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Autodeformation of Carburized Steel during Tempering

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The article analyses the results of autodeformation registered during tempering of carburized steel. Test pieces for the tests were carburized till the different depth in order to examine influence of depth of carburization on the deformation of steel during heat treatment operation. Carburization was performed on the one surface of test pieces seeking to analyze extent of acted normal stresses to autodeformation of steel. Different bending loads were applied for analyzed steel from 5 MPa to 100 MPa. Deflection of test pieces was analyzed. The obtained results proved that size and direction of deflection were affected by depth of carburization. Particular results of stretched and compressed surface examination showed different behavior of test pieces during tempering process. Test pieces, which undergo deformation at the beginning of martensitic transformation, after unloading bend further. When tempered test pieces with assimetrically carburized layer bend during hardening, its direction and extent of autodeformation depend on depth of carburization and tempering temperature. Kinetics of autodeformation (during tempering) is affected by difference of volume changes in the carburized part and in the unaffected low carbon part of specimen, and similarly by decomposition of retained austenite in the carburized part.

Keywords: carburized steel, deflection, autodeformation, tempering.

1. INTRODUCTION

Control of steel deformation is one of the most common concerns within the metals processing industry. Numerous surveys have been conducted by various authors in recent years to assess the critical needs of the industry [1].

Selfdeformation very often appears making different types of machine components and device details. When manufactured details are heat treated or case hardened, they more or less undergo selfdeformation, so after treatment it is recommended or even attempt to straighten it. In all cases it is faced up with elastic plastic deformation of steel, which magnitude considerably depends on steel plasticity [2].

One of the most perspective methods to solve this problem is to use steel kinetic plasticity. In the crystal materials, especially in the metal alloys, bonds of interatomic connections locally reduce when inner transformation proceeds. At this moment, when appropriate number of atoms undergoes phase transformation, it means changes dependence to one or other phase, rigidity of the structure decreases. If at this moment system is in the field of external forces directional structural move could appear, id est plastic deformation.

Notably significant regularity of kinetic plasticity can be observed in the case hardened parts with asymmetric case hardened parts. On hardening it intensively deforms and accuracy of the system decrease.

One of the important and troublesome problems occurring during heat treatment process is deflection. A lot of efforts to develop a computational model to predict the deflection and dimensional change during heat treatment of the mechanical parts have been made for a long time. The deflection and shape change mainly happens during quenching due to both thermal and transformation stresses. The deflection may also occur, to some extent, mainly due to the microstructural change like carbide precipitation even during tempering, which is performed to improve the toughness and ductility of the martensite without a great loss of the strength [3].

Deflection may be a combination of elastic and plastic deformations [4]. First with a view to distinguish elastical deformation, authors of study calculated from elastic theory the deflection of test pieces, assuming that they consist of two distinct layers, the carburized case and the core, and their thermal expansion are different. The result of calculation is that the deflection is proportional to the difference of thermal expansion of each layer.

Manuscript [5] considers results of investigations into structure evolution, properties and deformation behaviour of stainless steel at severe plastic deformation by equal channel angular pressing. The investigation showed that fiber like ultrafine-grained structure is formed it resulted in strengthening the steel by twice while ductility remains at level sufficient for further strain processing. Mechanism of cold deformation of steel is replaced in ultrafine-grained state.

The aim of this paper is to examine behavior of carburized steel during and after deformation by bending.

2. MATERIALS AND METHODS

Steel used for the production of hot-rolled plates, pinions, shafts, worm gears, cam clutches, piston pins and other carburized parts, to which the claim of high strength, ductility and toughness of core and high surface hardness, operating under impact loads and at low temperatures bimetallic seamless pipe for ship building with an outer

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layer of steel and an inner layer of copper was chosen for investigation. Chemical composition of steel: C – 0.14 %, Mn – 0.42 %, Si – 0.22 %, Cr – 0.77 %, Ni – 2.9 %.

Steel test pieces were case hardened (carburized) at the temperature of 930 °C using solid carburizator, which composes of 72.86 % of coal, 19 % of barium carbonate, 1.3 % of calcium carbonate, 0.04 % of sulphur, 0.2 % of silicon oxide, 3.3 % of volatile substance and 3.3 % of water. Granulometric compound of substance: the rest of mass segment 5 %, for separator of No 100 not more than 5 %, for separator of No 6 not more than 94 % and on the pallet 1 %. Test pieces were carburized using the mixture of 50 % of new and 50 % of used carburizator. One portion of test pieces were carburized throughout whole surface, another portion – one surface carburized with some allowance left for milling. Obtained depth of carburization was evaluated using metallographic method: 0.54 mm, 0.85 mm, 1.35 mm and 1.99 mm.

Test pieces under the test were carburized till the different depth of carburization 0.54 mm, 0.85 mm, 1.43 mm and 1.99 mm, and then hardened from the temperatures of 830 °C and 890 °C under the bending load of 100 MPa and 5 MPa. During the tempering at the temperatures 277 °C and 480 °C alternation of deflection on heating and holding at the tempering temperatures was measured.

Evaluating autodeformation of the test pieces on heating for tempering, test pieces were placed into the kinetic plasticity device and heated in the furnace in the circulating air; deflection alternation of test pieces were measured [6].

3. EXPERIMENTAL

During tempering at 480 °C of throughout surface carburized test pieces with different depth of carburized layer (from 0.54 mm till 1.43 mm) its deflection decreased from 0.04 mm to 0.17 mm (Fig. 1).

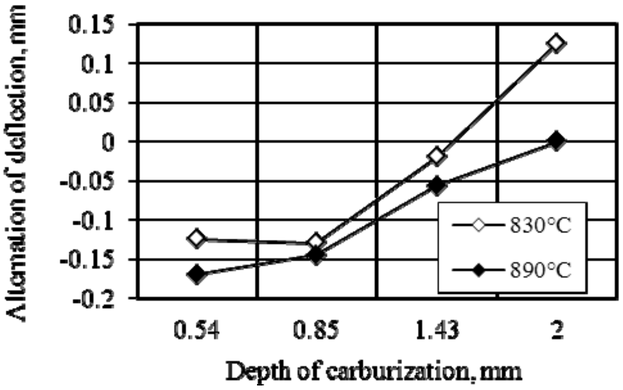

Fig. 1. Alternation of deflection on heating for tempering at 480 °C of throughout surface carburized steel test pieces. Maximum normal bending stresses 100 MPa

It formed from 7 % to 1.5 % of plastic deflection composed during hardening (Fig. 2). When carburized depth was 1.99 mm and whole cross sectional area of the test piece was 89 % carburized, autodeformation of test piece was positive: its deflection increased from 0 mm to 0.12 mm, id est from 0 % to 7.5 %. These results proved that size and direction of deflection were affected by deep carburized layer with huge amount of retained austenite.

Comparative volume of phase composition exchanges after case hardening. It can be calculated using these expressions:
for austenite

$$V_{\mathrm{A}} = 0.12282 + 8.56 \cdot 10^{-6}\, T + 2.15 \cdot 10^{-3}\, C_p \,, \tag{1}$$

for martensite

$$V_{\mathrm{M}} = 0.12708 + 4.45 \cdot 10^{-6}\, T + 2.79 \cdot 10^{-3}\, C_p \,, \tag{2}$$

where T is absolute temperature, C_p is specific heat.

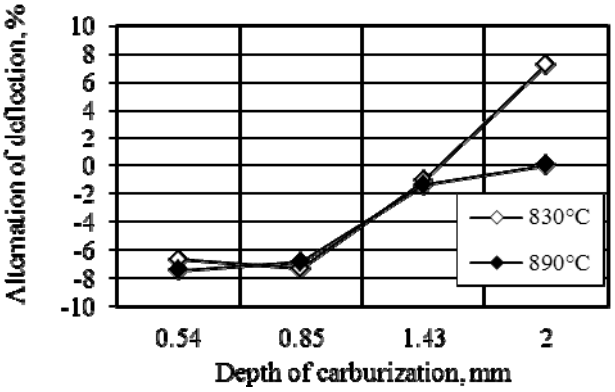

Fig. 2. Relative autodeformation on heating for tempering at 480 °C of throughout surface carburized steel test pieces. Maximum normal bending stresses 100 MPa

Calculated comparative volumes of phase composition of unaffected steel core and carburized layer with average amount of carbon equal to 1 % are presented in the Table 1.

Table 1. Relation between comparative volume (cm^3/g), carbon content and temperature

Comparative volume of phases, cm^3/g		Carbon content, %			
		0.12	0.20	0.50	1.00
Austenite	200 °C	0.12478	0.12498	0.12560	0.12667
	100 °C	0.12393	0.12413	0.12474	0.12582
	20 °C	0.12325	0.12345	0.12406	0.12514
Martensite	200 °C	0.12829	0.12852	0.12936	0.13075
	100 °C	0.12785	0.12808	0.12892	0.13031
	20 °C	0.12750	10.12773	0.12857	0.12996

Test pieces with one surface carburized layer with different carburized depths were used seeking to analyze influence of depth of carburized layer and extent of acted normal stresses to autodeformation of steel. Carburized surface during hardening was stretched or compressed under the normal bending stresses of 100 MPa. Part of testing batch was loaded with minimal normal bending stresses 5 MPa in order to evaluate influence of volume changes of carburized layer and unaffected core to autodeformation. Such a minimal stresses ensured nominal pressing while measuring deflection and had minimal influence to extent of plastic deflection.

When martensitic transformation started in the unaffected low carbon part (M_s = 380 °C), test piece because of volume change began to bend in a direction of deflection top. After martensitic transformation volume of steel calculated according data presented in the Table 1 increased approximately in 2.8 %. Martensitic transformation in the carburized layer began at the temperature $M_{S} = 100$ °C. After whole transformation volume of carburized layer increased approximately in 3.8 % (calculating changes of volume it was taken that medium concentration of carbon in the carburized layer was 0.8 % and influence of alloying elements to volume changes was not evaluated). Because of considerably higher volume increments in the carburized layer in the first period deflected specimens with carburized depth of 0.54 mm and 0.85 mm, straightened fractionally (Fig. 3).

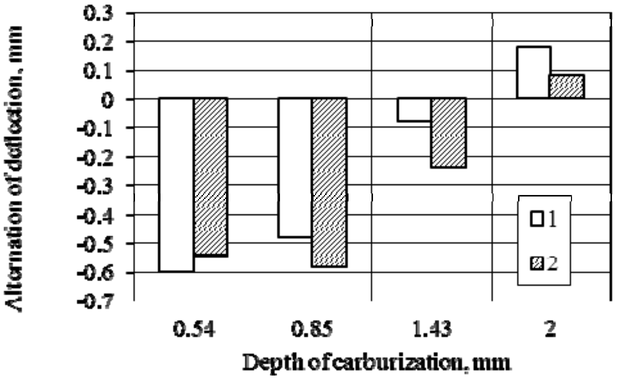

Fig. 3. Relation between alternation of test pieces deflection and depth of carburization. Normal bending stresses 5 MPa. Case hardened surface was stretched. Temperature: 1 – hardened from 830 °C, 2 – tempered at 480 °C

When depth of carburization was 1.43 mm residual deflection of specimens was minimal. The highest depth of carburization showed us bending of specimens to opposite side.

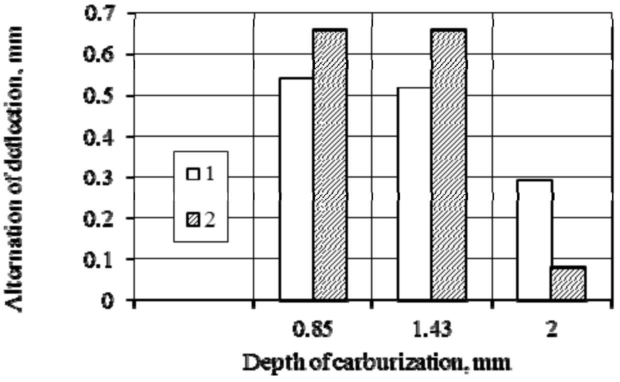

Fig. 4. Relation between alternation of test pieces deflection and depth of carburization. Normal bending stresses 5 MPa. Case hardened surface was compressed. Temperature: 1 – hardened from 830 °C, 2 – tempered at 480 °C

When tempered at 480 °C, test piece's deflection altered. It associated with reduction of volume caused by martensite transformation to ferrite and mixture of alloyed carbides in the unaffected low carbon surface of the test piece. In the carburized surface decrement of volume in some extent during martensitic transformation is compensated by presence of retained austenite which transforms to lower bainite, therefore volume increases. Consequently, depth of carburizing and character of acting stresses has great influence on size and direction of autodeformation.

When carburized layer was compressed (Fig. 4), volume changes in the carburized and unaffected low carbon test piece volume bigger than those defined in Fig. 3, as a result autodeformation of test pieces was noticeably higher. It can be assumed that specimens, who undergo higher stresses during hardening, sustained more selfdeformation during tempering. In order to clear up this statement, additional tests were executed, and all the results are presented in the Fig. 5 – Fig. 7.

One surface carburized test pieces with different depth of carburization were bent during hardening under the load of 100 MPa normal stresses followed by tempering at the temperatures of 285 °C and 480 °C. On heating for tempering alternation of deflection were observed and registered, according to these data curves presented in the Fig. 5 – Fig. 7 was constructed.

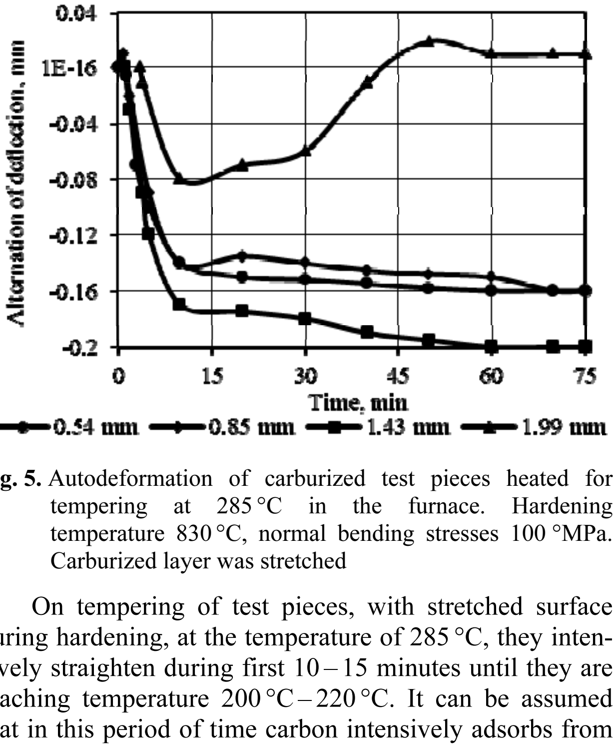

Fig. 5. Autodeformation of carburized test pieces heated for tempering at 285 °C in the furnace. Hardening temperature 830 °C, normal bending stresses 100 °MPa. Carburized layer was stretched

On tempering of test pieces, with stretched surface during hardening, at the temperature of 285 °C, they intensively straighten during first 10 – 15 minutes until they are reaching temperature 200 °C – 220 °C. It can be assumed that in this period of time carbon intensively adsorbs from the case hardened layer, so comparative volume of this layer decreased (Fig. 5). Specimens with 1.99 mm depth of carburization at first stages straighten, but after 10 minutes of heating changed direction of autodeformation. Deflection of test pieces on heating them from 200 °C to 270 °C increased by 0.1 mm. One of the reasons of that can be presence of retained austenite, which in the carburized layer transforms to low bainite, as a result comparative volume increased more that decreased because of at the same time running martensitic transformation.

When carburized layer during hardening was compressed (Fig. 6), at the beginning of heating for tempering till reaching the temperature of 200 °C – 250 °C deflection of specimens increases. Further heating till the temperature range 250 °C – 280 °C, cause reduction of deflection. It can be explained by the fact that retained austenite in the carburized layer transformed and volume of this layer increased, that's why specimen started to straighten.

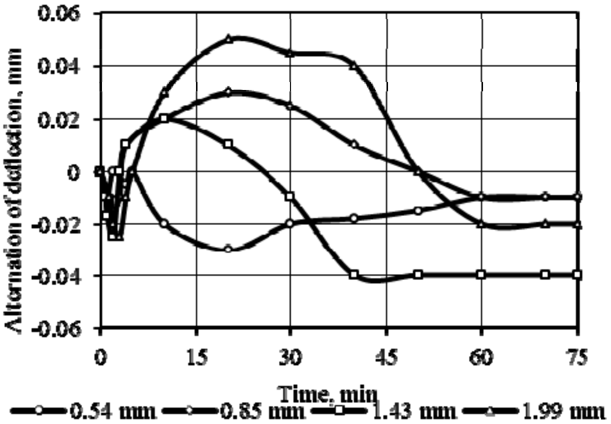

Fig. 6. Autodeformation of carburized test pieces heated for tempering at 285 °C in the furnace. Hardening temperature 830 °C, normal bending stresses 100 °MPa. Carburized layer was compressed

Bent during hardening test pieces on tempering at 480 °C (Fig. 7), showed considerably higher values of autodeformation when tempered at the temperature of 285 °C. There were no remarkable results about alternations of autodeformation, because on quick heating at high tempering temperature test piece's volume changes because of martensite and austenite transformation compensate itself.

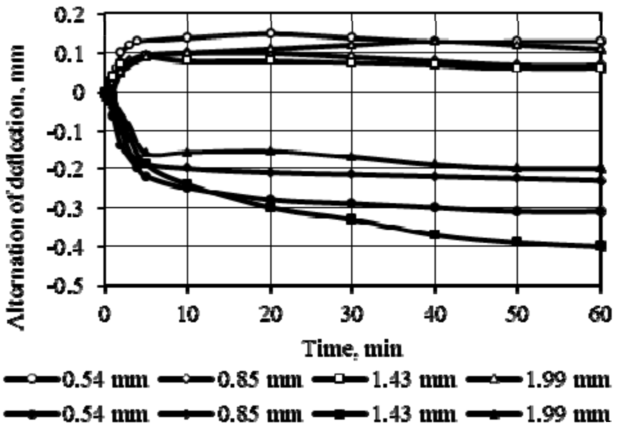

Fig. 7. Autodeformation of carburized test pieces obtained on heating for 480 °C tempering in the furnace. Hardening temperature 830 °C, normal bending stresses 100 MPa. Case hardened layer: upper portion of curves – compressed, lower portion of curves- stretched

4. CONCLUSIONS

1. During martensitic transformation steel possess kinetic plasticity, which magnitude can be evaluated by modulus of kinetic plasticity and by relative rate of kinetic plasticity.
2. Steels with heterogeneous chemical composition (case hardened – carburized layer) have less plasticity than homogeneous steel possess.
3. Kinetic plasticity of case hardened steel depends on rate of heterogeneity (cross sectional area ratio of decarburized layer and unaffected core).
4. In the stretched part of carburized test pieces less retained austenite composed comparing with compressed part. Microhardness in the stretched part was higher in 500 MPa – 2000 MPa than in compressed. Heterogeneous microstructure is the reason of autodeformation.
5. Test pieces which undergo deformation at the beginning of martensitic transformation, after unloading bend further. Deformed at the temperature higher than temperature of martensitic transformation, test pieces at the beginning bend, later started to straighten. The highest autodeformation was obtained when test pieces were unloaded at the beginning of transformation, when approximately 8 % – 12 % of martensite was composed, and deflection of test pieces increased in 30 % – 50 %. When unloading was done on reaching 50 % of martensite obtained autodeformation was minimal.
6. When tempered test pieces bend during hardening, its deflection increased depending on normal bending stresses and tempering temperature.
7. Deflection of wholly carburized and bend during hardening test pieces depends on depth of carburization, which is close to linear dependence, and equal from –8 % to +8 % of its plastic deflection.
8. When tempered test pieces with assimetrically carburized layer bend during hardening, its direction and extent of autodeformation depend on depth of carburization and tempering temperature. Kinetics of autodeformation (during tempering) is affected by difference of volume changes in the carburized part and in the unaffected low carbon part of specimen, and similarly by decomposition of retained austenite in the carburized part.

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