

ON THE DEVELOPMENT OF CT-TYPE SPECIMEN FROM VVER-1000 SURVEILLANCE SPECIMEN MATERIALS RECONSTRUCTION PROCEDURE

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A reliable evaluation of current status of reactor pressure vessel (RPV) and determination of its lifetime necessitate receiving direct data of material fracture toughness which are used in RPV resistance to brittle fracture calculations.

The fracture toughness data for reactors placed in commission before 2002 can be obtained only with small-size specimens (of 10×10-mm cross-section) of SE(B)-type that are included in VVER-1000 surveillance specimens programs. The reactors placed in commission after 2002 and all new projects of reactor plants have surveillance specimens located on internal surface of pressure vessel in flat containers that provide for accommodation of full-scale specimens of CT-type; the testing data for these specimens give more accurate information on fracture toughness.

This paper suggests to use test results of reconstructed specimens of CT-type made of halve-pieces of Charpy or SE(B)-type tested specimens using electron-beam welding to enhance of the forecast dependence of fracture toughness as compared to that obtained with SE(B)-type specimens.

We have prepared reconstructed specimens of CT-type with insertions sized 10×10 mm and 20×10 mm. While making welded seams, the insertion temperature was measured in the place of anticipated fracture location. Tests and fractographic examinations were carried out to study reconstructed and non-reconstructed specimens. The analysis have confirmed fine precision of test results for non-reconstructed specimens of CT-type.

The fracture toughness test results for non-reconstructed and reconstructed specimens and structural peculiarities of fractures testified that employed reconstruction procedures produce no significant influence on the mechanisms of brittle fracture origination and characteristics of fracture toughness specimens.

INTRODUCTION

The paper [1] suggests making the reconstituted CT specimens of the halves of tested Charpy or SE(B)-10 specimens, which are used in reactor power vessel (RPV) resistance to brittle fracture calculations, for receiving the direct data on crack resistance of VVER-1000 RPV materials.

Numerous results show that the CT specimens' data provides more accurate measure on fracture toughness of RPV materials when compared to SE(B)-10 specimens [2, 3].

Therefore, in order to increase the level of justifying an extension of VVER-1000 pressure vessels lifetime period up to 60 years or more, the methodology for reconstitution and testing the CT specimens out of broken Charpy or SE(B) specimen fragments was developed and implemented into the surveillance specimens' research practice.

The present paper is dedicated to the selection of welding conditions for reconstitution and the comparative mechanical testings of standard and reconstituted CT-type specimens, made of the surveillance specimens from VVER-1000 RPV materials with a view to confirm justifying calculations presented in [1].

TEST MATERIALS

The Sv-09HGNMTA-A weld metal (WM) made using the argon-arc welding had been selected as a test material. Table 1 provides the test material chemical composition.

Table 1 – Test material chemical composition

Material	Chemical composition, weight %								
	C	Si	Mn	Cr	Ni	Mo	S	P	Cu
WM	0,07	0,36	0,93	1,71	1,22	0,64	-*	0,007	0,04

* - N/A

SELECTION OF THE TECHNOLOGY FOR THE CT SPECIMENS RECONSTITUTION OUT OF THE CHARPY AND SE(B) SPECIMEN MATERIALS

In general terms, the reconstitution process represents the welding of the vessel steel casing element on the test material's central insert, as illustrated in Figure 1.

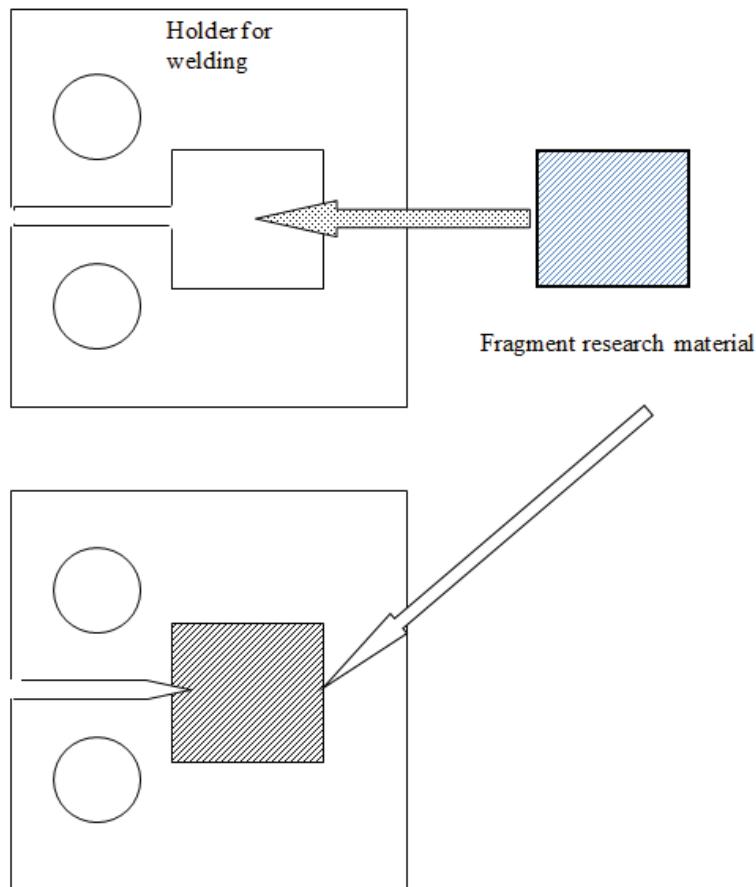


Figure 1. Reconstituted CT-type specimen chart

The technology for the CT specimens reconstitution should comply with the number of requirements for the test results accuracy, relating to the central insert's geometry (10x10 mm section and 10 to 20 mm long) and the reactor operational factors: the weld must be solid and poreless; the welding

technique must provide the weld width of not more than a 3 mm heat-affected zone (HAZ); during the welding process the central insert's temperature must not exceed the irradiation temperature for irradiated specimens under reconstitution, and must not exceed 350°C for non-irradiated specimens.

In accordance with the fragment sizes of reconstituted Charpy and SE(B) specimens, the paper [1] suggested two configuration options for welding insert with an appropriate casing configuration referring to Figure 2.

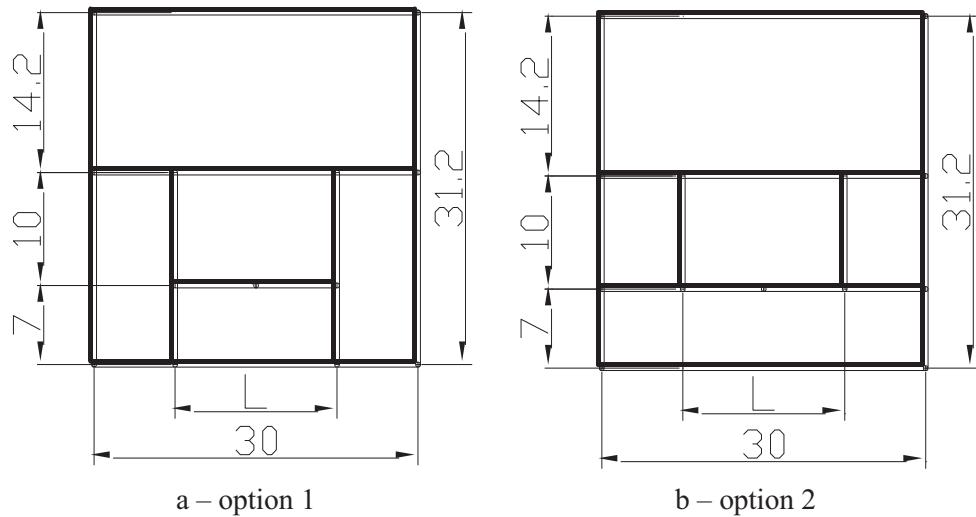


Figure 2. The layout chart for casing elements and inserts in reconstituted CT specimens with L×10×10 mm insert size: (a) – L=10 mm, (b) – L=20 mm.

For the options suggested in Paper [1], the strain-stress state calculations in reconstituted and in standard CT-type specimens have been performed. The calculations have been conducted using the finite-element method in a physically nonlinear formulation in the ANSYS-assisted 3D elastic-plastic design. Based on the calculations, the paper proposed a weld passage sequence, as shown in Figure 3.

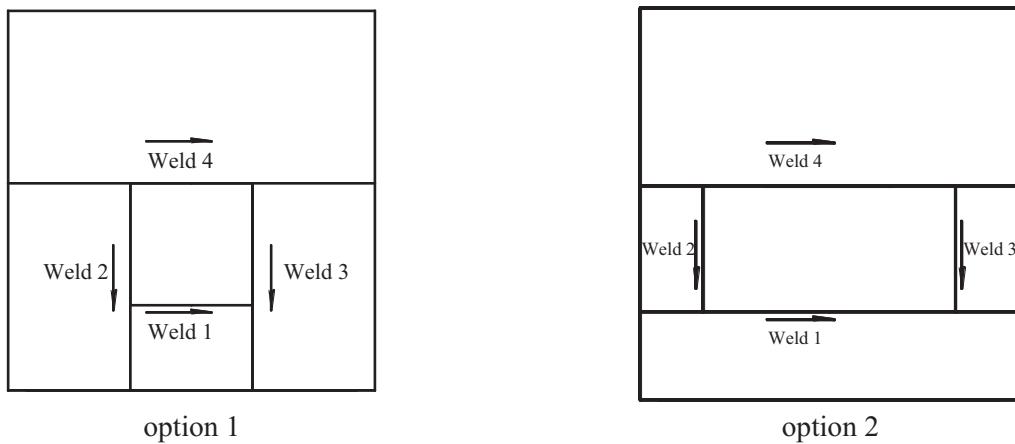


Figure 3. Weld passage options

The calculations also justified the differential range of yield strength ($\sigma_{0.2}$) admissible values for the central insert and the casing elements. Figure 4 illustrates the diagram determining a range of yield strength admissible values for the insert and the casing elements.

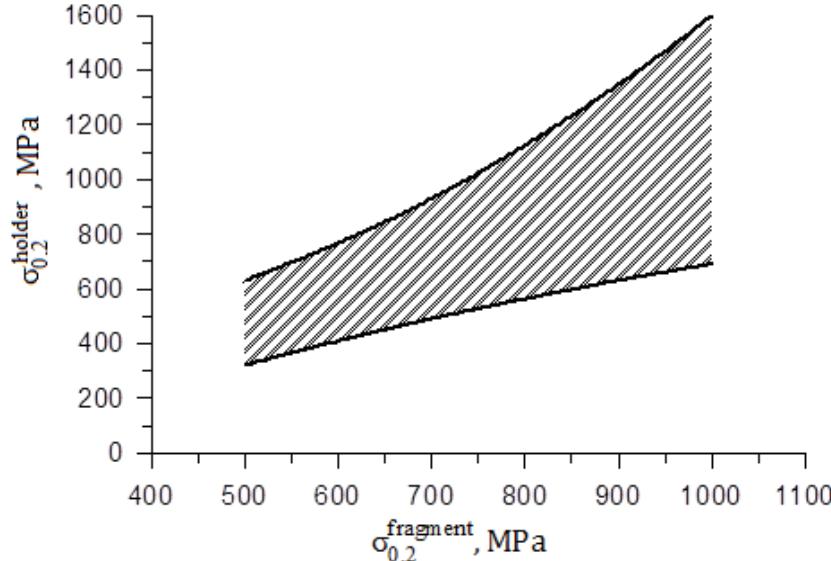


Figure 4. The range of yield strength admissible values for the casing metal, depending on the insert metal's yield strength, when making reconstituted CT-type specimens

SELECTING THE WELDING CONDITIONS FOR CT SPECIMENS RECONSTITUTION

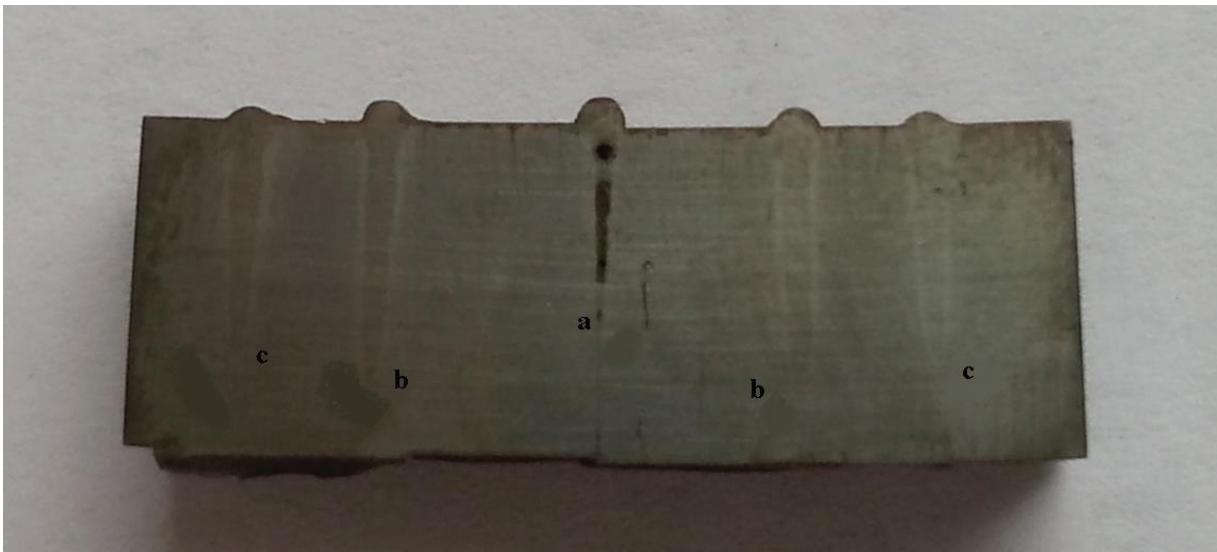
The reconstitution for CT specimens was performed with an electronic-beam welding system (EBS), you may see the parameters in Table 2.

Table 2 – The main EBS parameters and characteristics

Welder parameters	Dimensions
Vacuum chamber internal size, mm	500/500/500
Ultimate vacuum, Pa	7×10^{-3}
Beam power, kW	0–6
Maximum beam current, mA	0–100
Maximum weldment thickness, min, mm	20

The EBS manufacturer recommended the following welding conditions for the best weld's quality that meets the requirements: accelerating voltage is $U=40$ kW, beam current is $I=50$ mA, welding speed is $v=20$ mm/s. A welded test was made on vessel steel workpieces, using an electron-erosive cutting method. The specimen was deoiled with the SBP spirit and dehydrated with ethanol prior to welding.

The material boiled in the weld's area when making a welded test (Figure 5a demonstrates the macrosection), which occurred due to the brass particles from the wire, used in electron-erosive cutting. Thus, in addition to deoiling the surface, the necessary welding condition is the welded surface decontamination. Prepared workpieces also required to be kept in a hermetically sealed container in order to prevent an oxidation.



a – welding condition $U=40$ kW; $I=50$ mA. Weld's boiling;
b – welding condition $U=40$ kW; $I=50$ mA with a surface decontamination;
c – welding condition $U=40$ kW; $I=40$ mA.

Figure 5. The welded test macrosection with different EBS conditions used

После зачистки поверхности от латуни была сделана повторная сварная проба, которая показала, что сварной шов по режиму с параметрами $U=40$ кВ, $I=50$ мА проходит практически по всей толщине сварной пробы (рисунок 5, б), что недопустимо при двухсторонней сварке из-за двойной перекристаллизации. Поэтому было принято решение сделать сварные пробы по режимам с параметрами: $U=40$ кВ, $I=40$ мА (рисунок 5, в) и $U=40$ кВ, $I=35$ мА (рисунок 6, а).

Сварной шов, выполненный по режиму с параметрами $U=40$ кВ, $I=40$ мА, также проходит практически по всей толщине заготовки (рисунок 5, в), что недопустимо из-за двойной перекристаллизации свариваемого материала и может привести к увеличению зоны термического влияния.

На рисунке 6 представлен макрошлиф сварной пробы по режиму $U=40$ кВ, $I=35$ мА. Данный сварной шов удовлетворяет требованиям, предъявляемым к сварке. Далее была сделана сварная проба с двухсторонней сваркой (рисунок 6, б). Сварной шов получился сплошной и без видимых пор.

After removing the brass particles from the surface a retesting was conducted, and it demonstrated the weld with condition parameters $U=40$ kW, $I=50$ mA, that extends the full width of the welded test (Figure 5b), which is unacceptable in two-side welding due to the double recrystallization. So we reached a decision to make welded tests with the following condition parameters: $U=40$ kW; $I=40$ mA (Figure 5c), $U=40$ kW; $I=35$ mA (Figure 6a).

The weld completed in the following condition parameters $U=40$ kW, $I=40$ mA also extended the full width of the welded test (Figure 5c), which is unacceptable due to the weld material double recrystallization and may result in enlarging the HAZ.

Figure 6 demonstrates the welded test macrosection with the following condition $U=40$ kW, $I=35$ mA. The given weld meets all the welding requirements. Next comes the two-side welded test (Figure 6b). The weld is solid and without any visible pores.



a – unilateral welding; b – two-side welding.

Figure 6. Welded test macrosection performed with the EBS in the following condition parameters
 $U=40$ kW, $I=35$ mA, $v=20$ mm/s

As the result, the following welding condition was taken as a basis: $U=40$ kW, $I=35$ mA, and $v=20$ mm/s.

WELDING THE WORKPIECES FOR MAKING THE CT SPECIMENS AND EXPERIMENTAL TEST RESULTS ON FRACTURE TOUGHNESS

After choosing the basic welding condition the test specimens have been welded according to the schedule, shown in Figure 3.

During the welding process, the central insert's thermometry have been taken in passing through each weld. The maximum central insert temperature value was 208°C.

After the preparatory work was complete, we settled on reconstitution of the CT specimens out of the RPV materials. Twelve standard 12.5mm thick CT-0,5 specimens and eight reconstituted 10mm thick CT-0,5 specimens with inserts sized 10×10 mm and 20×10 mm have been prepared.

Fatigue crack growth has been performed with an electromechanical resonance machine («Rumul Microtron», Switzerland) on all reconstituted and standard specimens according to [4].

Conducting the fracture toughness tests, the data processing and the construction of fracture toughness temperature dependence $K_{JC}(T)$ were made in accordance with [4].

Figure 7 presents the fracture toughness test results for reconstituted and standard homogenous specimens of the WM material. The reference temperature value T_0 is minus 26°C for standard specimens, minus 24°C (10×10 mm sized insert) and minus 32°C (20×10 mm sized insert) for reconstituted specimens. Therefore, the difference in temperatures received for reconstituted and standard specimens is nonsignificant. As the Figure 7 shows, the K_{JC} values obtained with reconstituted specimens fit the scatter band of values obtained with standard CT specimens, and the reference temperature values T_0 are sufficiently close. The received close reference temperature values T_0 indicate a good correlation between the experimental data obtained with reconstituted specimens and the experimental data obtained with standard CT specimens.

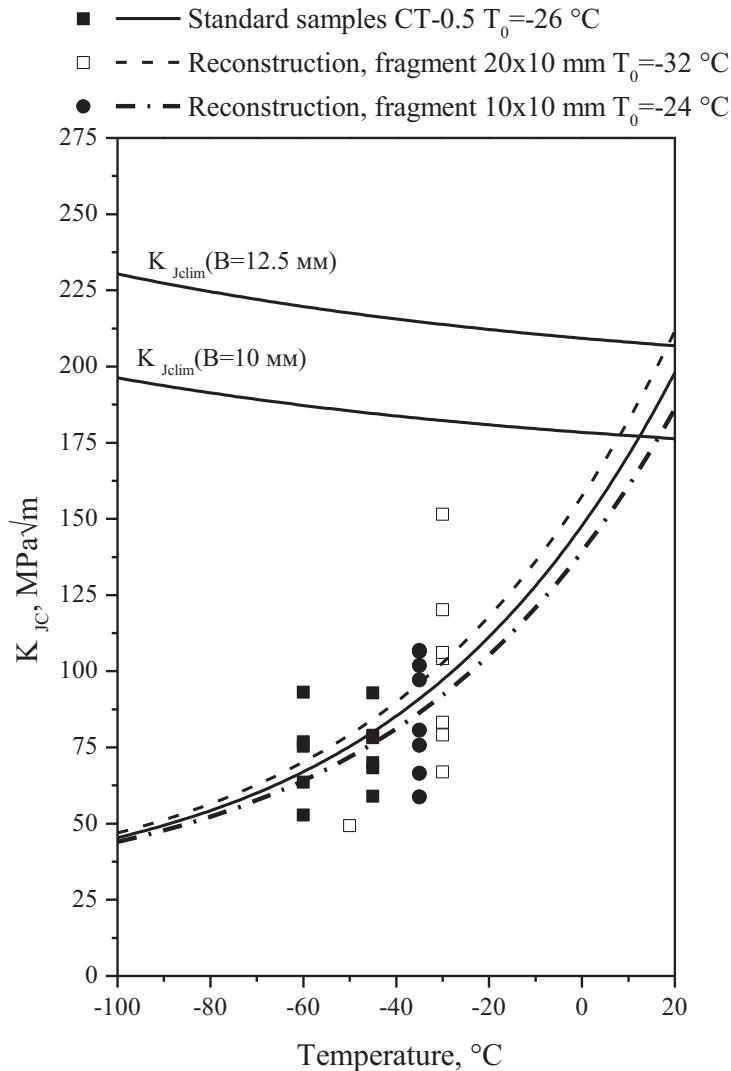


Figure 7. Standard and reconstructed CT-0.5 specimens' test results correlation (dots – experimental value K_{JC} , lines – dependences $K_{JC(\text{med})}(T)$ corresponding to $P_f=0.5$ и $B=25 \text{ mm}$)

CONCLUSION

1. The present paper justified the EBS applicability to making the welds on reconstituted CT specimens. The welding temperature and the EBS parameters, enabling compliance with the solidness and weld width requirements, were defined.

2. The CT standard and reconstituted specimens of the Sv-09HGNMTA-A WM made using the argon-arc welding were presented. The paper demonstrates that the maximum T_0 values difference does not exceed 6°C , which indicates a good correlation of the experimental data for the given types of specimens.

3. The results obtained from calculation and experimental tests provides an opportunity to recommend the suggested methodology for reconstitution of the CT specimens out of the broken Charpy or SE(B) surveillance specimens for irradiated materials fracture toughness determination, the results included in this paper are important contribution to the VVER RPV materials database on Fracture Toughness and to the higher operating safety.

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