DETERMINATION OF HARDENING CURVES OF HSLA STEEL IN THE PROCESS OF COLD ROLLING

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Abstract

Based on the methods and principles of the mathematical theory of experiment, in mechanical properties (yield strength, ultimate strength) the changes are investigated of hardly-deformed steel for the automotive industry (grades HC260LA, HC300LA, HC380LA, HC420LA to EN10268). It concerns the process of cold deformation. In industrial production of cold-rolled sheet a single-factor experiment was planned and carried out. To eliminate the influence on the result of independent factors (heterogeneity of chemical composition, mode of hot-rolled, of cold deformation) experimental randomization was performed. Samples of hot-rolled steel are selected for each brand from the strips of different heats. Three samples across the width of the strip were cut on sections of length with steady state regime of rolling. Cold rolling with a fixed level degree of deformation was performed on the laboratory mill for each group of samples with different combination of independent factors. Tensile test was performed under identical conditions for all samples with different sets of independent factors and degree of deformations. A statistical appraisal of the results of the experiment was executed. Obtained values of the yield strength and the ultimate strength for each test steel were smoothed by a three-parameter dependence of A.V. Tretyakov, using the method of least squares. An algorithm for approximating the results of the experiment is implemented as a program. Hardening curves of HSLA steel were built in cold deformation process. Results of the experiment are used in a mathematical model «Cold Rolling» for calculating and optimization modes of cold-rolling of HSLA steel on the mill 2030.

Keywords: curve of hardening, cold rolling, high-strength light-alloy steel, single-factor experiment, experimental randomization, approximation by linearization.

Introduction

In recent years in the global automotive industry one of the main areas of consumption cold-rolled products demand for steel of high strength properties with satisfactory ductility, weld ability and high corrosion resistance is growing. High-strength low-alloy steel (HSLA, EN10268) have such properties. They are used in power components of cars, bumpers, doors amplifiers, elements of passive safety. The number of orders for HSLA steel is steadily growing. To date their share in the automotive steel is about 12%. Manufacturers of cold rolled sheet steel for automotive industry tend to maximize and make the best use of resources of active mills in the competitive activity. This leads to adjustment of rolling technology of low-alloy hardly-deformed steel on continuous mill 2030 designed for cold rolling of carbon steel. Construction of adequate mathematical model describing the process of cold rolling and predicting behavior of mill in different regimes of the initial configuration is demanded. Materials differ from each other by their mechanical and physical properties, by behavior under various conditions of external influence. Mathematical model creating for describe the deformation of low alloy high strength steel is impossible without taking into account the physical and mechanical properties of the material. In the literature information about the properties of HSLA steel is poor that’s why it is necessary to conduct additional research of mechanical properties of HSLA steel during cold rolling. In the present article it is described the results of experimental investigation of hardening low-alloy hardly-deformed steel.
1. DETERMINATION OF HARDENING CURVES OF HSLA STEEL IN THE PROCESS OF COLD ROLLING

1.1 Planning a single-factor randomized experiment

On the industrial mills there is a tendency to minimize the cost to put into operation technology of new steel grades. Such approach demands the use of mathematical models of the process for designing the behavior of the mill when processing new steel grades and for choice of optimal initial configuration settings of rolling. Optimization through mathematical modeling of rolling is most effective when there is the most accurate data on the hardening curves of investigated steel. That is why dependence plastic properties of steel on the degree of deformation and external factors in the conditions of metallurgical production of continuous cold rolling mill is necessary to study. Such data may be obtained as a result of the experiment in which we solve the problem of determining the dependence of mechanical properties of steel from the total degree of deformation during cold rolling. Goal – to make an exact mathematical dependence (equation) for it's inclusion in the model of cold rolling and defining the initial configuration parameters of the cold rolling mill. In our case, to determine the dependence of the yield strength of steel HSLA (EN10268) from the total degree of cold deformation was required. I. e. to conduct single-factor experiment where the independent variable is the total deformation in cold rolling and yield strength of steel is the dependent variable. In industrial conditions on the yield strength (resistance to deformation) in the process of cold rolling (in addition to the total degree of deformation) is affected a number of other independent factors (variability of chemical composition, mode of hot-rolling, cold-rolling, the heating of the metal during cold deformation). Experimental randomization is required to eliminate the influence uncontrollable factors on the outcome of the experiment [1]. The effects of uncontrollable variables are averaged at randomization. To achieve the goals and objectives of research the experiment was planned as follows: selection of hot rolled HSLA steel samples; cold rolling of samples on a laboratory mill with different total deformation; tensile test of samples, analysis of test results - mathematical formulation of cold-rolling hardening. Randomization of the experiment was provided by the following methods:
- heterogeneity of the chemical composition was compensated by selection of hot-rolled samples of each investigated brand from several melting and then the results of mechanical tests averaging;
- samples were cut from the strips with the most identical technological processing parameters of hot rolling;
- hot-rolled samples were cut at the sites of the strip with steady-state condition of rolling;
- all groups of samples with a different set of independent factors are rolling on a laboratory mill with the same step of the total deformation;
- tensile test performed under identical conditions for all samples with different sets of independent factors [1].

Thus was formed an array of randomized data, conducted it's statistical analysis, screening errors, the averaging of data and the subsequent construction of the required yield strength depending on the degree of deformation during cold rolling. Consider the sequence of the research by example of steel grades HC380LA and HC420LA (EN10268) the most problematic for treatment on five-stand cold rolling mill 2030.

1.2 Experimental research of resistance to deformation steel grades HC380LA, HC420LA in the process of cold rolling

Selection of hot-rolled samples. Samples of hard-steel grades HC380LA and HC420LA were taken after etching. The cards (length 210-250 mm) in the entire width of rolled strip were sampling at the entrance (recoiling machine) of cold rolling mill 2030. Each sample was divided into longitudinal sample width of 150 and 40 mm. Of the samples size of 150 mm blanks of "dumbbell" shape for mechanical testing were received. The samples size of 40 mm were designed for further cold rolling.

Fig. 1. Rolling mill 250
Cold rolling on a laboratory mill. Cold rolling of the hot rolled samples of hardly-deformed steels HC380LA and HC420LA different melting in the intermediate-thickness was performed on a laboratory mill 250 (Fig. 1) with using a concentrate of high effective emulsion. In the rolling of steel grade HC380LA maximum total degree of deformation was 83.16% (rolling from 2.85 to 0.48 mm) for steel HC420LA - 77.89% (2.76 → 0.61 mm). Each of the samples with various combinations of independent factors was rolled in 12 - 15 of intermediate thickness. The samples were then labeled and transferred to the laboratory for mechanical tensile test [2].

Tensile test. Hot-rolled (Fig. 2) and hardened samples after cold rolling were subjected to mechanical tensile test with measurement of the yield strength, breaking point, unit elongation and hardness. Determination of mechanical characteristics performed on a tensile testing machine company «Zwick» (Fig. 3) to EN10268 in an accredited laboratory of mechanical tests. Results and the distribution of measurements partially presented in Table 1 and Fig. 4, 5. Thus was formed an array of measurements of the yield stress and the total degree of deformation for each of the studied steels [2].

Summary. As a result of the work an array of measurements of the yield stresses for hot-rolled and hardened steel grades HC380LA, HC420LA was formed. During the experimental rolling a marked – the levels of deformation of the samples is dependent on heating of metal. Mechanical tensile test was conducted under identical conditions for all samples on high-precision equipment.

<table>
<thead>
<tr>
<th>Steel HC380LA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total degree of deformation, %</td>
</tr>
<tr>
<td>melt 1</td>
</tr>
<tr>
<td>14,97</td>
</tr>
<tr>
<td>29,19</td>
</tr>
<tr>
<td>31,94</td>
</tr>
<tr>
<td>34,62</td>
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<td>36,49</td>
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<tr>
<td>40,70</td>
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<tr>
<td>48,59</td>
</tr>
<tr>
<td>50,61</td>
</tr>
<tr>
<td>65,45</td>
</tr>
</tbody>
</table>
1.3 Mathematical construction of hardening curves steel grades HC380LA, HC420LA

After dropping out of errors and average of test data gap in each intermediate thickness the obtained values (Fig. 4, 5) were smoothed by three-parameter dependence of A.V. Tretyakov with using the method of least squares.

\[ \sigma_{0,2} = \sigma_T + b \varepsilon \varepsilon , \]

where \( \sigma_T \) - the initial yield stress of hot rolled steel, \( b \) and \( c \) - empirical constants showing the intensity of work hardening; \( \varepsilon \) - the degree of total reduction,\%.

To determine the empirical constants of work-hardening used the method of linearization:

\[ \ln(\sigma_{0,2} - \sigma_T) = \ln b + c \ln \varepsilon , \]
\[ \sigma_T = b' + c \varepsilon' . \] (3)

The coefficients \( b' \) and \( c \) are calculated by solving the system of equations:

\[
\begin{align*}
b'N + c \sum_i (\varepsilon'_i) &= \sum_i (\sigma'_i) \\
\sum_i (\varepsilon'_i) + c \sum_i (\varepsilon'_i)^2 &= \sum_i (\sigma'_i, \varepsilon'_i) \}
\end{align*}
\] (4)

where \( N \) - number of experimental points of approximation, \( i = 1, N \).

An algorithm for approximating the results of the experiment is implemented as a program.

As a result the dependences of the yield strength and ultimate strength of the total degree of deformation during cold rolling of high strength steels grades HC380LA and HC420LA are received:

\[
\begin{align*}
\sigma_T &= 483 + 19.026 \cdot \varepsilon^0.75 , \quad \sigma_B = 545 + 8.005 \cdot \varepsilon^0.942 , \\
\sigma_T &= 612 + 23.138 \cdot \varepsilon^0.689 , \quad \sigma_B = 675 + 17.807 \cdot \varepsilon^0.748 ,
\end{align*}
\] (5)

- for steel grade HC380LA (the correlation coefficient of equations is 0.963 and 0.966, respectively);

\[
\begin{align*}
\sigma_T &= 23.138 \cdot \varepsilon^0.689 , \quad \sigma_B = 675 + 17.807 \cdot \varepsilon^0.748 ,
\end{align*}
\] (6)

- for steel grade HC420LA (the correlation coefficient of equations is 0.977 and 0.982).

**CONCLUSIONS**

In industrial production of cold-rolled sheet single-factor experiment was planned and carried out. An experimental researching of hardening steel grades HC380LA, HC420LA was conducted. The yield strength and ultimate strength dependences on the total degree of deformation during rolling of HSLA steel were built. The coefficients of curve of hardening by equation of A.V. Tretyakov were determined. These coefficients for the calculations in different types of cold deformation (cold rolling, forming) may be used. During the experimental cold rolling a marked – the levels of deformation of the samples is dependent on heating of metal. More research is needed - to determine the dependence of hardening high-strength steels on the temperature of the metal during the cold deformation. Researching is planned to be held in the nearest future.

**LITERATURE**
