HAZ Structure Formation of Carbonaceous Steel at Impulse Welding

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Abstract. For increase of mining technique capacity at production and restoration wear resistant facings are widely applied. In this work, impacts of impulse welding of an intermediate layer on structural factors and facture toughness of wear resistant surfacing are studied. It, is established, that applying an intermediate layer with periodic impulse «teeth» forms a heterogeneous texture of intermediate layer, causing higher fracture toughness of wear resistant surfacing. It, is shown that defects made by current impulse have promoted a fine-grained structure of HAZ facing and grain-boundary allocation of grainy pearlite.

1. Introduction  
Breakages of working parts of mining machinery occur mainly because of adhesive worn-down process of various shafts in a pair metal-metal. Superficial weariness of excavator belts, rollers of bulldozers and dredges is noted [1].

Surfacing, is considered, one of operative kinds of restoration of parts. But, frequently, application of wear resistant surfacings is accompanied by splitting on the transition border from base metal to a weld layer. There is necessity in technologies, which by influence on a microstructure of weld metal and HAZ welding, on configuration of a fusion line would promote fracture resistant of repair surfacings of mining machinery.

Now there are adaptive impulse technological processes of welding and facing providing possibility to program heat input in a zone of welded joint, to operate processes of fusion and transfer electrode metal as well as to provide formation of finely dispersible structures of seam and thermal affected zone (HAZ) [2]. For studying the structure formation at pulse facing a mode of impulse profusion by changing speed of electrode supply is applied which in a combination with the facing nominal mode forms a gear contour of the intermediate layer between basic metal and wear resistant surfacing.

Aim: to study affection of impulse welding on formation of surfacing and HAZ structure and HAZ and predictive estimation of fracture resistance of surfacing by structural factors.

2. Materials and research methods  
For structural studies, surfacing was performed with impulse welding by Sv08G2S wire with diameter 1.5mm under AN-348A flux on steel samples made 40X.

The welding nominal current is Jn = 200 A., the pulse welding current is Ji = 600 A. Metallographic studies of weld metal in HAZ in the nominal and pulse modes were carried out by
means of the optical microscope Neofot. Brinell microhardness measurements, quantitative measurements of structural sizes of metal and compared zones were carried out.

3. Research results and discussion
Concentrated heat source during impulse heat supply affects certain conditions for the formation of weld pool. A mathematical model of impulse pulse welding for rotation bodies was created [3]. Based on this mathematical model, thermal cycles of pulse welding are constructed (Figure 1).

Figure 1. Thermal cycles at various depths from the surface of a welded cylinder: 1-on the surface; 2 - at depth 3 mm.; 3 - at depth 4 mm.

As known, the surface of pool mirror - $F_m$, mass - $G_n$, biphasic density - $p$, $V_{cn}$, wire feed speed - $\tau_a$, metal dwell time- $\tau_n$ are the main characteristics of pool used in metallurgical calculations [4].

$$\tau_n = G_n/p \cdot V_{cn} \cdot F_m$$

(1)

where $F_m$ is a cross-sectional area of the weld zone.

As $\tau_n$ at impulse welding can vary from 2 to 8 seconds, according to the magnitude of impulse current, the pool can differ from hemispherical to dagger shapes, which is confirmed by experimental data.

A very peculiar thermal cycle in the affected area of the welding current pulse, is noted: a current pulse contributes to a very sharp rise of the heating branch, implementation of a sharp peak of molten
metal into the mass of base metal leads to rapid cooling in the high-temperature zone. A lower branch of the cooling curve is quite flat due to the thermal affection of conventional surfacing (Figure 1).

Crystallization of pools, judging to on the microstructure of impulsive “tooth”, takes place from the bottom of pools to ascending direction. In pools of impulsive “tooth” a fine-grained isometric ferrite-carbide structure is formed (figure 2a). In the interval between impulse pools at weld nominal current \( J_n \) a metal welded layer is formed with dendrite texture (Figure 2b).

![Figure 2. The microstructure of impulse metal "tooth" (a) and conventional surfacing (b).](image)

Optical microscopy. Magnified x100.

The formation of the microstructure of welding pool of impulse metal "tooth" is connected with the development of hydrodynamic processes depending on parameters of the weld pulse current. According to the constructed thermal model at maximum parameters of the welding, current the pool reaches up boiling temperature of metal [3]. In this case a cavity can occur which is filled with liquid metal. The smaller pool the faster crystallization, is observed. The speed of hydrodynamic current of liquid is comparable to the speed of crystallization under the influence of metal steams. At dagger, welding the vertical current of liquid is possible, similar to the affection of heat concentrated sources. Thus, metal steams moving out of the cavity at the expense of friction about lateral walls of the cavity can set the motion of liquid surfacing metal [5]. The difference of superficial tension at the cavity bottom and on the pool surface can be the second possible cause of moving the melt in the vertical direction. As a result, of the specified hydrodynamic processes the homogeneous finely crystallized microstructure of impulse facing is formed.

The depth of welding by the current pulse is 3 mm. Therefore, the thermal cycles 2, 3 corresponds for describing the thermal processes in the fusion and overheating zone. Under the influence of the heat of the surfacing layer deposited in the nominal mode, the descending branch of the thermal cycles is 2, 3 flat, the calculated cooling rate is 7 deg./sec. In accordance with this, the crystallization of the metal microstructure in the zone of fusion and overheating occurs in the ferrite and perlite regions. The microstructure of the fusion zone and HAZ compared to a similar section of the microstructure of conventional surfacing is characterized by a finer grain of initial austenite. An important distinguishing factor is the difference in properties of the boundaries of initial austenite. In the fusion zone and HAZ of impulse “tooth,” the borders are jagged and almost indistinguishable, and they could only be considered when defocusing from the surface of the microsection (Fig. 3a).

Considerable diminishing of excess ferrite is characteristic on the borders of grains of initial austenite. Instead of it in the grain border-line areas pearlite with dispersible grainy cementite is identified. At high-rate of supercooling austenite in an interval 700-500° S the precipitation of perlite must prevail above ferrite [6,7].
On the other hand, such signs of borders and border-line areas are characteristic for phase riveted austenite and likely connected with advancing introduction of defects by the impulse current [8]. Similar intensification of carbide reaction was noted in steel at the welding cycle of explosively hardened steel [9,10]. As known, movement of carbon atoms to defects is accompanied with considerable heat allocation and diminishing of specific volume. In this case, carbon atoms located in the internodes move to fresh dislocations fixing them [11]. Such submicroscopic carbon stratification is observed during high-temperature deformation of austenite in steel HTMP processing steel and causes its hardness and ductility [12].

The indicated features of the formation of the HAZ microstructure under a pulsed “tooth”, in all likelihood, show the stability of the introduced defects by the current pulse and their effect on the products of austenite decomposition.

In the fusion zone and overheating with conventional surfacing, the grain boundaries of the initial austenite are straight and excess ferrite is released along them (Fig. 3b).

![Figure 3. Microstructure of HAZ metal under an impulse “tooth” (a) and under conventional surfacing (b).](image)

In both types of surfacing within the grains of initial austenite, granular perlite, is released within the limits of subgrains of the first order. In HAZ of pulsed tooth, granular perlite is more common and confined to the boundaries of austenitic grains.

According to the results of measuring the dimensions of the structural components, grinding of the average dimensions in pulsed surfacing is almost 2 times higher than that of conventional surfacing (Table 1).

| Surfacing technique                  | Position of analysed structure     | Structural components | Grain Diameter D μm |
|--------------------------------------|------------------------------------|-----------------------|---------------------|
| Impulse surfacing                    | HAZ of impulse pool                | Perlite grain         | 25,82               |
|                                      |                                    | Initial austenite grain | 41,00              |
| Surfacing in the nominal regimen     | Surfacing HAZ                       | Perlite grain         | 56,78               |
|                                      |                                    | Initial austenite grain | 90,00              |
As shown in table 1, the size of the phases in the zone of overheating of the pulse tooth and the nominal surfacing is smaller than 2 times. Features of the structure formation of the ZTV pulse surfacing metal are due to high heating and cooling rates. With fast heating, it is possible to change the sequence of phase transformations in comparison with slow heating. In addition to the process of nucleation of grains at the border of cementite and ferrite particles, two new processes appear: intensive nucleation of grains at the border of austenite with ferrite, as well as in the volume of ferrite grains. In addition, during rapid heating, austenite crystals can occur not only at the boundaries of ferrite grains, but also at the boundaries of blocks. The formation of austenite from many centers contributes to the formation of a very fine-grained structure. [6].

In order to evaluate the fracture toughness of surfacing, it is necessary to analyze the Brinell hardness distribution. The Brinell hardness data, are shown in Figure 4.

![Figure 4. The distribution of hardness by HB in various zones of surfacing and HAZ.]

The Brinell hardness that characterizes the indentation resistance at large plastic strains is often indicated in the standards for the material as an independent characteristic of the metal [13]. Strength characteristics, are calculated, according to the following empirical formula:

$$\sigma_b = 0.345 \times \text{HB (HB 1500 - 5000 MPa)}$$  \hspace{1cm} (2)

$$\sigma_{0.2} = 0.367 \times \text{HB - 240 (HB > 1500 MPa)}$$  \hspace{1cm} (3)

$$\delta = \frac{420}{2\sigma_b+\sigma_{0.2}} \times 100\%$$  \hspace{1cm} (4)

The calculated strength characteristics, are presented in table 2.

| Table 2. Predicted mechanical characteristics of surfacing in impulse and nominal conditions. |
| --- |
| Surfacing technique | Position of analysed structure | $\sigma_b$ MPa | $\sigma_{0.2}$ MPa | $\delta$ % |
| --- | --- | --- | --- | --- |
| Impulse Surfacing | Metal of impulse pool | 720,30 | 526,42 | 21,35 |
| | HAZ under impulse “tooth” | 867,70 | 683,00 | 17,36 |
| Surfacing in the nominal regimen | Surfacing metal | 670,90 | 473,80 | 23,13 |
| | Surfacing HAZ | 853,3 | 679,33 | 17,60 |

The hardness of HB in the area of impulse tooth over the entire section is higher than the hardness of the metal of conventional surfacing, then, respectively, higher than $\sigma_b$ and $\sigma_{0.2}$. It is known that the fatigue limit of structural steels ($\sigma_w$) increases with higher ultimate strength $\sigma_b$ [14]. The effect of
A grain-size increase on the cyclic hardness of metals is considered, to be the interpretation of the Petch-Hall equation for static loading. Grain boundaries during cyclic loading are obstacles to the propagation of fatigue cracks. Hence, it can be assumed that the metal of impulse tooth, that has increased hardness of HB and, accordingly, σ_{0.2} σ_{0.2} as well as crushed grain of the initial austenite, will have increased resistance to fatigue damage.

According to the theory of V. E. Panin during fatigue deformation the movement of grain as a whole is noted. In this case, the notch of the grain boundary resists the rotation process [15]. According to the rotation theory, the compared HAZ metal of steel 40X of conventional surfacing with excess ferrite along the boundary of the initial austenite is more susceptible to grain-boundary slippage during cyclic deformation.

Application of an intermediate layer with periodic impulse “teeth” forms a heterogeneous texture of the intermediate layer. Such a structure is close to composite materials in properties and should prevent the development of microcracks between the base and wear-resistant coating and thereby significantly increase the durability of mining equipment parts.

4. Conclusions
1. As a result of pulsed hydrodynamic processes, a finely crystalline, homogeneous microstructure of impulse surfacing, is formed.
2. It has been established that under the influence of impulse current in the HAZ of surfacing, a microstructure is formed in which the average size of the structural components is almost 2 times smaller than in the microstructure of HAZ of the conventional surfacing.
3. Due to the high rate of cooling of austenite in the range of 700-500 °C in the metal of the zone of fusion and overheating, fine-grained perlite, is released, which forms the jagged character of the border of the initial austenite. The toothed boundaries of the initial austenite inhibit grain-boundary slippage when exposed to welding stresses, thereby preventing the development of cracks.
4. The predicted mechanical characteristics of surfacing in impulse and nominal conditions show the increase in crack resistance of the intermediate layer.

5 References
[1] Kuzmin V R, Ishkov A M 1996 Prediction of cold resistance of structures and operability of equipment in the North (M) Mechanical Engineering p 303
[2] Saraev Yu N 1994 Pulse technological processes of welding and surfacing (Novosibirsk) Nauka p 108
[3] Moskvitina L V, Struchkova G P 1993 Trans. Int. conf. Computer methods in welding technology Calculation of parameters of thermal processes during surfacing with pulse penetration Essen (Germany) pp 25-30
[4] Prokhorov N N 1976 Physical processes in metals at welding (M) Metallurgy vol 2 p 600
[5] Vedenov A A, Gladush G G 1985 Physical processes in laser processing of materials (M) Energoatomizdat p 206
[6] Kidin I I 1969 Physical bases of electrothermal processing of metals and alloys (M) Metallurgy p 204
[7] Gulyaev A P 1986 Metallurgy Textbook for high schools 6th ed (M) Metallurgy p 544
[8] Kurdyumov G V, Utevsky L M, Entin R I 1977 Transformation in iron and steel (M) Science p 238
[9] Pashkov P O, Cheprasov D P, Peitssh S 1999 Effect of shock waves on the structure and properties of hardened steel J. FMM vol 87 2 pp 54 -58
[10] Moskvitina L V 2017 Proc. Int. Conf. on Advanced Materials with Hierarchical Structure for New Technologies and Reliable Structures Effect of explosive processing on martensitic transformation of high-tensile steel (Tomsk, Russia) AIP Conf. Proc. 1909 020144
[11] Volkov A E 2001 Microstructural modeling of deformation of alloys during repeated martensitic transformations Bull. Russ. Acad. Sci. Ser. Physical vol 66 9 pp 1290-1297
[12] Bernstein L M, Brunzel Y M, Golovanenko S A 1983 Metallurgy and heat treatment of steel (M) Metallurgy vol 3 p 215
[13] Markovets M P 1979 Determination of the mechanical properties of metals by hardness (M) Mechanical Engineering p 189
[14] Ivanova V S, Terentyev V F 1975 The Nature of metal fatigue (M) Metallurgy p 455
[15] Panin V E 1990 Structural levels of plastic deformation and destruction (Novosibirsk) Nauka p 251