TECHNOLOGY

SPECIAL FEATURES OF THE FABRICATION OF HEAT-EXCHANGER TUBES WITH PROFILED ENDS

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The application of heat-exchanger tubes with profiled outer ends (Fig. 1) in the fabrication and repair of tube bundles of heat exchangers [1] greatly increases the strength and tightness of rolled joints under the conditions of elastic or elastoplastic controlled deformation of bridges in the tube plate.

However, the fabrication of tubes with external ring-shaped projections (thicker parts, belts) is a relatively complicated process. For example, cold extrusion of thickened areas of tube blanks is associated with the possibility of formation of defects such as cracks of three types: failure of the thickened areas on the planes with the maximum normal stresses; surface cracks in the upper end of the thickened area; shearing ring-shaped cracks in the area of transition from the cylindrical part of the blank to the thickened area [2,3]. In addition, the pinch-type defects [4] can form in cases in which the wall thickness of the tube blanks is smaller than the width of the thickened area.

The authors have developed (and obtained patents and a positive decision for issuing patents) technological processes of profiling the ends of heat-exchanger tubes: rolling in a pressing jig; machining; machining combined with rolling the external surface of the end; cold extrusion with one-sided allowance of the material of the tube for the formation of ring-shaped projections in a stationary die; cold extrusion with two-sided allowance for the formation of ring-shaped projections in a floating die.

We shall examine the special features of the technological process of shaping ring-shape projections in a floating die (transverse-straight extrusion, combined with compression of the tube) in which it is possible to regulate actively the kinematics of the flow and stress state of the process material in the cavity of the processing jig by the formation of two local areas of deformation.

Special design features of the ends of the heat-exchanger tubes are the equality of the external diameter of the ring-shaped projections to the initial outer diameter of the tube (for new tube plates) or its diameter being larger than the initial outer diameter of the tube (for the tube plates requiring repair). If these diameters are equal, the first shaping operation on the tube is compression. It is well-known [4] that after compression the outer diameter of the tube is slightly smaller than the diameter of the hole in the die. In particular, after compressing the ends of a tube with an outer diameter 25 mm and a wall thickness of 2.5 mm (25 × 2.5 mm) made of steel 10 (at a compression coefficient of 0.95), the outer diameter of the compressed part of the tube with a wall thickness of 2.57–2.63 mm was 23.8 mm. The inner diameter of the compressed end of the tube is not constant.

It should be noted that the length of the compressed end of the tube 1 (Fig. 2a) takes into account the necessary allowance for the shaping of the outer ring-shaped projection and selection of the gaps in the technological jig.

The compressed end of the tube 1 with the surface, cleaned to bare metal, is placed in the cavity of the compound die 2, formed by two half-dies split along the generating line, with two circular grooves with the trapezoidal cross-section. One of the variants of the geometrical dimensions of the grooves: larger base 4 mm, smaller base 2 mm, depth 0.5 mm.

The die is positioned by moving it in the cavity of the thick-wall holder 3 made of high-strength material with the possibility of axial displacement. In the cavity of the die on the side of the internal end there is a conical section with the angle α.

The tube is fixed with the clamp 4 under the effect of radial pressure on the external side (outside limits of the holder). The gap h (the first special feature of the new process) forms between the die and the clamp at the ends. This gap takes into account the allowance for filling the internal circular grooves in the die and the corresponding gaps in the technological jig by the material of the tube (Fig. 2a).

The new technology is based on the following procedure. The stepped plunger 5, with the conical section on the small step, is inserted into the hole in the compressed end of the tube. Since the internal diameter of the compressed end of the tube is not constant, the installation of the stepped plunger takes place with some force P causing the tube to expand. This is determined by the transition of the tube material to the elastoplastic state (the second special feature of the new technological process). The dimensions of the inner diameter of the tube are determined by the diameter d of the small step of the plunger, and the outer diameter of the compressed part of the tube D0 becomes equal to the diameter of the cylindrical cavity in the die.

The third special feature of the new technological process is the application of an axial force deforming the tube only to the inner circular part of the end of the tube, i.e., the diameter D of the larger step of the plunger is smaller than the diameter D0 of the die cavity. It is thus possible to avoid the formation of pinch-type defects because the effect of the moment, bending the tube (the width of the circular grooves, being 4 mm, is greater than the wall thickness of the tube, which is 2.5 mm) is compensated by the deformation resistance of the outer unloaded ring-shaped layer of the tube.

The applied force increases up to P1 and pressures, higher than the yield limit of the tube material (which slightly increases as a result of compression in comparison with the initial yield limit), form on the ring-shaped contact surface below the end of the plunger. Local axial compression of the tube results in the formation of shear surfaces (Fig. 2b, dashed lines). According to the results, in the case of a 25 x 2.5 mm tube made of steel 10, the force causing filling the outer ring-shaped groove of the die with the tube material from the external allowance along its length is 115–120 kN. It should be noted that the filling of the outer ring-shaped groove of the die is not accompanied by the axial displacement of the latter.

The increase of the deformation force P2 results in the propagation of plastic deformation of the tube material in the axial direction and in the displacement of the die in the direction of applied force. As a result, the conical section of the die cavity, acting on the tube, compresses it on the small step of the plunger (Fig. 3a). The moving (in relation to the tube) die initiates the contact friction of the resistant force (stress τj), and active friction forces (stress τa) form in the surface layers of the compressed end of the tube. The internal ring-shaped groove of the die is filled with the tube material which is now extruded from the internal allowance along its length.

It is well-known that the active friction forces decrease the force deforming the tube. For example, in the case of a 25 x 2.5 mm tube made of steel 10, the internal ring-shaped groove in the die is filled at a force of 155–160 kN. The difference in the forces, deforming the tube, during filling of the ring-shaped grooves of the dies is ~40 kN. This is required to compress the tube.

The formation of the ring-shaped projections is completed by the sizing stage (Fig. 3b). The maximum force for steel 10 tubes is 0.29–0.3 MN.