CAUSES OF STRUCTURAL HETEROGENEITY LOW-CARBON SHEET STEEL AND ITS ELIMINATION

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Abstract

Based on the analysis of mechanism development of ferrite recrystallization processes, on example of lowcarbon hot-rolled sheet steel, measures are proposed reduce heterogeneity of structure rolled products. Creating a certain gradient in distribution defects of crystalline structure over the thickness of sheet lowcarbon steel allows after annealing to reduce the structural heterogeneity of the metal.

Keywords: deformation, dislocation, ferrite, grain size, recrystallization

1. Introduction

In the process hot rolling of a sheet low carbon steels to a thickness of 2 mm, a texture with parameters (110) [001] form mainly in the surface layers of metal [1-3]. During cooling process of a sheet metal roll, the advantages growth nucleus recrystallization with the texture characteristics of (110) [001] lead to the achievement of a high degree structural heterogeneity in the sheet thickness. The crystal structure such nuclei determines the achievement of increased growth rate in comparison with neighboring micro volumes of the metal [4, 5]. The grain growth is based on coalescence, due to the small disorientation of their crystal lattices [2,6]. Based on this, layer with size of ferrite grains exceeding sizes in middle of sheet by more than 10 times is formed along sheet thickness.

By changing mechanism and driving forces of recrystallization, a qualitatively different grain size distribution can be achieved. Thus, introduction of certain number defects of crystal structure, for example, from cold plastic deformation, will lead to change conditions for the development of recrystallization processes during metal annealing. In this case, the

recrystallization centers will be volumes in which the deformation was carried out by active slip systems, and the recrystallization mechanism is based on movement of grain boundaries with large disorientation angles [3]. When the driving force of recrystallization is gain in surface energy, and mechanism is based on coalescence of grains, in a cold-deformed metal the driving force is the difference in density accumulated defects of crystal structure. Based on this, it can be assumed that introduction of a certain number of defects, and primarily dislocations, into the volumes of hot-rolled metal with the texture characteristics of (110) [001], will allow changing recrystallization mechanism during annealing. The given position is confirmed by the structure of sheet metal formed after cold rolling and annealing [1]. As a result, the thickness of layer with an enlarged grain size of ferrite on the surface decreases several times [2, 4]. However, the above technology for increasing the uniformity of structure ferrite has certain limitations. During cold rolling, in addition to changing thickness of sheet, it is rather difficult to control formation certain gradient of introduced defects in crystal structure, primarily dislocations.

Considering the inversely proportional dependence of grain size after recrystallization on degree cold plastic deformation, reduction in existing grain sizes differentiation in the thickness rolled product is possible only in case of metal deformation with degree proportional to grain size. At the same time, development of strain hardening processes will change the texture parameters and recrystallization in metal will be carried out by a different mechanism.

2. Material and research methods

The material for the study was steel with content of carbon by 0,08%. Samples for testing were made in form of sheet with thickness of 1,5mm, a width of 200mm and length of 1,5-2m. The structure state steel after hot-rolled.

The microstructure was investigated using light microscopy. Determination of size grain ferrite was carried out according methodologies of quantitative metallographic [7]. Bending deformation was carried out in a laboratory setup [8]. The degree of deformation was evaluated by angle of metal coverage by deforming roller in one pass of bending stand. The microhardness was measured by PMT-3 device. The load of indentor device was 10-50g.

Sheet metal tensile tests were carried out on a universal "Instron" machine. During the test, a tensile diagram was recorded, which was subsequently converted to true coordinates. This is due to fact that determined load from deformation diagram should not be attributed initial cross-sectional area of the sample, but to its true value, taking into account preservation volume of deformed metal unchanged.

Evaluation ability of sheet metal to deep drawing was carried out during tests for extrusion of a spherical hole according to the Abraham M. Erickson method, on a machine such as NTL-10G.

3. Results

In Fig.1 shows microstructure hot-rolled low-carbon steel, 1.5 mm thick. Regardless of orientation investigated section, relative direction of rolling, the metal has a rather significant layer of large grains. As you move from the surface layers deep into the sheet, the ferrite grain size from 180 - 210 µm gradually decreases and reaches a value of 25 - 30 µm at a distance from the surface of 0.3 - 0.5 mm. Considering the existence of different thicknesses (from different metal surfaces) of the zone of large grains, the structure was evaluated both for the initial and after bending-tensile loading for two surface layers. Microhardness measurements showed, firstly, the normal distribution of values both in the surface layers and in the internal (near middle of the sheet) metal volumes (Fig.2a). Moreover, the absence of unambiguous relationship between the values of microhardness and grain size of ferrite draws attention. However, the analysis of significant experimental material showed that as a result of one pass deforming stand (coverage angle 8°), the microhardness ($H\mu$) was aligned with the cross section of the metal (Fig. 2b).

Studies of microstructure showed that, regardless of orientation studied section relative to direction of rolling, hot-rolled steel has a rather significant grain size (Fig. 1). By annealing metal at 680°C for 1 to 3 hours, the grain size of ferrite in surface layer of hot-rolled metal is insignificantly reduced, from 150 to 130 μ m. At the same time, as in inner, initially fine-grained zone with

grain size about 25 μ m, there is a significant increase in grain size. After 3 hours of exposure during annealing, the grain size reaches values about 110 μ m.

In contrast change in the grain size of ferrite over the thickness of sheet after cooling in roll, steel subjected to alternating bending and subsequent annealing has a







different grains size distribution. So, in hot-rolled state in surface volumes of sheet, after one hour of exposure, a significant non-uniformity of metal structure is observed (Fig. 1). At the same time, the grain size of internal volumes sheet is noticeably smaller. In a first approximation, as follows from a joint analysis experimental data (Fig. 2), one can speak of a qualitatively different character grinding of ferrite grains on surface and in middle of the sheet, depending on processing scheme [9].

As a result of reverse bending, the creation certain gradient of defects crystal structure over the sheet thickness leads to an decrease grain size ferrite of surface volumes by three times (from 150 to 50 μ m) after annealing. At the same time, a 2-fold increase in the size of ferrite grain is observed in the middle of sheet. This allows, after annealing of 1 h at 680 ° C, to

achieve a significant alignment of the structure along cross section. It should be expected that the observed qualitatively different development of recrystallization processes, even with the same grain size of ferrite, should lead to a change of properties metal. Indeed, the nature of dependence microhardness on grain size





Fig. 2. Statistical distribution of microhardness ferrite on the study site: (a) - a section of a hot-rolled sheet;(b) after bending tensile load. Surface I – (1), Surface II – (2), middle of the sheet – (3).

differs significantly for hot rolled and annealed metal after bending strain (Fig. 3). From the analysis of dependencies presented in Fig. 3, qualitatively different effect grain size of ferrite on microhardness metal follows. Indeed, for the state of metal after hot rolling, the microhardness decreases with increasing grain size (Fig. 3a). On contrary, the introduction of alternating bending operation leads to a change in nature this dependence (Fig. 3b).

The presented differences in nature of ratio microhardness – size grain ferrite, are due qualitative

differences in the development of microstructure formation processes. Considering, even an insignificant amount of cementite particles in studied steel (up to 1% of volume fraction), their presence is already sufficient to influence on structural transformations. So, during annealing of hot-rolled metal in parallel with the increase grains of ferrite, the processes of dissolution and coalescence carbide particles proceed. On this basis, upon annealing of hot-rolled sheet, the diffusion of carbon atoms on regions nearly boundary of ferrite grains leads to decrease carbon concentration inside them. Such large grains have lower hardness.

In steel subjected to alternating bending, the introduction of defects into the crystalline structure changes the character of the dependence at annealing. In this case, plastic deformation (alternating bending)





will contribute to an increase number of cementite particles with inter granular arrangement. The specified particles of cementite, which were generation in the first stages of annealing, will begin to dissolve and the diffusion flux carbon atoms to grain boundary will lead to an increase carbon concentration in ferrite. Larger grains of ferrite before dissolution of cementite particles will have increased values of microhardness. As acceleration processes of recrystallization and decrease of ferrite grain size, the concentration of carbon inside grains will decrease, which will be lead to softening of metal.

Thus, both in hot-rolled and alternating-bent metal, the development of recrystallization processes during annealing is aimed at aligning the structure with the thickness of the sheet. However, introduction operation deformation of alternating bending can further stimulate the acceleration of recrystallization processes.

From the analysis of the microstructure follows (Fig. 4), that use of alternating bending allows not only to increase the uniformity of ferrite structure in the thickness hot-rolled sheet after annealing, but also to grind her effectively.

Taking into account that thin-sheet products made of low-carbon steels are often used to obtain products by cold stamping, it was interest to evaluate the plastic properties. First of all, the ability metal to deep stamping is largely associated with uniformity structure over cross section of sheet. Based on this, the sheet steel test after processed using various technologies at index on Erickson was evaluated. Samples of sheet steel with structures shown in Fig. 4, showed an increase depth of recess according to Ereksen from 11.4 mm (hot rolling, annealing 680 $^{\circ}$ C, 3 h) up to 12.1 - 12.2 mm after hot rolling, variable bending (coating angle 15 $^{\circ}$), annealing 680 $^{\circ}$ C.

A similar effect of alternating bending is observed on tensile properties. The hot-rolled steel after annealing was $650 - 680^{\circ}$ C, with a holding time of 3 hours, had a yield stress made up of 200 - 260 MPa, a tensile strength of 290 - 320 MPa, and determined elongation 30 - 37 % in length equal 4 times more of wide

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specimen. Subjecting metal to alternating bending and annealing, the properties, respectively, amounted to: 220 MPa; 310-315 MPa and 40-42%.

Thus, by subjecting hot-rolled thin-sheet low-carbon steel with a inhomogeneous grain ferrite structure in thickness, to alternating bending at subsequent recrystallization annealing, at temperatures prior to the phase transformation, the get alignment of structures. Moreover, the metal properties reaches of level coldrolled annealed steel.

4. Findings

1. The creation of a certain gradient in distribution of defects crystalline structure near surface of hot rolled sheet low-carbon steel makes it possible to change mechanism of development recrystallization processes during annealing.

2. Using alternating bending operation allows to increase uniformity structure of ferrite in thickness of hot-rolled sheet after annealing.

3. As a result of proposed processing, the formed structural state made it possible to increase plastic properties and ability metal to deep draw during sheet stamping.

5. References

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