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Comparison of the static characteristics of 1x1 spacer grids

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1. Introduction

The characteristics such as buckling load, stiffness and energy absorption rate of zirconium alloy spacer grids have been changed under irradiation environment by coolant temperature, spring relaxation, hydrogen embrittlement and so on[1]. The purpose of this paper is to compare buckling characteristics of 1x1 as-built spacer grid, those of spring relaxed spacer grid and hydrogen absorbed spacer grid.

2. Hot-cell Examination of the Spacer Grids

Under irradiation, grid spring force decreases and the gap opening between rod and grid occurs with spring relaxation. Spring relaxation affects buckling load and stiffness of the spacer grid. Therefore, influence of the relaxation can be estimated by measuring cell size of irradiated grid.

Post-Irradiation Examination(PIE) on the irradiated spacer grid has been performed at the Post-Irradiation Examination Hot-cell Facility of Korea Atomic Energy Research Institute. The schematic configuration of an elementary grid cell is shown in Figure 1.

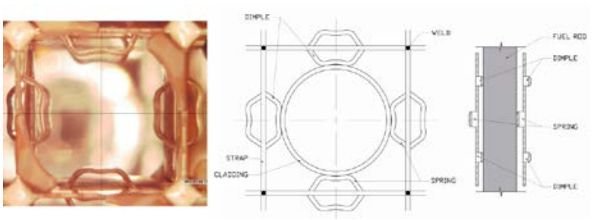


Figure 1. Configuration of an elementary grid cell

The hot cell results show that the cell sizes of the mid-grid increased up to about 4 % as compared to the as-built data. Therefore, cell setting was performed that of target value 4% larger than as-built data.

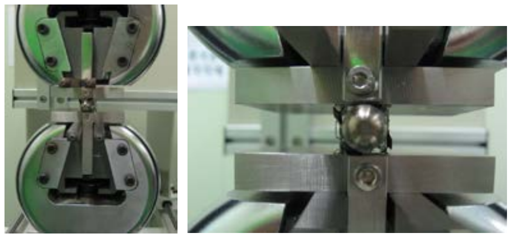
3. 1x1 Grid Static Buckling Test

Static buckling test were performed using artificially manipulated 1x1 spacer grid cell with being inserted fuel rod section to consider the effects of spring relaxation and hydrogen absorption. In this paper, the relaxed grid is only relaxed spring to adjust cell size and the hydrided grid is hydrogen absorbed grid with spring relaxation.

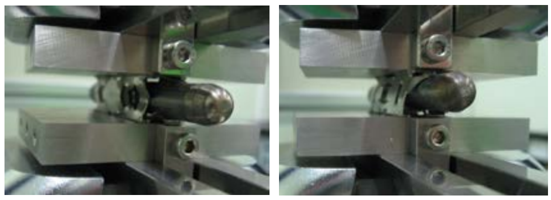
The Number of static grid test specimen is shown in Table 1 and the before and after static grid buckling test are shown in Figure 2.

Table 1. Number of static grid test specimen

Test Specimens and Support Component	EA
1x1 as-built spacer grids	20
1x1 relaxed spacer grids	20
1x1 hydrided spacer grids	20
Fuel Rod Sections	AR



(a)Test jig and Before test specimen



(b)After test specimens

Figure 2. Static buckling test

4. Statistical Evaluation

The typical test result is shown in Figure 3.

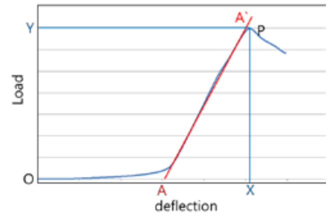


Figure 3. Evaluation method

In this figure, the buckling load is the maximum load(point P) and the stiffness is the maximum gradient(A-A`) of the test graph. The energy absorption rate is the value which is the energy absorbed by test specimen divided by total amount of energy during the test. The equation of the energy absorption rate is as follows:

$$E_{abs.}\ \text{Rate}= [\int_o^x (f(x)dx]/(YP*PX) \quad (1)$$

2 sample t-test was used for statistical analysis of each test and level of significance is 5%(α=0.05)[2]

- Null hypothesis: the values of test result are same level.
- Alternative hypothesis: the values of test result are different level.

The differences of each test values are evaluated by P-value. (P>0.05: Null hypothesis selected)

The results of 2 sample t-test are shown in Figure 4.

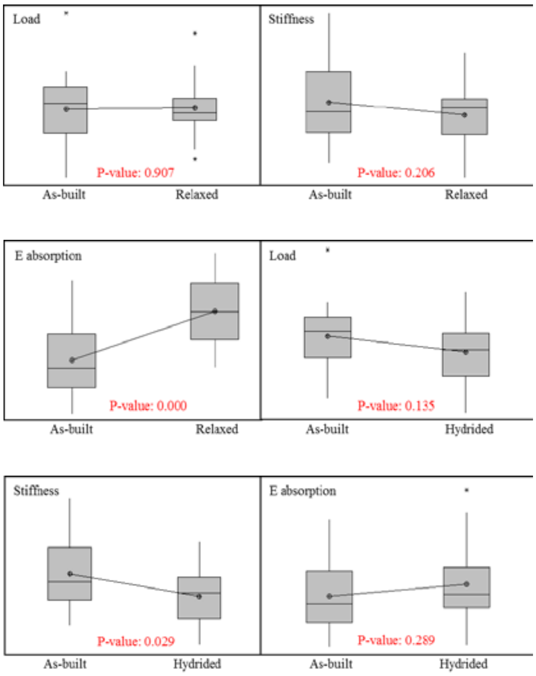


Figure 4. Results of the 2 sample t-test

5. Test Result

The result of static test such as buckling load, stiffness and energy absorption were shown in Table 2. The comparisons of each test and statistical analysis results were shown in Table 3 and 4, respectively. The standards of each characteristic are the as-built characteristics.

Table 2. 1x1 grid buckling Test results

	As-Built	Relaxed	Hydrided
Avg. Buckling Load	1.00	1.00	0.93
Avg. Stiffness	1.00	0.92	0.84
Avg. E Absorption	1.00	1.33	1.08

Table 3. Comparison of each test results

	As-built vs Relaxed	As-built vs Hydrided
Avg. Buckling Load	-0.5	-7.2
Avg. Stiffness	-7.8	-15.5
Avg. E Absorption	33.2	8.4

Table 4. Statistical analysis result

	As-built vs Relaxed	As-built vs Hydrided
Avg. Buckling Load	Same	Same
Avg. Stiffness	Same	Different
Avg. E Absorption	Different	Same

As shown in the analysis results, the as-built grids statistical average stiffness analysis results comparing with relaxed grid analysis results, even though difference is existed, are same level but hydrided grids analysis results are different level. As already mentioned the full size grid crush test[1], only spring relaxation do not affect enough to grid stiffness. However, adding hydrogen embrittlement to spring relaxation grid affect grid stiffness due to brittleness increase.

The results of statistical average energy absorption analysis between as-built grids and relaxed grids are different level in contrast of the results of analysis between as-built grids and hydrided grids. The stiffness of relaxed grids is decreased by gap due to spring relaxation. The gap leads to quick absorption of deformation energy. It is the reason why the relaxed grids energy absorption rate is higher than as-built grids rate. Although the stiffness of hydrided grids is decreased due to brittleness increase, the energy absorption rate of hydrided grids is almost same level in the rate of as-built grids.

The results of statistical average buckling load of as-built grids, relaxed grids and hydrided grids are same level, even though differences are existed in test results. These results show conflicting result of full size grid test which is spring relaxation effects buckling load[1]. There are lots of differences between 1x1 grid and full size grid such as strap length, hinge at the weld point and so on. It is the reason why the results conflict between two tests.

5. Conclusions

This study discussed the characteristics of 1x1 spacer grid, which is affected by spring relaxation and hydrogen embrittlement. All tests are statistically analyzed and the results are derived.

To make more detail test result, because 1x1 grid test cannot represent full size grid, bigger grid test should be performed such as 6x6 grid and full size grid.

6. References

[1] J.Y. Lee, et al., “A study of impact characteristics of spacer grids of PWR Fuels” 2013 Transactions of the Korean Nuclear Society Spring Meeting, May 30-31, Gwangju, Korea.

[2] Minitab, Minitab 15 User’s Guide, Minitab, Inc., 2006.