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Methods for producing ultrafine-grained microstructure in steels

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ABSTRACT: This article examined the superplastic deformation of steel at 45 different temperatures. We also studied the temperature dependence of impact toughness in the region of room and low temperatures in order to determine the cold brittleness threshold.

KEY WORDS: Superplasticity (SP), ultrafine-grained (UFG), deformation, normalization, cold brittleness, impact strength.

I.INTRODUCTION

Systematic studies of a large group of industrial alloys made it possible to establish that, using the features of preliminary hot and cold deformation, phase and structural transformations during heating and cooling of alloys, it is possible to propose easily realized methods for producing an ultrafine-grained (UFG) microstructure in many industrial alloys.

For grinding grain in steels, several methods are applicable, including phase transformation, recrystallization, pressure treatment of duplex (two-phase) alloys, and phase separation in duplex alloys. In the case of the first two methods — phase transformation and recrystallization — the task is to generate several new (during transformation or recrystallization) grains inside each grain of the initial structure. In the third method - deformation of duplex alloys - both phases are crushed and spheroidized. Deformation is usually accompanied by recrystallization in both phases, which makes an additional contribution to the overall grinding of the grain. In the fourth method of grain refinement — phase separation in duplex alloys — the initial structure is not an equilibrium duplex microstructure; it is either martensite or an over-saturated solid solution. The separation of the metastable phase into two equilibrium phases can give an ultrafine-grained duplex structure. Often several such methods are jointly used. The circuit shown in Fig. 1. illustrates the described four methods of grinding grain [1].

As shown in many studies, the conversion of ferrite to austenite was used to grind grain in steels [2,3].

In recent years, it has been proved in many articles that temperature cycling near the phase transformation temperature leads to the formation of very fine grains [4,5.6].

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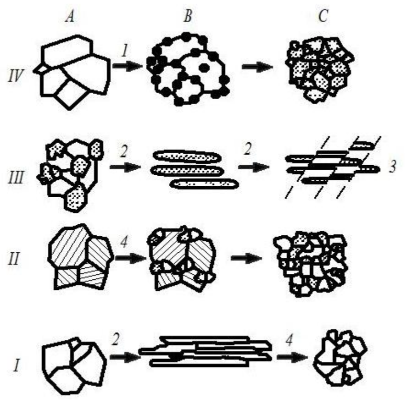

Fig.1. Scheme explaining the basic mechanisms of grain grinding: I - recrystallization; II - phase separation in alloys with a duplex structure; III - inhomogeneous deformation of alloys with a duplex structure; (V — phase transformation; A, B and C — initial intermediate and final microstructures; 1 — heating, cooling; 2 — deformation; 3 — shear bands; 4 — annealing [1])judgments. For example, the simplest and earliest versions (such as the one available with Microsoft's Hotmail) can be set to watch for particular words in the subject line of messages and to exclude these from the user's inbox.

If high-speed heating is used during thermal cycling, then in this case it is possible to obtain the finest-grained structure in 40KhF steel using induction heating at a speed of 215^{0}C / sec. Subsequent quenching, austenite grains are crushed from 45 to 2 µm [7].

II. SIGNIFICANCE OF THE SYSTEM

In [8], in order to grind austenite grains of structural steel containing 0.15–0.25% V or 0.1–0.15% Ti, it was heated from 20 to 900^{o}C and held for 20-30 seconds and cooled. After four times the heat treatment, the grain size decreased to 1.0 µm. The efficiency of thermal cycling in the presence of diffusion and martensitic transformations depends on the number of heating-cooling cycles, ceteris paribus. It was found that after one cycle of fast austenization, an inhomogeneous microstructure with different austenite grain sizes forms. A homogeneous structure with ultrafine grains is achieved after five cycles of rapid heating and cooling.

III. LITERATURE SURVEY

A detailed study of factors affecting the degree of grain refinement during thermal cycling was carried out in [9] using C 5% Ni + Cr + No + V steel as an example. It was found that the size of the final grains depends on the chemical composition of the steel, the initial microstructure, the heating rate in the transformation interval, the maximum heating temperature, the exposure time above the Ac_3 point, the number of “fast heating – cooling” cycles, and the tempering mode after processing cycles. Subject to the optimal ratio between these parameters, it is possible to obtain a fine-grained microstructure with a size of 4 µm. and less.

The use of thermal cycling is limited by steel piercability; therefore, the most effective method for producing fine grain in steel is preliminary cold or hot deformation. With a clear advertising of the heating regimes for deformation, the degree of deformation, the temperature of its completion, after deformation holdings, recrystallization annealing, it is possible to obtain a microstructure with the necessary grain size [10].

In the present work, we studied the microstructural changes during hot deformation and the method of obtaining a fine-grained microstructure of U8 steels and the possibility of transferring to a superplastic state.

The microstructure of the studied material U8 steel in the delivery state is shown in Fig. 2. Steel U8 in the delivery state has a pearlite structure of eutectoid composition. The chemical composition of C is 0.79%, Mn is 0.35%, Si is 0.2%, S is 0.03%.

The results of mechanical tests in the delivery state at temperatures of 650^0 - 900^{0}C indicate that there are no signs of superplasticity (Fig. 5).

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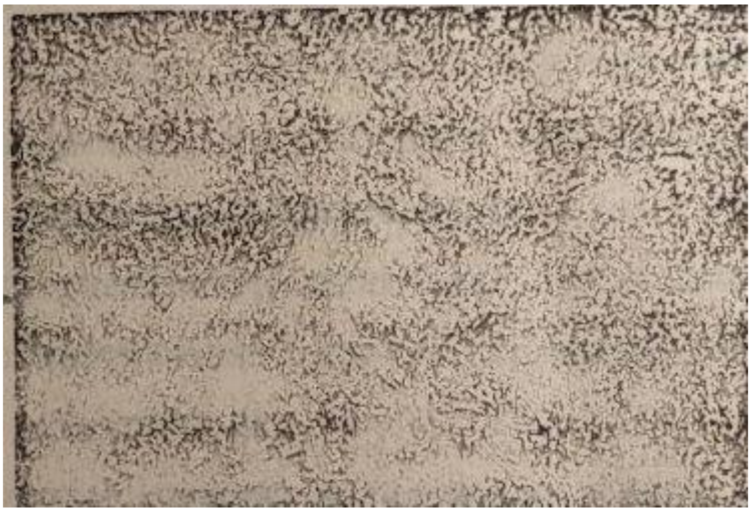
Fig. 2. Steel U8 in the delivery state.

In order to study the influence of the initial state on high temperature ductility, preliminary hot deformation was used to grind the microstructure of steels.

IV. METHODOLOGY

When sedimenting, two groups of samples were used. The first group is small samples of Ø10 mm with a height of 15 mm, they were deformed on a universal machine 1232U10. ε - from 30% to 80%. These samples were used to systematically study structural changes and mechanical properties during the development of methods for obtaining the UFG structure (Fig. 3).


650^0 680^0 700^0 750^0 800^0

Fig. 3. Samples deposited at various temperatures for structural studies.

Another group of larger samples with a diameter of 30 mm and a height of 60 mm was besieged in an isothermal die block on a modernized hydraulic press RNM - 100 A, with a force of 100 tons. The degree of deformation was at least 60%. Standard samples for mechanical tensile tests were cut out of large billets (washer) obtained after upsetting (Fig. 4).

At least 3 samples were used for each test point. The following were determined: elongation δ, flow stress σ_{20}.

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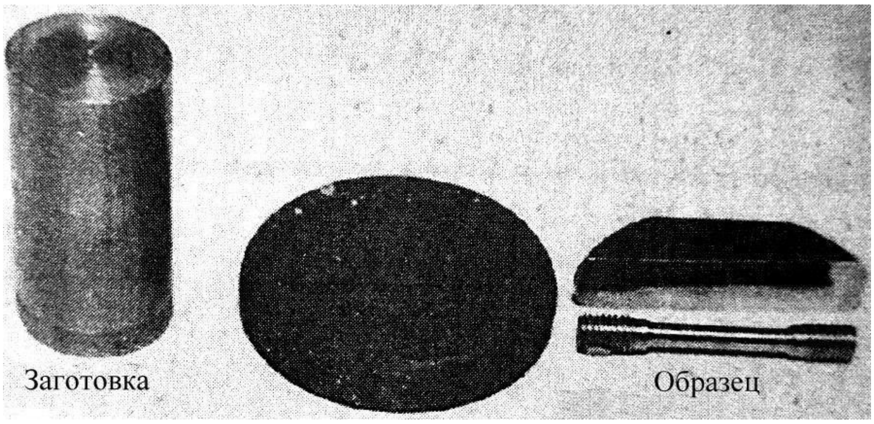

Fig. 4. Samples for mechanical tensile testing.

Of. fig. 5. It is seen that the dependence of the relative elongation on the strain temperature varies nonmonotonically. An increase in the strain temperature leads to an insignificant increase in δ, however, ductility decreases markedly with an increase in the strain temperature above Ac_1.

The dependence of the flow stress on the deformation temperature is also nonmonotonic: it weakly depends on temperature when approaching the Ac_1 point, and with a subsequent increase in the temperature of deformation, the flow stress decreases again.

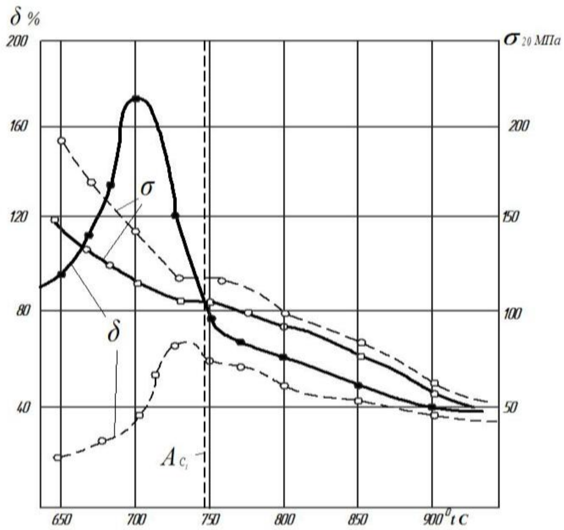

Fig.5. Dependence of flow stress σ_{20}, elongation δ on deformation temperature of U8 steel with initial coarse-grained (---------) and fine-grained (————) microstructure.

An analysis of the dependence of σ on the strain rate έ shows that with a decrease in έ the flow stresses decrease slightly. The speed sensitivity coefficient *m* does not exceed 0.15.

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V. EXPERIMENTAL RESULTS

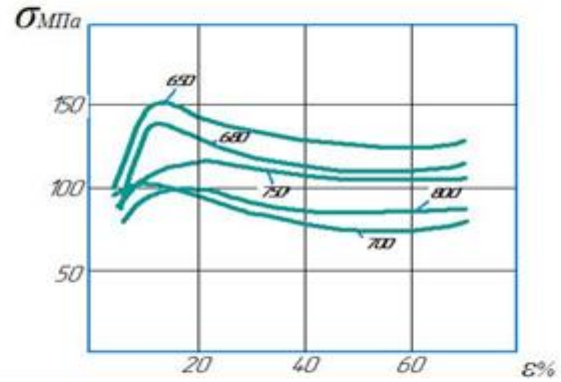
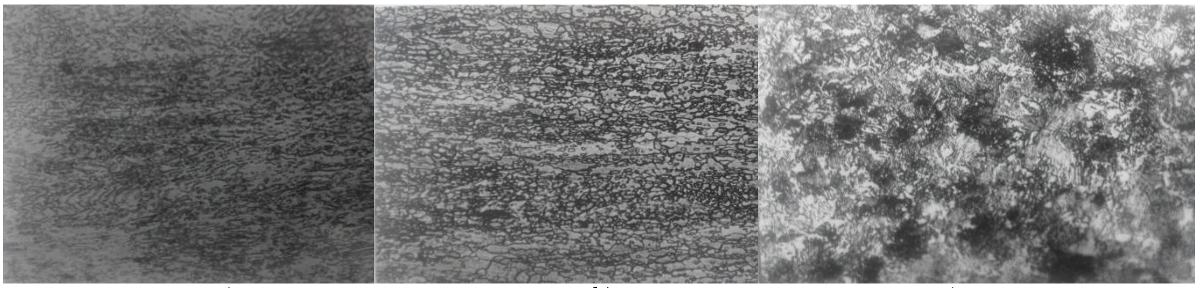


Fig. 6. The dependence of the flow stress σ on ε and the strain temperature in the delivery state.

In fig. 6. The dependence of the flow stress on the degree and temperature of deformation for steel U8 in the delivery state is shown. It can be seen that the nature of the flow stress curves σ = *f* [ε] substantially depends on the strain temperature. At a temperature of 650^0C, the deformation at the initial stage proceeds with strong hardening, the flow stresses are maximum at έ = 25% and decrease with a further increase in ε. Deformation at a temperature of 700^0C, in contrast to higher temperatures, is characterized by a less steep dependence of flow stresses on the degree of deformation.



a) b) c)

Fig. 7:

VI.CONCLUSION AND FUTURE WORK

The study of the microstructure of deformed samples at different temperatures showed that it significantly depends on the temperature of deformation. So, at a temperature with a higher 650^0C, the deformation is accompanied by the formation of a metallographic texture and the lamellar microstructure is preserved, the structure is inhomogeneous over the cross section of the blanks (Fig. 7.a). At a deformation temperature of 700° C, a much more uniform fine-grained microstructure along the sample cross section is observed. It can be seen that the optimum temperature for the formation of the UFG structure for U8 steel is 700^0C (Fig. 7.b).

After deformation at temperatures above Ac_1, a coarse-grained microstructure is formed (Fig. 7.c).

The study of the influence of the strain rate at the optimum temperature of formation of the UFG structure showed the following: The most homogeneous and fine-grained microstructure in U8 steel is formed in the speed range $10^{-4} \div 10^{-2}s^{-1}$.

The results of mechanical tests are shown in Fig. 3. It is seen that the dependence of the relative elongation on temperature is characterized by a maximum at a temperature of 700^0C.

With an increase in the test temperature, the ductility in U8 steel in the γ - region sharply decreases, this is due to the hardening of the structure, since heating above Ac_1 leads to a rapid increase in grain in the γ - region and the loss of superplasticity.

The dependence of the flow stress on the deformation temperature is characterized by the fact that, when the temperature rises to intercritical, a decrease in σ is first observed, and at temperatures Ac_1 - 30 ÷ Ac_1, the flow stresses are equal. A subsequent increase in the deformation temperature above Ac_1 again leads to a decrease in flow stresses.

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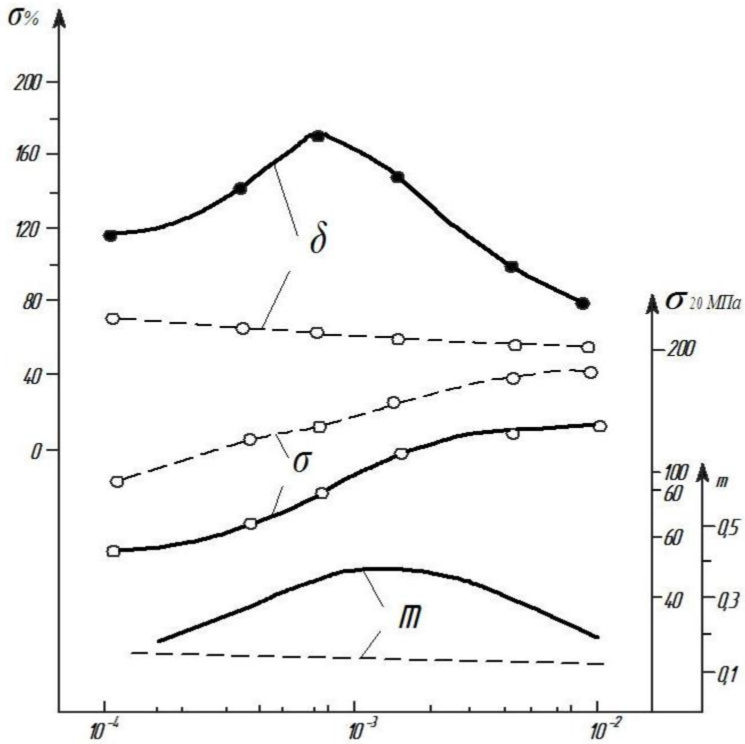

Fig. 8.

Thus, the ductility of fine-grained Y8 has a pronounced maximum in the ferrite-cementite region at a temperature of 700^0 C, above Ac_1, δ decreases sharply. In steel with an UFG structure, practically in the entire temperature range studied, substantially larger elongations are observed than in coarse-grained (Fig. 5).

The initial microstructure also affects the velocity dependence of the flow stress. The coefficient of speed sensitivity m for coarse-grained steels does not exceed 0.15, for fine-grained steels it is not less than 0.37.

It should be noted that the flow stress is higher in the delivery state at all investigated strain rates than for steel with a fine-grained microstructure (Fig. 8).

The main difficulty is a narrow range of deformation temperature. Deformation should be carried out in a narrow temperature range, otherwise there is virtually no deformation in the superplastic mode.

The problem of deformation in a narrow temperature range (theoretically at the same temperature) is solved using the so-called isothermal stamping.

The essence of this method is that the workpiece and the deforming tool are heated to the same temperature, i.e. create conditions of deformation at one temperature. The degree of isothermal stamping is probably ensured by redistributions of ± 10° C. Under these conditions, practically "At the maximum plasticity" occurs [12].

FINDINGS. The purpose of this study was to develop effective methods for teaching in steels UFG structure, providing the manifestation of superplastic properties.

The superplasticity of U8 steel with UFG structure is established is observed in the temperature range 680 ÷ 720^0 C and strain rates $10^{-3} \div 10^{-4}$ s^{-1}.

Thus, the methods for obtaining the UFG structure in steels are very diverse. In each specific case, it is necessary to develop processing modes directly for the material under study. Meanwhile, the manifestations of the effect of superplasticity in steel will be determined not only by the initial microstructure. It is very important to keep it in the process of heating and deformation.

It should be noted that these issues are important, since the superplastic properties of the material depend on the nature of the UFG structure.

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