Quantitative assessment of efficiency of mechanisms of hardening ferritic-pearlitic steels

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Abstract. As a result of the analysis of literary data and own experimental studies is quantitatively estimated the contribution of various mechanisms of hardening to a limit of fluidity low-carbonaceous and low-alloyed steels. It is established that for hot-rolled steels the greatest contribution to a limit of fluidity give solid-solution and grain-boundary hardening (54% and 29% of the Steel 3calm, 61% and 27% for steel 10CrNiCuP), and in the low-alloyed steel 16Mn2NV along with these components are discussed hardening prominent role dispersion hardening.
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Introduction

It is known that that one of the main problems of modern metallurgical science is establishment of quantitative communication between structure and properties of alloys. Identification of a role and contribution of various mechanisms of hardening to such major characteristics of constructive durability as the limit of fluidity and a stock viscosity, and also in formation of other mechanical properties of steel allows to come nearer to the solution of the specified problem. Therefore represents theoretical and practical interest a quantitative assessment of a contribution to a limit of fluidity of separate mechanisms of hardening carbonaceous and low-alloyed steels, widely applied in construction and mechanical engineering, and to compare settlement and experimental data for receiving a reliable information about operating mechanisms of hardening after this or that processing and an alloying.

The main characteristics construction steels, defining their constructive durability, are the limit of fluidity and tendency to fragile destructions.

The limit of the fluidity estimating durability of steel is determined by a known ratio of Holl-Petch, which for conditions of stretching has an appearance:

$$\sigma_T = \sigma_i + k_y \cdot d^{-1/2} \qquad (1)$$

where [sigmai]-tension of friction of a lattice at movement of dislocations in grains;

k_y - the coefficient characterizing a contribution of grains in hardening;

d - diameter of grain.

$$\sigma_i = \sigma_0 + \Delta\sigma_{tr} + \Delta\sigma_p + \Delta\sigma_d + \Delta\sigma_{du} \qquad (2)$$

In this equation of [sigmai] represents the sum of tension of friction of a lattice of alpha-Fe – [sigma0], increase the strength of solid solutions at an alloying - [dsigmatr], hardenings due to formation of perlite -[dsigmap] deformation -[dsigmad], dispersive - [dsigmadu] strengthening.

In work [1] it is shown that influence of all listed mechanisms of hardening on a limit of fluidity is linearly additive, i.e. can be summarized. Therefore a fluidity limit the ferrite-pearlite steels to which all steels St3c investigated to steel concern. St5sc. St5c. 35MnSi, 16Mn2NV, 10CrNiCuP, it is possible to consider as a sum of terms in the equation (2). The share of a contribution of separate factors of hardening (the equation 1 and 2) in the general limit of fluidity of steel isn't identical and it depends on a type of alloying elements and degree of an alloying, existence and dispersion of the strengthening phases, applied thermal or deformation and thermal hardening and other factors.

The analysis of this equation shows that the share of a contribution of separate factors of hardening in the general limit of fluidity of steel is not identical.

The ratio (1) with a sufficient accuracy is applicable to ferritic steels at grains from 0,3 to 400 microns in size; from it follows that the limit of fluidity of a material raises with reduction of size of grain [2].

Tendency of steel to fragile destructions is estimated on transition temperature from a viscous state in fragile, which is defined as the relation of the area of a viscous fracture to initial settlement section. Than is lower transition temperature from viscous in a fragile state, the more reliable material therefore more often, seek to apply a material at which temperature of transition is lower than temperature of operation [3, 4 and 5].

As it was specified, the share of a contribution of separate factors of hardening (the equation 1 and 2) in the general limit of fluidity of steel is not identical and it depends on a type of alloying elements and degree of an alloying, the availability and dispersion of the secondary phase.

Methodology

Proceeding from the known mechanisms of hardening described by the equation (2), we carried out the analysis of efficiency of various mechanisms of hardening low-carbonaceous and low-alloyed by the steels St.3c, the St.5sc, 10CrNiCuP, 16Mn2NV used in construction and differing not only a chemical composition, but also the applied heat treatment. The size of separate factors of hardening and their contribution to the general limit of fluidity specified by the steels determined by known empirical formulas. Coefficients necessary for calculation are taken from literary data [6, 7 and 8]. Thus calculated values of a limit of fluidity investigated by the steels compared with experimental data in accordance with GOST 380, GOST 19281, GOST 5781, GOST 10884.

Determination of parameters of structure (the content of perlite in steel, diameter of ferritic grains, the size and a volume fraction of a carbonitride phase, etc.) for a quantitative assessment of a limit of fluidity is executed by methods of a quantitative metallography on a research horizontal microscope of NeoPhot 21 and an electronic microscope of UEMV-100. As diameter of ferritic grains (d) used the average length of a segment of a straight line crossing grain in the plane cut [9].

Volume fraction of disperse particles (f) and their diameter (D) in the low-alloyed steel 16Mn2NV determined by a method of the electronic photo thin foil.

Share of a perlite component determined by a method of Rozival according to which the areas of structural components calculate on lengths of pieces of the straight line which has got on each of structural components according to the principle of Cavalieri. Density of dislocations deformation thermally strengthened by the steel St.5sc determined by the X-ray diffraction analysis in a form of diffraction lines, and in a hot-rolled condition steel density of dislocations quantitatively estimated by means of translucent electronic microscopy thin foils (table 1). Proceeding from skilled data it is accepted that in ferrite it is dissolved ~ 0,015 (C+N), other amount of carbon and nitrogen are connected in carbides and nitrides.

Table 1. Basic data for a quantitative assessment of a limit of fluidity investigated by the steel

# i/o	Characteristic became	Grade studied steels				
		St.3c	St.5sc hot-rolled	St.5sc heat-treated	16Mn2NV	10CrNiCuP
1	Content of alloying elements in alpha-Fe, %: Mn Si P V Ni Cr Cu (C+ N)	 0,52 0,21 0,04 - - - - 0,015	 0,65 0,11 0,04 - - - - 0,015	 0,65 0,11 0,04 - - - - 0,015	 1,5 0,45 0,035 0,11 - - - 0,015	 0,45 0,27 0,095 - 0,45 0,665 0,40 0,015
2	Hardening phase	-	-	-	VN	-
3	Share of perlite, %	22	35	26	17	14
4	1. Grain size, d, mm	0,056	0,051	0,033	0,014	0,028
5	Volume fraction of disperse particles, f,%	-	-	-	0,096	-
6	Size of dispersed particles, D, nm	-	-	-	30	-
7	Density of dislocations, cm^{-2}	10^8	10^8	10^{10}	10^9	10^9

Results and discussion

Tension of friction of a lattice of alpha-Fe (Payerls-Nabarro's tension) is estimated on a formula:

$$\sigma_0 = 2 \cdot 10^{-4} \cdot G \qquad (3)$$

Where G - the module of shift of iron. G = 84000 MPas.

Payerls-Nabarro's tension is the minimum tension necessary for movement of a dislocation in a crystal and it is defined by properties of a crystal lattice and characterizes in it friction forces. At an alloying of metal there is an increase in friction forces, i.e. the alloying increases resistance of dislocations, owing to interaction of the dissolved atoms of alloying elements with dislocations.

As a first approximation, Payerls-Nabarro's tension can be compared with a limit of fluidity of a monocrystal of metal.

This size significantly depends on the content of impurity in metal. Therefore, as purity of metal improved and degree of perfection of crystals turned out the lesser value of a limit of fluidity of monocrystals. Taking into account literary data in calculation tension of friction of a lattice of alpha-Fe [sigma0] is accepted, equal 30MPas.

We will note that now there is no the theory which is well describing mechanisms of hardening. There are only the approximations describing mechanisms of hardening which don not give a strict quantitative assessment of a limit of fluidity. Other factors of hardening, except the lattice resistance to dislocation movement, taking into account known assumptions quantitatively estimated for investigated steel on known formulas [10]. The principle of linear additivity of hardening on separate mechanisms is thus used.

For descriptive reasons and conveniences of comparison and the analysis of efficiency of various mechanisms of hardening results of calculations are presented in the form of column charts (fig. 1).

In the carbonaceous steels of the St.3c, the St.5sc (a hot-rolled condition) the main composed hardenings are solid-solution and grain boundary hardenings which share makes respectively 54% and 29% for St.3c steel. On an absolute value, they are equal 140,5MPas and 89,9MPas. In steel of the St.5sc subjected to deformation heat treatment, the essential contribution to the general hardening is made by deformation (dislocation) hardening. If the share of deformation hardening in steel of the St.5sc cooled on quiet air from temperature of the end of rolling of 1050 °C (a hot-rolled condition) makes ~ 3%, in the same steel deformation-heat-treated by the scheme interrupted quenching and subsequent high self-release (the heat-treated condition) the share of deformation hardening increases in the same steel to 27%. =104MPas (absolute value). It is explained probably by increase in density of dislocations at combination of hot rolling with the subsequent immediately quenched and tempered. As it was stated above, recrystallization processes are suppressed with sharp cooling and are fixed considerable part of the dislocations, which have arisen at hot rolling of austenite. Thus, there is an inheritance of dislocation structure of hot-rolled austenite by being formed martensite in the course of phase austenite-martensite transformation.

The dominating mechanism of hardening in the low-alloyed steel 10CrNiCuP is solid-solution. Cr, Ni, by Cu and P in steel 10CrNiCuP are dissolved in alpha-Fe. Coefficients of hardening of ferrite of these elements make K_{Ni}=30, K_{Cu}=40, K_{P}=690, K_{Cr}=30 [11]. Noting efficiency of this mechanism of hardening and its applicability, at the same time it is necessary to emphasize that there is probably any optimum degree of an alloying of alpha-Fe because saturation by impurity atoms of replacement and introduction leads only to dangerous elastic deformation of a lattice and decrease in viscosity of destruction of an alloy.

If to consider that solid-solution hardening is caused by a difference of nuclear diameters of a matrix and an alloying element and their modules of elasticity, the high share of solid-solution hardening in steel 10ClNiCuP can be explained with resistance to moving dislocations from the dissolved atoms.

In the low-alloyed steel 16Mn2NV as show by the diagram, the role of dispersive hardening - 20% of [dsigmadu] = 94,0MPas is noticeable. Apparently, from table 1, in this steel the dispersed carbo-nitride phase V (C, N) which strengthens ferrite on Orovan's mechanism. It is supposed the carbo-nitride phase V (C, N) uncoherent with matrix alpha-Fe and therefore dislocations bypass the allocation of V (C, N). However there are opinions that in low-alloyed construction the steels small particles carbo-nitrides, allocated directly from a matrix, can be associated with it coherently [12].

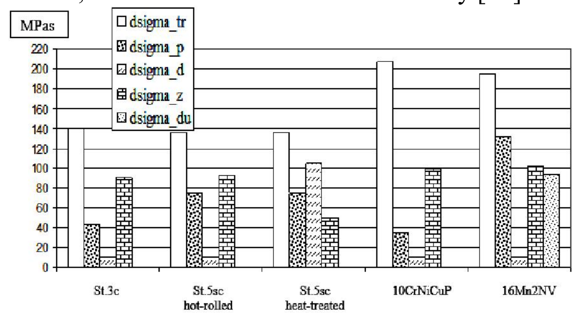

Figure 1. The column chart composed hardenings investigated by the steels

On the efficiency and prospects of dispersive hardening indicates the influence of disperse phases on grain size. From table 1 follows that in steel 16Mn2NV in which structure there is a disperse carbo-nitride phase V (C, N) is formed more fine grain of d = 0,014 mm. It is explained by germinal influence of particles V (C, N) upon transition through critical points of As_1 and As_3. Besides, the carbo-nitride phase slows down growth of grain of austenite at further heating up to temperature of dissolution of these phases in austenite. These two circumstances lead to that in steel 16Mn2NV there is a noticeable crushing of ferritic grains. Thus, disperse particles of a carbo-nitride phase V (C, N) in steel cause additional grain-boundary hardenings. Such feature of hardening dispersed the carbo-nitride of phases is specified in the works [13].

In low-carbonaceous and low-alloyed the steels of the main phase and structural component is ferrite, its share in these the steels reaches 90-95%. When the load deformation begins to develop in ferrite and pearlitic colonies are “barriers” to such deformation. Therefore, hardenings from a pearlitic component also makes a certain contribution to the general hardening (in a fluidity limit).

It is visible that the hardening share from formation of perlite makes about 10-20%, on an absolute value of [dsigmap] =75MPas for the hot-rolled steels St.3c and the St.5sc. It should be noted also, as nonmetallic inclusions can have impact on mechanical properties of these steels. However, their volume fraction in the steel does not exceed 0.1%, they have no strengthening effect and therefore in this research the behavior of nonmetallic inclusions was not considered. In fig. 1 for descriptive reasons comparison and the analysis of efficiency of various mechanisms of hardening results of calculations are presented in the form of the column chart.

Apparently from this chart, in all investigated the steels makes the main contribution to a limit of fluidity the solid-solution hardening which absolute value makes from 140 to 200MPas.

Thus, the contribution of various mechanisms of hardening to a limit of fluidity low-carbonaceous and low-alloyed construction steels different. For hot-rolled steels the greatest contribution to a limit of fluidity give solid-solution and grain-boundary hardening (54% and 29% of the St. 3c, 61% and 27% of St. 10CrNiCuP), and in the steel 16Mn2NV along with these components are discussed hardening prominent role dispersion hardening (22%). Deformation heat treatment of steel of grade of the St. 5sc leads to growth of size of dislocation hardening to 27% due to growth of density of dislocations and preservation of the most part of dislocations at the accelerated cooling of hot-rolled austenite.

Conclusions

Low-carbonaceous and low-alloyed by the steels it is necessary to read out as effective and perspective ways of increase of durability solid-solution hardening by an alloying way by rather cheap alloying elements (Mn, Si), and also dislocation and dispersive hardening by application of the combined deformation heat treatment in combination with a microalloying from carbide and nitride-forming elements (V, Al).

1. The quantitative assessment of durability the ferritic-pearlitic low-carbonaceous and low-alloyed steels on a chemical composition and parameters of structure allows to reveal approximately a contribution of each mechanism of hardening to a limit of fluidity of steel and to predict the balanced mechanisms of hardening.

2. Reduction of the size of the actual grain is effective way of increase of durability constructional steels, which at the same time reduces tendency of ferritic-pearlitic steels to fragile destruction.

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References

1. Goldstein, M. I., V. S.Litvinov and B. M. Bronfin, 1986, Metal-physics of high-strength alloys. Moscow, Metallurgy, pp: 312.
2. Workham, J.L. and T.A. Casino, 1976. High-Speed Casting and Rolling System, Continuous Steel Casting: Proceedings of an International Conference, Biarritz, Denis, B., Ed., London: Metals Society.
3. Weng, Y., H. Dong and Y. Gan, 2011. Advanced Steels: The Recent Scenario in Steel Science and Technology Metallurgical Industry Press, Beijing and Springer-Verlag GmbH Berlin, pp: 511.
4. Tercelli, K. and D. Disaro, 2010. Continuous Bloom Casting with Mild Dynamic Compression at the Posco Plant (Korea), Metallurgical Plant and Technology, 1: 15-21.
5. Bogomolov, A.V., P.O. Bykov and R.I. Serzhanov, 2014. Shift cogging modeling of the continuously cast bars.Life Science of Journal, 11(6s): 167-170.
6. Brandon, D. and W.D. Kaplan, 2008. Microstructural Characterization of Materials. John Wiley & Sons Ltd., Chichester, England, pp: 536.
7. Kanaev, A. T., E. N. Reshotkina and A.V. Bogomolov, 2010. Defects and Thermal Hardening of Reinforcement Rolled from Continuous Cast Billet. Steel in Translation, 40(8): 586–589.
8. Flewitt, P.E.J. and R.K. Wild, 2003. Physical Methods for Materials Characterisation, Taylor & Francis, pp: 602.
9. Saravanan, R. and M.P. Rani, 2012. Metal and Alloy Bonding: An Experimental Analysis. Charge Density in Metals and Alloys. London: Springer, pp: 151.
10. Doege, E., and B. Bernd-Arno, 2007. Umformtechnik. Grundlagen, Technologien, Maschinen. Springer Berlin Heidelberg New York, pp: 913.
11. Guo, Z.X., 2005. The Deformation and Processing of Structural Materials. Cambridge: Woodhead Publishing Limited; Boca Raton: CRC Press, pp: 331.
12. Lenard, J.G., 2002. Metal Forming Science and Practice. Elsevier Science, pp: 378.
13. Lin, J., D. Balint and M. Pietrzyk, 2012. Microstructure evolution in metal forming processes. Cambridge: Woodhead Publishing, pp: 402.

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