Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-27, 2012

On the Impact Analysis of a PWR Spacer Grid

Keenam Song [a*], S-H Lee [a]
[a] *Korea Atomic Energy Research Institute, P.O.BOX 105 Yusong, Taejon, KOREA*

[*] *Corresponding author: knsong@kaeri.re.kr*

1. Introduction

A spacer grid, which is an interconnected array of slotted grid straps and is welded at the intersections to form an egg-crate structure, is one of the most important structural components in a PWR fuel assembly. From a structural point of view, the spacer grid is required to have sufficient crush strength under lateral loads so that nuclear fuel rods are maintained in a coolable geometry, and that control rods can be inserted [1]. The capacity of a spacer grid to resist lateral loads is usually characterized in terms of its crush strength, and it was reported that the lateral crush strength of the spacer grid is closely related with welding quality of the spacer grid [2].

Microstructures in the weld zone, including a heat affected zone (HAZ), are different from that in a parent material [3]. Consequently, the mechanical properties in the weld zone are different from those in the parent material to some extent. When a welded structure is loaded, the mechanical behavior of the welded structure might be different from the case of a structure with homogeneous mechanical properties. Nonetheless, mechanical properties in the welded structure have been neglected in many structural analyses [4-7] of the spacer grid due to a lack of mechanical properties in the weld zone. When the weld zone is very narrow and the interfaces are not clear, it is difficult to take tensile test specimens in the weld zone. The reason for this is that the mechanical properties in the parent material are usually used in the structural analyses in the welded structure. As an aside, it has been recently determined that the ball indentation technique has the potential to be an excellent substitute for a standard tensile test, particularly in the case of small specimens or property-gradient materials such as welds [8].

In this study, to investigate the effect on the mechanical behavior of the spacer grid when using weld mechanical properties, strength analyses considering the weld mechanical properties recently obtained [9] by an instrumented indentation technique are performed, and the analysis results are compared with the previous research using the parent material properties.

2. Zircaloy Spacer Grid

Zircaloy is the prevailing material of a spacer grid because of its low neutron absorption characteristic and its extensive successful in-reactor use. Generally, a spacer grid with a deeper weld penetration results in larger crush strength of the spacer grid [7]. The diameter of the weld bead is about 2 *mm* and the width of the HAZ is just below 1 *mm* for the Zircaloy spacer grid strip of 0.457 *mm* thickness. That is to say, the weld zone including the weld bead (or fusion zone) and the HAZ is very narrow and the interfaces are not so clear. Thus, it is usually difficult to get the mechanical properties in the weld zone from a conventional tensile test specimen.

3. Measurement of Weld Properties

An instrumented indentation method is known to be a remarkably flexible mechanical test to obtain properties including hardness, Young's modulus, yield stress, and tensile strength with minimal specimen preparation [8] by continuously measuring the load and depth if an indentation is made. The additional advantage of indentation is the ability to obtain the mechanical properties in a narrow or inaccessible region through other methods such as uni-axial tension or a compression test.

Based on the measured data using an instrumented indention method, normalized mechanical properties in the parent material, the weld, and the HAZ of Zircaloy-4 were obtained [9]. The mechanical properties in the weld bead, HAZ, and parent material are different to some extent, and thus might affect the structural behavior and crush strength of the spacer grid.

4. Strength Analysis and Discussion

When performing a crush strength test and analysis on a full-size spacer grid (16x16 array), too much time and cost is required to fabricate and model the full-size spacer grid specimen. Previous research [4,6] has reported that a sub-size spacer grid specimen (7x7 array) represented the tendency of the crush strength of the full-size spacer grid well when estimating the crush strength. Thus, as an alternative, a crush strength test and analysis on the sub-size spacer grid specimen is carried out in this study. The crush strength test was performed on 5 specimens and the average crush strength was obtained.

An Finite Element (FE) model for predicting the crush strength of the sub-size spacer grid has been established, reflecting a real test environment. Fig. 1 shows the FE model of the sub-sized spacer grid and the boundary condition. 24,448 two- dimensional linear quadrilateral shell elements were used for the inner/outer straps. Since the slot width in the inner straps is wider than the inner strap thickness, there may be a gap at the interconnected parts. Thus, surface-to-node contact elements were used at these interconnected parts to simulate the gap conditions. As shown in Fig. 1, a rigid and mass element was used for simulating the impact hammer and all degrees of freedom were fixed at the rigid surface of the bottom side. The applied boundary condition simulated the actual test condition. The initial impact velocity at the reference node (at the center of the upper rigid surface) is applied, and the output accelerations for the initial impact velocity are obtained at this node.

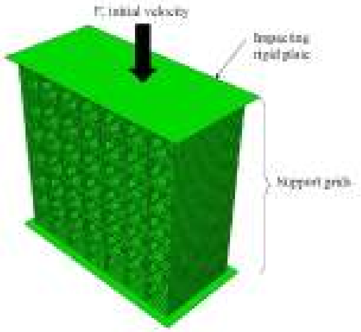

Fig. 1. FE model of sub-size spacer grid.

Crush strength analyses were carried out using a commercial FE code, LS-DYNA [10]. For the crush strength analysis using the parent material properties, the stress-strain curve of the parent material is used as the material properties [11]. On the other hand, for a crush strength analysis using weld material properties, stress-strain curves in the weld zone including the weld and HAZ are generated by the multiplying the stress-strain curve of the parent material by normalized mechanical properties [9].

Fig. 2 shows the results of the crush strength analysis on the FE model using the parent material and weld properties. The crush load increases and becomes saturated to the maximum values as the impact velocity increases, as shown in Fig. 2. From Fig. 2, a following the observation of note is found. The maximum crush load using weld material properties for the FE model is much lower (about 22%) than that using the parent material properties. The reason for this seems to be attributed to the yielding and deforming that first occurs in the parent material with lower yield stress, while yielding in the weld zone with higher yield stress seems to be delayed.

The crush strength is taken from Fig. 2 and compared with the test results. A comparison of the crush strength ratios is summarized in Table 1. According to Table 1, the crush strength ratios, in other words, the crush strength, from using the mechanical properties in weld zone closes a gap in the test results by up to 50% compared to that using the parent material properties.

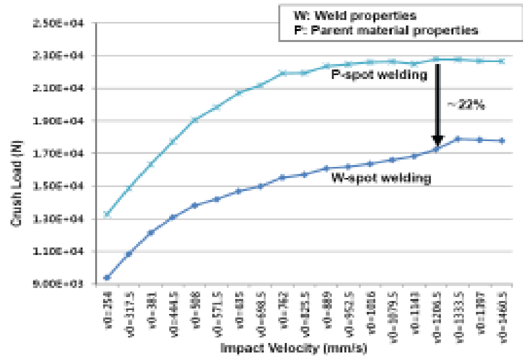

Fig. 2. Crush load vs. impact velocity.

Table 1 Comparison of crush strength ratio

Analysis/Test	
with parent material properties	with weld material properties
1.935	1.429

5. Conclusions

1. The crush load when using the weld material properties is much lower than that when using the parent material properties for a crush strength analysis of the Zircaloy spacer grid.
2. The crush strength of the Zircaloy spacer grid obtained from the analyses using the weld mechanical properties closes a gap in the test results compared to those from the analyses using the parent material properties.

REFERENCES

[1] H. J. Kunz and K. N. Song, Siemens/KWU Work-report U6/312/87/e326, Siemens/KWU, 1987.
[2] K. N. Song and S. S. Kim, *Mater. Sci. For.*, Vols. 580-582, p. 507, 2008.
[3] George E. Linnert, *Welding Metallurgy 1*, American Welding Society, New York, p. 6 and 310, 1965.
[4] K. N. Song, S. B. Lee, M. K. Shin, J. J. Lee and G. J. Park, *J. Nucl. Sci. Technol.*, Vol.47, p. 295, 2010.
[5] S. B. Lee, Y. W. Kim and K. N. Song, *J. of Mechanical Science and Technology.,* Vol.22, p. 2024, 2008.
[6] K. N. Song, S. S. Kim, S. H. Lee and S. B. Lee, *JLMN-Journal of Laser Micro/Nanoengineering,* Vol.4, p. 11, 2009.
[7] K. N. Song, S. H. Lee, S. S. Lee, *Int. J. of Modern Physics B*, Vol.22, p. 1228, 2008.
[8] ISO TR29381: Metallic materials - instrumented indentation test for measurement of indentation tensile properties, 2008.
[9] K. N. Song and D. S. Ro, *J. of the Korean Welding & Joining Society*, Vol.30, p. 249-254, 2012.
[10] LS-DYNA Keyword User's Manual, ver. 971, 2006.
[11] Technical data sheet: reactor grade zirconium alloys for nuclear waste disposal, Retrieved March 26, 2012 from http://www.wahchang.com/.