doi.org/10.15407/tpwj2017.12.06

IMPROVEMENT OF THE TECHNOLOGY OF PRODUCING EXTENDED COMPOSITE TRANSITION PIECES OF STEEL 20 — STEEL 08Kh18N10T MADE BY THE METHOD OF HOT SCREW ROLLING IN VACUUM*

B.V. BORTS, I.M. NEKHLYUDOV, N.D. RYBALCHENKO, V.I. SYTIN and **I.O. VOROBJOV****
NSC «Kharkiv Institute of Physics and Technology» of the NAS of Ukraine
1 Academichna Str., 61108, Kharkiv, Ukraine. E-mail: nsc@kipt.kharkov.ua

Changes in mill design using screw rolling in calibrated rolls were proposed and tested. Solid-phase welding in upgraded vacuum rolling mill was used to produce extended bimetal transition pieces with a helical texture that allows making sound solid-phase joints of more than 200 mm length of low-carbon steel and 08Kh18N10T steel. Investigation results were used to develop the technology of screw rolling in calibrated rolls. 12 Ref., 8 Figures.

Keywords: *vacuum screw rolling, extended tubular element of the transition piece, bimetal composites, upgrading*

Operating nuclear power plants of the second and third generations require improvement and extension of service life of piping in joints of dissimilar metals, which differ by their composition and properties, such as low-carbon steels with austenitic steels. Up to now such joints have been made in nuclear power plants by fusion welding, and are known to be the most susceptible to corrosion fracture.

In 2010–2012 during performance of a comprehensive «Resource» Program NSC KIPT developed new devices for solid-phase welding of composite materials by hot vacuum rolling in sheet rolling mill DUO-170 manufactured by KIPT [1, 2].

Developed technology of pack rolling of composite materials of steel 20 – steel 08Kh18N10T allows manufacturing circular transition inserts of different diameters, which have been introduced for long-term trials in the turbine department of Zaporizhya Nuclear Power Plant (ZNPP) and have demonstrated their performance under full-scale operating conditions.

Based on the developed technology of producing the new composite material, «Program of certification testing of composite welded joints of steel 20 – steel 08Kh18N10T made by solid-phase welding technology» was prepared, coordinated and approved in SC NEGC «Energoatom» in 2013.

During fulfillment of the comprehensive «Resource» program, it was found that composite transition inserts made by pack method, do not completely satisfy the needs of NPP technological documentation PNAE G-7-008-89 on dissimilar metal welding.

These deviations from the approved requirements of NPP technological documentation were the bases for substantiation of the possibility of upgrading the available equipment for vacuum screw rolling in calibrated rolls of extended transition elements from composite of steel 20 – steel 08Kh18N10T of 30 mm diameter and more than 200 mm length.

Analysis of experimental samples of extended transition pieces revealed several drawbacks of billets rolled in DUO-170 mill that necessitated development of the drawing for the design of a higher-capacity new mill DUO-175-2 with additional upgrading to eliminate these drawbacks.

Metal deformation and contact stresses in groove rolling. Rolling processes belong to high-efficient cost-effective methods of manufacturing metal products. Further development and improvement of these processes requires a comprehensive study of rolling parameters and ensuring optimum conditions of equipment operation.

In this connection, it is expedient to consider the distribution of deformations and contact stresses in rolling mill roll grooves during rolling, to establish the regularities of the change of contact tangential stresses and derive the dependencies for determination of

*Published be the materials of performance of targeted comprehensive program of NANU «Life and safety of structures, facilities and machines» («Resource») in 2013–2015.

**I.M. Korotkova, O.O. Lopata, O.T. Lopata participated in the work.

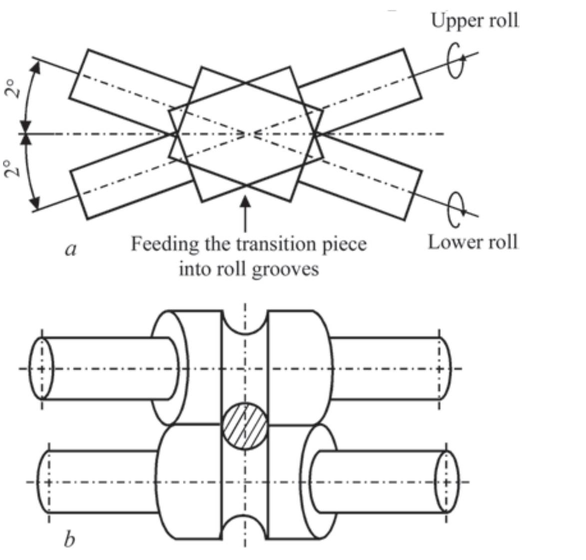

Figure 1. Schematic of roll positioning: *a* — plan view; *b* — end view

contact and total pressure of metal on the rolls, torque and position of neutral section in groove rolling. It is necessary to calculate the contact area in rolling in simple and complex grooves, as well as study the influence of outer zones on contact pressure in groove rolling, when $l/h_{av} < 1.5$ (l is the length of geometric center of deformation; h_{av} is the average height of deformation center).

Performance of comprehensive studies of industrial rolling mills [4-6] enabled establishing the values of metal pressure on the rolls, torques, energy parameters, forward slip, groove wear and accuracy of rolled stock dimensions. Mill reserves were revealed and recommendations on improvement of the technology of steel shape rolling were proposed.

Developed measures increase the productivity of rolling equipment, and improve the quality and accuracy of rolled stock dimensions.

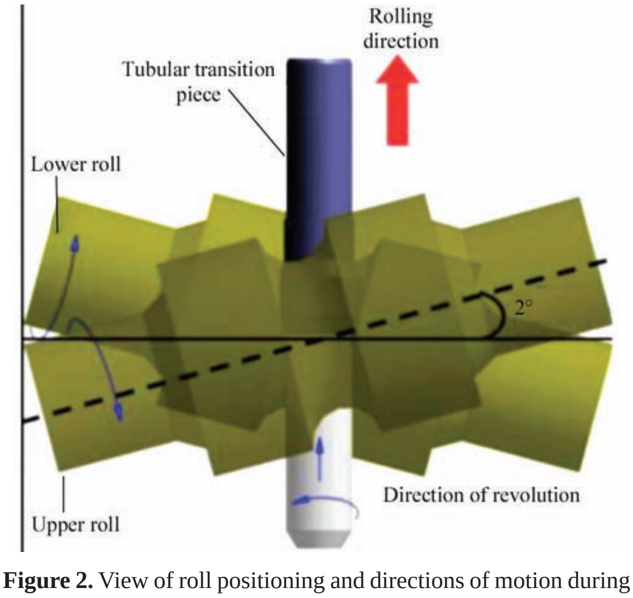

Figure 2. View of roll positioning and directions of motion during rolling (*top view*)

Mill upgrading. Mill upgrading consisted in determination of optimum calibration of roll bodies for rolling a round billet of 30 mm diameter, development of drawings and manufacturing new rolls with grooves, initially for 14.8 mm and then finishing the grooves in a semi-arc to 15.5 mm, to provide the finish diameter of 30 mm in the rolled and lathe-machined billet. Changes in groove size were due to a too large amount of metal flash on the horizontal slit of roll grooves. As it turned out after the first experiments on rolling the extended transition piece, the mill does not have the required rigidity (total deformation and sagging of rolls, screw gear of the stop screw). Nominal gap between the bodies of rolls brought together to metal contact, should be equal to 0.5–1 % of the body diameter, that is up to 1 mm on average. In the mill the roll return actually was equal to 2.3 mm. As a result, the outer layer of stainless steel turned into flash, and the uniformity of the composite outer layer was disturbed.

Analysis of experimental samples showed differences in the degree of deformation over the transition piece cross-section. Non-uniformity of deformation was determined from the data on microhardness of the components measured on templates of the cross-section of rolled billet of the transition piece of steel 20 – 08Kh18N10T composite. Microhardness was measured by Vicker's method at 25 g load in LM 700AT instrument of LECO. Non-uniformity of component deformation over the billet cross-section was also determined by measurement of the size of component grains to the rolling direction [2, 7].

In order to reduce the found drawbacks, during improvement of the technology of producing extended transition elements, it was envisaged to perform compression with screw rolling that provides the helical texture. For this purpose, drawings were developed, manufacturing and mounting of grooved rolls in the mill was performed not in the traditional position, normal relative to the rolling direction, but with each roll turned at an angle of 2° to the axis of mounting the rolls in DUO-170 mill and facing in opposite directions (Figures 1, 2).

Thus, the rolls were turned by 4° relative to each other, that should make the billet additionally rotate around its axis during forward motion at the moment of rolling. This should provide reduction of material loss as flash due to increase of the zone of its texture displacement along a helix (Figures 3, 4).

Changes of roll position led to additional changes in the design of the run-in and run-out chutes (see Figure 5), which were made, allowing for the arising forces of torque on the sample during movement of the billet being rolled, as well as to essen-

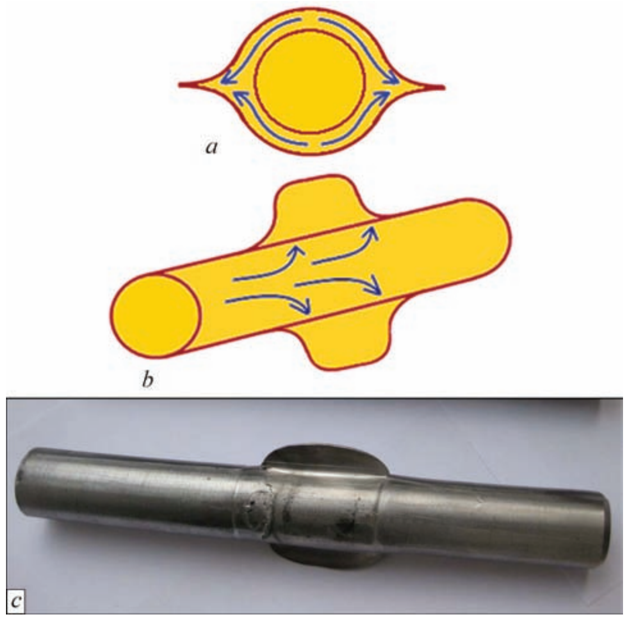

Figure 3. Direction of metal flow (*a*, *b* — schematic from sample end face) at application of parallel rolls (*c*)

tial changes in the design of the fastening of roll chocks to bearings.

Changes in the transition piece billet design were additionally made, namely two grooves are first cylindrical and then conic, as well as in the design of the tip of rod billet of steel 20 to achieve its tighter fitting in the initial billet body. These changes prevent the billet rod being pushed out at the initial moment of rolling when entering the roll grooves.

Unlike the previous experiments, when rolling was performed in the mill without helical motion, in the mill with screw rolling the inlet cone on the transition piece billet was changed from 45 to 25° for better gripping of the billet by rolls.

Making samples of an extended transition piece by the improved technology and quality control. Testing on model material — aluminium was performed to assess the mill performance during rolling of extended transition elements in rolls with screw rolling by the new procedure. The billet was made by drawings of the composite transition piece.

Testing of the new rolling technology confirmed the possibility of providing axial rotation of the billet

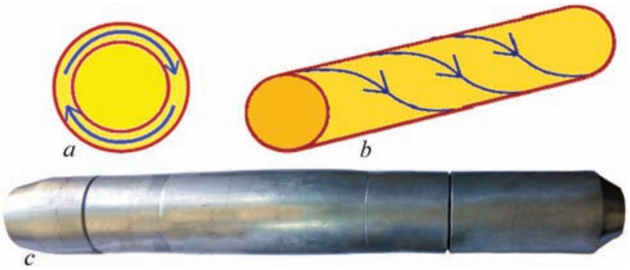

Figure 4. Direction of metal flow at screw rolling with application of helical texture: *a* — sample end view; *b* — general view of texture; *c* — test sample from aluminium

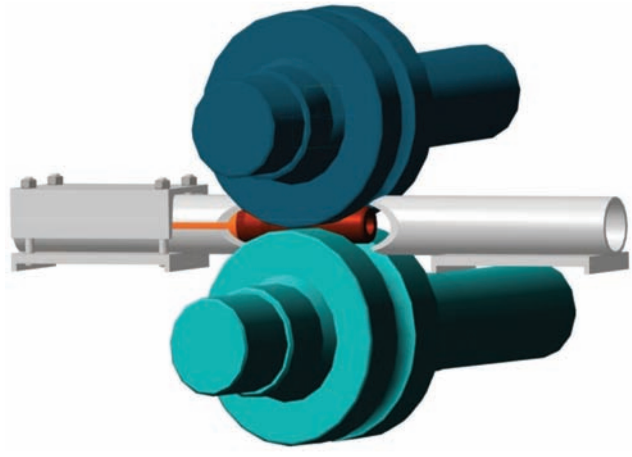

Figure 5. Positioning of grooved rolls with guides

in combination with its simultaneous forward motion during rolling at solid-phase joining of the transition piece components.

As shown by experiments, rolling of extended transition piece by the improved technology with screw rolling proved to be correct.

Produced experimental samples had helical texture that provides uniform compression of the material around the total perimeter of the billet in the sites of solid-phase joining of two dissimilar materials (Figure 6).

Conducting non-destructive ultrasonic testing of manufactured extended tubular transition pieces from steel 20 – 08Kh18N10T. Among the many methods [8] of conducting ultrasonic testing (UT) selection of a particular one should be based on the maximum possibility of defect detection. Appearance of the tested sample is given in Figure 6, *b*. The work was performed using ultrasonic flaw detector UD4-76.

For extended tubular transition pieces of steel 20 – 08KhN10T two procedures were selected, namely echo-method using combined direct piezoelectric transducers (PET) with 2.5 MHz frequency and echo-mirror method.

Before UT the instrument was calibrated on test standard defective and sound samples using both direct and inclined PET. In case of the presence of a defect when using echo-mirror UT, the amplitude of the transition region signal will be higher than that of the transition zone of sound standard test sample. In case

Figure 6. Extended tubular element made in DUO-175-2 mill; *a* — before rolling; *b* — after rolling and machining

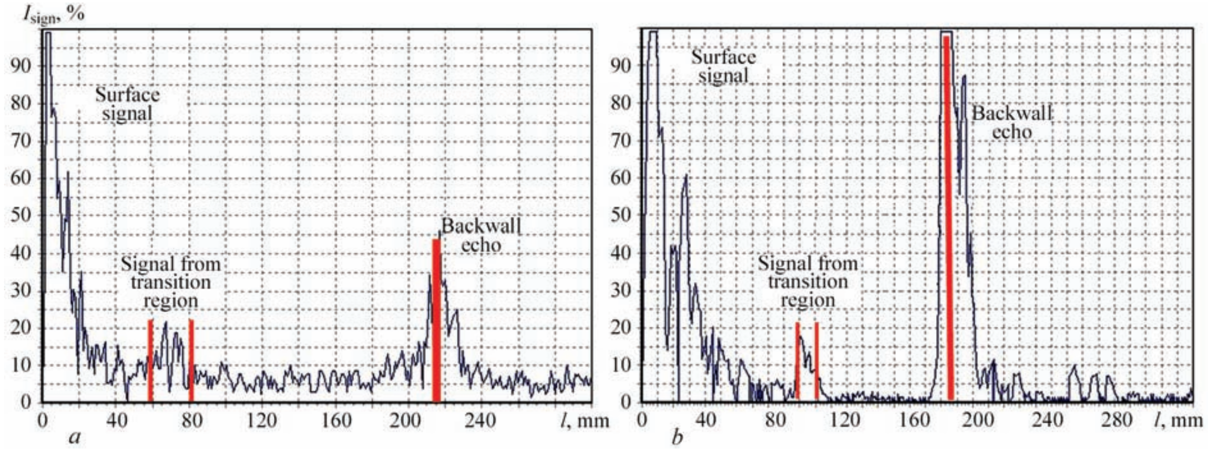

Figure 7. Oscillogram of the transition region of test sample from steel 20 – 08Kh18N10T (echo-method): *a* — from the side of 08Kh18N10T steel; *b* — from the side of steel 20

of application of UT echo-procedure, the transition region signal should be compared with the backwall echo of the studied sample. Presence of a defect will be indicated by backwall echo signal amplitude that is higher than that of transition region signal.

Results of UT of extended tubular transition pieces by the echo-method are given in Figure 7, and those of echo-mirror method are shown in Figure 8. As one can see from the oscillograms, defects in the form of cracks, voids or unwelded areas are absent both in the body and on the boundary of the components.

Development of technological instructions on solid-phase welding of extended transition pieces with outer sleeve from 08Kh18N10T steel and inner rod from steel 20. To ensure compliance with the requirements of NPP technological documentation PNAE G-7-008-89 [9] technical documentation has been developed on manufacture of extended composite transition pieces, which contains technological instructions on operating sequence for solid-phase joining of transition elements from dissimilar metals by the method of hot vacuum rolling. A series of mandatory testing on quality control has been specified in keeping with the requirements.

The instructions give the following list of such manufacturing stages:

- process of initial material preparation: machining of the sleeve and rod from steel 20 before assembly into the initial billet before rolling and assembly of the packs for rolling;
- process of joining the transition piece elements in vacuum rolling mill DUO-175;
- safety requirements during joining of the components of composite transition pieces;
- final operations after producing the transition element;
- quality control of the joint of the components in the finished product.

As the main conditions for producing composite transition pieces were providing high strength and tightness, quality of the made products was assessed based on the requirements of the main document of control rules (CR) requirements for NPP equipment and piping, welded joints and surfaced parts PNAE G-7-010-89 [10].

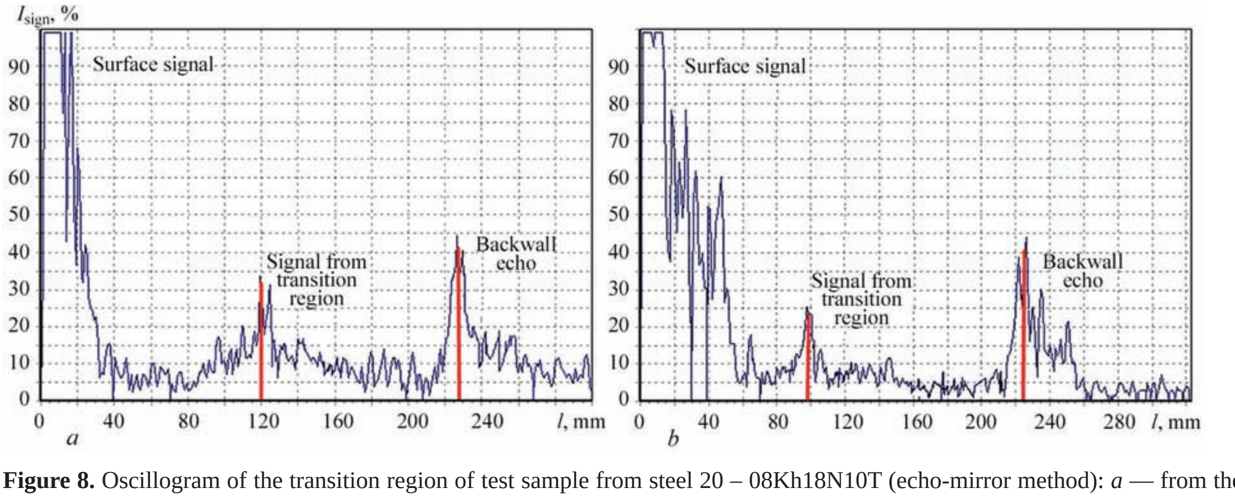

Figure 8. Oscillogram of the transition region of test sample from steel 20 – 08Kh18N10T (echo-mirror method): *a* — from the side of 08Kh18N10T steel; *b* — from the side of steel 20

CR data are the guidelines for design, development, manufacture and mounting of equipment and piping, and they specify the procedure, kinds, scope and methods of control and criteria for assessment of the quality of welded joints and surfaced parts (products).

In keeping with CR requirements as per PNAE G-7-010-89 the following kinds of testing are envisaged for our products:

● nondestructive method of ultrasonic testing on the surface in the area of joining layers of dissimilar metals in keeping with GOST 14782–86 [11];

● tightness control by hydraulic testing at filling of the tubular billet inner part with liquid (water) under pressure and soaking for a day under up to 200 bar pressure;

● mechanical shear strength testing of layers of the composite components in keeping with GOST 14759–69 [12] for adhesive joints of sheet materials;

● metallogrpahic studies of tightness and length of the joint boundary as well as layer thickness and degree of structure deformation in the zone of the component metal joint.

Quality control is performed as follows: in keeping with item 1 — 100 % pieces in the batch; in keeping with item 2 (hydraulic tightness tests) — one sample from a batch after 100 % UT; in keeping with items 3, 4 — one product from the transition piece batch.

Conclusions

1. A design of rolling mill assemblies was developed and upgraded that allowed producing extended tubular transition pieces for NPP due to rotation of the piece during rolling.

2. Mock-up samples of extended tubular transition pieces after rolling demonstrated screw structure along the sample surface, as well as absence of billet curvature when using upgraded rolls, mounted at an angle to each other.

3. Design, manufacture and additional upgrading of new higher-capacity vacuum mill DUO-175-2 instead of badly worn mill DUO-170, enables producing higher quality transition pieces from steel 20 with stainless steel of 08Kh18N10T type, which are intended for introduction in nuclear power stations.

4. Nondestructive ultrasonic testing showed absence of defects in the bod and on the boundary of the components.

5. Procedures of quality control of the transition elements, in keeping with the rules of control of «Equipment and piping of nuclear power plants, welded joints and clad products. Control rules» (PNAE G-7-010-89) were developed and technological instructions on solid-phase welding of extended transition pieces with outer sleeve from 08Kh18N10T steel and inner sleeve from steel 20 were prepared.

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Received 02.10.2017