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ANALYSIS OF MECHANISMS FOR HARDENING CONSTRUCTIONAL STEELS BY STRUCTURE PARAMETERS

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Contribution of different hardening mechanisms into tensile strength of carbon and low alloy steels has been evaluated on the basis of analysis of research papers and own experimental studies. It has been found out that solid solution and grain boundary strengthening provide the most contribution to tensile strength of normalized steel, whereas in structural low alloy steel low alloy steel the role of dispersion strengthening is noticed (21,4 %) along with the above strengthening components. It has been shown that thermal and chemical treatment of St5 grade steel leads to around 27,6 % growth of dislocations strengthening in rolled steel in case of accelerated cooling of hot wrought austenite.

Keywords: steel, thermal treatment, phase components, tensile strength, hardening

INTRODUCTION

Identification of physical mechanisms for formation and evolution of gradient-laminated structures in heat treated steels underlies development and creation of new efficient ways for increase of performance characteristics of structural steels in the modern materials engineering. In case of three-dimensional loading the plastic deformation processes are localized in a certain part of material volume, where accumulation of structural defects, strains concentration and origin of destruction center occur, whereas processes of plastic deformation and destruction of surface layers are differentiated in the first turn through complicated distribution of strain over the whole contact zone. Involvement of all metal layers located in the contact zone in plastic deformation and destruction is equally possible in any spot of surface layer [1, 2].

Continuous overlapping of plastic deformation and destruction cycles occurs in the process of wear and destruction of surface layer, which leads to dynamic structural changes in the surface layer. High concentration of internal strains in metal surface layer can be explained through cyclic recurrence of such changes. As a result, the thin formation and structure of surface layer might turn to be completely different in the process of wear, than original structure and formation in the metal volume. These peculiarities of surface layer wear and destruction have led to the fact that over the last years in the course of reinforcement rod production the technology of deformation and heat strengthening is applied at an increasingly higher rate; this strengthening is connected with intensive and regulated cooling of rolls in the process line of section rolling mill [3].

Identification of peculiarities of formation of structure and properties of steels subjected to different heat treatment allows to come closer to solution of the indicated problem. The purpose of this paper is performance of comparative evaluation of tensile strength of carbon and low alloy steels by their chemical composition and structural parameters.

DATA AND RESEARCH METHODS

As primary data for calculation (evaluation) of steel hardness by tensile strength the chemical composition, distribution of constant and alloying additives between phases as well as quantitative structural parameters have been used: grain dimensions, correlation between phase and structural components, distribution thereof, distance between strengthening particles, dislocations density and other.

Dislocations density in St5, 09Mn2 and 16Mn2V steel grades has been determined in this research paper by means of the method of electronic microscopy of thin foils.

Comparative analysis of the role and contribution of different strengthening mechanisms into total tensile strength of carbon and low alloy steels being used in construction, agricultural and transport engineering has been performed in accordance with methods proposed in the research paper [4]. Studied steels are differentiated not only through chemical composition but also through strengthening heat treatment applied. High temperature heat and mechanical treatment of St5 grade steel has been carried out as per interrupted hardening scheme: temperature of rolling finishing is 1050 ºC, a break between finishing of rolling and commencement of intensive cooling was 2 s., self-tempering temperature was ~ 500 °C.

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Surface plasma hardening of wheel steel (analogue of 60 grade steel) has been performed under electric arc current of 275 A. Samples for evaluation of tensile strength after plasma hardening have been cut out from near surface area, where the structure is represented by fine-needled martensite.

Estimated values of tensile strength of studied steels have been compared with data of GOST 5781, GOST 10884, GOST 1050 and GOST 19281 with the purpose of obtaining reliable data on applicability of the method for tensile strength evaluation by structure parameters.

Structure parameters (perlite content in steel, measurement of interlamellar spacing, ferrite grain diameter, dimensions and volume percent of carbonitride phase and other) for quantitative evaluation of tensile strength has been determined by quantitative metallography methods by means of Neophot 21 optical microscope and UEMV-100 multi-purpose electronic microscope.

RESEARCH RESULTS AND DISCUSSION

As it is seen from the provided data (Tables 1 and 2) the share of contribution of individual strengthening factors into total steel tensile strength value is not the same. It depends on the type of alloying components and the alloying extent, availability and dispersion of strengthening phases, applied heat, heat and mechanical, plasma treatment and other factors.

The basic strengthening components in St5 grade carbon steel (hot rolled condition) are solid solution and grain boundary strengthenings, the share of which is ~ 65 %. The share of these additive components by absolute value is equal to 125,3 MPa and 128 MPa. Total strengthening of St5 grade steel subjected to high temperature heat and mechanical treatment is significantly increased by deformation (dislocation) strengthening. If the share of dislocation strengthening in St5 grade steel cooled on still air from rolling end temperature of 1050 °C (hot rolled condition) is equal to ~ 1,5 %, the deformation strengthening share increases up to 27,6 % in the same steel heat treated and mechanically treated as per interrupted hardening scheme with subsequent high self-tempering (heat-strengthened condition), absolute value 140 MPa. This is explained, apparently, through increase of dislocation density when combining hot rolling with subsequent immediate hardening. Whereas intensive cooling suppresses the recrystallization processes and a significant part of dislocations is fixed, which have been occurred under hot rolling of austenite, dislocation structure of hot wrought austenite is inherited, which austenite is formed by martensite in the process of austenite-martensite transformation. Besides, breaking up of austenite grain during heat and mechanical treatment leads to breaking up of martensite crystals [5-7].

Solid solution strengthening is conditioned upon the difference of atom diameters of ferrite and alloying component, their elasticity modules, therefore the large percentage of this strengthening might be explained through resistance to moving dislocations by dissolved atoms [8].

Conspicuous is strong breaking up of structure in case of surface plasma hardening: average grain dimension of plasma hardened steel is 0,007 mm versus 0,012 mm of steel after high temperature heat and mechanical treatment (interrupted hardening with subsequent self-tempering) [9]. Such decrease of grain dimensions and significant increase of total length of boundaries lead to growth of grain boundary strengthening of 60 grade steel (335MPa).

16Mn2V low alloy steel shows the role of dispersion strengthening. V (C,N) disperse carbonitride phase is formed in this steel, which phase strengthens ferrite as

Table 1 **Data for quantitative evaluation of steels studied tensile strength**

Steel characteristics	Grade and heat treatment of steels studied				
	St5, hot rolled	St5, heat treatment	09 Mn2	60, plasma hardened	16 Mn2V
Content of alloying elements in α-Fe / %: Mn	0,55	0,58	1,5	0,63	1,5
Si	0,11	0,15	0,3	0,36	0,30
P	0,04	0,04	0,03	0,033	0,035
V	-	-	-	-	0,11
Share of perlitic structures with different interlamillar spacing / %	22	25	15	24	17
Grain dimensions: / mm	0,051	0,012	0,021	0,007	0,014
Nature of dislocation structure / cm^{-2}	10^8	10^9	10^8	10^9	10^8

Table 2 **Comparative evaluation of steel tensile strength**

Strengthening components indicators / MPa/% of GOST tensile strength	Grade and heat treatment of steels studied				
	St5, hot rolled	St5, heat treatment	09 Mn2	60, plasma hardened	16 Mn2V
Strain of grit friction	30/8,7	30/5,9	30/7,1	30/4,3	30/6,1
Solid solution strengthening	125,3/ 36,5	129,6/ 25,6	125/ 29,8	150,7/ 21,5	115/ 23,5
Strengthening to be made by means of perlitic structures	55,2/ 16,0	60/ 11,8	36/ 8,6	59,3 /8,5	40/ 8,2
Dislocation strengthening	5/ 1,5	140/ 27,6	5/ 1,2	126/ 17,9	5/ 1,0
Dispersion strengthening	-	-	-	-	105/ 21,4
Strengthening by means of grain boundaries	128/ 37,3	147,4/ 29,1	224/ 53,3	335/ 47,8	195/ 39,8
Estimated value of tensile strength	343,5	507	420	701	490
Tensile strength value according to GOST	285	440	540	590	440

per Orowan mechanism. It is supposed that V (C,N) carbonitride phase is incoherent with α-Fe matrix and therefore dislocations circumvent V (C,N) releases thereby causing dispersion strengthening.

Also impact of dispersion phases on grain dimensions points out to efficiency and prospectiveness of dispersion strengthening. From chart 1 it follows that a finer grain d = 0,014 mm is formed in 16Mn2V steel, the structure of which contains V (C,N) dispersion carbonitride phase. Carbonitride phase slows down austenite grain growth during further heating down to the temperature of dissipation of these phases in austenite. These two circumstances lead to occurrence of noticeable breaking up of ferrite grains in 16Mn2V steel. Thus, dispersion particles of V (C,N) carbonitride phase in the steel cause additional grain-boundary strengthening [10-11].

As it is known, the basic phase constituent in low carbon and low alloy steels is ferrite, its content share in these steels reaches up to 70 - 75 %. Strengthening due to perlitic component contributes to a certain extent to the total strengthened condition as well. The given charts show that the strengthening share from perlite content is within limits from 8,2 % for 16Mn2V steel and 16,1 % for heat strengthened (thin plate-like) condition of perlite in St5 steel.

CONCLUSION

Data analysis of comparative evaluation of carbon and low alloy steels tensile strength by structural parameters shows that the basic mechanisms of strengthening thereof are solid solution strengthening by means of alloying with relatively cheap alloying components (Mn, Si) as well as dislocation and dispersion strengthening with application of strengthening heat treatment and micro-alloying of steel with carbide and nitride forming elements V (C, N).

Forming of gradient-laminated structure in surface layer of an item with combination of hot deformation with subsequent hardening in process flow of rolling and ultra-fast heating and cooling during plasma hardening lead to significant increase of tensile strength (endurance) of steel, and thereby lead to wear resistance of surface layer. It is also important that gradient-laminated structure excludes formation of abrupt point of transition from martensite structures to mixed plate-like perlitic structures, which is one of the basic factors increasing contact-fatigue endurance of steel and facilitating its crack resistance.

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Note: The responsible for English translate is Gulden Samiyeva, Nur-Sultan, Kazakhstan