APPLICATION OF AUTOMATIC ORBITAL WELDING TO FABRICATE ABSORBING INSERTS FOR SPENT NUCLEAR FUEL STORAGE CONTAINERS

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Considered is application of automatic orbital TIG welding for production of tight butt-lock joints on absorbing elements, which are the base of absorbing inserts of spent nuclear fuel storage containers. Results of optimisation of the TIG welding technology and ranges of optimal parameters for making of such joints are presented. The commercial unit designed for welding of the lock joints on the absorbing elements and the results of its test operation are described.

K e y w o r d s : *automatic orbital welding, absorbing inserts, nuclear power plants, butt-lock joints, technological rig, nuclear safety*

In compliance with requirements for nuclear safety of water-moderated reactors (WWER type) of power generating units operating at nuclear power plants (NPP), to maintain the required level of subcriticality the fuel assemblies (FA) are fitted with absorbing rods of the control and protection system (AR CPS). The same principle of securing the nuclear safety is used for storage of the spent nuclear fuel. According to this principle, under conditions of normal operation and in design accidents the value of the neutron multiplication factor should not exceed 0.95 [1–3].

One of the methods for securing the nuclear safety of charges of ventilated storing containers for dry storage of the spent nuclear fuel (VSC DSSNF) is fitting up of spent FA with absorbing inserts (AI), which are used along with spent AR CPS and compensate for deficit of the latter.

The absorbing insert used in VSC DSSNF of the Zaporozhie NPP, which was developed by the National Science Centre «Karkov Institute of Physics and Technology» (NSC KhIPT), consists of a cross-arm and 18 absorbing elements (AE). The AI cross-arm serves for simultaneous transportation of the AEs and their ranging during transportation and technological operations. The AEs are intended for placement of an absorbing material in guide channels of spent FA. AE is analogue of AR CPS in design, shape, overall and setting-out dimensions.

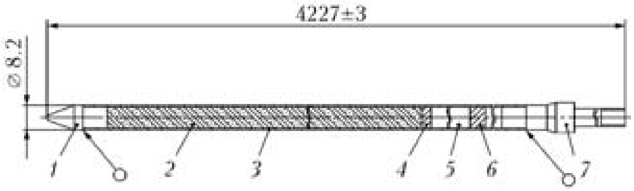

Figure 1. Schematic of absorbing element: *1* — cone (cap); *2* — filling material (boron carbide powder); *3* — shell; *4*, *5* — plugs; *6* — weighing material; *7* — tip

AE consists of a shell (Figure 1) filled up with vibrocompacted boron carbide powder, weighting material, tip, cone (cap) and plugs. The shell is manufactured from a pipe with a diameter of 8.2 mm and wall thickness of 0.6 mm made from austenitic chrome-nickel steel 08Kh18N10T or 12Kh18N10T, tip and cone (rod of the same steel).

According to the AI manufacture technology developed and applied by NSC KhIPT, the sealing butt-lock joints between the shell of AE and its tip and cone are made by the roll butt TIG welding method, in which the workpiece is rotated about its axis at a welding speed, while the torch with tungsten electrode is in a fixed spatial position. The shell is welded to the cone in argon, and to the tip — in a controlled atmosphere (helium) [4]. Specialised units ASTE-7 and SA-281 developed by the Research and Development Institute of Construction Technology (NIKIMT) (Moscow) are used for the welding process [5].

This technology provides the required quality of the welded joints on AE, which is proved by the experience of manufacture of the AIs and their application in VSC DSSNF of the Zaporozhie NPP. At the same time, increase in output of AE caused by the emerging growth of the demand for AI is limited to a certain degree by peculiarities of operation of the durable roll butt welding units, their functional possibilities and level of the end productivity, difficulties in upgrading of this equipment or its replacement by the new one. Also, the noted peculiarities of the equipment employed hamper upgrading of some components of the AE technological manufacture cycle.

One of the possible ways of improving the existing AI manufacturing technology is the technology for sealing of the butt-lock joints on AE by the method of orbital position butt TIG welding, as well as the equipment used to implement this process, which were developed by the E.O. Paton Electric Welding Institute (PWI) in collaboration with Separated Structural Unit «Atomenergomash» of State Enterprise «National Nuclear Energy Generating Company ENERGOATOM».

The technology for TIG welding of the shell of AE to its tip and cone was optimised by using automatic device ADTs 627 U3.1 for orbital position butt welding of pipelines, which was developed by PWI and is commercially produced now.

Specifications of automatic device ADTs 627.U3.1

Range of diameters of pipes welded, mm 8–24
Minimal inter-pipe distance, mm 60
Limits of regulation of welding current, A:
lower, not more than 8
higher, not less than 260
Limits of regulation of arc voltage, V 8–24
Maximal deviation of welding current from the preset value at mains voltage fluctuations not above the rated value and length variations not above ±2.0 mm from the preset value, % .... ±2
Accuracy of maintaining of the preset value of arc voltage, V, not worse than .... ±0.20
Limits of regulation of rotation speed of welding head chuck, rpm 0.3–12.0
Rated diameter of tungsten electrode (grades VL, VI or VT), mm 1.6
Rated radial displacement of torch, mm 15
Maximal displacement of torch across a joint, mm .... ±1
Quantity of arc passes 1–4

Device ADTs 627 U3.1 provides implementation of two types of operations («Setting Up» and «Welding»), two types of control («Manual» and «Automatic»), and the preset cycles of welding in a continuous mode, step-pulse mode or at the modulated current. The device comprises chopper-type multifunctional power source ITs 616 U3.1 for TIG welding, controller unit (control system) ITs 616.20.00.000, remote control panel (operator's panel) ITs 616.30.00.000, welding head ADTs 627.03.00.000 and collector ADTs 625.07.00.000.

Optimisation of the technology for welding of the butt-lock joints on AE was based on the results and recommendations of the earlier studies [6, 7], which had identified the following peculiarities of TIG welding of thin-walled parts without filler wire:

• key factors affecting the quality of the welded joints include a character of variations in heat and energy input during welding, shape of the tip and state of the working surface of tungsten electrode, and state of the surface of the base metal;

• main parameters of TIG welding without filler wire are welding current, arc voltage, welding speed and inert gas flow rate, the proportion of the values of which should correspond to the range of welding parameters determined by the calculation-experimental method that ensures the high quality of the welds [8];

• compared to butt joints, the overlap types of the welded joints (which include the butt-lock joints on AE) are less sensitive to instability of the welding parameters, but to make such joints it is necessary to displace the electrode to some distance (up to 0.5 mm) from the joining line and incline it to an angle of 15° towards a higher heat removal [7] (Figure 2).

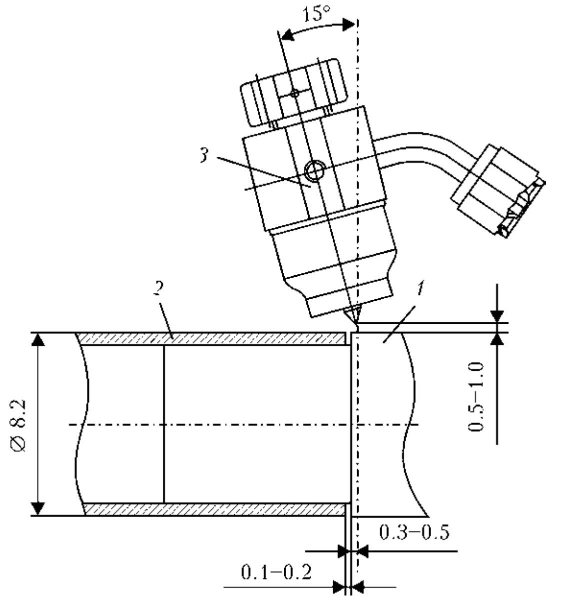

Figure 2. Schematic of fit-up of the butt-lock joint on absorbing element: *1* — cone (tip); *2* — shell; *3* — torch with tungsten electrode

Experimental joints on AE samples (mockups) were made to determine the ranges of optimal parameters of TIG welding of the butt-lock joints between the AE shell, cone and tip. The samples were prepared for welding by trimming edges of the shell mockups (pieces of the 8.2 mm diameter pipe of steel 08Kh18N10T) and degreasing these mockups, cones and tips. The joints were assembled for welding following the scheme shown in Figure 2 by providing the tight fit (d10) of the cone or tip on the shell.

The shell to cone welding was performed in argon by varying the following process parameters: welding current — 25, 28, 30, 32 and 35 A, arc voltage — 9 to 11 V at an arc length ranging from 0.5 to 1.5 mm, welding speed — 11.5 to 13.5 m/h (7.64 to 8.97 rpm), time of gradual increase of the current — 0.5 to 1.5 s, time of heating (time interval between the moment of the end of gradual increase of the current and that of the beginning of rotation of the arc) — 1.0 to 1.5 s, time of gradual decrease of the welding current at the final stage of the welding process (welding up of crater) — 1.0 to 2.5 s, and inert gas flow rate — 5 to 8 l/min.

The shell was welded to tip in helium based on the arc characteristics stipulated by its thermal- and electrophysical properties. In this case the welding current was 16, 18, 20, 22 and 25 A, arc voltage — 18.0–21.5 V at the arc length of 0.5–1.5 mm, time of gradual decrease of the welding current (welding up of crater) — 1.0–3.5 s, values of the other welding parameters being varied within the limits accepted for experimental welding of the AE shell to cone in argon atmosphere.

The quality of the experimental joints was assessed by visual and measuring control, metallographic ex-

Main parameters of TIG welding of joints on absorbing elements

Parameter	Shell-cone	Shell-tip
Grade of 1.6 mm diameter tungsten electrode	EVI-1, EVI-2, EVI-3, EVI-15 and EVI-20 acc. to GOST 23949–80, or «Abicor Binzel» WT-20, WR-2 and WR-2D	
Shielding gas	Argon acc. to GOST 10157–79	Helium acc. to TU 51-940–80
Welding current, A	30.0±1.2	20.0±1.0
Arc voltage, V	9–10	19–20
Arc length, mm	0.5–1.0	
Welding speed (rotation speed of welding head chuck), m/h (rpm)	12.0±0.4 (7.98±0.27)	13.0±0.45 (8.63±0.30)
Time of gradual increase of welding current, s	1.0±0.1	
Heating time interval, s	0.75±0.05	
Time of gradual decrease of welding current (welding up of crater), s	2.0±0.1	3.0±0.1
Shielding gas flow rate, l/min	5.9–7.1	4.9–6.1
Time of preliminary purging of welding zone with shielding gas (time interval «gas before welding»), s, not less than	5–10	
Time of purging of welding zone with shielding gas at final stage of welding cycle (time interval «gas after welding»), s, not less than	10–20	

aminations, intercrystalline corrosion (ICC) resistance tests and leakage tests. The visual and measuring control was carried out in compliance with requirements of the standards in force in the industry [9] by using a micrometer, as well as a magnifying glass and binocular microscope (e.g. MVS-9) with the ×(8–10) magnification. The metallography was done on the macrosections cut out from the resulting welded joints by using a metallurgical microscope with the ×(50–100) magnification to determine the penetration depth, defects in the weld metal (non-metallic inclusions, pores, wormholes and lacks of fusion), structure of the weld and HAZ metal, and austenite grain sizes. The ICC resistance tests of the weld and HAZ metal were conducted by the AMU method according to GOST 6032–89. The leakage tests were conducted by using a mass-spectrometer and helium leak detector PTI-10 by the vacuum chamber method in compliance with the requirements and procedures specified in the operating regulatory-technical documents [10].

Welding of several series of the experimental joints between the AE shell, cone and tip, comprehensive inspection of the quality of these joints and analysis of the obtained results allowed a conclusion that to ensure the consistent high quality of the butt-lock joints on AE the main TIG welding parameters should correspond to those indicated in the Table.

Results of the experimental and technological development efforts made by PWI for optimisation of the technology for TIG welding of the sealing butt-lock joints on EA proved the expediency of commercial application of this technology for mass production of both AI for VSC DSSNF and (in the future) AR CPS for FA of the WWER type reactors.

The special technological rig, the schematic of which is shown in Figure 3, was developed and manufactured to implement TIG welding of sealing joints

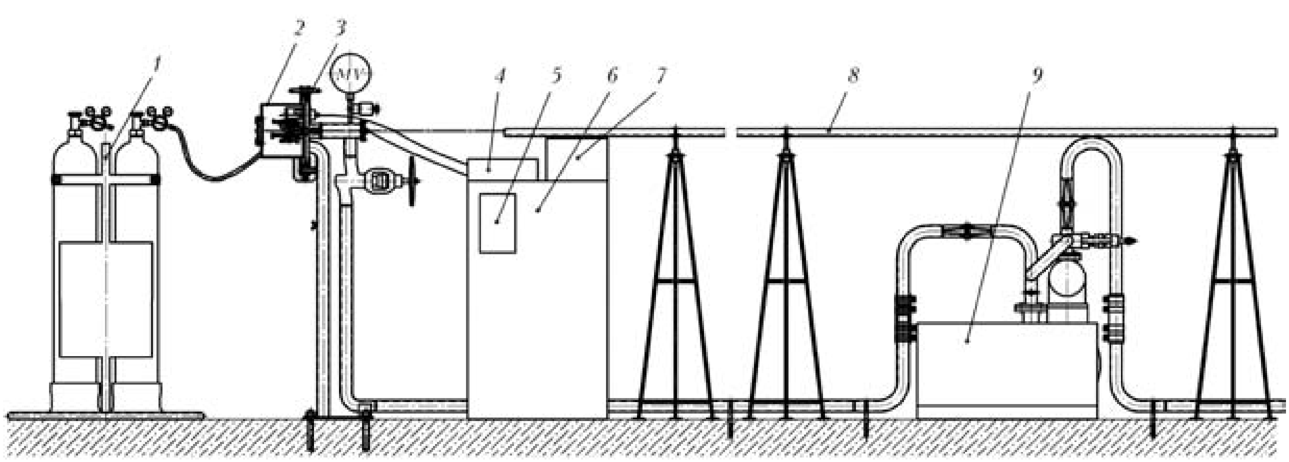

Figure 3. Schematic of the rig for TIG welding of butt-lock joints on AE: *1* — gas bottle rack; *2* — welding chamber; *3* — welding head ADTs 627.03.00.000; *4* — collector ADTs 625.07.00.000; *5* — remote control panel ITs 616.30.00.000; *6* — power source ITs 616.U3.1; *7* — controller unit ITs 616.20.00.000; *8* — cradle; *9* — vacuum valve unit

on AE and similar parts commercially fabricated by «Atomenergomash».

The rig comprises all components of ADTs 627 U3.1 for orbital position butt TIG welding, a welding chamber, vacuum valve unit, guide cradle and gas bottle rack.

The chamber (see Figure 3) with the welding head rigidly fixed inside it provides:

- repeatability and, if necessary, adjustment, fixation of the spatial position and alignment of the butt-lock joints on AE prepared for welding with respect to tungsten electrode of the torch mounted on the welding head chuck;
- free access to the welding head and adjustors of spatial position of the torch with the tungsten electrode, thus facilitating maintenance of the head without its removal from the chamber;
- electric insulation of the current and gas supply lines of the welding torch and control circuits of its rotator with respect to the chamber casing, weldment and other non-current-conducting components of the rig;
- meeting the leak tightness requirements in evacuation of the internal volume of the chamber for subsequent creation of the controlled atmosphere in it by filling it with helium and maintaining the excess pressure at a level of (1.96±0.2) kPa;
- possibility of observation of the course of the welding process through a viewing window.

The general view of the chamber is shown in Figure 4.

The valve unit (see Figure 3) is intended for evacuation of the internal volume of the chamber with rarefication to a level of not less than 1.33 Pa.

The cradle is a guide support for placement of an absorbing element to be welded in the rig. It protects the AE shell from deformation and mechanical damage during preparatory and final operations, and during welding of the sealing joints on AE.

Testing of the PWI technology for TIG welding of sealing joints on AEs under industrial conditions of «Atomenergomash» showed that the use of the rig (see Figure 3) does not only provide the consistent high quality of the welded joints on AEs, but also leads to some decrease in labour intensiveness and to reduction of duration of the setting up operations preceding the welding process (compared to the existing roll butt welding technology), and simplifies training of welders and attending personnel. The test results served as forcible arguments in favour of arrangement of the specialised sector for commercial fabrication of absorbing elements at «Atomenergomash». Technological fitting of this sector and its productivity with one rig used for welding allow producing up to 1200 AEs a year. The equipment of the sector was used to fabricate an experimental batch of AEs, the samples of which were subjected to comprehensive tests (including by the destructive testing methods) at NSC KhIPT. These tests proved a full correspondence of the quality of the joints on AEs made by the orbital TIG welding technology to the requirements of the standards. Also, it was established that the butt-lock joints on AEs made by the orbital TIG welding technology are identical in their penetration depth, structure of the weld and HAZ metal, austenite grain sizes and mechanical strength to those made by the existing roll butt welding technology.

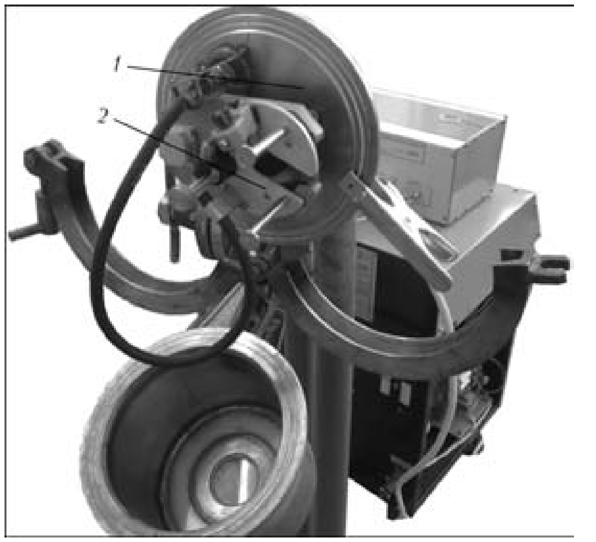

Figure 4. General view of chamber (*1*) and welding head ADTs 627.03.00.000 (*2*)

CONCLUSIONS

1. The developed technology for TIG welding of overlap joints on different-thickness small-diameter bodies of revolution by using automatic orbital welding devices of the ADTs 627 U3.1 type provides the high-quality butt-lock joints on AEs and similar parts.

2. Commercial application of the developed TIG welding technology and corresponding technological equipment will allow manufacturing AIs, AR CPS and similar parts in volumes that meet the nuclear power generation needs.

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