ABSTRACT

This paper reports results connected with the reconstitution of the Cv-type specimens by electron beam welding technology. The experiments were carried out using a 15 kW Leybold Heraus welding unit in a range of power between 1.5 and 3.5 kW, and welding speed from 0.5 cm/s to 1.5 cm/s. Material which used in this study is 15Kh2NMFA reactor pressure vessel steel. Weldability of pressure vessel steel by electron beam was investigated in accordance EN ISO 13919-1 1996.

Charpy impact tests show good agreement between original and electron beam reconstituted specimens.

1 INTRODUCTION

Regulatory codes require surveillance tests to evaluate the degree of irradiation embrittlement of reactor pressure vessel steel during plant operation. In the nuclear power plants Cv specimens are used to assess the embrittlement of reactor pressure vessels (RPV). The surveillance capsule assemblies in each capsule contain typically 12 Charpy and 3 tensile specimens. However, to address future plant life management, especially for older NPP's, it is necessary to obtain more statistics on the pressure vessel embrittlement.

The technique to construct specimens from a small quantity of material is commonly called "reconstitution"[1,2]. This technique consists in welding extensions to the piece of material of interest (the insert). It allows creating a "new" sample from broken surveillance specimens.

In practice, several reconstitution techniques such as arc stud welding (ASW) [2], laser and electron beam welding [3-5], projection and upset butt-welding are used [6]. All these methods give satisfactory weld quality, weld and heating area zone (HAZ) thickness. However, laser and electron beam welding have a number of decisive advantages over conventional techniques. Especially, the high energy density achievable means that narrow welds and heat-affected zones are created. Depending on the processing variables such as density distribution of the laser beam power, the interaction time and the material properties,
different physical processes such as optical absorption, heat conduction, phase transition, fluid dynamics, evaporation kinetics, and plasma dynamics are involved determining the process results. Despite significant improvements in power beam welding technology over recent years, it still remains impossible to characterise laser beam welds in a unique fashion and to produce quantifiable mechanical properties. Its application, therefore, asks for a thorough feasibility study.

This study concentrates on the problems connected with the reconstitution of the Cv-type specimens by electron beam welding.

2 EXPERIMENTAL PROCEDURE AND MATERIAL

Figure 1 represents the scheme of reconstruction of Charpy specimens by electron beam welding technology. The specimens with dimensions 10×10×55 mm are machined from reactor pressure vessel steel 15KhNMFA. The central pieces (A), insert with dimensions 10x10x10mm are made from previously broken specimens. The other two extra pieces (B), studs with 22.5x10x10 mm are made from plate RPV steel.

![Figure 2: Reconstitution flow chart by Electron Beam Welding](image-url)
The experiments are carried out on Leybold – Heraeus electron beam welding equipment ESW300/60-15.

The material used in this study is RPV steel 15KhNMFA. The kinetic of austenite transformations of 15KhNMFA is represented on Figure 2 [7].

![Figure 2: Kinetic of austenite transformations of 15KhNMFA steel](image)

Metallographic study of the welded joint are carried out on optical microscope Neophot 2. The specimens are prepared in accordance with ASTM E407-93. A non-destructive test of welds is made by X-ray system -"Eresco 200/8", Seifert. For determined the microhardness of the base metal, HAZ and weld metal is used Zwick Microhardness Tester, with range 100N.

The Charpy V impact tests are performed according to the ASTM E23-98 by impact testing machine WPM, Germany, range 300J.

3 RESULTS AND DISCUSSION

3.1 Determination of the optimum welding parameters

To determine the optimum welding parameters some 25 weld lines were introduced in the plate material. The beam power \( P=UI \) (U - accelerating voltage, I - beam current, \( I_f \) - current of focusing coils) and the welding speed \( V \) were varied systematically between 2 to 3.5 kW and 0.5 cm/s to 1.5 cm/s, respectively Table 1.

<table>
<thead>
<tr>
<th>№</th>
<th>P [kW]</th>
<th>I [mA]</th>
<th>V [cm/s]</th>
<th>( I_f ) [mA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.5</td>
<td>41</td>
<td>0.5-1.5</td>
<td>497</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>50</td>
<td>0.5-1.5</td>
<td>497</td>
</tr>
<tr>
<td>3</td>
<td>3.5</td>
<td>58</td>
<td>0.5-1.5</td>
<td>497</td>
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</tbody>
</table>
The plates are sectioned in order to determine the thickness of the heat affected zones and the welds. All welds are controlled using radiographic methods. The defects are qualified in accordance with EN ISO 13919-1:1996.

Radiograms from radiographic tests (Figure 3a) show that welds, which are made at welding parameters №3 (Table 1), consist of allowed defects like undercuts, gas pores, lack of penetration. The evaluation of welds which is done using parameters №2 (Figure 3b) does not show any defects in weld and HAZ. In some welded joints there are single gas pores but according to ISO 5817:2003 their quality is evaluated as class B.

During welds line on the plate, temperature control measurements are carried out with K-type thermocouples of 1 mm diameter, brazed into dummy specimens at different distances (1.5, 2, 3, 4, 6, mm) from the weld lines. The signals from the thermocouples are recorded with a multi-channel data acquisition system.

The maximum temperature dependence for parameters №2 is shown in Figure 3. The maximum temperature is less than 300 °C at a distance larger than 3 mm from the interface. This is in agreement with the ASTM standard [2].

Figure 3 shows a typical for EBW (P=3 kW; V=1 cm/s.) shape of the weld and HAZ, with a variable width of weld along the depth of the welded joint. The shape of weld and HAZ and non homogeneous structure are closely connected with heat widespread during EBW. Previously our calculation of temperature distribution during electron beam welding of specimens from RPV steels at P=3 kW, V=1 cm/s. [8] showed large temperature gradients.
between different parts of the weld zone. For example cooling rates $W_{\text{cool}}$ varied from 18.5 $^\circ\text{C}/\text{s}$ near the surface of the weld up to 32 $^\circ\text{C}/\text{s}$ in the root of weld.

This results explains the formation of different structures along the high of the welded joint. In section I and II (Fig.5 and 6) is formed martensitic-bainitic structure and in section III (Fig.7) martensitic structure. The investigation do not show any cracks in the weld and the HAZ.
On the base of result presented above reconstitution of 15 Charpy specimens were made at following welding parameters: \( P=3 \) kW; \( U=60 \) kV, \( I = 50 \) mA, \( V=1 \) cm/s; \( I_f=497 \) mA.

### 3.2 Hardness test

Fig. 8 shows microhardness distribution along the reconstructed specimen - in base metal, HAZ and weld. Sudden change of microhardness is closely connected with microstructural transformations as a result of thermal cycle of welding. The growing of microhardness is a result of forming a martensitic structure (or martensitic-bainitic structure) in weld and HAZ.
3.3 Impact test

Results from Charpy tests and the comparison of reconstituted specimens with non-reconstituted specimens are given in Figure 9.
The conventional parameters - absorbed energy, shear fracture appearance and lateral expansion - were measured. The tests were performed according to ASTM E-23 on the same testing machine. The data of the reconstituted specimens are in good agreement with those of standard specimens.

4 CONCLUSIONS

The most important results of this study are:
1. Electron beam welding can be successful applied for the reconstitution of Charpy -V (10x10x55 mm) test specimens with size of the insert 10x10x10.
2. Charpy impact tests show good agreement between the data of electron beam reconstituted and non-reconstituted specimens.
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REFERENCES


