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RESEARCH BY DIRECT METHODS OF THE BASE METAL OF MAIN CIRCULATION PIPELINE OF THE POWER UNIT 3 OF THE SOUTH UKRAINE NPP AFTER 200 THOUSAND HOURS OF OPERATION

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The base metal (BM) of the main circulation pipeline (MCP) of the unit 3 of the South Ukraine NPP, which has been in operation for 200 thousand hours, was investigated by direct methods. It is shown that the mechanical properties and structure of BM of the MCP after 200 thousand hours of operation satisfy the requirements of regulatory documentation for metal. A comparison of the test results of the BM in the initial state and after 100 and 200 thousand hours of operation was carried out. It is shown that in the process of operation there is a decrease in the rate of changes in the mechanical properties of BM, in particular, during the last 100 thousand hours of operation in comparison with the previous ones.

INTRODUCTION

The reliability and safety of NPP operation depends on the reliable operation of its structural elements; their reliability depends on the current state of the materials from which they are made. The main circulation pipelines (MCP) of the WWER-1000 reactors are among the most responsible elements that ensure the safe operation of the NPP. The impossibility of replacing the MCP during the long term of operation of the Ukrainian NPP necessitates periodic monitoring of the properties of the base metal (BM) of the MCP.

In accordance with the main regulatory document ПНАЭ Г-7-008-89 [1], which regulates the safe operation of nuclear power plant equipment and pipelines, control of the mechanical properties of the metal of the pipelines is carried out by destructive and (or) non-destructive methods at least through every 100 thousand hours of operation for a nuclear power plant with a water-water power reactor (WWR) [2].

Currently, the results of monitoring by direct methods of BM of MCP of power units 1 and 2 of the South Ukraine NPP after 100 and 200 thousand hours of operation [3], and power unit 3 only after 100 thousand hours [4] are published. This work is dedicated to research methodology by direct methods of BM (steel 10ГН2МФА) of the MCP of power unit 3 of the South Ukraine NPP after 200 thousand hours of operation and a brief summary of the obtained results.

METHODS

Methodology for control by direct methods of BM of MCP, which is in operation, is grounded on the cutting out of MCP samples of metal for further investigation in laboratory conditions, without affecting the operational characteristics of the object under examination. Metal samples were cut out on the compressed side of the MCP bend in a section with an increased wall thickness compared to the designed one. The cutting of metal samples was carried out by the electroerosion method [5] using the mobile complex "MICRORES". The general layout of the equipment for cutting out the BM sample of the MCP is shown in Fig. 1.

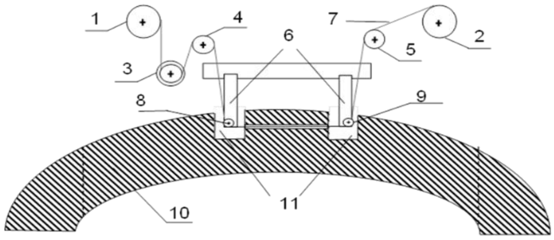


Fig. 1. The equipment for cutting out the BM sample of the MCP: 1 – coil with wire; 2 – coil with spent wire; 3 – unit for wire tension; 4, 5 – rollers for deflecting the wire; 6 – supports; 7 – wire; 8, 9 – rollers supporting the wire in the zone of separation of the BM sample; 10 – MCP; 11 – grooves in the body of the MCP

The equipment was mounted directly on the controlled section of the MCP of the power unit. To reduce the influence of the "natural" spread of BM properties over the volume of the controlled pipeline on the test result, samples were taken in a close area from the place where the sample was cut after 100 thousand hours of operation.

A brass wire with a diameter of 0.2 mm was used as an electrode, which was fed along the cut trajectory below the level of the outer surface of the MCP [6] with uniform tension [7]. The size of the selected sample of BM is ≈ 60×60×3 mm.

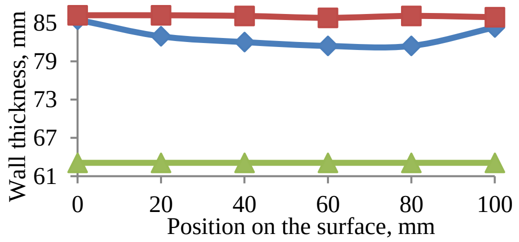


Fig. 2. Thickness of the wall of the bend in the area of cutting out the BM sample from the MCP of unit 3 of the South Ukraine NPP:
– normative; – initial;
– after sampling

at the site of cutting out the BM sample from the MCP of the unit 3 of the South Ukraine NPP after 200 thousand hours of operation.

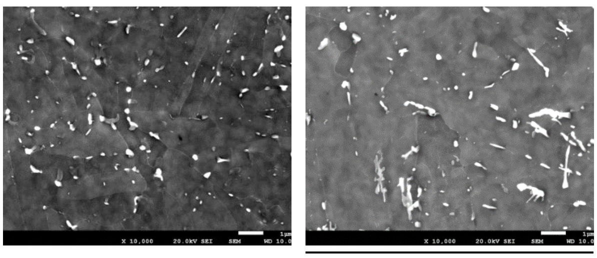
It can be seen from the figure that the residual thickness of the pipe wall is greater than the normative one. The cutting of the BM sample did not affect the operational characteristics of the MCP.

The thickness of the samples during the studies did not exceed 2 mm. It should be noted that in accordance with ПНАЕ Г-7-002-86 in the nuclear power industry, the main type of test specimens for impact tests is the Charpy specimen type 11 (10x10x55 mm with a V-shaped notch). At the same time, ГОСТ 9454-78 [8] allows the use of samples of other dimensions, in particular, of type 14 (2x8x55 mm with a V-shaped notch). Scale factors were taken into account by introducing correction factors [9].

An optical microscope MMO-1600-AT, a scanning electron microscope JEOL JSM-7001F with a Schottky cathode, a transmission electron microscope JEM-2100, an electron microscope JSM 7001F, an INCA Energy 350 spectrometer, an Instron-5581 test set, and a pendulum coper model Instron SI-1M with a maximum energy reserve of 450 J were used in the study of BM of MCP.

STRUCTURE OF THE BM OF MCP

The BM structure after 200 thousand hours of operation consists mainly of an uneven pearlite-ferrite mixture. The average grain size of BM at the time of control corresponds to 9–10 points [10]. During the last 100 thousand hours of operation, metallographic studies did not reveal any significant changes in the structure of the BM of MCP. At the same time, scanning electron microscopy showed the growth of secretions along the boundaries of BM grains. Fig. 3 shows the surface of the samples of the BM of MCP of the unit 3 of the South Ukraine NPP after 100 and 200 thousand hours of operation, respectively.



A B

Fig. 3. The surface of the BM of:
A – after 100 thousand hours of operation;
B – after 200 thousand hours of operation

Images of the surfaces were obtained in the mode of registration of secondary electrons. In the figures, the images of the allocations are presented in lighter tones.

The examination at higher magnification showed that the secretions are located both on the borders of the grains and in their bodies. Moreover, the size of allocations along the grain boundaries increases during the operation of the MCP. Based on the research conducted during the last 100 thousand hours of operation in the BM, the number of discharges (larger than 80 nm) decreased by ≈ 33 % while simultaneously increasing their average size by ≈ 39 % (increasing the cross-sectional area of discharges).

It is natural to assume that there is a merger of already existing allocations and an increase in their size due to the migration of individual elements from the body of BM grains (in particular, carbon).

Studies of the structure of BM in a transmission electron microscope showed that in individual grains after 200 thousand hours of MCP operation, there is a significant increase in the density of dislocations relative to the average level (Fig. 4).

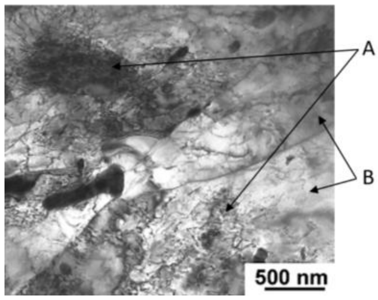


Fig. 4. The structure of the BM of the MCP after
200 thousand hours of operation:
A – a cluster of dislocations; B – BM grains

On the background of light grains, the allocation in the form of globular dark particles is clearly visible. The ratio of components in the composition of particles can change, but at the same time they can be characterized as complex carbides.

MECHANICAL PROPERTIES OF BM OF MCP

The technical requirements for the BM of MCP of the WWER-1000 reactors and the results of mechanical tensile tests of the samples of BM of MCP of the unit 3 of South Ukraine NPP after 200 thousand hours of operation are given in Tables 1 (20 °C) and 2 (350 °C).

Table 1

The technical requirements for the BM of MCP of the WWER-1000 reactors and the results of mechanical tensile tests at 20 °C ($R^т_m$ – strength limit; $R^т_{P\,0.2}$ – yield strength; A – relative elongation; Z – relative narrowing)

Regulatory document or period of operation	$R^т_m$, kgf/mm^2	$R^т_{P\,0.2}$, kgf/mm^2	A, %	Z, %
ПНАЭ Г-7-002-86	No less			
	55	35	16	55
ТУ 975 Е004511 5th ed.	No less			
	55	35	16	55
Passport on the pipe bend	54.5	41.6	21.5	68.9
Initial metal	52.5	39	26.5	71
100 thousand hours	63.2	47.3	20.4	66.5
200 thousand hours	67.0	55.5	26.0	74.5

Technical requirements for the impact strength of the BM of the MCP of the WWER-1000 reactors and the results of tests on the impact strength at 20 ºC of samples of the BM of the MCP of the unit 3 of South Ukraine NPP, taking into account the appropriate amendment, are given in Table 3.

Table 2
The technical requirements for the BM of MCP of the WWER-1000 reactors and the results of mechanical tensile tests of the samples of BM of MCP at 350 °C

Regulatory document or period of operation	$R^{т}_{m}$, kgf/mm^2	$R^{т}_{P\ 0.2}$, kgf/mm^2	A, %	Z, %
ПНАЭ Г-7-002-86	No less			
	50	30	14	50
ТУ 975 Е004511 5th ed.	No less			
	50	30	14	50
Passport on the BM	58.9	44.3	25.5	71.1
Initial BM	59	44	28	75
100 thousand hours	72.0	57.7	22.4	67.5
200 thousand hours	61.5	44.6	22.3	71.5

Table 3
The technical requirements and the results of tests on impact strength at 20 ºC of the samples of BM of MCP

Regulatory document or period of operation	Impact strength KCV, (kgf·m)/cm^2
ТУ 975 Е004511 5th ed.	≥ 4.8
200 thousand hours	22.1*

*In accordance with РД.00.ЭК.ХФ.МО.М.09-09

It can be seen from the tables that the mechanical properties of the BM of the MCP of the unit 3 of South Ukraine NPP after 200 thousand hours of operation meet the requirements of regulatory documents.

The typical topography of the fracture surface of the sample of BM of the MCP after mechanical tests is presented in Fig. 5.

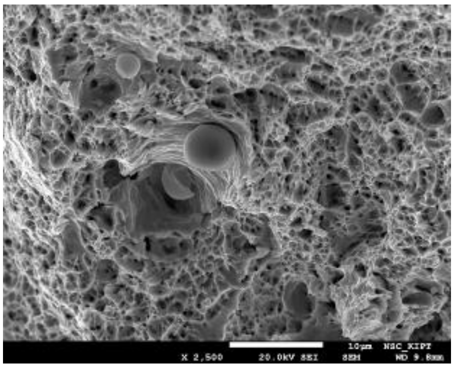


Fig. 5. Relief of the central fracture zone of the sample of BM of the MCP after tensile tests at 20 °C

The fracture surfaces after all mechanical tests of samples of BM of the MCP are characterized by a pitted relief, areas with faceted relief were not detected. The destruction has a viscous intragranular character.

CHANGE OF THE MECHANICAL PROPERTIES OF THE BM DURING THE OPERATION OF MCP

Forecasting the future operation of the MCP requires the determination of the kinetics of changes in the properties of the BM during the previous periods of operation. Tables 4 (20 °C) and 5 (350 °C) show the relative changes in mechanical properties over 200 thousand hours of operation at a temperature of 288 °C (the operating temperature of the “cold thread” of the MCP). In order to reduce the influence of the “natural” dispersion of BM properties, samples were taken from adjacent areas of the same MCP after different periods of operation.

Table 4
Change in mechanical properties (20 °C) of the BM of the MCP of the unit 3 of South Ukraine NPP during operation

Stage of operation of the MCP	Change $R^{т}_{m}$, %	Change $R^{т}_{P\ 0.2}$, %	Change A, %	Change Z, %
First 100 thousand hours	+20.4	+21.3	-23	-6.3
Last 100 thousand hours	-2.7	-5.7	+9.3	+7.5

Table 5
Change in mechanical properties (350 °C) of the BM of the MCP of the unit 3 of South Ukraine NPP during operation

Stage of operation of the MCP	Change $R^{т}_{m}$, %	Change $R^{т}_{P\ 0.2}$, %	Change A, %	Change Z, %
First 100 thousand hours	+22	+31	-20	-10
Last 100 thousand hours	-6.9	-3.8	+16	+10.4

Based on the above tables, it follows that at the initial stage of operation (up to 100 000 h) the BM of the MCP of the unit 3 of South Ukraine NPP is strengthened (strength and yield strength increase and relative elongation and narrowing decrease). Over the last 100 thousand hours of operation, a slight weakening of the BM has been observed. This is observed both at 20 °C and at 350 °C tests.

CONCLUSIONS

1. A microsample of BM of the MCP of the unit 3 of South Ukraine NPP after 200 thousand hours of operation was studied by direct methods. In particular, metallographic and electron-microscopic studies, tests on static tension, shock bending were carried out.

2. The results of structure research, tests on static tension and shock bending show that the properties of BM meet the technical requirements for the metal of MCP of WWER-1000 reactors, the destruction of samples during experiments is of a viscous nature.

3. It is shown that in the process of operation, a decrease in the rate of changes in the mechanical properties of BM is observed, in particular, during the last 100 thousand hours of operation in comparison with the previous ones.

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ДОСЛІДЖЕННЯ ПРЯМИМИ МЕТОДАМИ ОСНОВНОГО МЕТАЛУ ГЦТ ЕНЕРГОБЛОКУ №3 ЮЖНО-УКРАЇНСЬКОЇ АЕС ПІСЛЯ 200 тис. годин ЕКСПЛУАТАЦІЇ

Р.Л. Василенко, С.В. Гоженко, Є.О. Крайнюк, О.Г. Руденко

Досліджено прямими методами основний метал (ОМ) головного циркуляційного трубопроводу (ГЦТ) третього блоку ЮУ АЕС, що знаходиться в експлуатації 200 тис. годин. Показано, що механічні властивості і структура ОМ ГЦТ після 200 тис. годин експлуатації задовольняють вимогам нормативної документації до металу. Проведено порівняння результатів випробування ОМ у вихідному стані та після 100 і 200 тис. годин експлуатації. Показано, що в процесі експлуатації спостерігається зменшення темпу змін механічних властивостей ОМ, зокрема, за останні 100 тис. годин експлуатації ГЦТ у порівнянні з попередніми.