FEATURES OF CHROMIUM FILLER MELTING DEPENDING ON LASER RADIATION PULSE SHAPE IN WELDING AND SURFACING PROCESSES

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Laser technologies are becoming ever wider applied in modern industry in welding and surfacing of metals. Here control of filler material heating and melting, its transfer and formation on the item is important. Laser radiation shapes for filler material melting and transfer with its minimum evaporation have been established with application of mathematical modeling of thermal processes. Pulse front parameters are determined, which ensure minimum energy consumption for heating and melting of chromium filler. Obtained results can be used in development of procedures of pulsed laser welding and surfacing of metals and alloys. 8 Ref., 1 Table, 9 Figures.

Keywords: *laser surfacing, pulse shape, power density, pulse duration, filler material, chromium, thermodeformational melting, solidification, weld pool, energy consumption, temperature fields*

Extensive application of lasers in modern industry for metal welding and surfacing depends on solving a number of problems, which may include the need for development of high quality and efficient processes with the capability of their further automation.

Laser welding and surfacing of metals is accompanied by a set of concurrent processes, the main of which are thermal impact on the metal surface, thermodeformational melting and solidification of metal in weld pool volume. Development of technological processes, which use pulsed laser radiation and filler material in the form of wire, should take into account several features, influencing the nature of formation and dynamics of the melt in weld pool zone.

It is experimentally established that under the conditions of laser welding [1], ensuring reliable contact between the filler and base promotes transfer of molten filler metal to the base and welded joint formation. Problems in welded joint formation develop, when there is no contact between the filler and base. In this case, the formed melt stays on the filler and after the laser impact stops, it solidifies in the form of a sphere. This kind of problems are the most common in those technological processes, where an automatic machine is used to feed the filler wire. This leads to interruption of the surfacing process and deterioration of the produced coating quality.

One of the variants of solving such problems can be application of laser radiation pulses of a special shape, providing not only heating and melting of the filler, but also molten metal transfer to the base. The transfer process can be implemented due to formation of a section with higher radiation intensity in the pulse, the impact of which on the filler initiates the process of

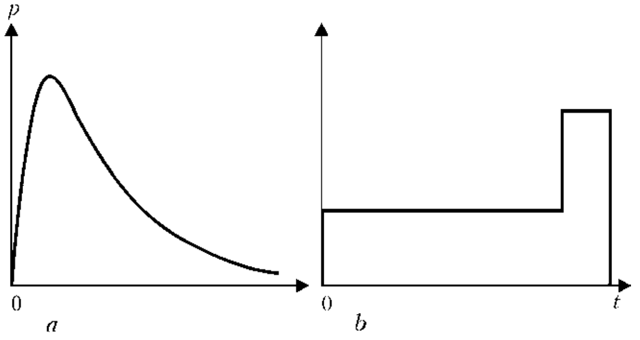

Figure 1. Laser pulses shaped in time (for *a* and *b* see the text)

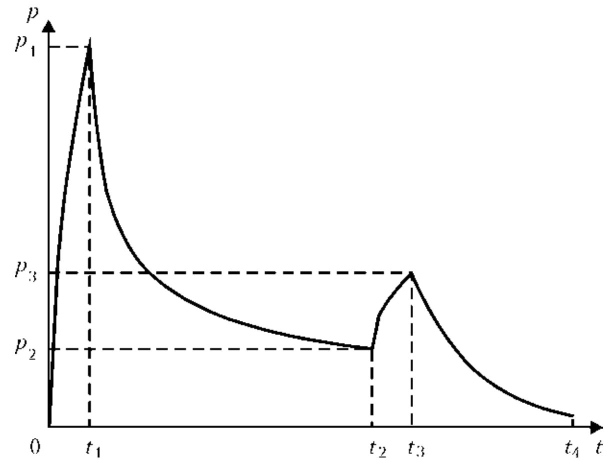

Figure 2. General view of time dependence of laser pulse power density

metal evaporation and generates the vapour recoil force, promoting molten metal separation from the filler wire.

Many batch-produced laser process systems use a pulse, the shape of which is shown in Figure 1, *a*. In this case, the maximum of laser radiation intensity fall to the pulse first part, and the decreasing trailing edge of this pulse does not create the conditions for molten metal separation from the filler wire.

Work [1] suggests using for filler material melting a pulse, the shape of which is given in Figure 1, *b*. Filler melting is performed by the pulse first part, and separation of the formed melt drop from the wire is provided by its second part. However, the nature of the dependence of power density on time imposes certain limitations at selection of the technological modes of the melting process.

The objective of this work was determination of the time and energy parameters of laser radiation pulse, ensuring filler material melting and transfer to the base with minimum metal evaporation in welding and surfacing processes.

It is proposed to use for this purpose a pulse, the shape of which is given in Figure 2. Pulse power density distribution in time can be presented as follows:

$$p(t) = \begin{cases} \dfrac{2T_{\mathrm{m}}\lambda}{t_1\sqrt{\alpha\pi}}\sqrt{t}, \ 0 < t \le t_1, \\[2ex] \dfrac{2T_{\mathrm{m}}\lambda}{t_1\sqrt{\alpha\pi}}(\sqrt{t} - \sqrt{t - t_1}), \ t_1 < t \le t_2, \\[2ex] \dfrac{2T_{\mathrm{m}}\lambda}{(t_3 - t_2)\sqrt{\alpha\pi}}\sqrt{t - t_2 + q(t_2)}, \ t_2 < t \le t_3, \\[2ex] q(t_3)e^{\frac{t - t_3}{\tau}}, \ t_2 < t \le t_4, \end{cases}$$

where α is the filler material temperature conductivity; λ is the specific heat conductivity of filler material; T_{m} is the filler material melting temperature; $t_1 - t_4$ is the time of completion of the first-fourth pulse front, respectively; τ is the time of pulse front decrease.

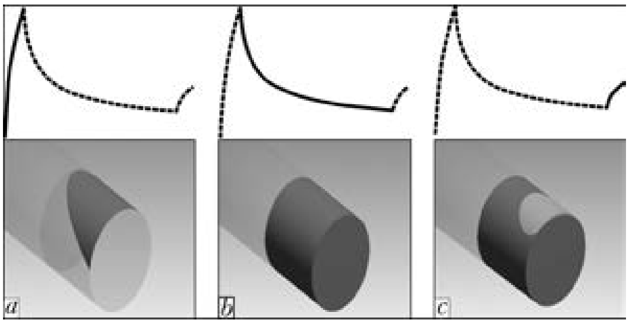

Figure 3. Schematic of laser radiation impact on filler material (for *a*–*c* see the text)

The pulse has a steep first front, reaching maximum value, which corresponds to power density, required for filler material surface melting in the zone of laser radiation impact (Figure 3, *a*), and decreasing second front, which ensures melting of the entire filler material volume (Figure 3, *b*) [2]. With steep third front, separation of molten filler material occurs under the impact of the recoil force, generated at metal evaporation from the melt surface (Figure 3, *c*). The fourth pulse front (see Figure 2), as a result of relatively slow decrease of radiation intensity, promotes the molten metal filling a recess, formed in the pulse initial part, as well as formation of the deposited bead before the moment of the start of metal solidification [3].

To determine the parameters of a pulse, ensuring melting and transfer of filler material to the base with minimum evaporation of metal, it is necessary to synchronize the time of initiation of the evaporation process and time to complete melting of filler material in the area of laser radiation impact. During investigations modeling of the process of laser surfacing with chromium filler wire of 0.2–0.4 mm diameter of base a of the same material, was performed. Temperature

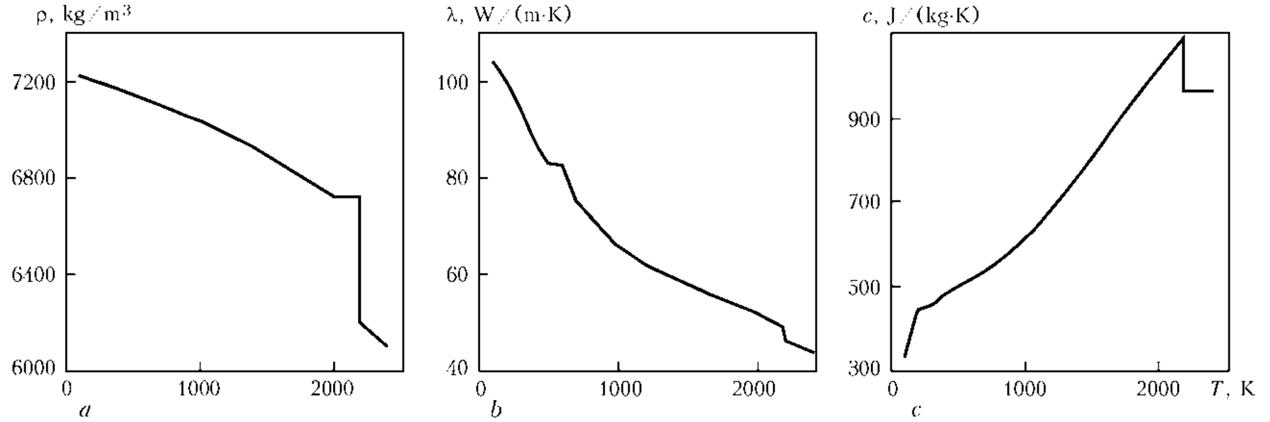

Figure 4. Temperature dependence of chromium thermophysical properties: *a* — density; *b* — specific heat conductivity; *c* — specific heat capacity

Time energy parameters of pulse first and second front

Filler surface temperature, °C	Peak power density $p_1 \cdot 10^{10}$, W/m^2	Duration of pulse second front$\cdot 10^{-3}$, s	Pulse energy$\cdot 10^{-3}$, J		Total energy of the first two fronts$\cdot 10^{-3}$, J
			First front	Second front	
2000	7.88	22.5	13.5	129.5	143.0
2100	8.27	16.5	14.2	108.9	123.1
2200	8.67	11.2	14.9	91.8	106.7
2300	9.06	7.7	15.5	77.4	92.9
2400	9.46	5.7	16.2	67.7	83.9
2500	9.85	4.0	16.9	16.9	77.7

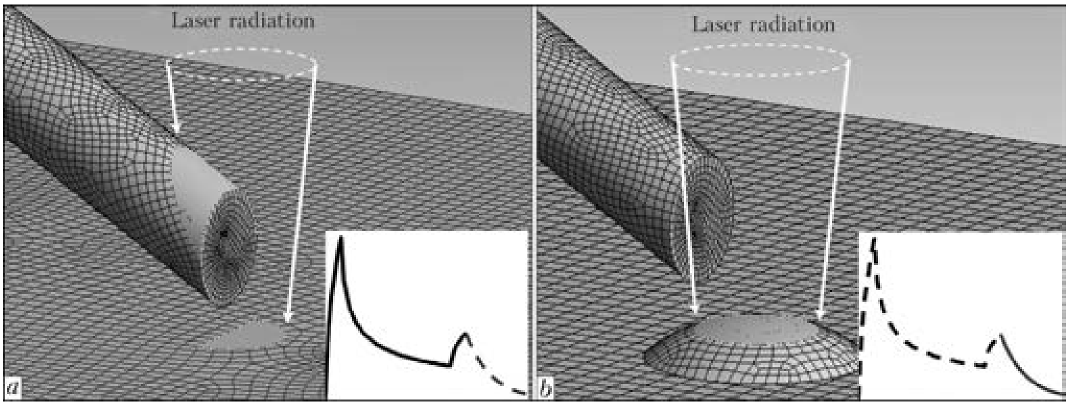

Figure 5. Finite element discretization and schematic of laser radiation impact on the surface of both filler and base (*a*) and deposited bead surface (*b*)

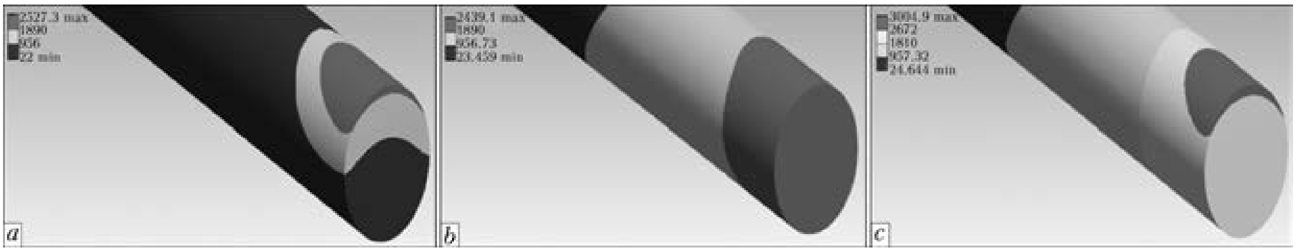

Figure 6. Temperature field distribution in chromium filler of 0.2 mm diameter: *a* — t_1 = 0.5; *b* — t_2 = 4.0; *c* — t_3 = = 4.5 ms

fields were calculated within 3D finite element model, which solved the nonlinear equation of heat conductivity [4–7]. Nonlinearity of the equation is due to temperature dependence of material thermophysical properties (Figure 4) [8]. Laser radiation power density distribution over the beam cross-section was considered to be uniform (see the expression, given above).

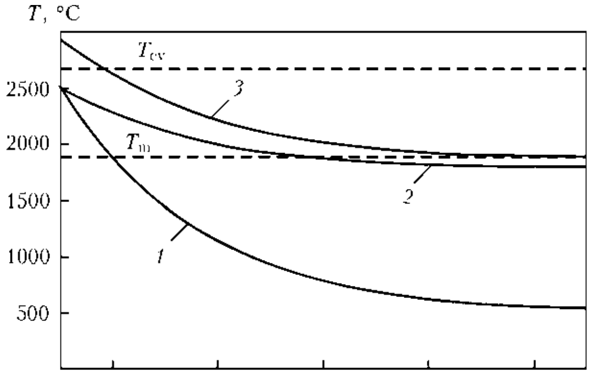

Figure 7. Temperature distribution by filler depth at specified moments of time: *1* — t_1 = 0.5; *2* — t_2 = 4.0; *3* — t_3 = 4.5 ms

Finite element discretization and schematic of laser radiation impact on the surface of the filler and base are given in Figure 5. Laser beam is focused so that 50 % of the energy is consumed by the filler, and 50 % — by base metal (Figure 5, *a*). During time $0 < t \le t_2$ the filler metal in the area of laser radiation impact is heated and melted; at moment of time t_3 melt drop under the impact of gravity and recoil force, generated at metal evaporation from the surface, separates from the filler, drops onto the base and spreads over it. Fourth front of laser pulse during time $t_3 < t \le t_4$ promotes deposited bead formation (Figure 5, *b*).

During investigations energy parameters of the first two pulse fronts, shown in the Table,

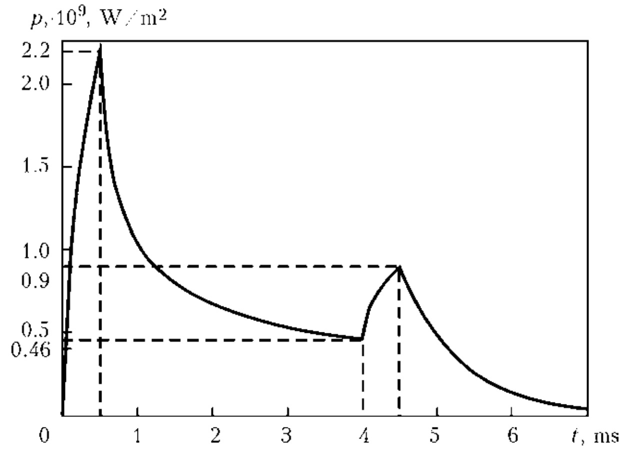

Figure 8. Pulse shape of focused laser radiation for melting 0.2 mm diameter chromium filler

have been determined, which have a significant influence on the dynamics of filler material heating up to temperature T ($T_m \le T < T_{ev}$).

As is seen from tabulated data, minimum energy consumption ($77.7 \cdot 10^{-3}$ J) for metal heating and melting in the area of impact of the first two fronts of laser radiation pulse (see Figure 3) is ensured at second front duration of $4 \cdot 10^{-3}$ s. In this case, the filler surface temperature is equal to 2500 °C.

Thus, optimization of the processes of filler material heating and melting can be implemented by changing the time and energy characteristics of the first two fronts of laser radiation pulse.

Distributions of temperature fields in 0.2 mm chromium filler wire at moments of time, corresponding to ends of pulse fronts, are shown in Figure 6. So, at the moment of time t_1 = 0.5 ms the filler is molten to the depth of 0.02 mm (Figures 6, *a* and 7), at t_2 = 4 ms the melting depth is equal to 0.09 mm (Figures 6, *b* and 7), at t_3 = = 4.5 ms the volume of filler metal in the area of laser radiation impact melts completely, and melt surface is heated up to evaporation temperature (Figures 6 *c* and 7).

Thus, conducted studies allowed establishing the shape of time and energy parameters of laser radiation pulse for melting 0.2 mm chromium filler (Figure 8). Moreover, melting of 0.2–0.4 mm filler material is ensured due to application of this pulse shape, and is implemented by selection of the pulse second front duration (Figure 9).

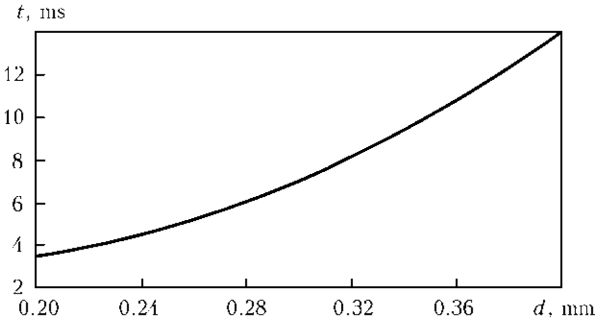

Figure 9. Dependence of second front duration of laser radiation pulse on filler diameter

Conclusions

1. Laser radiation pulse shape has been established for filler material melting and transfer to the base with minimum metal evaporation.

2. Parameters of the first two pulse fronts are determined, which ensure minimum energy consumption for chromium filler heating and melting.

3. Study results can be used in development of process modes of pulsed laser welding and surfacing of metals and alloys.

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