The effect of end plug shape on the torque strength of end plate weld and dimensional integrity of CANDU fuel bundle

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ABSTRACT: CANDU fuel bundles are fabricated by the electric resistance welding of end plug and end plate. Even under the same welding parameters, weld strength and dimensional integrity of fuel bundle change with the joint geometry of outer surface of end plug. This study has been carried out in order to find optimized joint geometry of outer surface of end plug for improving weld strength without impairing dimensional stability under the same welding parameters of fuel fabrication process. New joint geometry of outer surface of end plug having higher joule heat and limited amount of deformation in the weld showed higher average weld strength.

KEYWORDS: *CANDU Fuel, End plate welding, End plug shape, Weld strength*

I. Introduction

CANDU fuel bundles are assembled by electric resistance welding of end plates and end plugs of fuel elements. The end plates hold the fuel elements together in a bundle configuration. They have to be strong enough to maintain the configuration and also to allow axial loads to be distributed among many elements instead of being concentrated on a few. Simultaneously they should be flexible enough to allow differential axial expansion among the elements, and to permit bending and skewing of the bundle.

Even under the same welding parameters, weld strength and dimensional integrity of fuel bundles might be changed by the joint geometry of outer surface of end plug. It is important to enhance weld strength of end plate weld in order to keep dimensional stability of fuel bundle not only in the reactor, but also in spent fuel storage after reactor.

In this study, the end plate welding is reviewed to enhance the weld strength of end plate welding just by changing the shape of the outer surface of end plug. In addition, the effects on the variations of welding parameters such as, welding current, welding pressure, etc. are not considered, because if welding parameters are changed to increase the heat energy and weld area, the dimensional integrity of fuel bundle could not satisfy the required specification. Also, if the different shape of end plug affects the flow of coolant in reactor, then it is necessary to assess pressure drop and critical heat flux. Based on the above limitation, the four types of end plugs were suggested to assess weld strength of end plate welding and the dimensional integrity of the fuel bundle.

II. Experiment & Results

II.A. Design of outer surface shape of end plug

In order to enhance the weld strength of end plate weld, the shape of the outer surface of end plug was modified. Fig. 1 shows the drawings of four different types of end plugs. 37R type end plug is correspond to the current design of fuel bundle, which has the spherical radius on the joint geometry of outer surface of end plug. The outer surfaces of joint geometry of the other types were modified from 37R type's. Type A has sharp edge on outer surface with a small step in the outer surface of end plug. Type B has only sharp edge and the type C has flat outer surface of end plug.

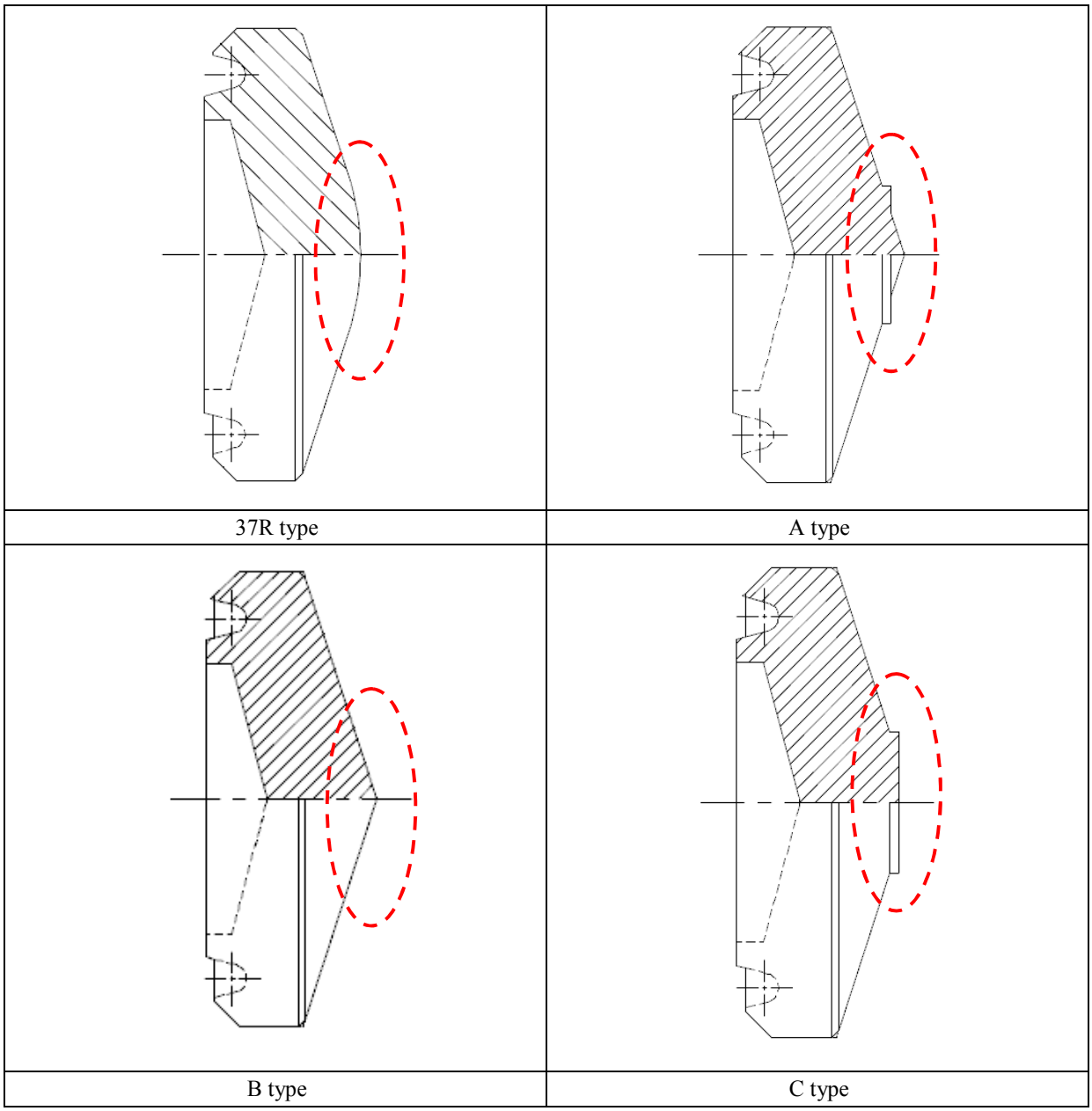


Fig. 1. The four types of end plugs

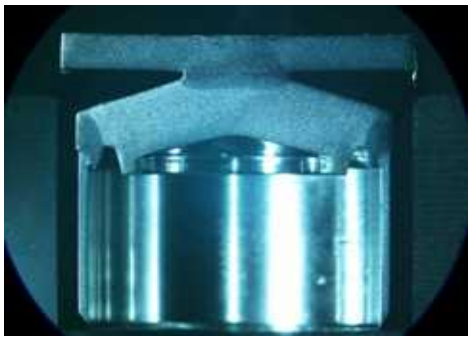
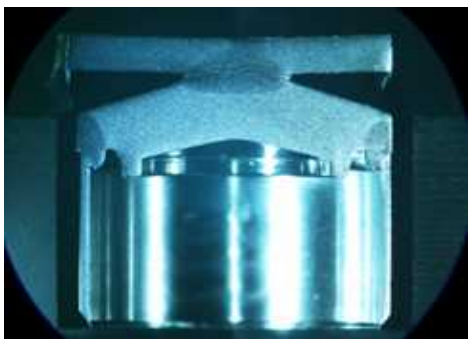
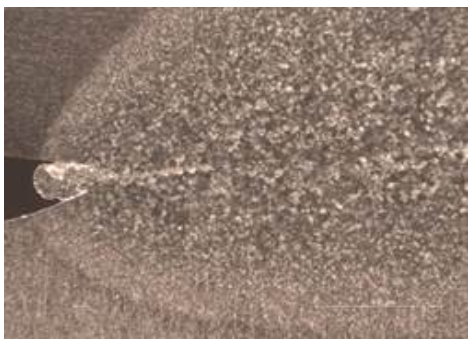
II.B. Preparation of the test specimens

Each of the four type end plugs was welded to 60 pieces of Zircaloy tubes of a 75mm length. Welding specimens were inserted to a fixture for end plate welding. Twelve specimens were inserted to outer fuel element position, and 3 pieces were inserted to inner fuel element position, because outer and inner fuel element have different weld strength criteria.

The welding parameters are as followings, welding current: 3.9 kA for outer fuel element, 3.3 kA for inner fuel element, welding pressure: 64 psi for both fuel elements. The measurements of weld strengths for each test specimen was performed with torque test apparatus which reads the peak datum of torque strength. The procedure of measurements are as followings: cutting end plates in a suitable size, fixing tube part of weld specimen, grasping web of end plate cut, twisting the web and measuring torque strength.

II.C. Results of the weld strength test

Fig. 2 shows the HAZ (heat affected zone) and microstructure of the each type of end plug. Although the shape of weld flash between end plate and end plug was changed, the microstructure of HAZ is quite similar to each type of end plug. Fig. 3 shows the weld strength of each type of end plug. Type A has higher weld strength comparing to other types in both fuel element positions. However, type C end plug has lower weld strength than 37R type end plug. Because, outer surface of type C end plug has flat contact area, the amount of electric resistance heat and degree of penetration depth in weld are lower than the 37R type end plug. Type B end plug has higher weld strength than 37R type end plug, but a little lower than type A end plug. The difference of type A and B is the existence of small step on the outer surface of end plug. It is assumed that small step makes stable formation of weld area during welding cycle, which cause much stronger weld strength in type A end plug. Also, based on the weld strength results, a dummy fuel bundle was manufactured by using type A end plug to assess dimensional integrity of the dummy fuel bundle.

End plug type	Heat affected zone (x20)	Microstructure of weld area (x100)
37R type		
A type		

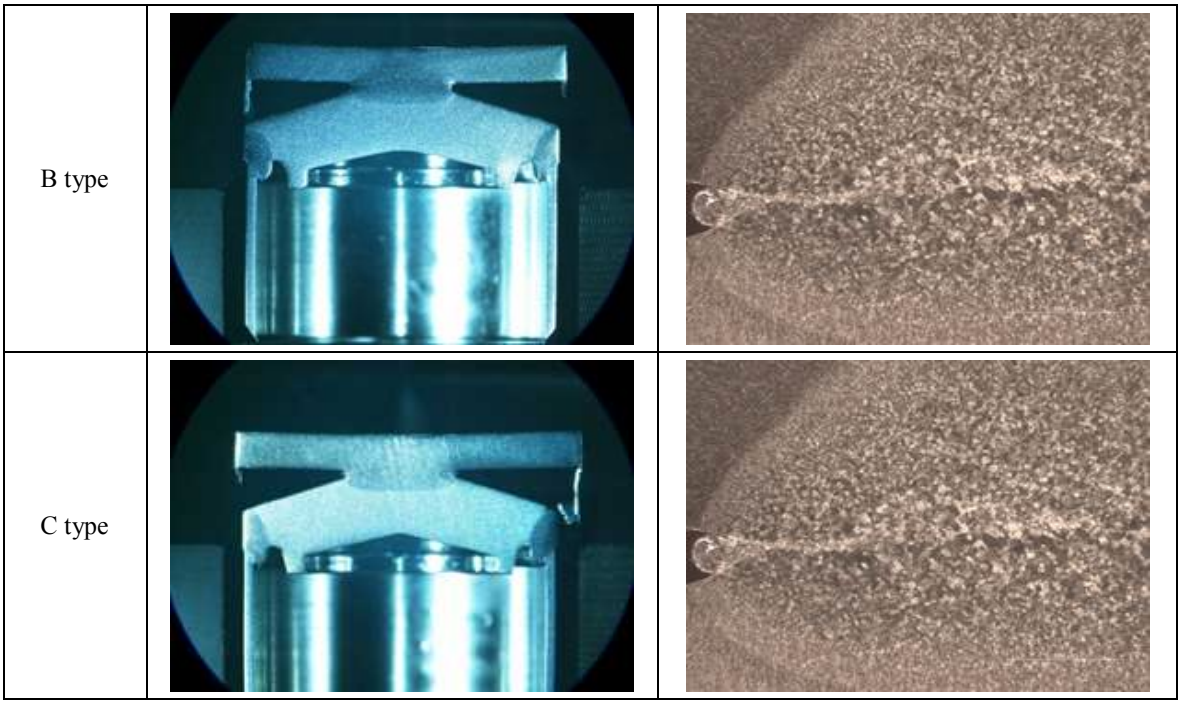


Fig. 2. Heat affected zone and microstructure in weld area

Type	Outer fuel elements									Inner fuel elements		
	1	3	5	7	9	11	13	15	17	20	23	28
37R	1.24	1.44	1.41	1.23	1.43	1.45	1.26	1.48	1.43	1.69	1.66	1.73
A	1.48	1.61	1.59	1.43	1.61	1.64	1.49	1.65	1.63	1.84	1.78	1.87
B	1.40	1.51	1.52	1.35	1.54	1.54	1.40	1.59	1.51	1.74	1.70	1.76
C	1.14	1.34	1.36	1.18	1.38	1.43	1.05	1.38	1.44	1.42	1.31	1.36

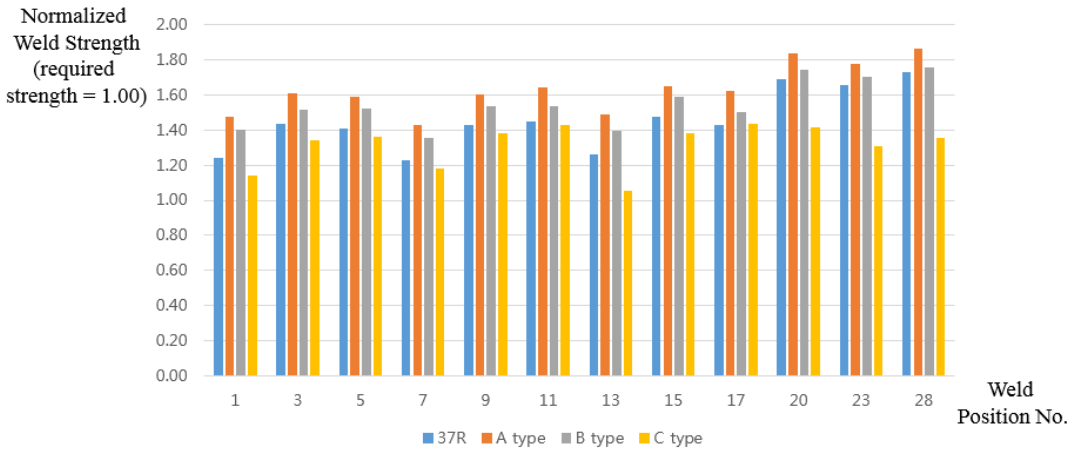


Fig. 3. Weld strength of weld specimens

TABLE Ⅰ shows the results of dimensional characteristics for dummy fuel bundle using type A end plug. The length of dummy fuel bundle exceeds the specification by 0.34 mm. Because height of type A end plug is approximately 0.40mm higher than that of 37R end plug, which caused increased length of fuel bundle.

The dummy fuel bundle was disassembled to measure weld strength, and Fig. 4 shows the specification of the weld strength were met at all fuel element positions.

TABLE I. Results of quality characteristics and acceptance criteria

Dimensional characteristics and acceptance criteria	Welding head	Results
Bundle length	-	Rejected
Changing length of fuel elements	-	Accepted
Minimum axial distance of end plug and end plate	Upper	Accepted
	Lower	Accepted
Maximum axial distance of end plug and end plate	Upper	Accepted
	Lower	Accepted
Perpendicularity of end plate	Upper	Accepted
	Lower	Accepted

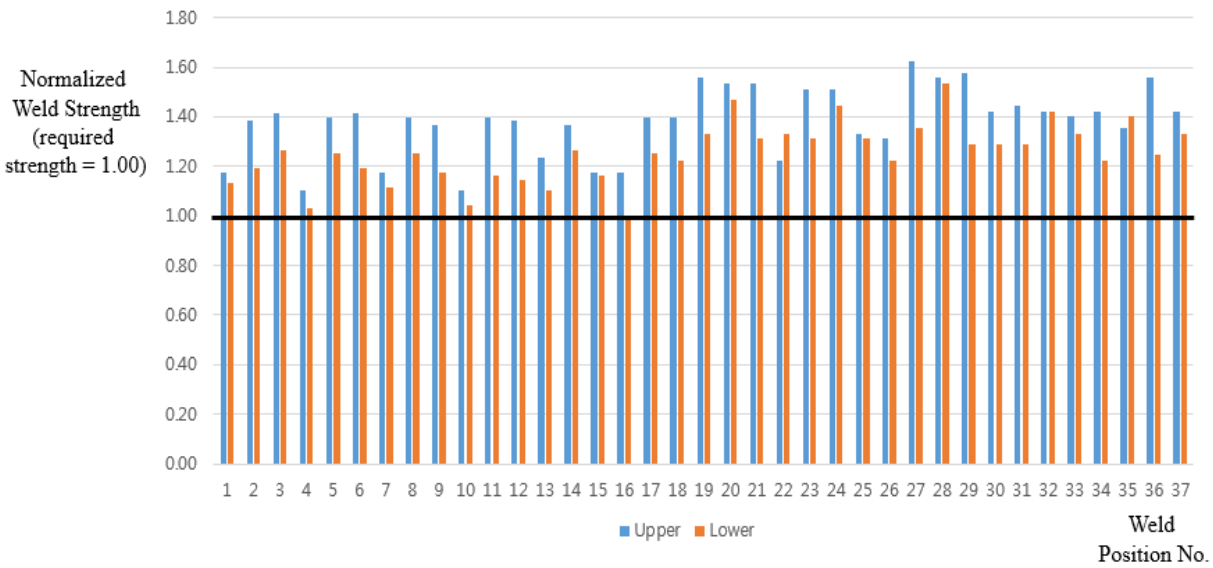


Fig. 4. Weld strength of dummy fuel bundle

II.D. Supplementary experiment of re-designed type A end plug

In order to satisfy dimensional integrity, type A end plug was re-designed as shown in Fig. 5 by reducing the length of end plug by 0.20 mm. Fig. 6 shows the difference of weld strength of two types of end plugs of welding specimens. Weld strengths of type A prime end plug were slightly lower than those of type A end plug, and it was caused by height decrease. In the previous section, it was assumed that the role of small step would form stable weld area during welding cycle. So, the decrease of weld strength could be possible because of decrease of step height of type A prime end plug. In order to evaluate dimensional integrity in fuel bundle, dummy fuel bundle was fabricated by using type A prime end plug.

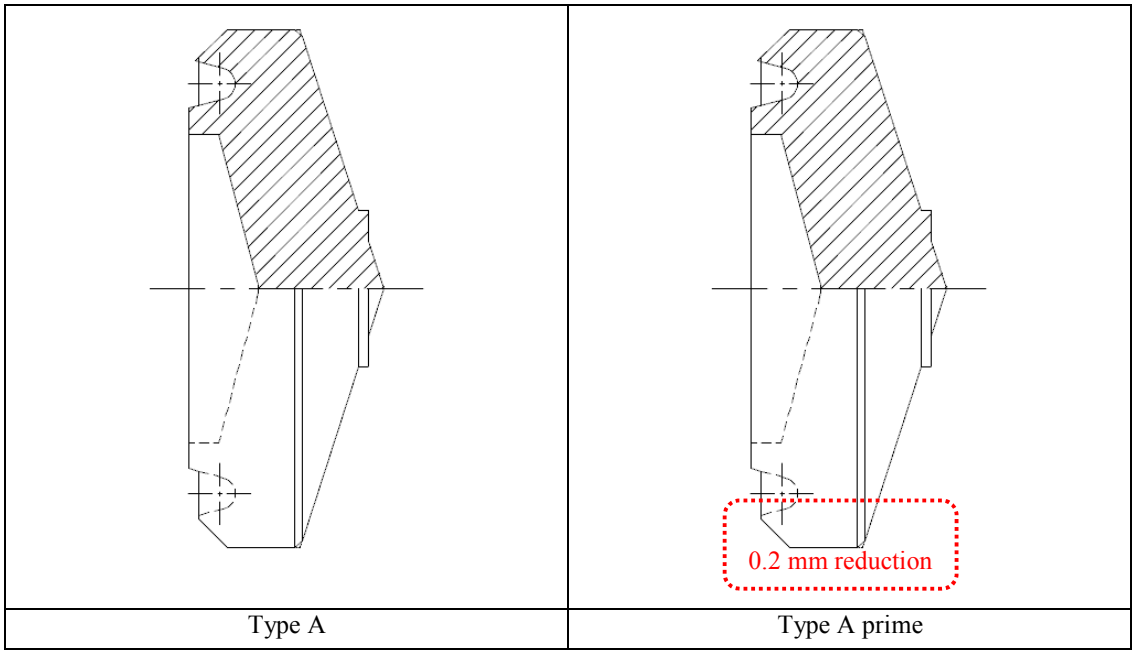


Fig. 5. Type A prime end plug

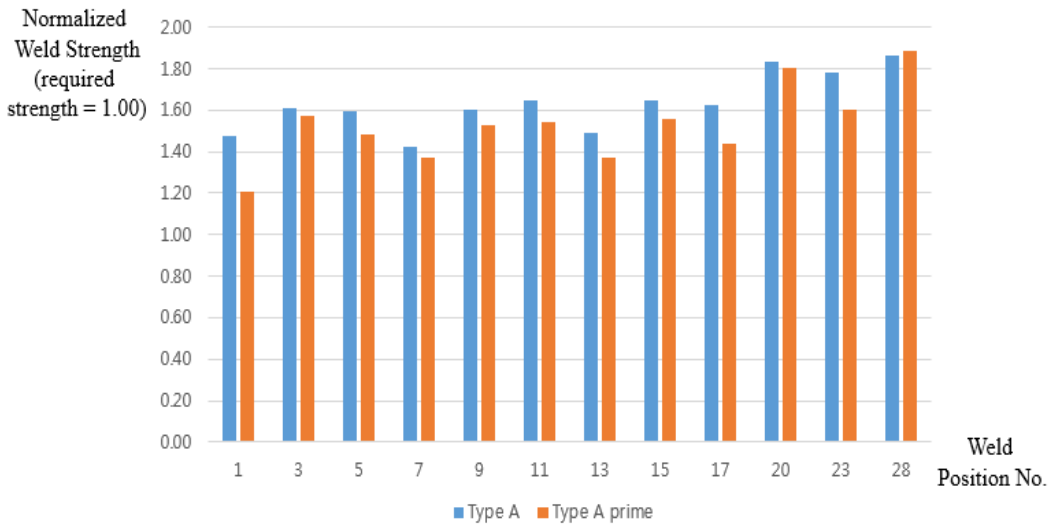


Fig. 6. Comparison of weld strength

TABLE Ⅱ shows the results of dimensional inspection of dummy fuel bundle of type A prime end plug. The fuel bundle length was shorter than previous fuel bundle welded by using type A end plugs, and satisfied dimensional specification.

Fig. 7 shows that weld strengths of each fuel elements were satisfied the specification except two fuel elements. It is assumed that the decreased step is not enough to make stable formation of weld area. In order to satisfy weld strength specification by using type A prime end plugs, further study is to be carried out to review weld parameters such as weld current and pressure.

TABLE Ⅱ. Dimensional characteristics and acceptance criteria

Dimensional characteristics and acceptance criteria	Welding head	Results
Bundle length	-	Accepted
Changing length of fuel elements	-	Accepted
Minimum axial distance of end plug and end plate	Upper	Accepted
	Lower	Accepted
Maximum axial distance of end plug and end plate	Upper	Accepted
	Lower	Accepted
Perpendicularity of end plate	Upper	Accepted
	Lower	Accepted

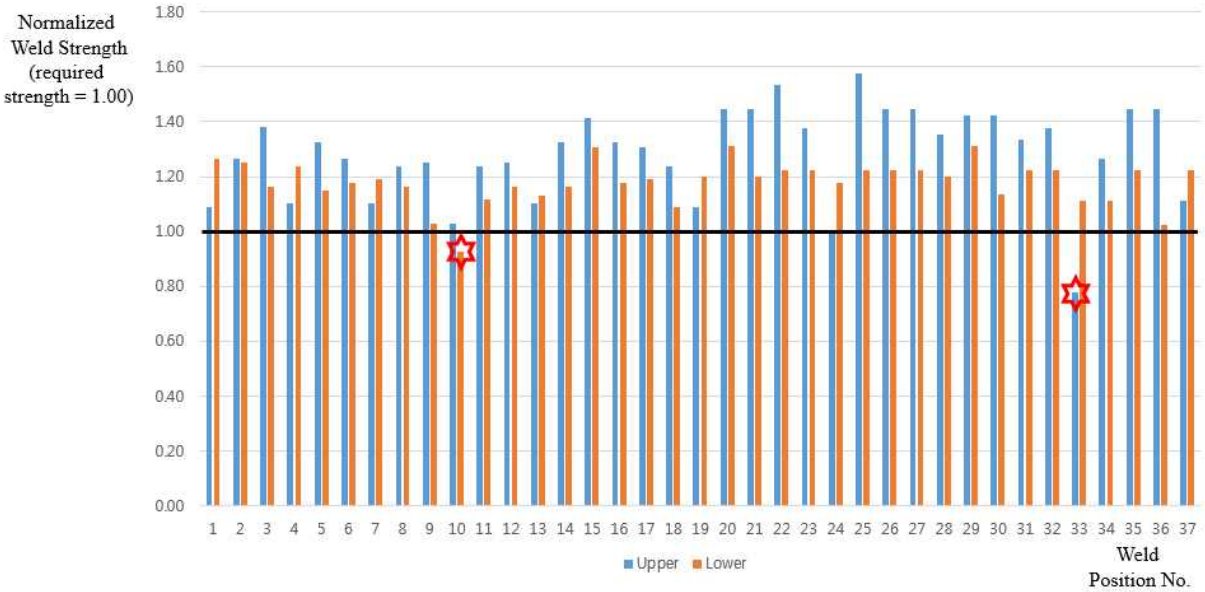


Fig. 7. Weld strength of dummy fuel bundle of type A prime end plug

III. SUMMURY

A preliminary study was conducted to review weld strength of end plate welding by changing the shape of weld joint geometry of outer surface of end plugs. The summaries obtained in this investigation are as follows.

1. The weld strength of CANDU fuel bundle could be increased by changing shape of outer surface of end plug under same welding parameters.

2. The end plug with sharp edge and small steps in outer surface has higher weld strength than that of 37R current end plug of weld specimens and dummy fuel bundle.

3. In order to meet weld strength and dimensional requirements, further study has to be carried out.

REFERENCES

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