OPTIMISING WELDING AND ASSEMBLING PROCESSES FOR MANUFACTURING PHWR FUEL ELEMENT AND BUNDLE

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ABSTRACT

In PHWR fuel fabrication, end-cap joint formed by Zircaloy fuel tube and cap is one of the most critical welds as it is expected to offer a hermetically sealed joint to contain the radioactive fission products. In view of their highly demanding function during reactor operation, these welds have to be produced to a high degree of reliability by careful selection of process and parameters.

PHWR fuel bundle is manufactured by joining end plates to elements at both ends. Resistance projection welding technique is used to weld the element ends to end plates. This being the final operation in PHWR fuel fabrication route, it plays very important role with respect to bundle dimensions and integrity. Jigs and Fixtures are used to assemble fuel elements and end plates. The quality of these fixtures affect the bundle dimensions, inter element spacing and orientation of fuel elements/end-plates.

While welding Zircaloy material, properties like coefficient of thermal expansion, thermal conductivity and thin oxide layers have to be considered. Generally high conductive material requires pre-heating before welding, while post-treatment of the weld is carried out if the metallurgical properties are changing in the Heat Affected Zone (HAZ). In resistance welding, selecting a suitable weld cycle pattern involves optimization of current, time, number of on/off cycles and current slope. Different current cycle patterns offer distinct advantages and certain disadvantages too with respect to weld bonding, sparking, HAZ etc.

State-of-the-art technology is being used to have better control on weld parameters and monitor them as well for further analysis. The paper discusses the effect of welding parameters including different weld cycle patterns like on/off cycle, up-slope cycle and constant current cycle. Improvements carried out to ensure dimensional integrity of the bundle are also dealt with in the paper.

1.0 INTRODUCTION:

At Nuclear Fuel Complex (NFC), indigenously developed special purpose welding equipment [1] are employed for fuel element and bundle production. Based on the vast experience gained in manufacturing 200,000 PHWR fuel bundles at NFC, more emphasis is laid on optimisation of the design features of these welding machines and processes. The present machines are provided with sophisticated power & welding controls and monitoring systems. Suitable weld cycle patterns with optimum parameters are to be selected for achieving consistent weld quality.

Generally high conductive (thermal and electrical) materials require pre-conditioning of the joining surfaces to achieve best results in the final welding. The incremental changes of joint geometry during the initial pre-heating cycles and the projection collapse pattern, are known to be the key factors influencing the heat generation, upset formation and weld quality. This process depends on mechanical, electrical, thermal and metallurgical factors. These factors in combination with the welding parameters have a significant influence on weld upset development and defect generation. The present paper summerises the effect of different weld cycle patterns on weld quality. The influence of jigs & fixtures employed for final assembling and welding on the integrity of the fuel bundle are also discussed in the following sections of the paper.

2.0 END CAP WELDING:

Weld joint formed by the tube and cap [2] is the most critical in PHWR fuel bundle, since it is expected to contain fission products. To achieve defect free weld, selection of optimum weld parameters is essential. In addition, certain precautions like machine alignment, electrode condition, secondary circuit resistance, and faying surface cleanliness are to be taken care of.

A common defect in end cap welding is sparking (expulsion). Sparking is linked to excessive current densities occurring mainly due to localised/microscopic contact areas and is also attributed to increased resistance encountered at the weld joint due the presence of oxidised surface layer or external contamination. Sparking condition will lead to more HAZ compared to normal good weld conditions. A typical end cap weld defect due to sparking is shown in Fig-1. In addition to weld joint configuration, squeeze force, pre-heat & weld heat currents and different timings are the main parameters controlling the weld integrity.

Two weld patterns, " PULSATING" and "UPSLOPE with current feed back control" as shown in Fig -2 and Fig- 3 are studied under various conditions. Selection of weld pattern depends on the collapse pattern of the tube projection so as to accommodate certain process variations like end squareness of cap and tube, cleanliness and profile variations. Weld parameters are fixed for both the weld cycle patterns for specified pre-heat upset and overall upset of the weld. Weld quality was evaluated with respect to 1) physical appearance of weld 2) spark generation 3) presence of non-fusion line 4) weld integrity by UT [3] 5) electrode condition etc, Certain advantages are observed with Up-slope pattern over the pulsating weld pattern. The results are given in Table-1. The frequency distribution with respect to weld fusion and plot of standard deviation for 12 sets of welds for both the patterns are given in Fig-4 and Fig-5.

3.0 END PLATE WELDING:

Fuel bundle is manufactured by joining end plates to elements at both the ends. Resistance projection welding [4] technique is used to weld the element ends to end plates. This being the final assembling operation, it plays a very important role with respect to bundle dimensions and integrity.

Specially designed jigs and fixtures are used for assembling the elements and endplates in proper position before carrying out welding. The dimensional accuracy of these jigs and fixtures are of utmost importance, since these are responsible for final bundle dimensions. Only identified, inspected and quality control cleared jigs and fixtures are used. Jigs and fixtures employed for the fuel bundle fabrication are simple to use and accurate. Central, Inner and Outer elements are welded to endplates at three different locations on endplates i.e., at central web, inner ring and outer ring. Each location of end plate has different web widths. It is desired to have uniform weld strength at all the 19 positions to have proper integrity of bundle. Weld cycle patterns with preheat and without preheat having same/different heat settings during weld heat for central, inner and outer rings are compared for uniformity of weld strength and deformation of end plate. The results are given in Table-2. The frequency distribution with respect to torque strength is given in Fig-6. Weld cycle pattern with pre heat and different heat settings during weld heat for central, inner and outer elements is being used, which gives consistent quality with respect to end plate deformation and torque strength.

4.0 CONCLUSIONS:

Employing UPSLOPE type weld pattern with constant current feed back in end cap welding has given better quality welds with respect to consistency, reduced rejects due to sparking, increased collet life and takes care of variations in joint configuration. Similarly weld cycle pattern with preheat and different heat setting for different element positions coupled with usage of simple and accurate jigs and fixtures for end plate welding has given better quality with respect to torque strength and dimensions. Operating the units with these optimised weld cycle patterns have resulted in improved quality and better fuel performance in the reactors.

5.0 ACKNOWLEDGEMENTS:

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6.0 REFERENCES:

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TABLE-1

S.No	Measured weld parameter	UPSLOPE	PULSATING
1	Pre-heat Upset (mm)	0.35-0.40	0.35-0.40
2	Flaring in tube area	Same	Same
3	Surface finish on the flared interface	Better	Poor
4	End-squareness correction	Higher	Average
5	Oxide Layer removal	Average	High
6	Wrinkles on the weld bead	Nil	Little
7	Collet life	Very high	Average
8	HAZ after welding	Less	Little more
9	Utilisation of current feed-back in Pre Heat	Possible	Not possible
10	Signal range in UT	Less	More

TABLE-2

CASE	SETTINGS	AVERAGE TORQUE STRENGTH (Nm)	STANDARD DEVIATION (Nm))	DEFORMATION OF END PLATE (mm)
1	Without preheat & different heat setting	8.4	0.45	0.187
2	Without preheat & same heat setting	8.7	0.54	0.212
3	With preheat & different heat setting	8.36	0.31	0.055
4	With preheat & same heat setting	8.5	0.39	0.109

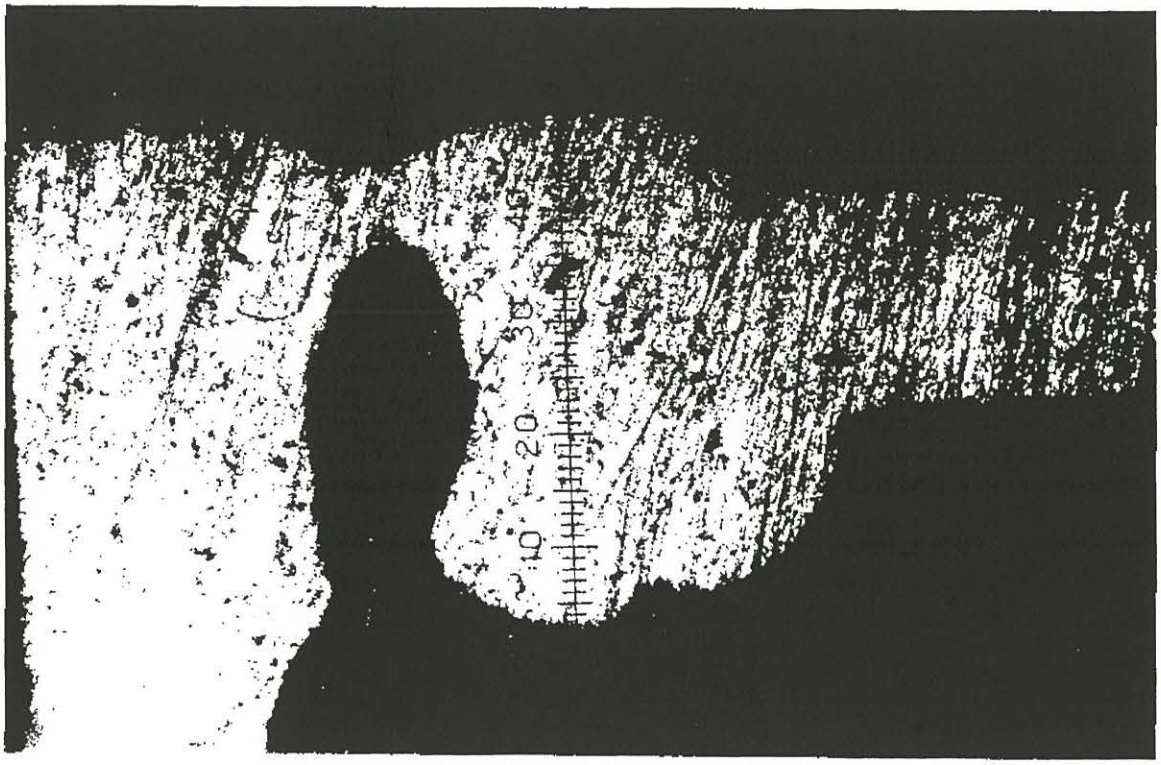


FIG 1: A TYPICAL END CAP WELD WITH SPARK DEFECT

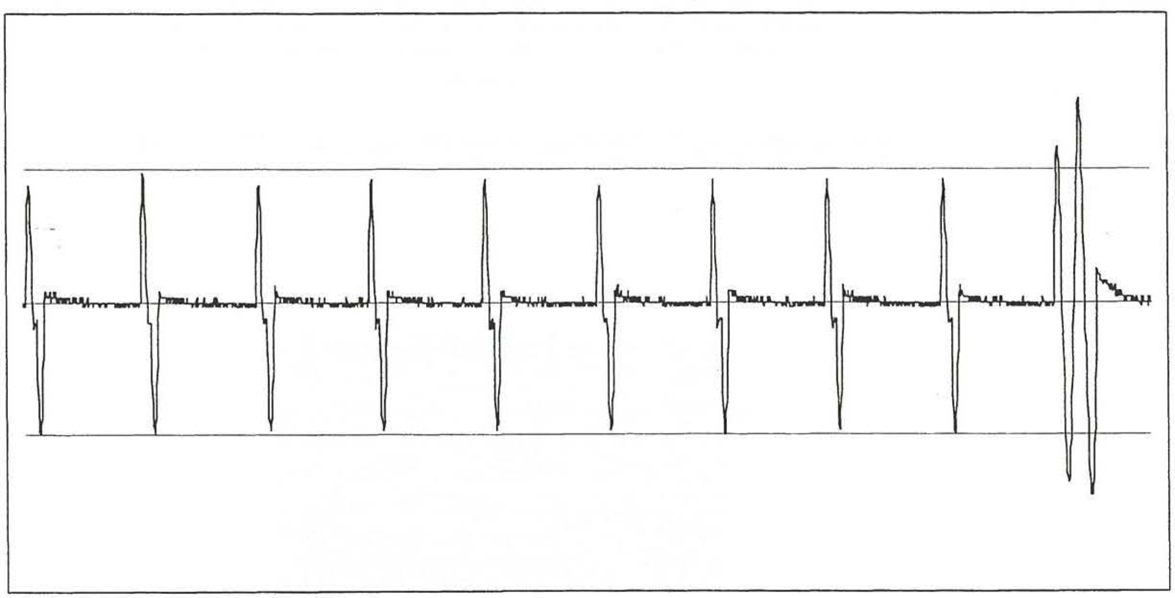


FIG 2: WELD CYCLE PATTERN - PULSATING

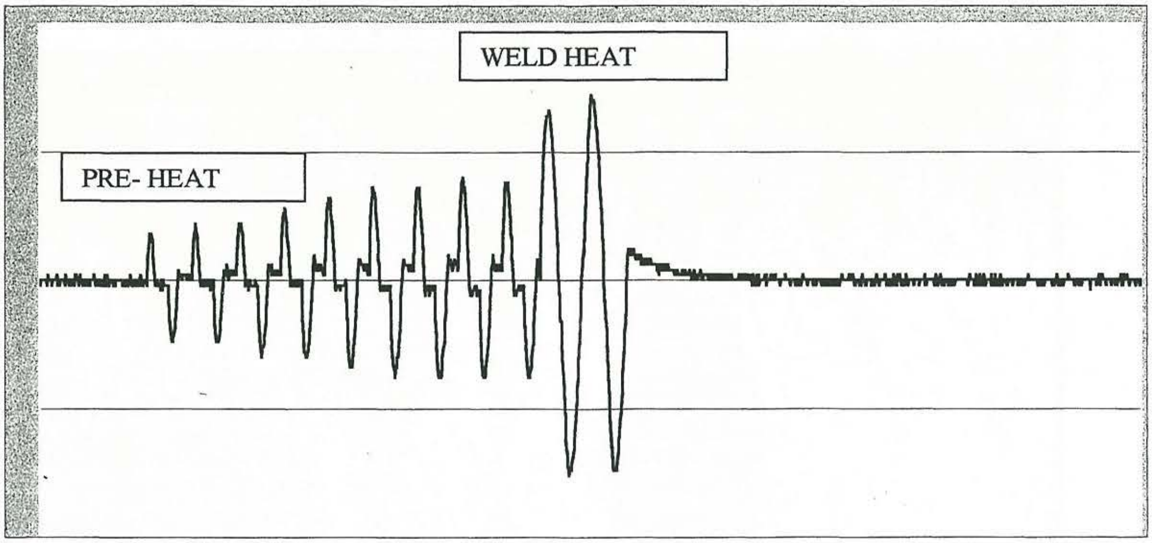


FIG 3 : WELD CYCLE PATTERN – UPSLOPE

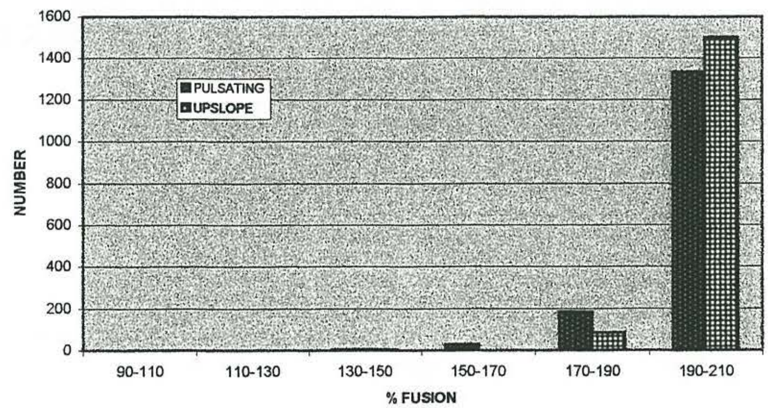


FIG 4: FREQUENCY DISTRIBUTION – WELD FUSION

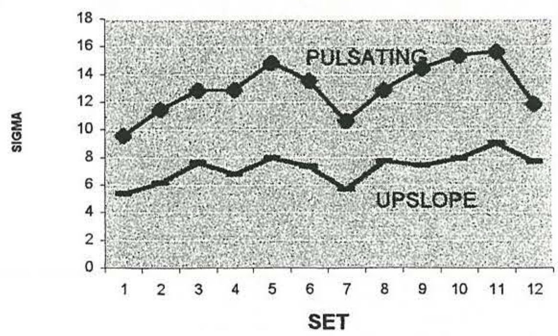
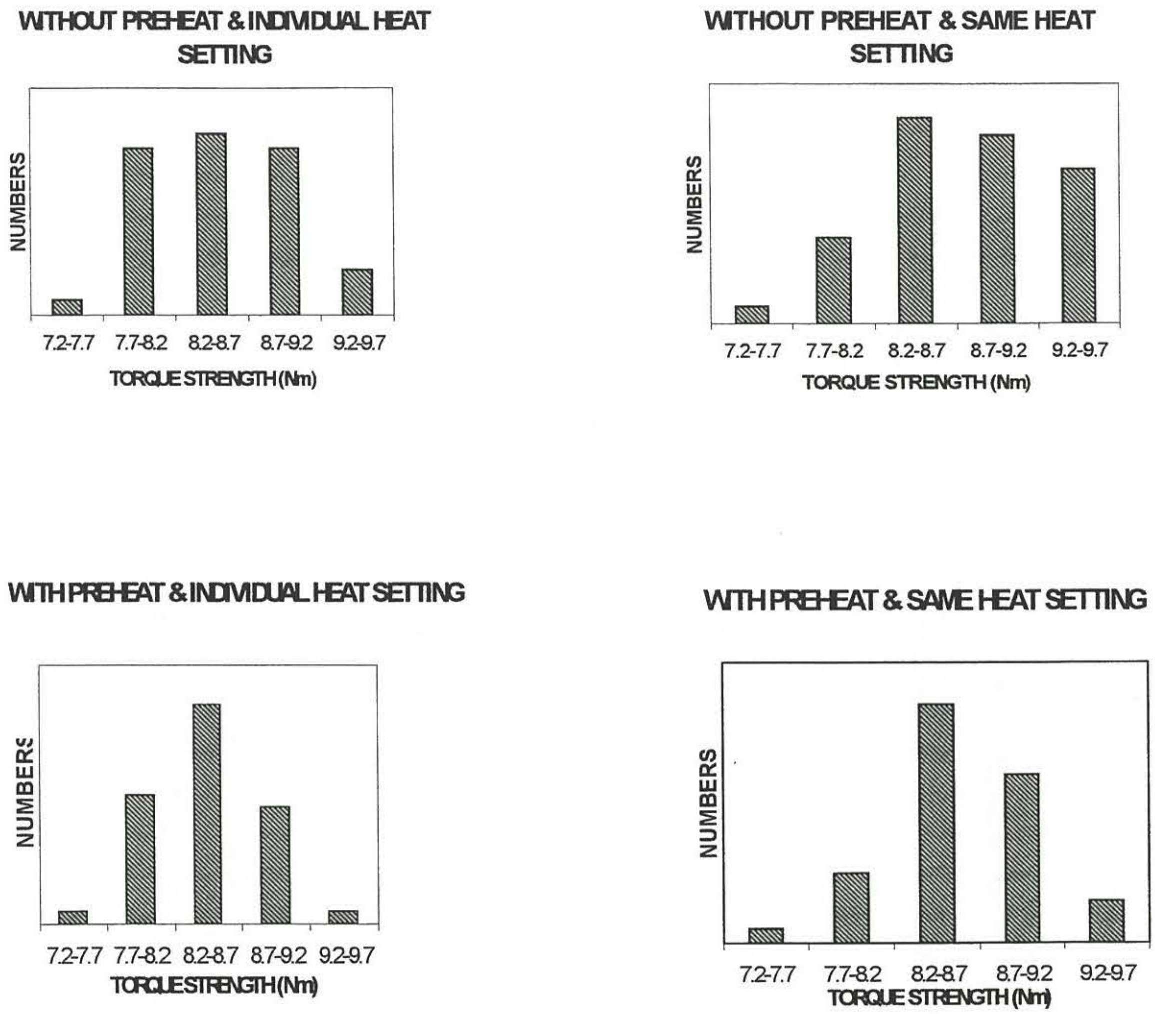


FIG 5: VARIATION OF STANDARD DEVIATION

CASE-1 CASE-2



CASE-3 CASE-4

FIG –6: FREQUENCY DISTRIBUTION – ENDPLATE TORQUE STRENGTH