Energy-Saving Manufacturing Technology for High-Strength Metal Products

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Abstract—The use of heat-strengthened blanks to manufacture cold-deformed rebar and high-performance bolts permits the elimination of some operations in the production process, with corresponding energy savings. The complete research cycle includes the development of the technology, formulation of the documentation, and industrial trials.

Keywords: energy conservation, rolled blanks, thermomechanical and mechanical treatment, cold deformation, rebar, bolts

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For a long time, a team under the leadership of K.F. Starodubov at Dnepropetrovsk Metallurgical Institute (since 1999, Ukrainian National Metallurgical Academy) has worked on increasing the strength of mass-produced metal products so as to reduce the consumption of steel in construction, manufacturing, and other sectors. This research has generated new technologies for thermal strengthening rolled metal products in the manufacturing process, on the basis of the heat of rolling [1]. These technologies are widely used in the manufacture of rebar, sheet, pipe, and other products for the construction industry.

The next step in the research was to increase steel strength by cold deformation (cold working) and to stabilize the resulting properties by various means [2–4]. That provided the basis for technologies producing cold-deformed pipe, bolts, rebar, and other components and culminated in the development of new reinforcing steel and rebar of classes At–ShS and At–1US for ferroconcrete components [5, 6], as well as energy-saving production technologies based on thermomechanical strengthening of the rolled steel and its subsequent conversion to the final metal product. Thus, at the end of the twentieth century, rolled steel of class At–ShS (A400S according to the new designation) was regarded as a commercial product for the construction industry, whereas today such steel is the raw material for the manufacture of high-strength products. In other words, new levels of quality have been attained. These developments reflect the continuing influence of Starodubov’s ideas.

ENERGY CONSERVATION

We know that the mass production of high-strength product (bolts, nuts, etc.) is based on energy-intensive heat treatment in the manufacture of both the blank and the final product. This is evident for the example of bolts of strength class 8.8 (or above), produced by the following operations:

<table>
<thead>
<tr>
<th>Traditional technology</th>
<th>Energy-saving technology</th>
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<tr>
<td>Annealing of hot-rolled material</td>
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<td>Acidic etching of scale on annealed material</td>
<td>Mechanical scale removal during thermomechanical strengthening of the rolled material</td>
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<td>Drawing of annealed material to produce blank</td>
<td>Drawing of annealed material to produce blank</td>
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<tr>
<td>Shaping of bolt</td>
<td>Shaping of bolt</td>
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<tr>
<td>Quenching of bolt</td>
<td>—</td>
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<tr>
<td>Tempering of bolt</td>
<td>Tempering of bolt (possibly)</td>
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<tr>
<td>Washing</td>
<td>—</td>
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<tr>
<td>Hot electroplating</td>
<td>Hot electroplating</td>
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</table>

The traditional technology includes three energy-intensive operations (annealing of the rolled material and quenching and tempering of the bolt), which significantly increase the production costs. In addition, acidic etching has not only direct costs (around $15/t) but also indirect costs associated with the loss of metal (up to 4 kg/t) and the regeneration and treatment of the etch solutions.

The energy-saving technology omits annealing of the rolled material and does not involve acidic etching.
The production cycle is shortened by using mechanical scale removal. The initial blank is a rolled product of elevated strength obtained by thermomechanical or thermal strengthening in the rolling mills; that eliminates the need for thermal strengthening (quenching) of the bolt produced. Tempering is retained in the manufacture of some products (bolts, pins, nuts) as a static–dynamic strain-aging operation. It may be combined with hot electroplating or some other method of obtaining an anticorrosive coating. These deviations from the traditional technology are intended to reduce energy consumption and production costs, without loss of product quality. That, in turn, should improve the competitiveness of the product.

In the energy-saving technology, in contrast to the traditional approach, the energy of cold deformation is used not only in shaping but also in strengthening the metal. In other words, the energy-saving technology relies on three basic procedures: (1) thermomechanical or thermal strengthening in the rolling mills; (2) strengthening by cold deformation; (3) final formation of the structural state in stabilizing tempering or cyclic deformation. This approach makes maximum use of the existing operations: hot and cold plastic deformation and the application of an anticorrosive coating.

In Fig. 1, we compare the traditional and energy-saving manufacturing processes for high-strength products. The operations in the energy-saving technology are the production of a cast blank; its hot deformation to obtain an intermediate product of the required size, with thermomechanical or other strengthening; subsequent cold plastic deformation to obtain the required product; and stabilizing treatment. Besides energy conservation, this technology reduces the consumption of alloying materials, because alloy steel is replaced by less expensive silicomanganese or carbon steel [7]. That reduces the cost of the final product.

THEORETICAL ASPECTS

As we know, structural treatments change the structural state of materials, without significantly changing their size, shape, or mass. The structural state includes three components: the phase composition, the structural morphology, and the mechanical stress state. Thus, the energy consumed in structural treatment is used in changing the components of the structural state. Since the properties of the object depend on the structural state that is formed, other conditions being equal, the components of the structural state and their characteristics may be interpreted as an informational code regarding the properties of the object. This code is revealed in the object’s responses to external disturbances (of technological or operational type). In quantitative terms, these responses are known as the properties of the object. It is important to note that the information regarding the properties of the object coded in the structural state is much richer than the information actually recorded in conventional certification tests. At the same time, this information always appears in operational disturbances of the part and may not agree with the information from certification tests. Therefore, the determination of the required characteristics of the structural state as a result of structural treatment is generally included in the certification of the part, along with the quantitative characteristics from the tests.

Note that such characteristics of the structural state include their distribution at different structural levels formed in different operations. These levels are as follows:

(a) the macrostructure;
(b) the microstructure;
(c) the crystal-defect (fine) structure;
(d) the atomic—crystalline structure;
(e) the electronic structure.

The notation used for the basic systems and levels of the structural state in Fig. 2 is as follows: G, C, E, the geometric, chemical (concentrational), and energetic systems of the structural treatment, respectively, characterized by the distribution of the structural elements in geometric, chemical (concentrational), and energetic internal subspaces of the object; macro, micro, F, at/cr, el, N, the structural levels of the macrostructure, microstructure, fine structure, atomic—crystalline structure, electronic structure, and nuclear structure, whose structural elements are distributed in the subspaces of the object; and the information supersystem, including the subsystems consisting of sensor S, control Co, and genetic Ge information. The information supersystem is based on the structural elements of the system and the structural levels as carriers of information regarding the object’s reactions to