A comparative study of the structure and mechanical properties of sheet and tube preforms from steel 35Kh after heat refining, cold rolling, and wobble forming is performed. It is shown that wobble forming produces a positive effect on formation of an α-phase with homogeneous and dispersed cellular substructure in the whole of the cross section of tube preforms, which ensures a favorable combination of strength, ductility, and impact toughness. It is recommended to subject the tube preforms to subsequent annealing in order to raise the parameters of ductility and impact toughness without lowering the strength.

Key words: wobble forming, dispersion of structure, mechanical properties of tube preforms.

INTRODUCTION

Development and installation of advanced technologies for increasing the output, reducing the consumption of materials, and simultaneously raising the service reliability of machine parts and structures remains an important task of mechanical engineering and materials science.

One such technology is deformation of a material by a wobbling tool (we will call it wobble forming). According to the idea of this method of pressure treatment, one of the tools (the female die or the male die) performs a wobbling (precessional) motion created by a special drive, while the other tool performs translational motion created by a conventional hydraulic drive (Fig. 1). This method of treatment is especially effective for making tube preforms and articles like pressure vessels and hydraulic cylinders. Today articles of this type are primarily produced with the help of mechanical treatment (drilling) or by bending and welding of initial sheet preforms followed by hardening heat treatment.

Wobble forming (WF) makes it possible to lower the consumption of metal and to simplify the process of manufacturing of tube preforms on the whole. In addition, results of studies performed in the last decades show that forming of this type raises the entire set of characteristics of mechanical properties and thus the reliability of the articles. Another positive feature of this kind of deformation is its high locality, which makes it possible to use conventional equipment for deforming materials with elevated and high strength level; the same microvolume of the metal can be deformed repeatedly, which produces a homogeneous structure and substructure in the cross section of the metallic preform.

It cannot be excluded that due to the locality and the repeated nature of the deformation in wobble forming (or any other treatment of the kind) the actual strain is substantially...

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Fig. 1. Scheme of deformation of a tube preform in a through wobbling facility: 1) precessional tool; 2) deformed tube preform; 3) arbor.
higher than the design one. Thus, the method of wobble forming is an example of commercial process that implements to this or that degree the mode of severe plastic deformation.

The aim of the given work was a comparative study of the fine structure and properties of sheet and tube preforms from steel 35Kh obtained by rolling and wobble forming and development of a process for manufacturing a reliable material for pressure vessels.

METHODS OF STUDY

We studied sheet and tube preforms from steel 35Kh. The chemical composition of the preforms is presented in Table 1.

The sheet and tube preforms were heat treated in a mode consisting of hardening from 860°C (40 min) in water and subsequent tempering at 570°C for 1 h with water cooling. After the heat refinement the preforms were subjected to cold plastic deformation. The sheet preforms were deformed by rolling with 30 and 60% shrinkage; the tube preforms were wobble formed with 42 and 63% shrinkage. Then the cold-deformed preforms were annealed in a temperature range of 300 – 650°C with 1-h and 2-h holds.

The sheets and the tubes was then cut into preforms with a thickness of 0.4 – 0.5 mm in an electrospark discharge machine and subjected to an electron microscopic study. Then the preforms were thinned mechanically against sand papers to a thickness of 0.05 – 0.10 mm and polished electrically using anode dissolution in a phosphorus-chromium electrolyte (860 ml orthophosphoric acid + 100 g chromic anhydride). The foils obtained were studied under an EM-12M electron microscope at an accelerating voltage of 100 kV and a JEM-200CX microscope at 160 kV. One structural state of the specimens was studied for at least 5 foils; the number of studied fields for each foil was at least 10.

The images were computer processed and the longitudinal and transverse sizes of fragments of the α-phase (laths, cells, or subgrains depending on the structural state) and of the cementite carbides were measured. The number of measurements in every case was no less than 500. We used formulas of mathematical statistics for processing the metallographic images [1] and computed the mean longitudinal and transverse sizes of the structural components, the variance, the standard deviation, the confidence interval, and form factor of each component.

The characteristics of strength and ductility were determined in accordance with the GOST 1497–73 Standard for short cylindrical specimens with initial diameter of 5 mm in a 1231U-10A universal testing machine at a deformation rate of 2 mm/min. The recorded stress-strain diagram was used to compute the ultimate rupture strength \(\sigma_r\), the yield strength \(\sigma_{0.2}\), and the elongation \(\delta\). The contraction \(\psi\) was evaluated in terms of the change in the diameter of the specimen. No less than 4 – 5 specimens were tested after each variant of treatment.

The impact toughness was computed using the results of the tests in an MK-30 impact machine in accordance with the requirements of GOST 9454–78 for specimens of types 3 and 17. The tests were performed at a temperature ranging from + 20 to – 60°C. Negative temperatures were obtained by mixing liquid nitrogen with ethyl alcohol. The temperature was controlled by a preliminarily calibrated copper-constantan thermocouple connected to a digital millivoltmeter.

The static crack resistance was evaluated in terms of the crack resistance limit \(I_c\). Preparation of the specimens, conduction of the tests, and processing of the results were performed according to GOST 25.506–85 for flat specimens with a thickness of 5 mm, a side notch, and a crack in the mode of three-point bending using an INSTRON 5882 machine at a deformation rate of 0.5 mm/min. The relative length of a crack \(\lambda\) determined in accordance with GOST 25.506–85 as the ratio of the total length \(l\) of the notch and of the fatigue crack grown from it to the width \(b\) of the specimen; in our tests \(\lambda = 0.45 – 0.55\).

The test error in determination of the mechanical characteristics did not exceed 5% in any case.

RESULTS AND DISCUSSION

Properties of Steel 35Kh in the Initial State

The structure obtained in the preforms after heat refinement may be classified as disperse tempered sorbite represented by elongated subgrains (or cells) of ferrite inherited from the martensitic structure and cementite carbides segregated primarily over boundaries of ferrite subgrains. The dislocation density inside the subgrains is not high.

In addition to the disperse tempered sorbite the structure bears microvolumes that have experienced secondary recrystallization. These microvolumes have a size of about 5 μm.

<table>
<thead>
<tr>
<th>Preform</th>
<th>Content of elements, wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-mm-thick sheet</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>0.34</td>
</tr>
<tr>
<td>Tube with wall thickness of 12 mm</td>
<td>0.35</td>
</tr>
</tbody>
</table>

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