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EFFECT OF HORIZONTAL MECHANICAL VIBRATION ON SERVICE PROPERTIES OF DEPOSITED METAL

Ch.V. PULKA, M.I. PIDGURSKYI, V.S. SENCHYSHYN, M.V. SHARYK and **V.Ya. GAVRYLYUK**
Ternopil Ivan Puluj National Technical University of MOS of Ukraine
56 Ruska Str., 46001, Ternopil, Ukraine. E-mail: Viktor_Synchyshyn@i.ua

Wear resistance and stability of thickness of the layer of metal deposited by the induction method was studied. It is shown that in surfacing using the powder-like solid alloy PG-S1 by ITES heating system (inductor, thermal and electromagnetic shields) with application of horizontal vibration and energy-saving surfacing mode, the wear resistance is 1.4 times increased, stability of deposited metal layer thickness grows by 10 % and deposited metal quality is improved (transformation from coarse- to fine-grained structure), as compared to the technology without horizontal vibration. 14 Ref., 3 Tables, 5 Figures.

Keywords: *induction surfacing, thin steel discs, horizontal mechanical vibration, microstructure, wear resistance, thermal and electromagnetic shields, energy-saving mode*

One of the most actual directions in the field of science and technology is the modification of surface of structural and tool steels in order to improve service characteristics of parts of machines and mechanisms operating in the conditions of increased operation and aggressive environments. Today, different methods of surface modification are widely used in machine-building and metalworking industries, such as application of wear-resistant coatings by physical and chemical methods, and different types of thermochemical treatment.

Among the physical methods of forming functional coatings, the method of induction surfacing is the most effective for applying a layer of multicomponent materials. At present, one of the most promising ways to improve the effectiveness of wear-resistant coatings is to introduce additional technological operations in the traditional way of induction surfacing, such as shielding thermal and electromagnetic fields, modes of surfacing with energy savings, exposure of the product to horizontal and vertical mechanical vibration in the process of surfacing, etc., which allow significantly increasing service properties of the deposited metal layer.

Induction surfacing is a process used to restore worn surfaces or to strengthen working surfaces during the manufacture of new parts [1, 2]. This surfacing process has become widely used in agricultural engineering [3]. An important prerequisite for providing a quality surfacing process is correctly selected parameters of surfacing mode, which further affect the quality of layer of deposited metal, and therefore the service life of a deposited part.

In induction surfacing, to insulate those part surfaces which are subjected to unwanted heating, thermal and electromagnetic shields are used. To application of thermal and electromagnetic shields during induction heating a number of works is devoted [4–6]. The shields are used in different technological processes to harden parts, surfacing, etc. They are usually used separately (i.e. only electromagnetic or thermal shield). Moreover, it is very difficult to control temperature in the surfacing zone to produce a high quality layer of deposited metal.

To improve the properties of deposited metal, the authors developed a new surfacing technology using the ITES heating system (inductor, thermal and electromagnetic shields) [7, 8], i.e. a combined simultaneous shielding of thermal and electromagnetic fields, which allows achieving a more stable thickness of layer of deposited metal due to the uniform temperature in the surfacing zone, since the powder-like solid alloy is melted from the surface of base metal during surfacing by heat transfer with a variable specific power over time (energy-saving mode of heating) [9].

It is of interest to study the properties of deposited layer of metal in the case when into the ITES system during the use of energy-saving mode of surfacing, additional technological operation, such as horizontal mechanical vibration of the part to be surfaced, at the moment of melting start of the powder-like solid alloy to its full melting and cooling [10, 11] is introduced, which will greatly improve the service characteristics of the deposited layer of metal.

Procedure of investigations. Measurements of microhardness were performed in the microhardness meter M-400 of Leko Company. The microstructure of the specimens was studied in the microscope NEOPHOT-32 (Germany). The etching of the specimens

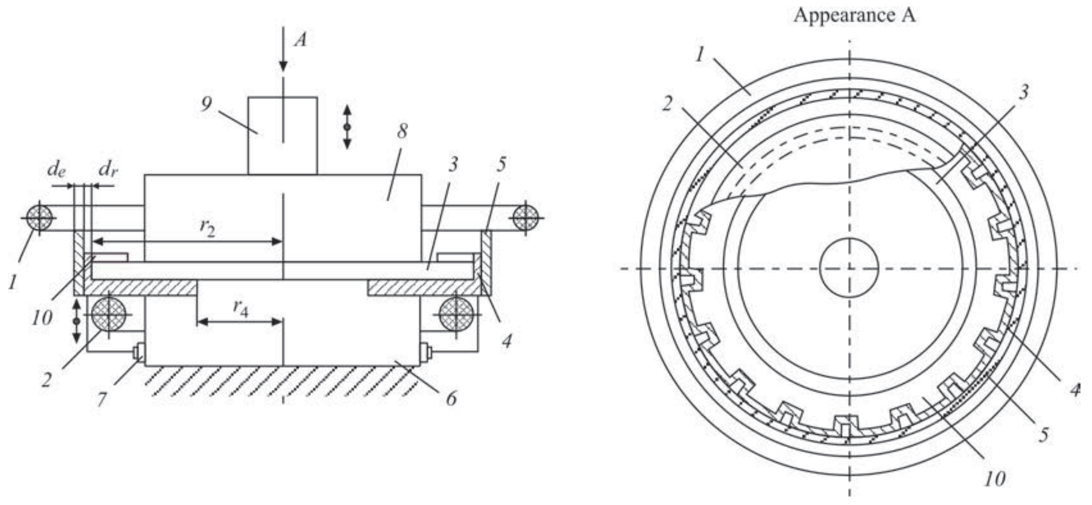


Figure 1. Device for regulating power in the zone of surfacing with thermal and electromagnetic shields rigidly fixed between each other (description *1–10* see in the text)

deposited by the wear-resistant alloy PG-S1 was carried out electrically in a 20 % water solution of chromic anhydride with a voltage of U = 20 V, holding time was τ = 5 s.

Analysis of elemental composition of deposited specimens was carried out in the micro-analyzer SX-50 (Camebax) of the Cameca Company. Tests for wear resistance of deposited metal were performed in the machine NK-M [12].

The results of investigations were expressed in terms of relative wear resistance, which is equal to the ratio of reference weight loss to the weight loss of studied specimens.

Surfacing was carried out simultaneously on the entire working surface with the use of a generator of type HFI-63/0.44 by mechanical horizontal vibration on the energy-saving heating mode, which was regulated by the device [13].

Investigation of the process of induction surfacing of thin discs were carried out with the help of a heating system (ITES) (Figure 1) [14], which consists of the upper *8* and lower *6* clamping plates, as well as the drive *9* for lifting the upper plate *8*. The part *3* with the charge *10* of a solid alloy PG-S1, preliminary poured on it, was installed in a two-turn annular inductor, *1* — upper, *2* — lower turn. At the end of the disc and at its lower surface opposite to surfacing, around its perimeter, a thermal shield *4* is located, and also at the end of the disc an electromagnetic shield *5* is installed, which are rigidly interconnected and fixed to the lower plate. Electromagnetic and thermal shields are manufactured with the possibility of vertical movement relative to the end of the disc *3* and turns of the inductor *1* and *2* by means of the drive *7*, fixed on the lower plate *6*, which allows regulating the temperature field in the surfacing zone, as far as in induction surfacing a powder-like solid alloy is melted from the surface of the base metal.

Investigation of the deposited metal produced by means of the ITES heating system with the use of horizontal vibration was performed on the microstructure, on the thickness of the layer of deposited metal and on wear resistance in order to provide a deposited bead with a width of 10–50 mm and a thickness of respectively 0.8–1.5 mm.

The obtained results were compared with those obtained by the heating system without horizontal vibration.

In this case, discs were used made of 3 mm thick steel St3 and a powder-like solid alloy PG-S1, the chemical composition of which is given in Table 1.

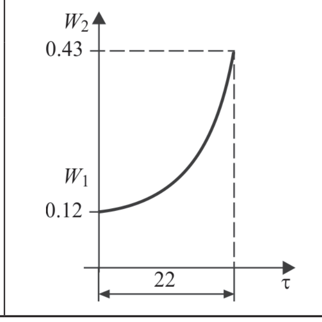
Table 2 presents heating systems and heating parameters in energy-saving mode of surfacing [9].

The process of induction surfacing was carried out simultaneously throughout the entire working surface by using the generator of type HFI-63/0.44 without rotation of the part. The technical characteristics of the generator with horizontal vibration are the same as without vibration, at the initial moment of time they were following: voltage on the circuit was 2.2 kV; volt-

Table 1. Chemical composition (wt.%) of powder-like solid alloy PG-S1

Deposited material / Powder	C	Cr	Si	Ni	Mn	B	Cu	W	Fe	Hardness of deposited metal *HRC*
PG-S1 sormite No.1 (U30Kh28N4S4)	2.5–3.3	27–31	2.8–4.2	3.0–5.0	0.4–1.5	–	–	–	Base	51

Table 2. Heating systems and surfacing modes

Heating systems	Surfacing modes					Type of generator	Nature of change in the specific power on the inductor $W\cdot10^9$, W/m^3
	Circuit voltage, kV	Anode voltage, kV	Mains current of the tube, A	Anode current of the tube, A	Surfacing time, s		
Without and with horizontal vibration	Variables					HFI–63/0.44	
	input numerator (τ = 0 s)			output denominator (τ = 22 s)			
	$\frac{2.2}{7.0}$	$\frac{8.3}{10.0}$	$\frac{3.6}{0.95}$	$\frac{1.1}{3.1}$	22		

age on the tube anode was 8.3 kV; current of the tube mains was 3.6 A; current of the tube anode was 1.1 A; surfacing time of the entire working surface of the disc was 22 s. The process was carried out without switching the generator, i.e., the specific power at the inductor was changed by the energy-saving mode, which has the form [9] and is determined by the formula

$$W_{set} = \frac{\lambda_g m^2}{sh(am^2\tau)} T_{set} e^{am^2 t},$$

where T_{set} is the temperature at which the quality surfacing is carried out, which is reached over the time τ; $\lambda_g = ca\gamma$, W/(m·°C); c is the specific heat capacity, a is the temperature conductivity, m^2/s; γ is the density, kg/m^3; $m^2 = Bi/2h^2$; $Bi = 2ha/\lambda$ is the Bio criterion; λ is the coefficient of thermal conductivity of the disc material, W/(m·°C); α is the coefficient of heat dissipation, W/(m^2·°C); t is the running time; τ is the surfacing time.

The final parameters of surfacing mode were respectively 7.0, 10.0, 0.95, 3.1. The specific power without vibration and with vibration, respectively, at the initial moment was $W_1 = 0.12\cdot10^9$ W/m^3 and at the end of surfacing $W_2 = 0.43\cdot10^9$ W/m^3 (see Table 2).

Let us consider metallographic examinations of the layer of deposited metal produced with the help of a heating system (ITES) with horizontal vibration and without vibration.

The examinations were conducted in two cases of induction surfacing with and without mechanical vibration. To investigate the structure and wear resistance of deposited metal, from the deposited workpieces the specimens were cut. Etching of the specimens for metallographic examinations was carried out step-by-step, electrolytically in a 20 % solution of chromic acid (voltage was 20 V and holding time was 10 s), the structure of deposited metal was determined by chemical etching in 4 % nitric acid solution.

The microstructure of the base metal represents ferrite and pearlite, and the microstructure of deposited metal of the investigated specimens consists of primary carbides (complex carbides of type $(Fe, Cr)_7C_3$ and $(Fe, Cr)_3C$) in the form of large fan-shaped plates having a hexagonal lattice with a clear boundary interface with the matrix of carbide eutectics and matrix austenitic structure.

The excessive carbides are usually arranged in the form of separate plate precipitations in the central part across the width and thickness of the deposited bead. Rectangular and hexagonal precipitations represent the carbides of different dispersions, a part of which are excessive plate carbides, which are fairly uniformly distributed in the matrix. The microhardness of the carbides varied within *HV* 0.5–11710–12830 MPa.

The common for the two variants of deposited metal are:

● the presence of hypoeutectic zone in the deposited layer adjacent to the joint line and is characterized by the formation of dendrites of solid solution (alloyed austenite) with the axes of the first and second order, as well as carbide eutectics crystallizing in the interdendritic space. The microhardness of austenite for the specimen without horizontal vibration was (*HV* 0.5–4550–5140 MPa and *HV* 0.5–5150–5900 MPa for the specimen with horizontal vibration. In addition, structural heterogeneity along the joint line was detected on the side of PG-S1 sormite, which evidences that hypoeutectic dendritic area has a nonuniform distribution;

● the formation of a limiting white strip of solid solution (alloyed austenite) between the deposited and base metal of variable width of 10–20 μm for the specimen without vibration with microhardness of *HV* 0.5–3030–3410 MPa, and for the specimen with vibration *HV* 0.5–4500 MPa;

● on the side of the base metal near the fusion line, a diffusion zone arises, which represents a thin-plate

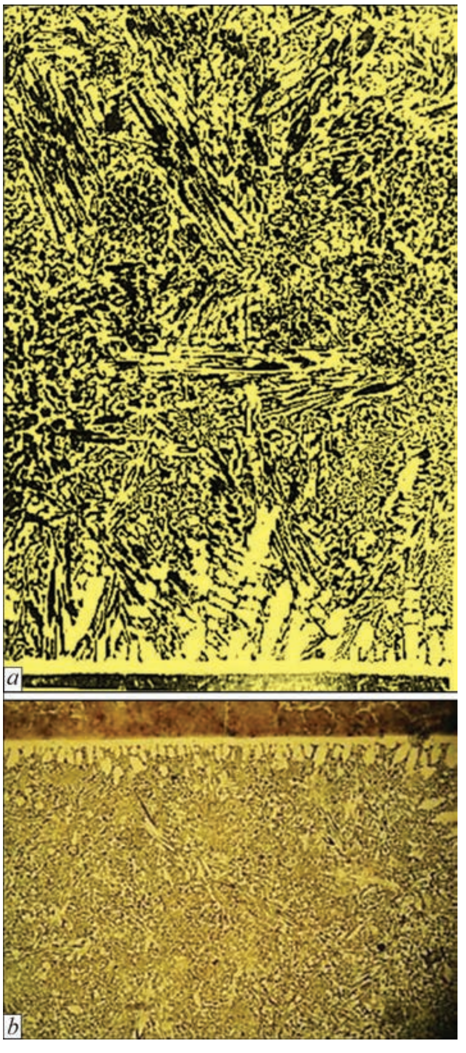


Figure 2. Microstructure (×200) of deposited metal specimens: *a* — without vibration; *b* — with horizontal vibration

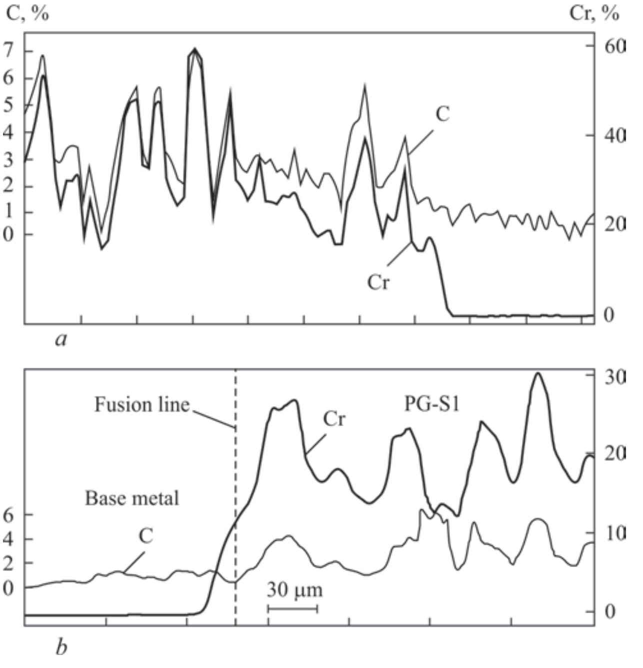


Figure 3. Distribution of carbon and chromium across the thickness of deposited metal: *a* — without vibration; *b* — with vibration

pearlite and ferrite along the grain boundaries, sometimes with a Widmannstatten orientation with a microhardness *HV* 0.5–2440 MPa, which has arisen as a result of diffusion of carbon with sormite into the base metal.

The microstructure of deposited metal is presented in Figure 2.

The characteristics of microhardness of the structural components are given in Table 3.

It is necessary to note differences in the structure of two variants of deposited metal. Horizontal vibration leads to a noticeable refinement of the carbide component (Figure 2, *b*). Carbides having the appearance of hexagons with an average side length of 10–12 μm without vibration (see Figure 2, *a*) are refined to 3.5–5.0 μm with horizontal vibration (Figure 2, *b*).

The maximum depth of the eutectic zone is in the specimen without horizontal vibration (see Figure 2, *a*) and the minimum depth is in the specimen with horizontal vibration (Figure 2, *b*) and it occupies the smallest percentage of austenitic dendrites along the length of surfacing as compared to the first case. During horizontal vibration, the joint line on the side of the sormite represents mainly a white strip with the formation of almost equiaxed grains of austenite (see Figure 2, *b*).

In order to determine the composition of structural components (chromium, carbon) and to establish their influence on properties of deposited metal, micro-X-ray spectral analysis of deposited metal was carried out (Figure 3).

In all cases, the analysis was performed at approximately the centre of the layer of deposited metal perpendicular to the fusion line at a depth of up to 350 μm from the fusion boundary.

It was established that in the metal of the investigated specimens, carbon was bonded into carbides of type $(Fe, Cr)_7C_3$ and $(Fe, Cr)_3C$, a noticeable redistribution of diffusive carbon near the fusion line was not observed.

Figure 4 presents the diagrams of relative wear resistance and hardness of deposited specimens (average for three tests).

As can be seen from Figure 4, for the case when surfacing is performed without vibration, the wear re-

Table 3. Characteristics of microhardness of structural components

Technological operation	Microhardness of structural components, MPa		
	Chromium carbides	Matrix	White strip (transition zone)
Without vibration	11710–12830	4550–5140	3030–3410
With vibration	14300–15440	5150–5900	4500

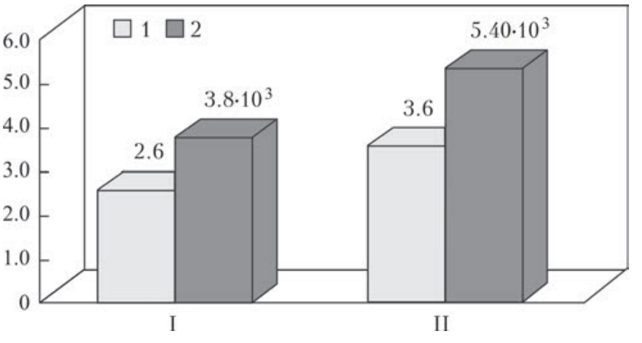


Figure 4. Relative wear resistance and hardness of deposited metal: I — without vibration; II — with vibration; 1 — relative wear resistance; 2 — hardness of deposited metal, MPa

sistance is 2.6 and the hardness is 3800 MPa, and in the case of applying horizontal vibration, the wear resistance is 3.6 and the hardness is 5400 MPa, respectively. This is achieved due to a more favourable distribution of alloying elements in the deposited layer of metal.

Figure 5 shows the curves of a normal distribution of thickness of the layer of deposited metal. The uniform thickness of the layer of deposited metal as compared to surfacing without horizontal vibration is increased by 10 % (see Figure 5), which provides a uniform distribution of liquid metal in the surfacing area.

Conclusions

The studies of induction surfacing of parts showed that with the use of horizontal vibration, combined shielding of thermal and electromagnetic fields and energy-saving surfacing mode, the wear resistance is increased by 1.4 times, the thickness of the deposited metal layer is increased respectively by 10 % and the quality of deposited metal is improved as compared to the technology without application of horizontal vibration.

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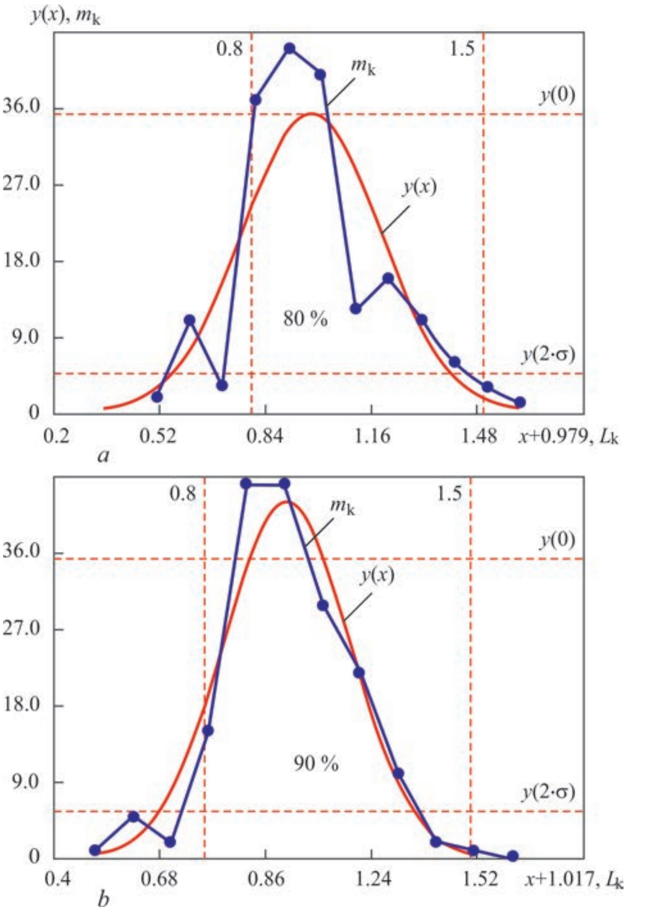

Figure 5. Curves of normal distribution of thickness of layer of deposited metal (*h*, mm) at simultaneous surfacing using the energy-saving mode (*n* is the number of points in the preset interval during measurement of thickness): *a* — without vibration; *b* — with horizontal vibration

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