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Features of Increasing the Wear Resistance of Machine Parts by Treatment with a Concentrated Heat Flow

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Abstract

The article discusses the possibility of using surface treatment of parts with a concentrated heat flow to increase the wear resistance of parts. This method provides conditions for the rapid crystallization of the metal structure after zonal surface melting of the sample surface with electric arc plasma. It has been found that the wear resistance of steel increases significantly with increasing scanning speed and decreasing current strength. The near-surface layers on the cross-sectional grinds of the melting areas were studied in comparison with the initial (without melting) state on the basis of diagrams of the method of continuous indenter immersion. The values of a number of micromechanical parameters characterizing the resistance to microplastic deformation and elastic-viscous properties of steel after strengthening heat treatment were obtained. It should be noted that with a fourfold increase in hardness, the wear resistance of the steel increased almost 10 times. This indicates that the wear resistance of metals under friction is determined not only by macroscopic strength and hardness, but also by the ability to relax local peak stresses under dynamic contact interaction.

Key words: GTAW method, surface hardening, wear resistance of steel, electric arc treatment, concentrated heat flux.

Statement of the problem

Heat treatment of working surfaces of machine parts with the use of concentrated heat flow of high power allows to solve technical problems associated with increasing the wear resistance of metal products. In this regard, from the economic point of view and technological capabilities, the electric arc plasma treatment method is of interest, allowing after surface melting to cause rapid crystallization of metal due to intensive heat transfer (GTAW method) [1]. However, the influence of technological parameters of the melting process with subsequent recrystallization of the metal on the forming microstructure and its rheological strength properties, determining the wear resistance, remains insufficiently studied.

Analysis of the available investigations

GTAW (Gas-Tungsten-Arc-Welding) has become one of the most common arc welding methods. This is due to the fact that the resulting welds are characterized by high quality. One of the main advantages of this technology is the possibility to weld a wide variety of materials: along with low-carbon, high-alloy and martensitic steels, more valuable is the possibility of high-quality welding of aluminum and magnesium alloys, and in addition, such metals and alloys as titanium, zirconium, molybdenum, nickel, copper, bronze, brass [2, 3].

Nevertheless, the works devoted to the application of this method do not consider its use as one of the possible methods of surface hardening of machine parts, which in the future will be subjected to friction conditions without lubrication. In this regard, the question of the possibility of applying the GTAW method as a method of pre-treatment of materials is relevant.

The Objective of the work

Evaluate the effectiveness of surface heat treatment of steel with electric arc plasma to improve tribological parameters.

Statement of the task

GTAW (Gas-Tungsten-Arc-Welding) method was used for surface hardening, which provides conditions of fast crystallization of metal structure after zonal surface melting by electric arc plasma of sample surface in the form of tiles (200 × 50 × 10 mm). The basis of the experimental setup was equipment FALTIG 315AC/DC with protective gas (argon) and the use of non-consumable tungsten electrode (diameter 2.4 mm), hardened by thorium oxide. Installation scheme and general view are shown in Fig. 1 and 2.

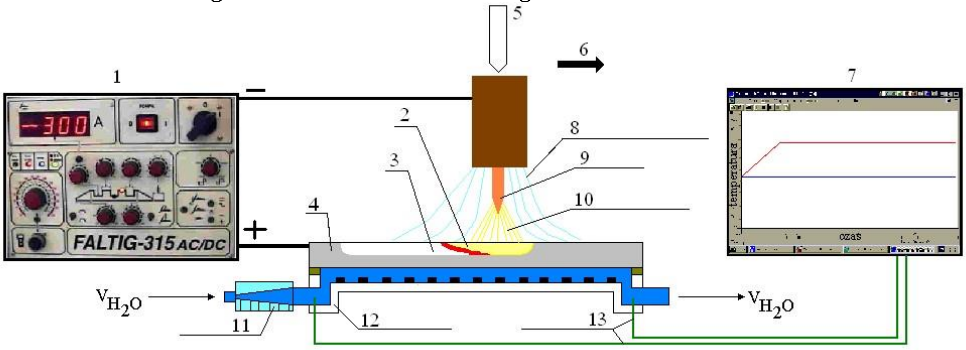


Fig. 1. Schematic of the installation for melting and calorimetric studies (method GTAW: Gas-Tungsten-Arc-Welding): 1 - current source, 2 - liquid metal welding bath, 3 - melted layer, 4 - sample, 5 - protective gas, 6 - direction of arc movement, 7 - temperature gauge, 8 - protective atmosphere, 9 - electrode, 10 - electric arc, 11 - flow meter, 12 – calorimeter, 13 – thermocouple

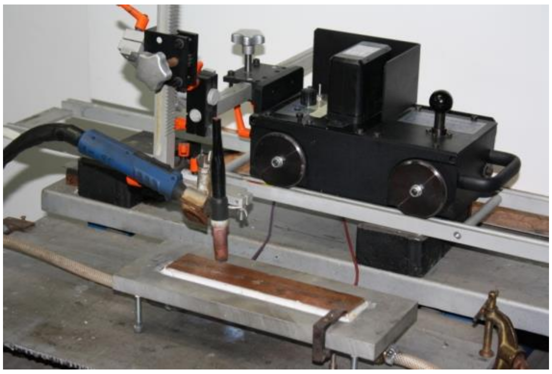


Fig. 2. General view of the installation

To intensify heat removal and accelerate crystallization, the sample tile was fixed as a flow calorimeter cover so that its lower plane was cooled by a water flow, while its upper surface was zonally melted. During arc scanning, the temperature of water at the inlet and outlet of the calorimeter was measured at the set water flow [4]. The heat absorbed by the tile material is spent for heating (Q_H) and melting ($Q_П$) of the scanning zone. The amount of heat absorbed in this way (taken by the calorimeter) was calculated by the formula:

$$Q_k = Q_H + Q_П = \rho \cdot V \cdot c \cdot \Delta t, \quad (1)$$

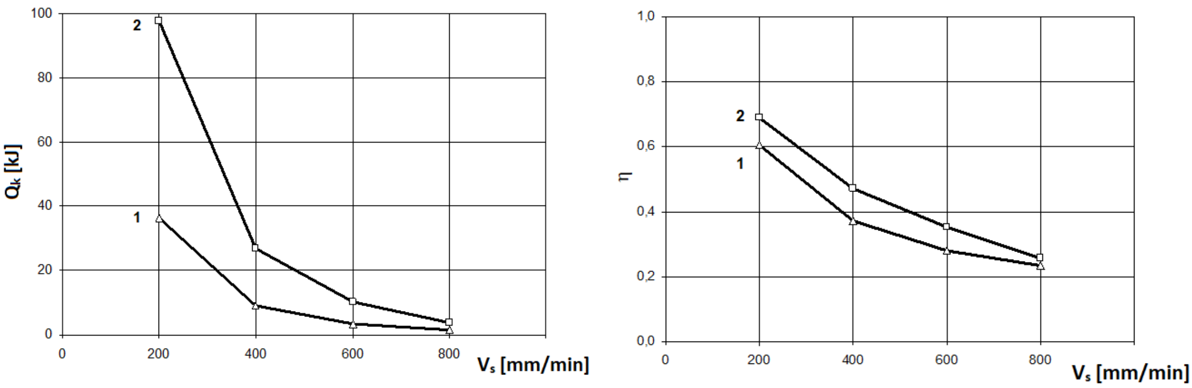
where ρ is the density of water; V is the volume of water consumed in the fusion process; c is the specific heat capacity of water; Δt is the temperature increase of water.

The efficiency of useful use of the heat released in the electric arc was evaluated by the thermal efficiency:

$$\eta = Q_k/Q, \quad (2)$$

where $Q = I \cdot U \cdot \tau$ is the total amount of heat released during time τ.

The influence of the main process parameters of the GTAW process (current strength and arc scanning speed) on the amount of heat taken by the tile sample during heating and melting ($Q_k = Q_H + Q_П$), as well as the effect on the thermal efficiency of the process η (Fig. 3) were studied. The arc voltage was of secondary importance.

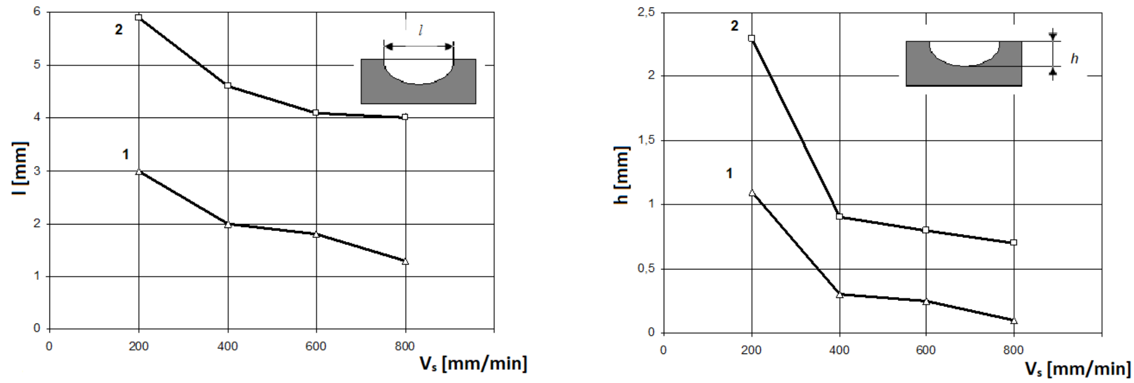


a b

Fig. 3. Dependence of the absorbed amount of heat Q_k (a) and thermal efficiency. η (b) as a function of arc scanning speed and current strength: 1 - I = 100 A; 2 - I = 200 A (U = 14 V)

The dependences obtained show that the efficiency of heat reception by the sample increases with increasing current strength and decreasing scanning speed. In the investigated range, the highest values of thermal efficiency. (η = 60 ÷ 70 %) were observed at the speed V_s = 200 mm/min.

Fig. 4 illustrates the influence of the studied technological parameters on the geometric parameters of steel sample melting. It can be seen that the width, depth and cross-sectional area of the melts increase with increasing current and with decreasing scanning speed. These geometrical characteristics are more sensitive to current variations at low scanning speeds. The values of Q_k and η, affecting the values of l and h, simultaneously form the temperature-rate parameters of the thermal cycle: heating - melting - crystallization - hardening - self-tempering of steel. The decisive factor influencing the formation of steel structure is the rate of heat removal from the melting zone.



a b

Fig. 4. Influence of current strength and scanning speed of electric arc on the width l (a) and depth h (b) of melting: 1 - I = 100 A; 2 - I = 200 A

Effect of electric arc treatment on the wear resistance of steel. Pre-eutectoid low-carbon steel 20 was investigated. The anti-wear properties of steel were determined by testing cube-shaped specimens (10 × 10 × 10 mm), which were cut from the fusion zones. In a friction machine, such a specimen was pressed with a controlled force against the surface of a 210 mm diameter rotating disc made of white cast iron (60 HRC). The specific load was Pn = 1 MPa, the sliding speed (without lubrication) V_t = 1.6 m/s, and the test time 2 hours. The wear intensity was calculated according to the formula:

$$Z = \frac{\Delta m}{\rho \cdot A \cdot L}, \tag{3}$$

where Δm is sample mass loss; ρ is steel density; A is contact area; L is friction path.

The comparison of steel wear resistance depending on the parameters of melting - current and scanning speed was carried out (Fig. 5). It was found that the wear resistance of steel increases significantly with increasing scanning speed and with decreasing current. Thus, after melting at a scanning speed of 800 mm/min and a current strength of 100 A, the intensity of wear decreases almost by one order of magnitude. This testifies to the fact that the increased scanning speed and reduced current contribute to such optimization of cooling and crystallization conditions, under which the microstructure with favorable strength and viscoelastic properties is formed.

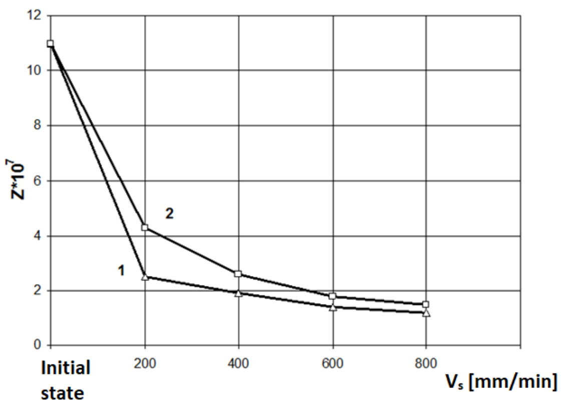
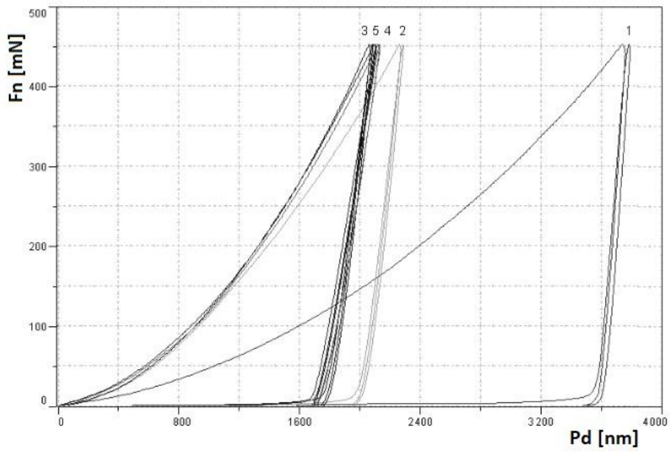


Fig. 5. Dependence of steel wear rate on electric arc scanning speed (Fn = 1 MPa, V_t = 1.6 m/s): 1 - I =100 A; 2 - I =200 A

The micromechanical and rheological properties of the surface layers were evaluated using the parameters of kinetic diagrams of continuous indentation of a Berkovich indenter on the NHT/NST unit of CSM Instruments (Switzerland) [5-7]. Double loading-unloading cycles with registration of the dependence of the indenter penetration depth (P_d) on the acting force (F_n) were investigated. At the same time the following were determined: microhardness $HV_{0,05}$, Young's modulus E, relaxation capacity R (relation of work of elastic aftereffects to the full work of indenter penetration), contact hardness S and hysteresis loop area W_H characterizing mechanical losses (cyclic viscosity) under repeated loading. The contact stiffness S is determined by the value of force reduction during indentor unloading per unit of deformation. The smaller the value of S, the more microplastic the material is.

Fig. 6 shows diagrams of tests of the materials under study by continuous indentation (two cycles of loading). The near-surface layers (at a depth of h = 50 μm) on the cross-sectional thin sections of the melting areas were investigated in comparison with the initial (without melting) state.



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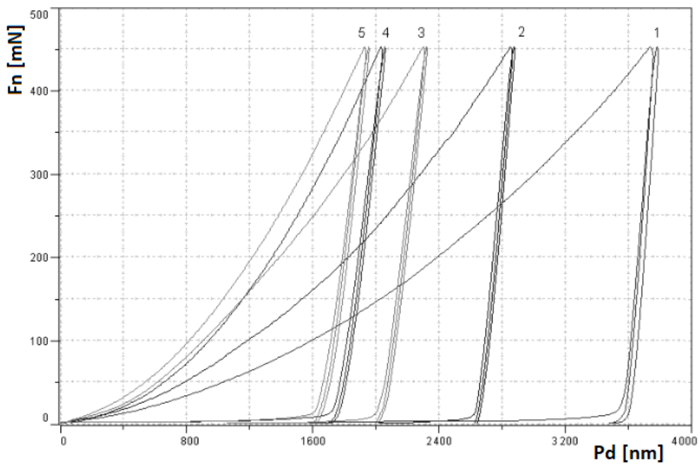

b

Fig. 6. Kinetic diagrams of continuous indenter microindentation after melting at arc current I = 100 A (a) and I = 200 A (b): 1 - initial state; 2 - 5 - V_S = 200, 400, 600, 800 mm/min

On the basis of recording of such diagrams the values of a number of micromechanical indices characterizing the resistance to microplastic deformation and elastic properties of steel after hardening treatment have been obtained (Fig. 7). A specific regularity is revealed: with increasing scanning speed during melting and subsequent rapid crystallization microhardness ($HV_{0,05}$), elasticity (E), relaxation indices (R_1, R_2) and dissipative capacity (hysteresis loop area WH) increase significantly. At the same time, the stiffness of the contact interaction between the indenter and the material (S) decreases. For clarity of comparison, these characteristics are summarized in Table 1 for scanning speed V_S = 800 mm/min.

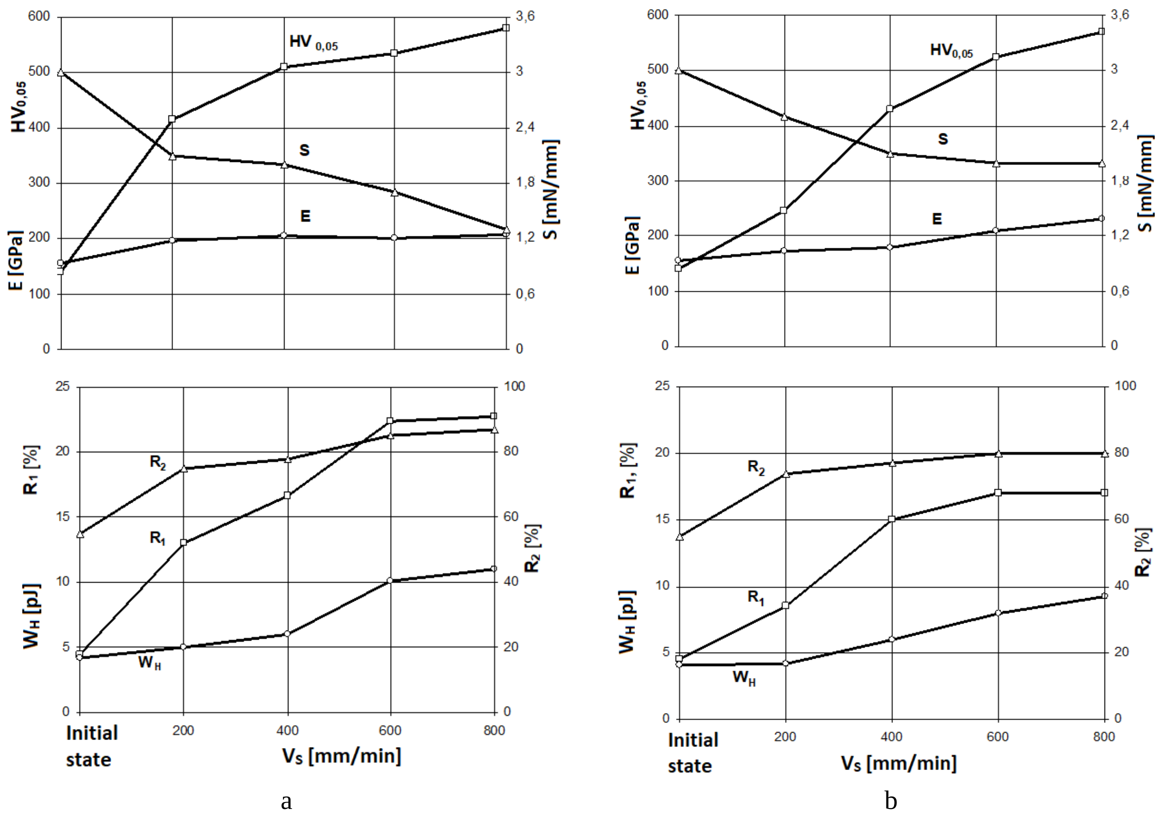

Fig. 7. Effect of arc scanning speed on the micromechanical properties of hardened surfaces at I = 100 A (a) and I = 200 A (b): $HV_{0,05}$ – microhardness; E – Young's modulus of elasticity; S – contact rigidity; R_1 and R_2 – relaxation capacity in the first and second cycles; W_H – hysteresis loop area

Table 1

Comparison of micromechanical parameters (Vs = 800 mm/min)

State of the material	Microhardness, $HV_{0,05}$	Modulus of elasticity E, GPa	Relaxation capacity		Hysteresis loop area $W_H \cdot 10^{-3}$, pJ	Contact rigidity S, mN/nm
			R_1, %	R_2, %		
Initial	140	155	4,5	55	4	3,1
Hardened at I = 100 A	580	205	23	87	11	1,4
Hardened at I = 200 A	570	230	17	78	9	2,0

From the above data it follows that the technology under study gives a 4-fold increase in hardness, 1.3 - 1.5 times increase in modulus of elasticity, 4 - 5 times increase in relaxation capacity, 2 - 3 times increase in dissipative capacity (cyclic viscosity) with a simultaneous reduction of contact stiffness in 1.5 - 2 times.

Conclusions

1. Optimized surface hardening process by electric arc plasma treatment (GTAW method) in terms of current strength and arc scanning speed, providing favorable conditions for rapid crystallization of zonally melted metal.

2. Surface melting of low-carbon steel by electric arc followed by rapid crystallization forms a vidmanstetted ferrite structure with a bainite strengthening phase. Such material at high hardness exhibits improved viscoelastic and relaxation properties, which provides a significant increase in wear resistance. In high-carbon bainite friction, unlike ferrite-perlite structures, the contribution of relaxation processes prevails over sticking during surface deformation. Therefore, martensite is additionally hardened by passing into a more ductile state and preserving high relaxation properties that ensure the development of non-damaging dissipative processes.

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Соколан Ю., Романішина О., Соколан К., Майдан П., Каразей В.Особливості підвищення зносостійкості деталей машин шляхом обробки концентрованим тепловим потоком

В статті розглядається можливість використання поверхневої обробки деталей концентрованим тепловим потоком з метою підвищення зносостійкості деталей. Цей метод забезпечує умови швидкої кристалізації структури металу після зонального поверхневого оплавлення електродуговою плазмою поверхні зразків. Встановлено, що зносостійкість сталі значно зростає зі збільшенням швидкості сканування та зі зменшенням сили струму. Досліджувались приповерхневі шари на шліфах поперечного перерізу областей оплавлення порівняно з вихідним (без оплавлення) станом на основі діаграм метода безперервного занурення індентора. Отримані значення ряду мікромеханічних показників, що характеризують опір мікропластичній деформації та пружнов’язкі властивості сталі після зміцнювальної теплової обробки. Слід зауважити, що при чотирикратному підвищенні твердості, зносостійкість сталі збільшилась майже у 10 разів. Це свідчить про те, що опір зношуванню металів при терті визначається не тільки макроскопічною міцністю та твердістю, але й здатністю до релаксації локальних пікових напружень в умовах динамічної контактної взаємодії.

Ключові слова: метод GTAW, поверхневе зміцнення, зносостійкість сталі, електродугова обробка, концентрований тепловий потік.