New plasma carburizing method

A E Balanovskii, M V Grechneva, Vu Van Huy, D A Zhuravlev

Irkutsk National Research Technical University, 83 Lermontov St., Irkutsk, 664074, Russian Federation

E-mail: fuco64@mail.ru

Abstract. The paper deals with a new plasma-assisted carburizing method and sodium silicate-based production of innovative carbon coating for carburizing. Microstructure and microhardness of a carburized layer were studied. It was found that during plasma impact for 0.1–1 sec the surface is carburized to white iron concentration. Microstructure and metal surface characteristics subjected to plasma carburizing were studied. Basic parameters of the carburized layer were determined: carburized layer depth is 35–250 µm, microhardness goes up to 12000 MPa.

1. Introduction
Formation of special structures in a surface layer of wearing workpiece surfaces which could increase their wear resistance is a topical issue. One of the promising fields is modification of wearing surfaces using a laser [1-3], electronic beam [4, 5], plasma arc [6,7], steel modification with nano-structural compositions [10,11].

Carburizing with carbon-containing pastes was described in [3,4,8]. As a metal surface heating source, a laser [3], an electronic beam [4], a plasma electric arc [8] were used. The method involves application of carbon-containing paste on the workpiece surface which is melted when exposed to concentrated energy flow (laser, electron beam, plasma arc or jet). Under gas-dynamic force of the plasma arc or jet, intensive mixing of liquid metal and carbon occurs. After crystallization, the alloyed layer of carbon is formed [3,4]. The works [8,9] show that plasma surface carburization based on the electric arc of the solid phase is followed by surface fusion, i.e. liquid metal formation. The workpiece suchwise hardened should be extra-finished, and it increases production costs.

We developed a new composition of carbon-containing mixture (liquid glass and graphite) which is applied on workpiece surfaces in combination with a new plasma forming gas composition (argon and carbon dioxide mixture). It enables to carbonize metal surface without weld pool formation.

2. Materials and methods
Plasma assisted surface carburization was carried out on steel grades 1018,1020 based on ASTM Specifications. Samples of 80×20×10 mm were used for developing plasma assisted carburization processes.

Figure 1 shows a scheme of graphite surface formation and further plasma carburization. The paste made of graphite, liquid glass, water and oil was used as a solid carburization surface.
The microstructure was studied using OLYMPUS GX51 microscopes having magnification of 100x and 500x. Electronic and microscopic analysis of metal sample surfaces was carried out with a scanning electron microscope LV-4501. Micro-hardness was measured with the HMV-2T (Shimadzu) micro hardness tester under load of 2–5 N. Layer depth was taken as a distance from the sample surface to the point of base hardness. X-ray crystallography was carried out with the ShimadzuXRD-7000 x-ray diffractometer. Retained austenite, arc breadth of $\alpha$- and $\gamma$-phases, crystal parameters of retained austenite, microstress in austenite were determined based on X-ray crystallography data.

3. Results
Studies of a new plasma-assisted carburizing method identified changes in metal surface macrostructure and microrelief across the breadth of a hardening track. Microstructure of the carburized layer is a martensitic and austenitic mixture hardened with equally distributed dispersion carbides the amount of which decreases with increasing in distance from the surface. After deep etching of a specimen in a cross section area, the carburized layer in the form of a white layer with hardness of 4000-12000 MPa (under load of 2 N) can be observed with the microscope. Surface microhardness depends on the relation of graphite and liquid glass depending on the cooling rate. The experiment proved that the optimum content of liquid glass in graphite coating is 30–83 %. If the amount of liquid glass is less than 30%, adhesion to metal is insufficient. If liquid glass content is more than 83%, carburization of a metal surface occurs. If liquid glass content is 30%, a chill layer consisting of ledeburite and martensite is formed. Microhardness of the first layer is 9000–12000 MPa. Microhardness of the second layer having small thickness of $15–25 \mu$m is 6000–8000 MPa. With increasing content of liquid glass up to 60%, chilled iron is formed on the surface. Hardened surface consists of 4 sub-layers: ledeburite, ledeburite+retained austenite+martensite, retained austenite+martensite, martensite (Fig. 2a,e).

On plasma assisted treatment of graphite surfaces composed of 80% liquid glass, a chill layer consisting of two layers (retained austenite and martensite) is formed (Figure 2b, f). The first layer cannot be etched and has low microhardness of 4000–5500 MPa. A large amount of retained austenite in the surface layer shows that cooling rate for plasma assisted carburizing is not sufficient. Using Visual environment 8.6, we determined the cooling rate for different treatment rates. Calculation showed that when the plasma arc moves at a rate of 5 mm/sec. and the sample size is $80\times20\times10$ mm, the colling rate is $V_{cool} = 1740 ^{\circ}C/c$. Figure 2c,g shows the microstructure of the carburized layer after plasma heating at a rate of the plasma arc of 10 mm/sec, the amount of martensite in the carburized layer increases. Microhardness of the layer is 5000–7500MPa. When the plasma arc moves at a rate of 10 mm/sec, cooling rate is 3450 °C/sec. With rising arc rate up to 20 mm/sec, cooling rate is 5600 °C/sec, and hardened layer consists of needle-type martensite with high hardness of 9000–11000 MPa (90%) and retained austenite (100%) (Fig. 2d,h).
Figure 2. Microstructure of the carburized case in different modes
a, e – 60% of liquid glass; b, f – 80% of liquid glass, \( V_{\text{cool.}} = 1740 \, ^\circ \text{C/} \text{sec} \); c, g – 80% of liquid glass \( V_{\text{cool.}} = 3450 \, ^\circ \text{C/} \text{sec} \); d, h – 80% of liquid glass; \( V_{\text{cool.}} = 5600 \, ^\circ \text{C/} \text{sec} \).

Layer X-ray crystal analysis of carburized layers was carried out with Shimadzu XRD-7000. The content of retained austenite was identified by correlation and intensity of X-ray maximums of austenite (111) and martensite (110). Sizes of blocks and microstress in austenite were calculated by the breadth of austenite’s X-ray lines (111) and (311) based on the method described in [8]. X-ray crystal analysis showed that the quantity of retained austenite in steels under study subjected to plasma carburizing is larger at a minimum arc speed. The quantity of retained austenite in the surfaces of steel grades 1018 and 1020 varies extremely. The maximum quantity of austenite is 40–60% at a layer depth of 20–60 \( \mu \text{m} \) (Fig. 3).

Figure 3. Distribution of retained austenite by the carburized layer depth depending on cooling rate
Figure 4. Micro-hardness distribution by depth of the carburized layer with a soft inner layer (60% liquid glass)

1 – ledeburite layer; 2 – retained austenite + plate-type martensite + ledeburite; 3 – needle-type martensite; 4 – TIZs and original structure

Figure 4 shows the results of microhardness measurement by the depth of a carburized layer at different compositions of coating and cooling rates. The results are presented as histograms. To improve the accuracy of results, measurements were performed in several points for each value in a cross-section area. The distance from the workpiece surface to the middle of the transition zone, where the structure corresponds to steel containing 0.4–0.45% C and hardness of 50HRC, was taken as the efficient depth of a carburized layer. The maximum hardness of steel grades 1018 and 1020 was less than 5000 MPa [1-5,8,9]; higher hardness values were due to carburization. Thus, the results prove the possibility of plasma assisted carburizing. The important parameters are carburizing paste composition and metal surface cooling rate. Due to positive properties of the developed coating (high conductivity, mechanical and thermal stability, high heat contents of argon and carbon dioxide plasma), the arc burns in a sustained way on the surface of the coating – metal system. It increases a carbon diffusion coefficient in a metal surface layer. When carburizing, skins can have traces of micro-melting without metal bath formation in the form of a thin layer. Diffusion of carbon into metal is accelerated. The advantage of the method is due to the fact that there is not metal surface failure, and metal surface roughness Ra is < 5 µm.

4. Conclusion
Plasma assisted carburizing enables carburizing workpiece surfaces for several seconds without significant surface fusion. The carburized layer on the surface of steel grades 1018 and 1020 can have a depth of 200-250 µm and micro-hardness of 8000-12000 MPa.

By controlling components of the carbon-containing coating and surface heating parameters, we can achieve different degrees of finite surface roughness and control depth and structure of a carburized layer.

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