

# Effect of Some Overlay Welding Regime With Longitudinal Magnetic Field on Hardness, Phase Composition And Welded Layer Wear By Arc Method With Flux Metal Wire

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**Abstract.** The paper defines the range of overlay welding current, frequencies and induction of a longitudinal magnetic field that enhance the wear resistance of welded layer adding the flux. The conditions of their mutual influence on the process of structure formation are stated as well as the mathematical models linking the overlay welding current, frequency and induction of a longitudinal magnetic field with hardness, wear resistance and phase composition of the welded layer, the use of which will allow to determine the welding modes to provide the necessary properties of the weld metal.

## 1. Introduction

The transition to automated production processes in engineering is associated with an increase in the number of interconnected machines and units operating in continuous movement, an unplanned stop of which leads to an enormous production loss [1]. During their operation the parts and components are subjected to considerable dynamic, heat, static, vibratory, and other loads, which are influenced by changing their geometrical dimensions. Therefore, the problem of increasing the wear resistance is one of the most important in engineering [2]. Restoration of the disrupted parts is carried out by means of welding. Thus the improvement of already known welding surfacing methods to provide the wear-resistance increase is very important.

One of the promising methods is weld facing with the solid cross-section under the flux layer using a longitudinal magnetic field [3,4]. This method allows to increase the weld facing productivity, to influence the geometric dimensions, the phase composition, hardness and wear resistance.

The aim is to develop mathematical models and to determine the hardness and wear resistance of the phase composition of the welded layers according to the weld facing regimes with the effect of a longitudinal magnetic field.

## 2. Problem setting

The object of the research is the process of arc welding surfacing adding flux with solid cross-section wire and the additional impact on the arc of an external electromagnetic field.

The subject of the research is the influence of welding surfacing parameters, frequency and induction of longitudinal magnetic field on the phase composition and properties of the welded layer.



The aim of this work is to study the joint effect of welding current (arc thermal power), induction and frequency of longitudinal magnetic field on hardness, wear resistance and phase composition of the welded layer adding flux.

### 3. Materials and methods

Experimental weldings were performed on carbon steel sheets St3sp GOST 380 (i.e. all-Union State Standard) adding flux AN-348A GOST 9087 with the impact of longitudinal magnetic field induction  $B_z = 0 \dots 80$  mT, frequency  $\omega$  0 to 50 Hz, wire of solid cross-section of Sv-08G2S GOST 2264 with a diameter of 3 mm. An external magnetic field was generated by a special device, consisting of a solenoid coil and its power supply unit [5]. Welding equipment: unit set of UD-209 type, power supply – universal rectifier VDU-506 (i.e. Multi-operated Arc Rectifier-506). Additional equipment: analog teslametr, EM-5511 digital multimeter, testing wear machine MI-1M, laboratory analytical balances, stationary hardness tester, microscope. The wear was evaluated by the gravimetric method. Method of hardness measuring (Brinell hardness) was performed according to GOST 9012.

When setting an experimental part of the research a non-linear planning on the matrix of non-composite plan of second order for three factors has been implemented. Experimental data processing were performed in the analytic STATISTICA system [6].

### 4. The results

In the research the following welding conditions have been imposed:  $I_n = 460 \dots 480$  A;  $U_o = 26 \pm 1$  B; rate of vapour deposition  $v = 18$  m / h; direct current of reverse polarity. Metal thickness  $10^{-2}$  m, diameter of the wire electrode  $3 \cdot 10^{-3}$  m.

Electrical stickout  $l_e$ , and the rate of welding surfacing  $v$  weren't changed. Such independent command variables were chosen: welding current  $I_n$ , and frequency induction  $B_z$ , frequency of longitudinal magnetic field  $\omega$ . Hardness  $H$ , wear-resistance  $\varepsilon$  and structure determined by Macrosection.

Table 1 – Experimental record

Trial №	$B_z$ , mT	$\omega$ , Hz	$I_n$ , A	$H$ , HB	$\varepsilon$ , units	<i>ferrit</i> , %	<i>perlite</i> , %
1	+	+	0	147	1.36	75	25
2	+	–	0	166	1.80	65	35
3	–	+	0	133	1.18	62	38
4	–	–	0	138	1.24	63	37
5	0	0	0	176	1.91	65	35
6	+	0	+	190	2.04	70	30
7	+	0	–	176	2.11	72	28
8	–	0	+	146	1.28	63	37
9	–	0	–	143	1.26	62	38
10	0	0	0	174	1.88	60	40
11	0	+	+	162	1.72	65	35
12	0	+	–	160	1.68	66	34
13	0	–	+	166	2.04	71	29
14	0	–	–	164	2.02	72	28
15	0	0	0	174	1.88	65	35

According to the data obtained during the experiment (Table 1) in the analytic STATISTICA 6.0 system, three-dimensional graphs of dependencies for hardness and wear resistance were shown.

Figure 1 shows the dependency diagrams of the hardness of the welded layer  $H$  from the frequency  $\omega$  and the induction  $B_z$  of the magnetic field. The area of maximum (170...180 HB) hardness data are formed when the magnetic field  $B_z = 45...80$  mT and frequency  $\omega = 5...35$  Hz.

Figure 2 shows a graph of the influence of the magnetic field and surfacing current on hardness of welded layers. As you can see, the dependency is complex, and the hardness of the weld beads gets maximum data (170...180 HB) under the magnetic field induction of  $B_z = 45...80$  mT and a surfacing current of  $I_n = 470...480$  A.

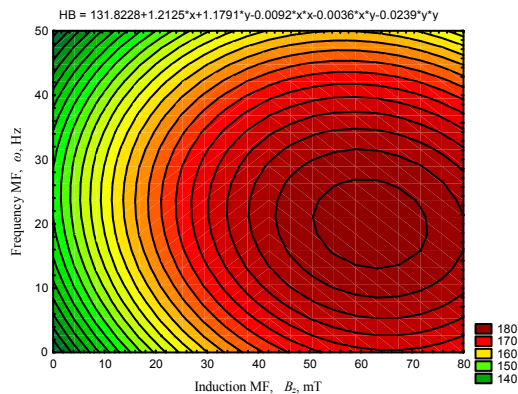


Figure 1 – Dependence of the hardness  $H$  of the build-up layer from the frequency  $\omega$  and the induction  $B_z$  of the magnetic field

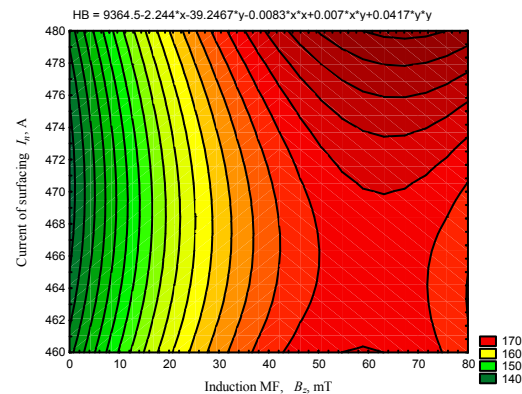


Figure 2 – Dependence of the hardness  $H$  of the welded layer from current  $I_n$  and induction  $B_z$  of the magnetic field

Figure 3 shows the effect of welding current and frequency of longitudinal magnetic field on hardness of welded layers. The dependency is nonlinear. Maximum hardness ( $H = 170$  HB) is observed at welding surfacing with the influence of longitudinal magnetic field of  $\omega = 15...30$  Hz frequency at a current surfacing  $I_n = 460...465$  or  $470...480$  A.

That is, to ensure the maximum hardness of weld metal we should use the following regimes: the magnetic field of  $B_z = 45...80$  mT, the magnetic field frequency  $\omega = 15...30$  Hz and welding current  $I_n = 470...480$  A.

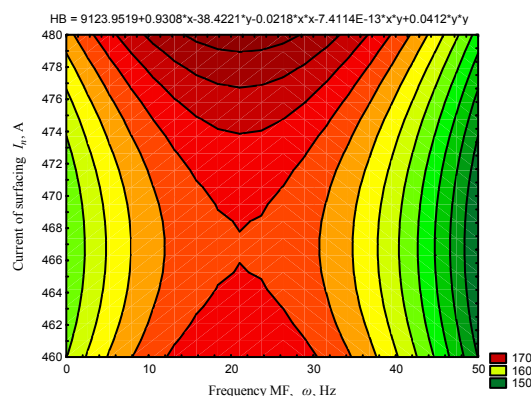


Figure 3 – Dependence of the hardness  $H$  of the welded layer from the welding current and magnetic field frequency  $\omega$

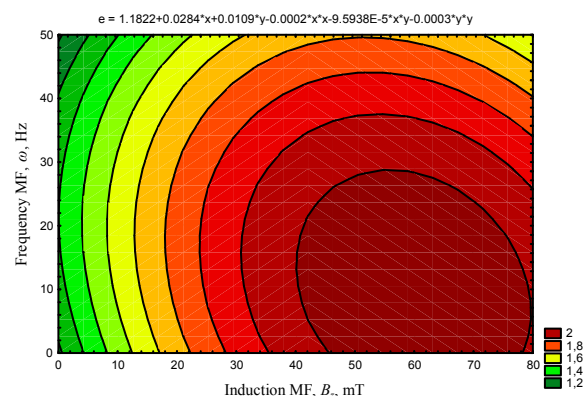


Figure 4 – Wear resistance  $\epsilon$  dependence of the welded layer from the frequency  $\omega$  and the induction  $B_z$  of the magnetic field

Figure 4 shows the effect of induction and frequency of longitudinal magnetic field on the durability of welded layers. It is evident that the increase of induction and frequency of longitudinal

magnetic field results in increase of the wear-resistance data. The area of maximum wear-resistance data of the weld bead is formed at the induction of longitudinal magnetic field  $B_z = 45...75$  mT, frequency  $\omega = 0...25$  Hz.

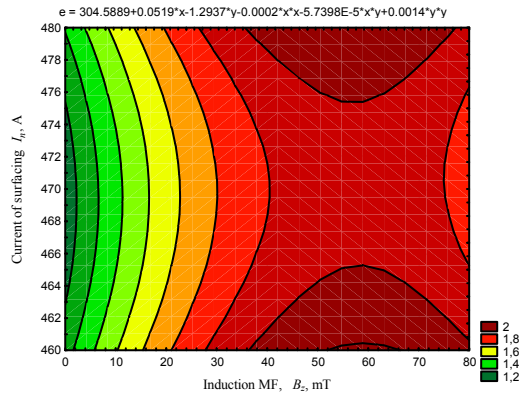


Figure 5 – Wear resistance  $\varepsilon$  dependence of welded layer from surfacing current  $I_n$  and induction  $B_z$  of the magnetic field

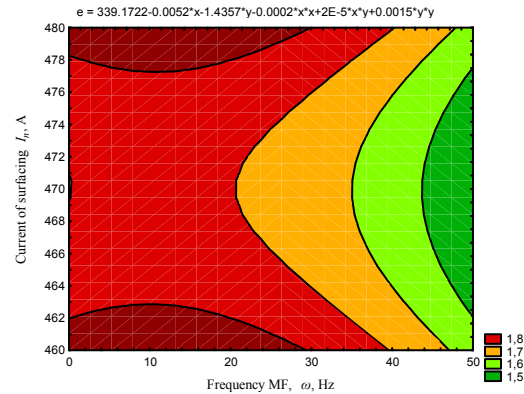


Figure 6 – Wear resistance  $\varepsilon$  dependence of welded layer from surfacing current  $I_n$  and frequency of the magnetic field  $\omega$

Figure 5 shows the wear resistance  $\varepsilon$  of welded layers from surfacing current  $I_n$  and the induction of the magnetic field  $B_z$ . As you can see, the dependency is complex and has two extreme zones. So, when surfacing with the influence of longitudinal magnetic field the durability of beads has maxima at the following modes: the magnetic field  $B_z = 45...75$  mT, welding current  $I_n = 460...465$  A; the magnetic field of  $B_z = 45...75$  mT, surfacing current  $I_n = 475...480$  A.

Figure 6 shows the effect of welding current and frequency of the magnetic field on the wear resistance. Wear resistance of welded layers obtains the maximum figures under the following conditions: frequency of the magnetic field  $\omega = 0...20$  Hz and the current surfacing  $I_n = 460...465$  A; frequency magnetic field  $\omega = 0...20$  Hz and welding current  $I_n = 475...480$  A.

That is, to ensure maximum wear resistance of the welded metal figures we should use the following mode: the magnetic field of  $B_z = 45...75$  mT, the magnetic field frequency  $\omega = 0...20$  Hz and welding current  $I_n = 460...465$  or  $475...480$  A.

Thus, for maximum hardness and wear resistance figures of the welded metal, we should use the following mode: the magnetic field of  $B_z = 45...75$  mT, the magnetic field frequency  $\omega = 15...20$  Hz and field current surfacing  $I_n = 475...480$  A.

The regression method was used to develop mathematical models for predicting the hardness and wear resistance of the welded metal. The equation of response surface, reflecting any monitored parameter  $y$  can be expressed as  $y=f(B_z, \omega, I_n)$ , where  $v_1$  represents  $B_z$ ,  $v_2 = \omega$ ,  $v_3 = I_n$ , and the selected dependency is a response surface of the second order:

$$v = b_1 + b_2 \cdot v_1 + b_3 \cdot v_2 + b_4 \cdot v_3 + b_5 \cdot v_1 \cdot v_2 + b_6 \cdot v_1 \cdot v_3 + b_7 \cdot v_2 \cdot v_3 + b_8 \cdot v_1^2 + b_9 \cdot v_2^2 + b_{10} \cdot v_3^2 \quad (1)$$

The analysis of the experimental results in the calculation of the regression coefficients which were performed using STATISTICA 6.0 software package. The regression coefficients are given in Table. 2.

Table 3 – Coefficients of the regression equation (1) for the revocation of  $H$  and  $\varepsilon$

		H	$\varepsilon$			H	$\varepsilon$
Coefficients	$b_1$	6858.7770	279.1011	$b_6$	0.007014	-0.000057	
	$b_2$	-2.096000	0.054854	$b_7$	0	0.000020	
	$b_3$	1.160345	0.000762	$b_8$	-0.009068	-0.000223	
	$b_4$	-28.611500	-1.184810	$b_9$	-0.023533	-0.000242	
	$b_5$	-0.003570	-0.000096	$b_{10}$	0.030417	0.001262	

The obtained equations for determining the hardness and wear resistance indicators of the welded metal depending on the induction of the magnetic field and the frequency of welding current:

$$H = 6858.777 - 2.096 \cdot B_z + 1.160345 \cdot \omega - 28.6115 \cdot I_n - 3.57 \cdot 10^{-3} \cdot B_z \cdot \omega + 70.14 \cdot 10^{-4} \cdot B_z \cdot I_n + 90.68 \cdot 10^{-4} \cdot B_z^2 - 23.533 \cdot 10^{-3} \cdot \omega^2 + 30.417 \cdot 10^{-3} \cdot I_n^2 \quad (2)$$

$$\varepsilon = 279.1011 + 54.854 \cdot 10^{-3} \cdot B_z + 7.62 \cdot 10^{-3} \cdot \omega - 1.18481 \cdot I_n - 9.6 \cdot 10^{-5} \cdot B_z \cdot \omega - 5.7 \cdot 10^{-5} \cdot B_z \cdot I_n + 2.0 \cdot 10^{-5} \cdot \omega \cdot I_n - 22.3 \cdot 10^{-5} \cdot B_z^2 - 24.2 \cdot 10^{-5} \cdot \omega^2 + 12.62 \cdot 10^{-4} \cdot I_n^2 \quad (3)$$

According to (Table 1) for the response function  $y=f(B_z, \omega, I_n)$  phase composition (%) Ferrite (F) and pearlite (P), the following regression coefficients were obtained (1):

Table 4 - Coefficients of the regression equation (1) for the response function F and P

		F	P			F	P
Coefficients	$b_1$	6306.005	-6206.01	$b_6$	-0.001895	0.001895	
	$b_2$	0.893602	-0.893602	$b_7$	0	0	
	$b_3$	-0.315101	0.315101	$b_8$	0.000341	-0.000341	
	$b_4$	-26.59460	26.59458	$b_9$	0.003733	-0.003733	
	$b_5$	0.002818	-0.002818	$b_{10}$	0.028333	-0.028333	

The equations are calculated to determine the effect of induction, magnetic field frequency and welding current on the phase composition:

$$F = 6306.005 + 0.8936 \cdot B_z - 0.3151 \cdot \omega - 26.5946 \cdot I_n + 281.8 \cdot 10^{-5} \cdot B_z \cdot \omega - 189.5 \cdot 10^{-5} \cdot B_z \cdot I_n + 34.1 \cdot 10^{-5} \cdot B_z^2 + 373.3 \cdot 10^{-5} \cdot \omega^2 + 283.33 \cdot 10^{-4} \cdot I_n^2 \quad (4)$$

$$P = -6206.01 - 0.8936 \cdot B_z + 0.3151 \cdot \omega + 26.59458 \cdot I_n - 281.8 \cdot 10^{-5} \cdot B_z \cdot \omega + 189.5 \cdot 10^{-5} \cdot B_z \cdot I_n - 34.1 \cdot 10^{-5} \cdot B_z^2 - 373.3 \cdot 10^{-5} \cdot \omega^2 - 283.33 \cdot 10^{-4} \cdot I_n^2 \quad (5)$$

Analysis of equations (4,5) showed that with increasing frequency and induction of the magnetic field, an increase in amount of ferrite at the magnetic induction data  $B_z = 70 \dots 80$  mT, the frequencies of the magnetic field of  $\omega = 35 \dots 50$  Hz F with ferrite index up to  $70 \dots 72\%$  is also observed. With the reduction of the induction magnetic field within  $B_z = 0 \dots 25$  mT at the welding current within  $I_n = 460 \dots 480$  A, we observe the increase in the amount of perlite.

Using the equations 4 and 5 we can predict the phase composition of the welded metal.

One of the factors that increases the wear resistance is the reduction of the welded metal grain. To determine the effect of longitudinal magnetic field on the grain size we estimate the grain size according to GOST 5639 for microsections.

Fig. 7 shows the scale distribution of welded samples of grain (welding current  $I_n = 480$  A) without external influence of a magnetic field (a);  $B_z = 40$  mT,  $\omega = 25$  Hz (b);  $B_z = 80$  mT,  $\omega = 25$  Hz (c); for the induction of  $B_z = 40$  mT, frequency  $\omega = 50$  Hz, welding current  $I_n = 460$  A (d).

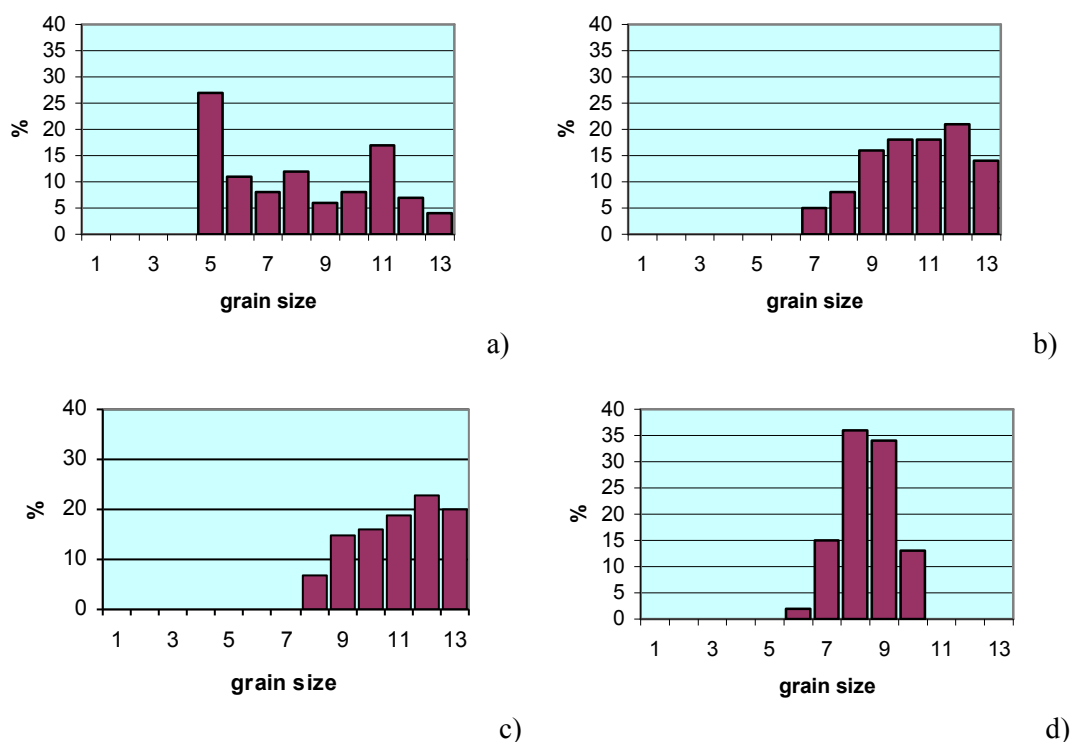


Figure 7 – The distribution scale of welded grain samples

## 5. Conclusions

In the analysis of experimental data we have got the nonlinear mathematical model of induction, magnetic field frequency and welding current dependence on hardness and wear resistance while surfacing that allow us to determine the effect of induction, magnetic field frequency and welding current on hardness and wear resistance of welded layers.

It was determined that for maximum wear resistance of the welded metal layer, we should use the following regimes: the magnetic field of  $B_z = 45 \dots 75$  mT, the magnetic field frequency  $\omega = 15 \dots 20$  Hz and welding current  $I_n = 475 \dots 480$  A.

## References

- [1] Gas-shielded welding of steels with consumable electrode. Engineering and technology of the future // Monograph / A.G. Potapjevskiy, Yu.N. Saraev, D.A. Chinakhov; Yurga Institute of Technology. – Tomsk: Tomsk polytechnic University Press, 2012. – 208 p.
- [2] Nosov D.G., Razmyshlyaev A.D. effectiveness of application of combined magnetic fields in submerged arc welding / D.G.Nosov, A.D.Razmyshlyaev // The Paton Welding Journal / № 4, 2009 (April), pp 16-20.
- [3] Nosov D.G., Maltsev V.V. The influence of magnetic fields by a melting rate of wire for arc surfacing under flux. Applied Mechanics and Materials, 2013, no 379, pp. 178-182.
- [4] Nosov D.G., Peremitko V.V. Influence of Frequency and Induction of Longitudinal Magnetic Field on The Electrode Metal Loss and its Spattering During MAG-Welding / D.G.Nosov, V.V.Peremitko // IOP Conf. Series: Materials Science and Engineering 91 (2015) 012011. – p 1–8.
- [5] Nosov D.G. Power source of electromagnetic system for arc welding using external magnetic fields control / D.G.Nosov // Welder. -2010. -№ 4. - pp.18-19.
- [6] <http://www.statsoft.ru/home/textbook/default.htm>