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RESIDUAL STRESSES, MICROSTRUCTURE AND FATIGUE BEHAVIOUR OF CARBURIZED LAYERS BEFORE AND AFTER SHOT PEENING

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The investigations were made on steel type 20HNM, used for carburizing. The specimens were carburized at different time periods as to obtain differentiated thicknesses of diffusion layers. The carburized layers of thickness HV550 from 0.6 to 1.3 mm were pneumatically shot peened with steel shot 0.8 mm (S280) and the time of exposition of the shot peened surface varied. The value and distribution of residual stresses at carburized layers as well as carburized and shot peened ones were determined. The measurements were done by destructive method. There were recorded the strains of the flat sample after the release of residual stresses in result of removing, by etching, a thin layer of the material. The fatigue characteristics were determined, for the preset technological parameters, at four-point bending. It was proved that the increase in fatigue strength was the result of the changes of value and distribution of compressive residual stresses caused by structural changes which appear at carburized layer after shot peening. By means of Mössbauer spectroscopy, the changes of retained austenite at carburized samples, which appear as the result of surface plastic strain caused by shot peening, were determined. The results of the investigation should be used in technology of hardening of highly loaded gears.

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1. Introduction

The extremely loaded parts of machines such as gear wheels, cams, bolts, working in complex conditions of mechanical, fatique-volume, fatique-contact loads and abrasive wear require hardening of surface. This surface hardening has its technical and economical reason. The hardening can appear as a result of structural transformation or dispersion process which occurs in materials in process of heat treatment. In practice all heat treatment methods have been already used up [1].

The plastic strain, gained by means of mechanical surface plastic treatment e.g. shot peening, results also in hardening of surface layers of machine parts [2]. The effects of combining both heat and mechanical processes of hardening are very interesting [3]. In the paper below the phenomena, appearing in carburized layers, caused by additional plastic treatment — shot peening, and their influence on fatigue behaviour have been described.

2. Purpose and scope of investigations

The purpose of the investigations was to define the influence of shot peening of the carburized layers on the changes of features of surface layer (residual stresses, structure and fatigue behaviour). The tests, made on 20HNM steel, covered mesurements of distribution of residual stresses of the different thicknesses of diffusion layer before and after shot peening. Two versions of shot peening were applied, differing with time of exposure. For one chosen thickness of diffusion layer the fatigue strength limits of carburized specimens as well as carburized and shot peened ones were determined. The results of fatigue tests have been presented as the Smith chart.

3. Materials for investigations

Tests were made on specimens of 20HNM steel whose chemical constitution has been presented in Table I.

TABLE I

Chemical constitution of 20HNM.

C	S	Mn	Si	P	Cr	Ni	Mo
0.215	0.017	0.81	0.56	0.021	0.57	0.74	0.16

The form and size of specimens were matched to the methodology of each test. All specimens had been previously carburized.

The carburizing by gaseous method was done in endothermic atmosphere at the temperature 920°C. The specimens for measurement of residual stresses distribution were carburized in various time periods to obtain three different thicknesses of diffusion layer: $g_1 = 0.6$ mm, $g_2 = 1.0$ mm, $g_3 = 1.3$ mm. The test pieces for measurement of fatigue strength and static strength were carburized to the depth $g_2 = 1.0$ mm. After carburizing they were quenched and tempered in temperature 170°C within 1 h. The thickness of diffusion layer was determined by measuring of distribution of hardness. The given values were the conventional thicknesses of diffusion layer HV550. The chosen part of carburized specimens assigned for investigations was shot peened. Shot peening was done by pneumatic method where steel round shot (hardness 40.0–45.0 HRC, granulation 0.6–1.0 mm) was used. Air pressure was 0.6 MPa. The length of exposure time of the surface was decided from the graph of saturation and equaled $t_1 = 5$ s ($f = 0.35$ A), $t_2 = 10$ s ($f = 0.37$ A).

4. Results of investigation and their analysis

4.1. Measurement of residual stresses

The value of residual stresses in function of distance from the surface were measured on the flat specimens by means of modified Weismann and Philips methods [4, 5].

The calculation of value of residual stresses in each layer was done basing on the results of measurement of changes of deflection of tested pieces in function of thickness of the remote layer of material. The measurement of pattern of residual stresses value were done on carburized specimens with diffusion layer $g_1 = 0.6$ mm, $g_2 = 1.0$ mm, $g_3 = 0.3$ mm and on carburized specimens with layers of the above thicknesses and shot peened in time $t_1 = 5$ s, and $t_2 = 10$ s. The results of measurements of residual stresses value in function of distance from the surface are shown as graphs.

The influence of thickness of carburized layer on value and distribution of stresses is shown in Fig. 1. The influence of thickness of carburized layer on value and distribution of residual stresses after shot peening is shown in Fig. 2.

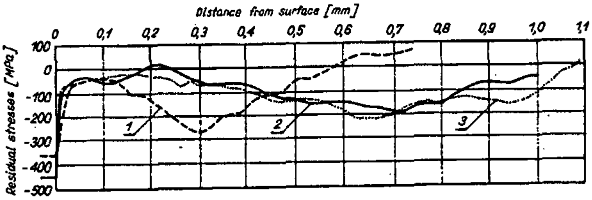


Fig. 1. The influence of thickness of carburized layer on value and distribution of residual stresses. 1 — $g_1 = 0.6$ mm; 2 — $g_2 = 1.0$ mm; 3 — $g_3 = 1.3$ mm.

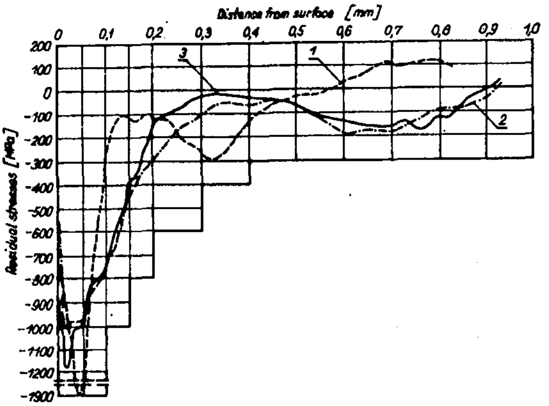


Fig. 2. The influence of thickness of carburized layer on value and distribution of residual stresses after shot peening. 1 — $g_1 = 0.6$ mm; 2 — $g_2 = 1.0$ mm; 3 — $g_3 = 1.3$ mm.

The results of measurements of residual stressed value allow to say that shot peening of carburized surfaces causes the considerable increase in gradient and maximal values of compressive stresses, which move down from the surface inside the material to the depth 30–40 μm. Shot peening causes also the growth of thickness of the layer in which compressive stresses appear. This thickness depends in the variable way on the thickness of diffusion layer. The extension of shot peening time causes the further increase in values of maximal compressive stresses with their very small movements into the depth of material [6]. The highest values of maximal compressive stresses $\sigma = 1800$ MPa appear in specimens carburized to the depth of 0.6 mm and shot peened in time $t = 10$ s.

4.2. Testing of fatigue strength

Testing of fatigue strength was done on specimens of stress concentration factor $\alpha = 1.02$.

The specimens carburized to the depth 1.0 mm were tested. The percentage of carbon on the surface of carburized layer = 0.8%, hardness 62 HRC. There were also tested specimens carburized as above and additionally shot peened in time $t = 5$ s with intensity $f = 0.35$ A [7]. The investigations were made in condition of one-size, four-point bending on the testing machine 10HFP-422 manufactured by Amsler with reciprocating movement of the element loading the specimen. To obtain the effect of bending a special attachment which allowed to obtain a constant bending moment on the gauge length of the specimen was used. The assumed base of testing $N_G = 10^7$ cycles. Medium value of stress cycles σ_m was taken as a fatigue strength limit. Tests were made for various values of stress ratio $R = 0.1$, $R = 0.3$, $R = 0.6$. The received values of safe fatigue life for 20HMN steel carburized as well as carburized and shot peened have been shown in Table II and as a graph in Fig. 3.

TABLE II

Value of fatigue strength limit.

	Stress ratio					
	$R = 0.1$		$R = 0.3$		$R = 0.6$	
Stress [MPa]	Carb.	Carburized and shot peened	Carb.	Carburized and shot peened	Carb.	Carburized and shot peened
σ_{max}	1775	2449	1918	2737	2571	3061
σ_{min}	178	245	575	820	1543	1836
σ_m	976	1347	1247	1777	2057	2449

The value of fatigue strength limit for carburized steel depends on values of stress ratio and at $R = 0.1$ equals $\sigma_m = 976$ MPa and at $R = 0.6$ $\sigma_m = 2057$ MPa. The process of shot peening causes the increase in fatigue strength limit from 13.7% to 50% depending on stress factor R.

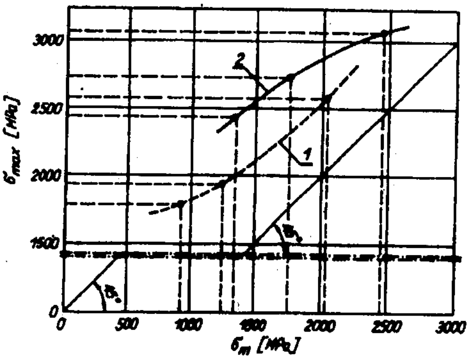


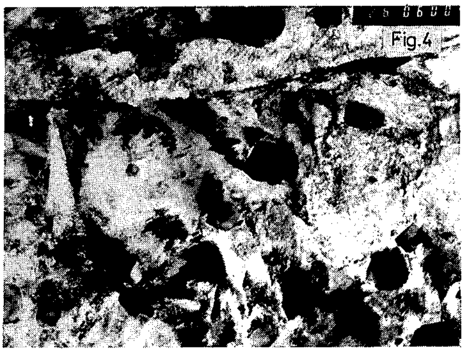
Fig. 3. Fatigue strength of steel 20HNM: 1 — carburized, 2 — carburized and shot peened.

4.3. Structural investigations

The influence of surface plastic treatment on the changes of structure in carburized layer was tested. The tests were made on specimens with dimensions 0.5×5×20 mm. From these test pieces the disc-shape leaf, diameter 3 mm, thickness 100 μm was taken. Electron microscope JEM 1000 C was used for testing.

The structure of carburized layer before plastic strain has been shown in Fig. 4. The structure of tempered martensite with numerous dispersions of cementite is well seen. As the result of plastic strain in the areas where cementite has appeared the martensite phase (Fig. 5) is seen.

Diffractometrical tests have shown that phase ε (Fe_2C and Fe_3C) occurs [8]. The testing of changes of structure in carburized layer caused by surface plastic treatment showed the reason of its hardening defined as the increase in compressive residual stresses. As the result of plastic strain, the plastic changes — destruction



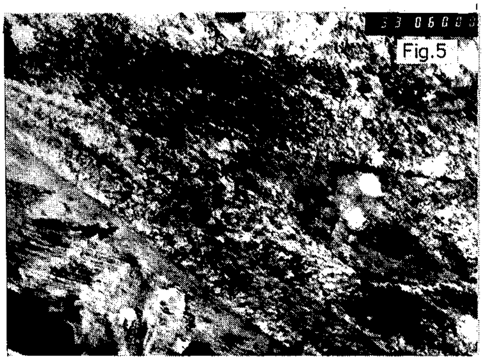


Fig. 4. Structure of steel before plastic strain — austenite areas well seen multiplied ×42 000.

Fig. 5. Structure of steel after plastic strain — martensite areas with dispersive separations of phase ϵ multiplied ×50 000.

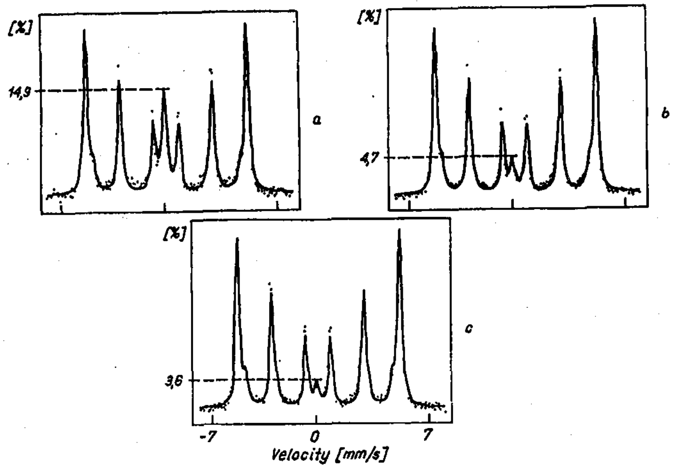


Fig. 6. Content [%] of retained austenite on the surface of carburized layer: (a) not shot peened, 14.9%, (b) shot peened in time T_1, 4.7%, (c) shot peened in time $T_2 = 2T_1$, 3.6%, measured and calculated from Mössbauer effect spectra.

of austenite, arising of martensite and appearing of new phase type ϵ — were observed.

The investigations to which Mössbauer effect was applied [9] proved that shot peening of carburized surface caused minimization of retained austenite from about 15% to about 5% (Fig. 6). The increase in time of shot peening by 100% did not make any significant changes of retained austenite content.

5. Conclusions

The described above process of global influence of heat treatment and mechanical surface plastic treatment on the hardening of surface layer has a great practical meaning. It allows to increase the fatigue strength even by 50% comparing to the processes without surface plastic treatment. It comes out from the above investigations that the global technological process of forming features of surface layer is not a simple additive one but it requires optimization at the processes of heat treatment — volumetric and surface ones — and at the process of plastic treatment.

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