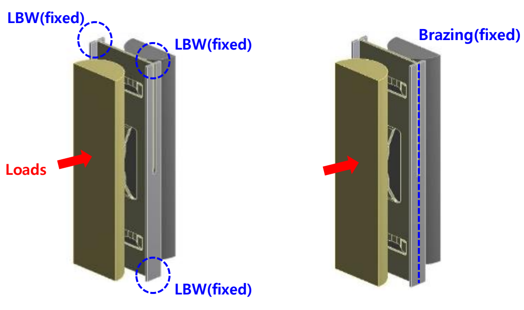


(a) Brazing process concept (b) Grid ass'y fabrication
Fig. 2. Brazing process for grid assembly

3. Crush Strength Characteristics

3.1 Effect of Load-bearing Area

In order to understand variations of the mechanical strength by applying the welding conditions, static load-deflection analysis was performed through simple assumptions as shown in Fig. 3. Analysis was considered for typical one cell and non-linear material property and boundary conditions were applied as real state of the grid assembly welding.



(a) LBW (b) Brazing
Fig. 3. Boundary and loading condition for typical cell

A commercial FEM software, ANSYS[3], was used to analyze the characteristics.

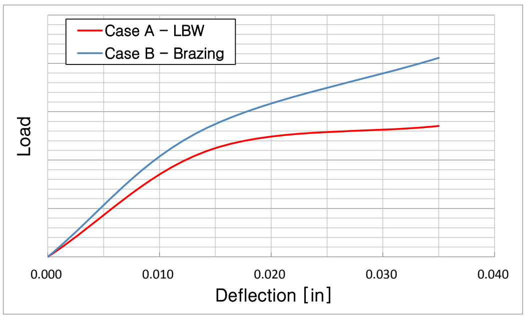


Fig. 4. Comparison of the load-bearing area effect for one cell

The load-bearing area effect analysis for typical one cell of Fig. 4 shows that the load varies by up to about 80% and the stiffness varies by about 66% in the linear range. The reason is that when brazing is substituted for the LBW of the spacer grid, the entire cross-contact vertical line by the intersection of the inner straps is constrained. Thus, it makes effect that load increases for the same displacement since the load-bearing area for carrying the load is increased.

3.2 Crush Test

The test equipment for the dynamic crush strength consist of the hammer, load cell and high temperature furnace. The weight of the hammer is equivalent to the weight of the fuel rods within one span supported by the spacer grid. Short fuel rod cladding tubes are inserted in each cell of the test grid. The temperature for the dynamic impact test is chosen considering reactor condition. In this test, two groups each of ten specimens with the same design were prepared separately for two different welding conditions. Figure 5 and 6 show the schematic of the dynamic crush test equipment and grid failure modes from dynamic crush. Both groups have similar failure modes that show slightly rotated shape at the corner or center of the outside. Also, some specimens are hard to distinguish visually since failures are occurred inside of the grid. These pictures are left out in this paper.

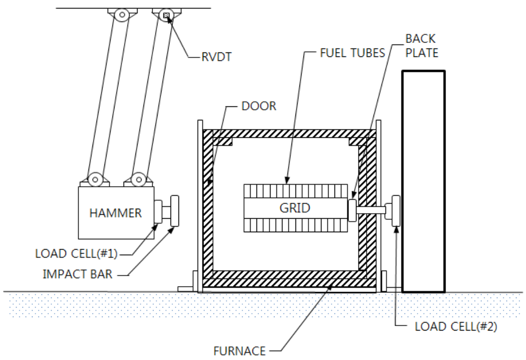
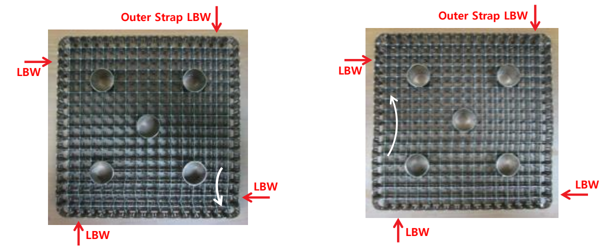
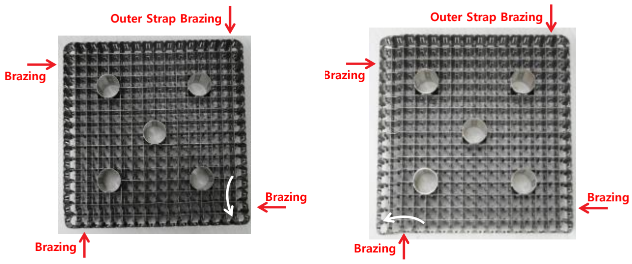


Fig. 5. Schematic of the dynamic crush test equipment



<Type 1> <Type 2>

(a) Case A - LBW(10EA)



<Type 1> <Type 1>

(b) Case B - Brazing(10EA)

Fig. 6. Grid failure modes from dynamic crush

The dynamic crush strength is the maximum impact load generated before the buckling of the inner spacer grid strap, and the impact force is reduced after the buckling of the spacer grid.

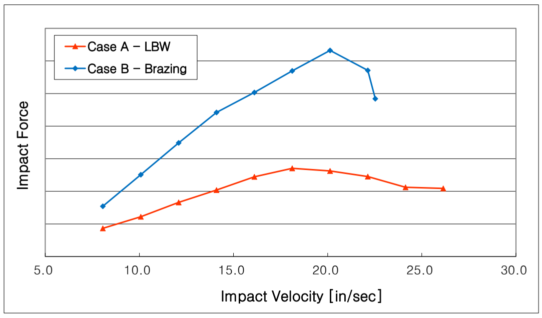


Fig. 7. Comparison of the dynamic crush test result graph for grid assembly

The dynamic crush test results for the grid assembly of Fig. 7 shows that the force varies by up to about 130% and the stiffness varies by about 180% at the maximum impact load. The impact strength, stiffness and seismic factor of the spacer grid are the main factors involved in the fuel seismic performance calculation of the nuclear fuel. The comparisons in Table 1 are relative values of dynamic crush test data. From this comparison, seismic performance of the fuel assembly of brazing can be superior since brazing characteristics are higher to LBW.

Table I: Comparison of the dynamic crush test data

	Case A (LBW)	Case B (Brazing)
Rel. Average Crush Strength	0.43	1.0
Rel. Average Stiffness	0.36	1.0
Rel. Seismic Factor	0.64	1.0

3.3 Statistical Verification

F-Test is used to test the null hypothesis that the variances of two groups are equal. Based on the evaluation in Table II, it rejects the null hypothesis. Since p-value of F-Test is under 0.05, the variances of the two groups are unequal. It requires unequal variance t-Test. And since p-value of t-test is under 0.05, the average number of crush strength between the two groups differ significantly. It means two test groups are independent.

Table II: Statistical evaluation for F-Test and t-Test

	Case A (LBW)	Case B (Brazing)	Note
Rel. Mean	0.43	1.0	-
Rel. Variance	3.46	1.0	-
Observations	10	10	-
P(F<=f) one-tail	3.92E-02		F-Test
P(T<=t) one-tail	2.21E-10		t-Test
P(T<=t) two-tail	4.43E-10		t-Test

4. Conclusions

From the study, it can be clearly seen that the spacer grid with larger constrained welding area has greater impact force and stiffness. This means that the dynamic impact characteristics of the spacer grid and seismic performance of the fuel assembly could be greater when brazing is applied instead of LBW. It is noted that there are still many factors to be considered for brazing method in terms of current grid design criteria and manufacturing feasibility, and LBW has many other advantages. Only for simply increasing crush strength, brazing is a good way to have extra margin of the required grid strength.

REFERENCES

[1] K.N. Song, S. H. Lee, S. B. Lee, J. J. Lee, 2010, “Study on the Lateral Dynamic Crush Strength of a Spacer Grid Assembly for a LWR Nuclear Fuel Assembly”, KSME, Vol. A-34-9, pp1175~1183

[2] J.Y. Ryu, Y.I. Yoo, N.G. Park, J.S. Yoo, 2017, “Prediction of 17x17 grid crush behavior with a 2D finite element model”, Proceedings of 2017 WRFPM, Sept. 10-14

[3] ANSYS 15.0 Workbench Mechanical Documentation