Determination of the Optimum Welding Parameters for a Laser Welded Spacer Grid Assembly for PWRs

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A spacer grid assembly, which is an interconnected array of slotted grid straps and welded at the intersections to form an egg crate structure, is one of the core structural components of the nuclear fuel assemblies of a Pressurized light Water Reactor (PWR). The spacer grid assembly is structurally required to have enough buckling strength under lateral loads due to lateral seismic accelerations, lateral Loss Of Coolant Accident (LOCA) blowdown forces, and shipping and handling loads so that the nuclear fuel rods are maintained in a coolable geometry, and that control rods are able to be inserted. The ability of a spacer grid assembly to resist lateral loads is usually characterized in terms of its dynamic and static crush strengths, which are acquired from tests. The crush strengths and spacer grid dynamic stiffness of a spacer grid assembly are required for the fuel assembly seismic and LOCA blowdown analyses to verify that a coolable grid geometry is maintained. Since the crush strengths of the spacer grid assembly are known to depend on the weld qualities at the intersections of the slotted grid straps, high-tech welding methods, such as the TIG welding, LASER beam welding or Electron beam welding method, have been used recently in the nuclear fuel manufacturing fields.

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1. Introduction

In a Pressurized light Water Reactor (PWR), the fuel assembly consists of several spacer grid assemblies, lots of fuel rods, a top nozzle, a bottom nozzle, several guide tubes, and one instrumentation tube as shown in Fig. 1. The spacer grid assembly, which is an interconnected array of slotted grid straps and welded at the intersections to form an egg crate structure, is illustrated in Fig. 2 and Fig.3. The primary function of the spacer grid assembly is to support and protect the fuel rods from external impact loads in an abnormal operating environment such as an earthquake or a Loss-Of-Coolant Accident (LOCA). Moreover, the spacer grid must maintain the guide tubes (or fuel skeleton structure) straight so as not to impede a control rod insertion under any normal or accidental conditions. Therefore a plastic deformation of the spacer grid assembly needs to be limited and it must be designed to have a sufficient enough lateral impact strength [1].

2. Spacer grid welding

2.1 Outline of a spacer grid welding

A spacer grid assembly, which is an interconnected array of slotted grid straps and welded at the intersections to form an egg crate structure, is one of the core structural components of the nuclear fuel assembly of a Pressurized light Water Reactor (PWR). Fig. 4 illustrates the spacer grid inserted with fuel cladding tubes. Two kinds of spacer grid assembly prevail in the PWR fuel assembly. One is an Inconel spacer grid assembly made of Inconel straps because of its high strength and high corrosion resistance. The other is a Zircaloy spacer grid assembly made of Zircaloy straps because of its high neutron economy. Brazing is used in a joining for the Inconel straps, while a TIG welding, EB welding, and LB welding are used in a joining for the Zircaloy straps. Nowadays a LB welding is prevailing for most of the Zircaloy spacer grid manufacturing vendors for the purpose of a smaller welding bead size and a larger welding penetration depth at the welding parts. The spacer grid assembly with a smaller welding bead size leads to a smaller pressure drop of the coolant flowing along the fuel assembly. And the spacer grid assembly with a larger welding penetration depth results in a larger buckling strength of the spacer grid assembly, which is very important for the seismic resistance of nuclear fuel assembly.

Tests and an examination of the welded parts of a spacer grid assembly are usually performed by external and internal test/examinations. External examination includes an external appearance such as a spattering, discoloration and weld bead size. Internal examination includes a metallographic examination, such as the texture, pores, and corrosion layers. In addition, a peeling test on the welded parts is performed to confirm whether the welding parts sustain an acceptable strength. Therefore, acceptable weld qualities are determined from the test and examination results.

Based on the mechanical design experience over 10 years on the nuclear fuel assembly, Korea Atomic Energy Research Institute (KAERI) has devised 16 kinds of spacer grid shapes and it has been applying them for domestic and foreign patents since 1997. To date, KAERI has obtained US, Japan, and Republic of Korea (ROK) patents for 15 kinds of spacer grid shapes among them and the others are under review for patent-right in the USA, EC, China, and ROK. Since 2003 KAERI has searched for a promising LB welder in Korea to manufacture the KAERI designed spacer grid. Fig. 5 and 6 show the welding jigs and LB welding machine for manufacturing the KAERI designed spacer grid.

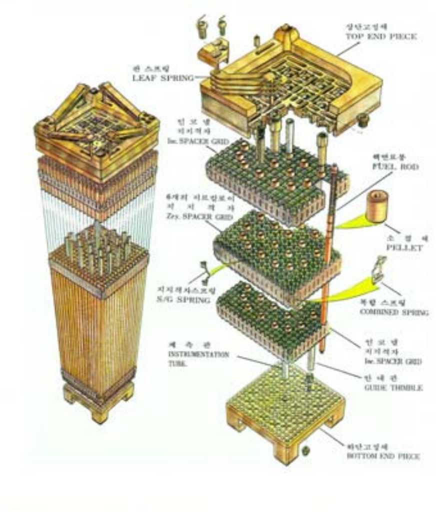


Fig. 1 Fuel assembly for a PWR.

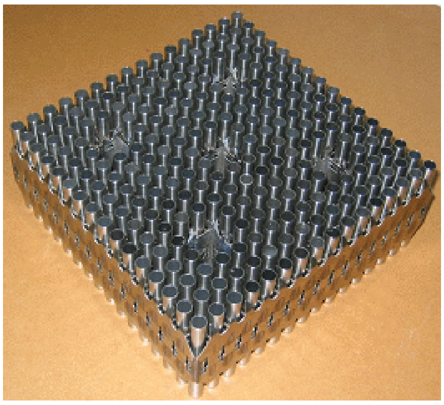


Fig. 2 Spacer grid inserted with fuel claddings.

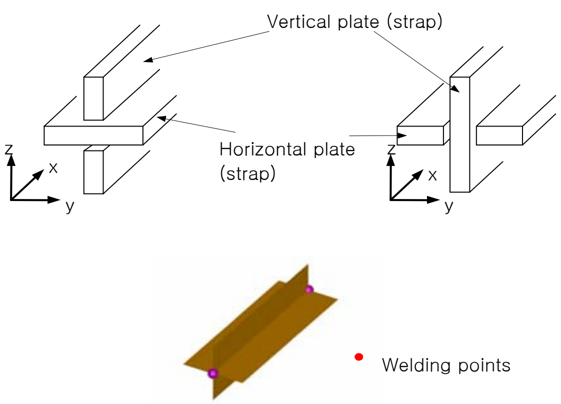


Fig. 3 Interconnected array of slotted grid straps.

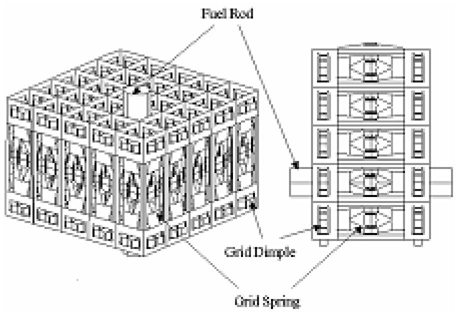


Fig. 4 Schematic view of a spacer grid.

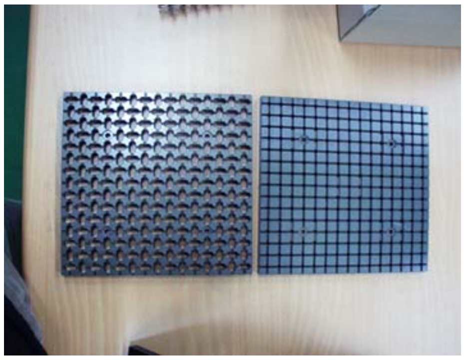


Fig. 5 Welding jigs (top/bottom plate).

Fig. 6 LASER welding machine.

2.2 Adjustment of the welding parameter combination

2.2.1 Settlement on the initial welding parameter

In order to settle on an initial welding parameter, first we selected four kinds of trial welding parameters (A) as illustrated in Table 1 by considering the commercial welding parameter (B). Welding qualities from the welding parameters of Table 1 are shown in Tables 2 and 3. From Tables 2 and 3, we select the recommended initial welding parameter as Condition C04 of Table 1.

2.2.2 1st adjustment of the welding parameter

As a result of analyzing the welding qualities from Condition C04 of the trial welding parameters, it is necessary to increase the welding bead size and the welding penetration depth. To do this, we adjusted the laser pulse

Table 1 Comparison of the initial welding parameter.

	A				B
	C01	C02	C03	C04	
Weld power(W)	411.4	416.5	413.1	442.0	430-435
Energy(J)	24.2	24.5	24.3	26.0	~25.44
Pulse width(ms)	8.4	8.0	7.5	9.0	8.0
Shot count	8	7	7	7	7-8
Peak power(kW)	3.0	3.2	3.4	3.0	N/A
Repeat(Hz)	17	17	17	17	17

Table 2 Comparison of the weld bead size (x T*).

	A				B
	C01	C02	C03	C04	
Top Weld					
- Mean	5.112	5.057	5.100	5.246	5.152
- S.D.	0.1008	0.1127	0.0963	0.0757	0.1368
- 95 % LCL	5.060	4.999	5.050	5.206	5.110
Bottom Weld					
- Mean	5.370	5.264	5.309	5.437	5.308
- S.D.	0.1105	0.0872	0.1276	0.0970	0.2904
- 95 % LCL	5.313	5.219	5.243	5.387	5.218

* T : Strap thickness

Table 3 Comparison of the weld penetration depth (x T*).

	A				B
	C01	C02	C03	C04	
- Top	3.74	3.80	3.94	3.73	3.718
- Bottom	3.63	3.65	3.93	3.54	3.958

* T : Strap thickness

width and peak power as shown in Fig. 7 by maintaining the energy per pulse. That is to say, we adjusted the peak power from 3.0 to 4.8 kW and the pulse width from 9.0 to 5.6 ms.

Fig. 8 shows the standard deviations of the welding bead size for each welding parameter. We can say that the welding bead size welded from the 1st adjustment of the welding parameter is very uniform when compared with that of the commercial welding quality because of the smaller standard deviations. Figs. 8 and 9 show the welding bead size and welding penetration depth for each welding parameter, respectively. According to Fig. 8, the weld bead size is increasing at first and it is gradually saturated as the peak power increases. It is likely that there is a limit to increasing the welding bead size by an increase of the peak power. Contrary to the weld bead size, the welding penetration depth is continuously increasing as the peak power increases as shown in Fig. 9.

2.2.3 2nd adjustment of the welding parameter

As a result of analyzing the welding qualities from the 1st adjustment of the welding parameter, it is necessary to adjust the welding parameter up to the peak power of 6.2 kW. Fig. 10 shows the standard deviations of the welding bead size for each welding condition. We can also say that the welding bead size welded from the 2nd adjustment of the welding parameter is very uniform when compared with that of the commercial welding quality because of the smaller standard deviations. Figs. 11 and 12 show the welding bead size and the welding penetration depth for each welding parameter, respectively. According to Fig. 11, the weld bead size is nearly constant as the peak power increases. It seems that the welding bead size dose not increase any more by an increase of the peak power. Contrary to the weld bead size, the welding penetration depth is continuously increasing as the peak power increases as shown in Fig. 12.

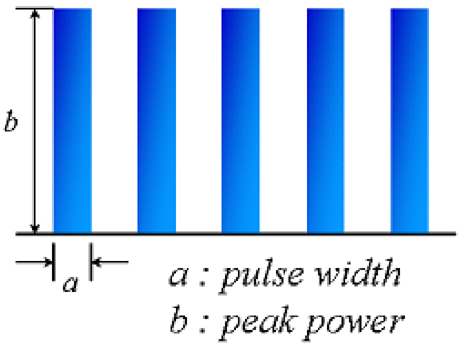


Fig. 7 Welding parameters.

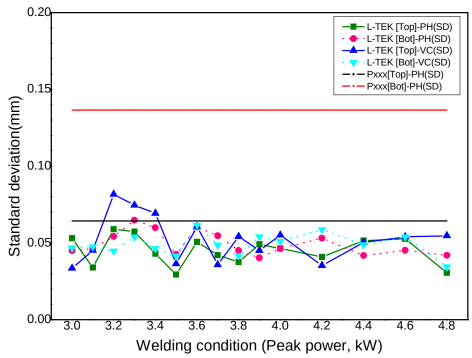


Fig. 8 S.D. of the weld bead size for the 1st weld.

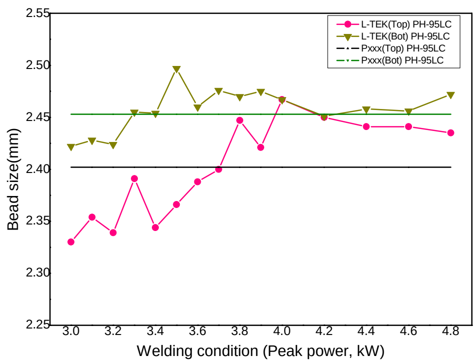


Fig. 9 Weld bead size variation for the 1st weld.

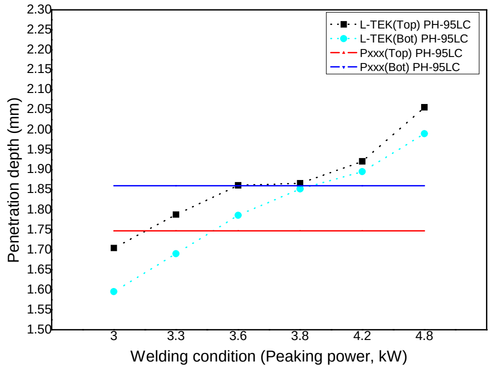


Fig. 10 Weld penetration depth for the 1st weld.

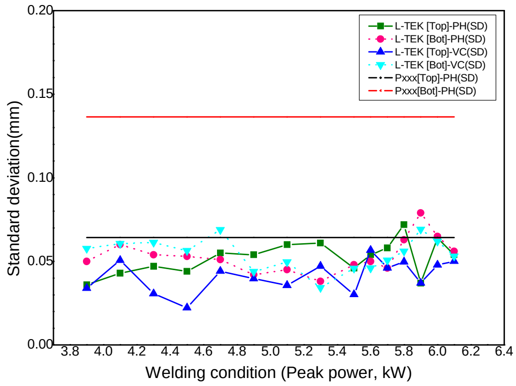


Fig. 11 S.D. of the weld bead size for the 2nd weld.

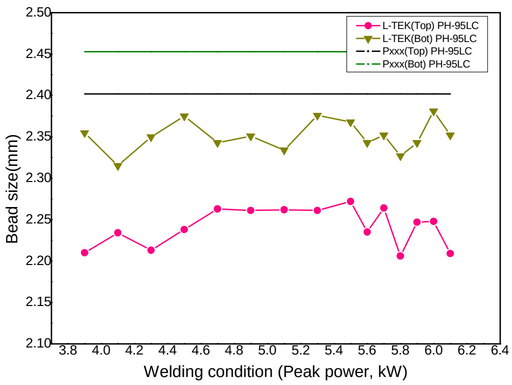


Fig. 12 Weld bead size variation for the 2nd weld.

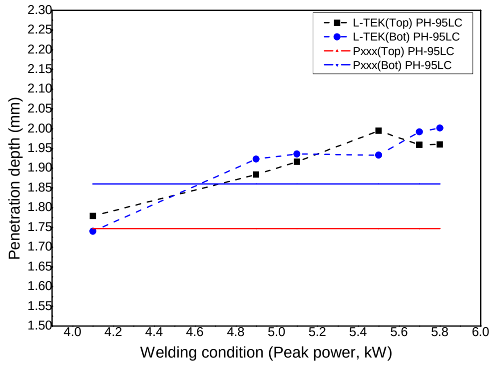


Fig. 13 Weld penetration depth for the 2nd weld.

2.2.4 3rd adjustment of the welding parameter

From the welding qualities of the 2nd adjustment of the welding parameter, four kinds of welding conditions as shown in Table 4 were selected and the welding qualities for the parameters of Table 4 are shown in Table 5. From Table 5 parameter C4 is selected as an optimum welding parameter for the manufacturing of the KAERI designed spacer grid assembly.

Table 4 Comparison of the 3rd welding parameter.

	A			
	C1	C2	C3	C4
Weld power(W)	184.8	159.0	159.0	144.0
Energy(J)	26.4	26.5	26.5	24.0
Pulse width(ms)	4.9	5.3	5.5	4.9
Shot count (Top/Bottom)	7/6	6/7	6/6	6/5
Peak power(kW)	5.5	5.1	4.9	4.9
Repeat(Hz)	17	17	17	17

Table 5 Comparison of the weld bead size (x T*).

	A			
	C1	C2	C3	C4
Top Weld				
- Mean	5.217	5.242	4.928	4.898
- S.D.	0.153	0.130	0.132	0.145
- 95 % LCL	5.177	5.211	4.894	4.861
Bottom Weld				
- Mean	5.288	5.841	5.241	5.102
- S.D.	0.115	0.120	0.087	0.183
- 95 % LCL	5.285	5.813	5.219	5.055

* T : Strap thickness

2.3 Weld qualities from an optimum welding condition

2.3.1 Weld bead size

We compared the welding qualities from the optimum welding parameter and the commercial product. Comparisons are shown in Table 6. From Table 6, the weld qualities from the optimum welding parameter are superior to those from the commercial welding product. Table 7 shows the typical shape of a weld bead for the KAERI designed spacer grid assembly and the commercial welding product.

Table 6 Comparison of the weld bead size (x T*).

	A (C4)	B
Top Weld		
- Mean	4.898	5.152
- S.D.	0.145	0.1368
- 95 % LCL	4.861	5.110
Bottom Weld		
- Mean	5.102	5.308
- S.D.	0.183	0.2904
- 95 % LCL	5.055	5.218

* T : Strap thickness

Table 7 Comparison of the weld bead shape.

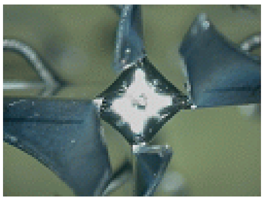
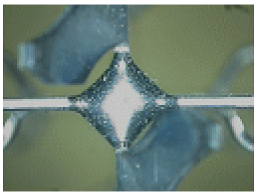
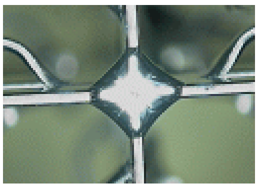
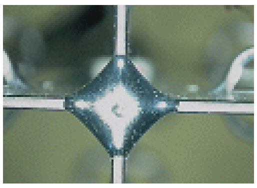
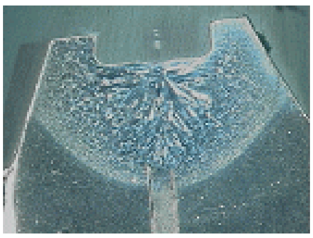
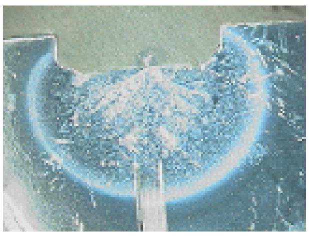
	A	B
Top		
Bottom		

Table 8 Comparison of the penetration.

A	B
	

2.3.2 Metallographic test

Table 8 shows the metallographic test results from the optimal welding parameter and the commercial welding product. Table 9 shows the weld penetration depth from the optimal welding parameter and the commercial welding product.

Table 9 Comparison of the weld penetration depth (x T*).

	A (C4)	B
Weld penetration depth		
- Top	3.988	3.718
- Bottom	4.146	3.958
Peeling test		
- fracture part	Parent matl.	Parent matl.
- strength (kN)	2.29	2.53

* T : Strap thickness

2.3.3 Welding strength

Table 9 shows the welding strength on the welded parts from the peeling test. From Table 8, the weld strength of the welded parts from the optimal welding parameter is acceptable as well as that of the commercial welding product.

3. Summary

By adjusting the LB welding parameters, an optimum welding combination of the LB welding parameters were searched for a welding of the KAERI designed spacer grid assembly. Welding qualities such as the weld strength, weld penetration depth, and weld bead size were inspected. The welding qualities for the optimum welding combination of the LB welding parameters are found to be comparable or superior to those of the commercial spacer grid assembly.

Acknowledgments

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