ESTIMATION TO OPTIMIZE ENERGY SPENT ON A SINGLE WELDING POOL CREATION IN MICRO-PLASMA POWDER DEPOSITION PROCESS OF JS32 NICKEL SUPERALLOY HPT BLADE'S BANDAGE SHELVE

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From the point of estimating the energy input forming a single welding pool, the experience of industrial application of micro-plasma powder welding deposition (MPWD) in large-scale repair of aircraft gas turbine engine (GTE) blades made of JS32 nickel-based superalloy has been analyzed. For some welding mode types, used in industry for the last 10 years, the conditions providing technological strength of "substrate-deposited metal" welding joint in bandage shelves refurbishment have been specified. Pecularities of a number of technological factors affecting heat-input into the workpiece at the stage of a single weld pool existence have been examined, proposing future directions for MPWD process optimization.

Index Terms - Aircraft gas turbine blades repair, hot cracking susceptibility, microplasma powder welding deposition, nickel superalloys, weldability, technological strength.

I. INTRODUCTION

A number of factors, such as complexity and high cost price of production, has created conditions in the beginning of 90-th of XX century to develop a complex of technological measures to prolong the operating resource of AN-124 "Ruslan" transport aircraft D-18T engine high pressure turbine (HPT) blades. In particular, this foresaw the replacement of blade material from JS6U to JS26 and JS32 [1], and also development and implementation of a number of subsequent generations of repair technologies for operational-damaged bandage shelve edges, such as: vacuum brazing of profiled wear-resistant HTN-61 alloy pads [2]; TIG-cladding of HTN-61 alloy [2,3]; micro-plasma powder welding deposition of JS-32 superalloy and vacuum brazing of HTN-61 or HTN-62 profiled pads [4-6]. The latest MPWD-based technology has allowed to increase the flight resource of HPT blades up to over 8-10 thousand hrs [6]. In Russian Federation similar problems of GTE blades refurbishment are being solved by the means of laser powder deposition technology [7].

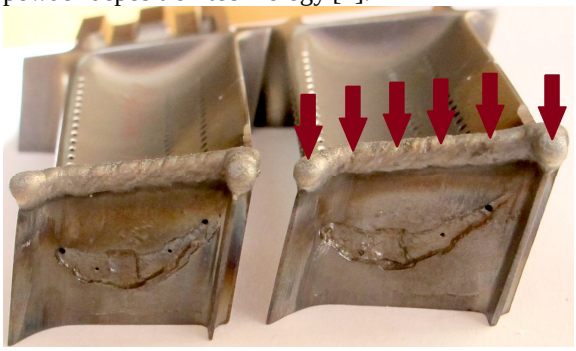


Fig. 1 – Refurbished bandage shelve edges of JS32-VI alloy HPT blade of D-18T aircraft GTE (MPWD deposition zones pointed with arrows)

Thereby, HPT blade of a D-18T aircraft engine (fig. 1) is a typical workpiece, being used for already 25 years to work out and develop large-scale repair technologies, particularly for more than 10 years using MPWD of JS32 superalloy (fig. 2).

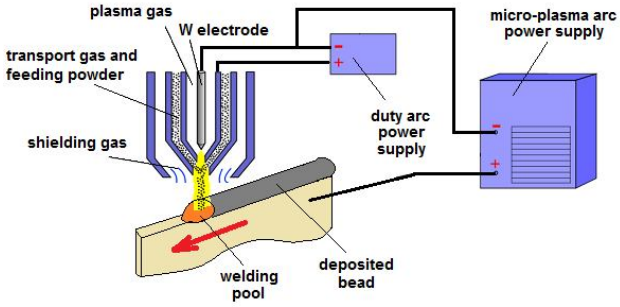


Fig. 2 – MPWD process schematic

Despite continuous industrial experience of large-scale repair of aircraft components and quite significant amount of research conducted [4-6, 8], the phenomena of enhancing weldability for JS32 limited weldability nickel-based superalloy (table 1) in MPWD process is researched insufficiently and the potential for the process optimization is not fully exposed respectively. Hot cracking susceptibility during fusion welding and subsequent technological heatings of nickel-based superalloys can be significantly decreased or even totally removed by the means of substantial limitation of the amount of heat input into the workpiece [4-10]. Therefore one of promising methods to prevent such cracking iduring MPWD process is to form new technological decisions based on heat input optimization at the stage of welding pool existence.

Table 1 – Basic alloying elements contained in nickel superalloy JS32-VI according to TU 1-92-177-91

mass %											
C	Cr	Ni	Co	Al	Mo	W	Nb	Ta	Re	Fe	B
0,12-0,18	4,3-5,6	Base	8,0-10,0	5,6-6,3	0,8-1,4	7,8-9,5	1,4-1,8	3,5-4,5	3,5-4,5	<1,0	<0,02

II. RESEARCH METHODS

Experiments on MPWD of bandage shelve edges of sample D-18T aircraft engine HPT blades have been conducted with the use of 2 specialized microplasma powder deposition machines. Welding modes have been set approximate to optimal. Considering difference in technical parameters for respective equipment, the welding current modes differed in period duration, regulation depth and duty cycle ratio ranged in 2-30 A, and powder feeding mode:

- UPNS304M2/M3 machine, PPS04 plasma torch (upgraded in Paton EWI NAS Ukraine) – impulse current duty cycle ratio S≈1,5 and portioned powder feeding rate G = 3,5 g/min;
- STARWELD PTA 190H machine, HPH80 plasma torch (Kennametal Stellite Gmbh) – impulse current duty cycle ratio S≈1,5 constant powder feeding rate G = 2,5 g/min

Sample blades welding deposition mode parameters have been registered with 1 kHz frequency. Data registration system has been assembled on the base of: Hall probes by LEM brand, marks LA 100-P and LV-25P for current and voltage measurements accordingly; ADC m-DAQ14 (National Instruments); Lenovo G570 laptop. The processing of welding current cyclograms registered has been implemented with the use of PowerGraph 3.3.8. software.

Having voltage values registered during impulse current powder deposition being actually constant, it has been agreed to consider the electric charge traveled through the catode-anode arc gap during powder deposition time t, as the exact quantitive index of heat input into the workpiece. This welding mode energy index was visually estimated as the area of a figure, surrounded by curve $i(t)$ and axe t on the interval being analyzed. It was calculated as definite integral of welding current by time:

$Q^I = \int_0^\tau i(t)dt$, [A·sec] or [C]. (1)

Based on experimentally defined values of this energy index, the effective heat arc power q_i [11] and total heat input Q_Σ (considering energy conversion efficiency [11]) have been calculated

$$q_i = k_q \cdot \int_0^\tau i(t)dt + c_q \cdot t \text{ , [W];} \quad (2)$$

$$Q_\Sigma = q_i \cdot t \text{ , [J] ;} \quad (3)$$

where k_q and c_q – are linear approximation coefficients of function $q_i = f(I)$, experimentally defined with flow calorimetry of microplasma arc on water-cooled copper anode (e.g. [12]).

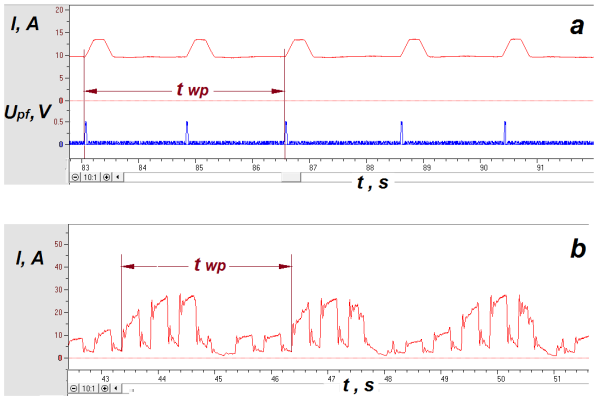


Fig. 3 – Basic types of analyzed welding modes with typical intervals t_{wp}, characterizing the stage of a single welding pool existence: a – UPNS-304M2/M3 welding machine; b – STARWELD PTA 190H welding machine.U_{pf} – periodic signal activating the powder feeding mechanism.



Fig. 4 – Repair zone of D-18T aircraft GTE HPT blade and the thermocouple insertion point

To analyze the stage of single welding pool existence, a linear section of bandage shelve deposition (fig. 4) with constant values of welding current amplitude characteristics, was examined. The stage of a single welding pool was identified by next MPWD mode composition pecularities: for UPNS304M2/M3 machine – double-portioned powder deposition; for STARWELD PTA 190H machine – typical periodic impulse current amplitude varying cycle. The duration of single welding pool existence, amount of heat input into the workpiece and average effective heat arc power, have been determined as average values of

respective parameters, defined by analysis of welding current oscillogram interval covering existence of 10-16 welding pools.

In current research, the next base MPWD technological setup has been used: argon shielding gas; JS32 of 63-160 μm fraction feeding powder containing next gases: [O] = 0,0124 and [N] = 0,0004 (mass %). The next technological factors affecting the base MPWD setup have been examined: 10%H_2 addition into the shielding gas contain; narrower feeding powder fraction size range; increasing feeding powder's oxygen and nitrogen contain; varying welding current regulation methods. During the estimation of single or multiple technological factors others were left unchanged.

The deposited bead's cross-section area has been calculated using AutoCAD 2012 software, by means of measuring the areas of macrograph images, previously being cut from medium zone of linear bandage shelve deposition and etched using Marble's Reagent. The deposited bead height and surface penetration depth have been estimated by direct measuring compared to the opposite non-deposited bandage shelve edge. The substrate part in the deposited bead γ_S, [%] was calculated as:

$$\gamma_S = \frac{F_B - F_S}{F_B} \cdot 100; \quad (4)$$

where F_B – total area of deposited bead's cross section; F_S – total area of melt substrate's cross section.

In addition, to analyze typical MPWD modes, cooling rates have been registered, with a thermocouple inserted into the back of the welding pool at the beginning of linear bandage shelve zone deposition (see fig. 4). For registration, next equipment had been used: ADC ADAM-4118 with ~0,1 sec temperature measurement discreteness and wolfram-rhenium 0,3 mm diameter thermocouple VR-5/20. $T(\tau)=f(U_{tc}(\tau))$ relation, where τ [sec] – thermal cycle measurement duration, T[ºC] – metal temperature, U_{tc} [mV] – heat-affected thermocouple signal, defined according to GOST 3044-94.

III. EXPERIMENTAL DATA

Calculated average time and energy characteristics of single welding pool existence (weld pool melt metal existence duration t_P, effective heat arc power q_i and total MPWD heat input into the workpiece Q_Σ) during D-18T GTE HPT blade's linear bandage shelve zone MPWD are given: for UPNS304M2/M3 welding machine – table 2; for STARWELD PTA 190H welding machine – table 3.

Table 2 – Average time and energy characteristics of single welding pool existence during D-18T GTE HPT blade linear bandage shelve zone MPWD with UPNS304M2/M3 welding machine

Exp. setup num.	Estimated technological factor	Single weld pool existence stage characteristics			Deposited bead cross section characteristics	
		t_{WP}, sec	q_i, W	Q_Σ, J	F_B, мм^2	γ_S,, %
1	base technological setup	3,56	247,77	880,50	11,47	12,44
2	+shielding gas 90%Ar+10%H_2	3,22	219,37	705,21	11,23	10,60
3	+shielding gas 90%Ar+10%H_2 + feeding powder fraction 160-200 μm	1,55	181,50	562,60	10,64	10,46
4	+ shielding gas 90%Ar+10%H_2 + feeding powder fraction 63-80 μm	1,10	200,80	447,20	9,75	9,59
5*	+ shielding gas 90%Ar+10%H_2 + increased cross section bead deposition	11,2	205,34	2299,31	28,36	8,40
6	+ shielding gas 90%Ar+10%H_2 + impulse current cyclic regulation range 5-15 A	3,27	156,20	509,60	10,61	7,83

Note: * + direct current cyclic regulation range 7.5-15 A

Table 3 – Average time and energy characteristics of single welding pool existence during D-18T GTE HPT blade linear bandage shelve zone MPWD with STARWELD PTA 190H welding machine

Exp. setup num.	Estimated technological factor	Single weld pool existence stage characteristics			Deposited bead cross section characteristics	
		t_{WP}, sec	q_i, W	Q_Σ, J	F_B, mm^2	γ_S, %
1	base technological setup	2,80	190,37	531,34	10,04	8,30
2	+ feeding powder fraction 40-63 μm	2,95	152,51	450,45	9,71	15,76
3	+ [O] = 0.038 mass %; [N] = 0,004 mass % (feeding powder fraction 63-160 μm)	3,25	202,71	660,30	11,19	15,96

Experimentally defined deposited metal cooling rate T(τ) relations for 3 main technological setups for D-18T aircraft engine HPT blade's bandage shelve MPWD, used in their refurbishment are displayed on fig.5: setup 1 – corresponds to setup 1 in table 2 and is similar to the one described in [6]; setup 2 – corresponds to setup 2 in table 1; setup 3 – corresponds to setup 5 in table 1 and is similar to those described in [4, 5].

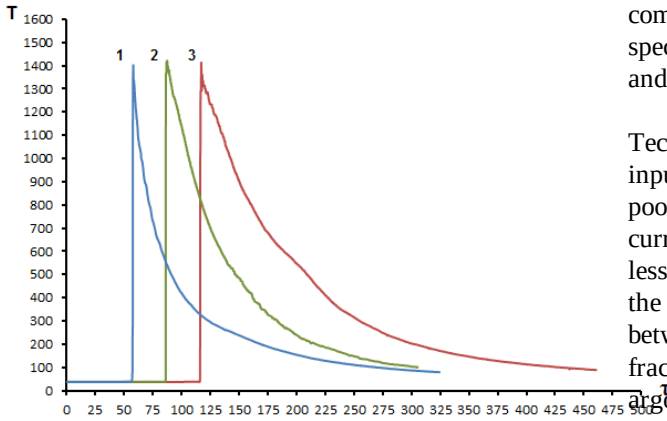


Fig. 5 – Temperature T to time τ relation during deposited metal cooling for main technological setups used in D-18T aircraft GTE HPT blade's bandage shelve: 1 – setup 1; 2 – setup 2; 3 – setup 3

IV. RESEARCH RESULT ANALYSIS

It has been determined that technological strength of "substrate-deposited metal" welding joint during D-18T aircraft engine HPT blade refurbishment with welding current up to 15 A, is ensured with not less than 95% probability, when next single welding pool characteristics are provided: existence time – 1,1…11,5 sec; average effective heat arc power of micro-plasma arc – 150…250 W; total heat input into the workpiece, during formation of a deposited bead with desired cross section area – 450…2300 J; deposited metal cooling rate from melting temperature to 700°C – 12…35°C/sec. Hereby the established deposited bead's cross section area reaches from 9,7 to 28,3 mm^2, and substrate part in deposited bead is from 7,8 up to 16,0 %.

Total heat input into the workpiece is proportional to single welding pool existence stage's heat input. It is determined by average effective heat arc power and duration of welding pool filling with feeding powder to form desired deposited bead's cross-section. Additional influence of negative technological factors increases values of these parameters (see table 2, exp. setups num. 1,5; table 3, exp. setup num. 3), influence of positive factors – decreases (see table 2, exp. setup num. 2-4, 6; table 3 exp. setup num. 2). The negative effect of some unpleasant technological factors can be compensated by widened technical characteristics of specialized equipment (see table 2, exp. setup num. 2 and table 3, exp. setup num. 1).

Technological factors, significantly lowering heat input into the workpiece at the stage of single welding pool existence are: cyclic regulation of welding current with upper to lower amplitude values ratio not less than 2,5; lowering oxygen and nitrogen contain of the feeding powder used; limitation of the difference between upper and lower range of feeding powder fraction sizes between 20-40 μm; using argon-hydrogen, particularly 90%Ar+10%H_2 compositions as shielding gas.

It was formerly recognized, that simultaneous combination of formerly listed positive technological factors, when compiling D-18T aircraft engine HPT blade's bandage shelve MPWD refurbishment setup, can decrease total heat input into the workpiece by at least 20-40% compared to optimal setups given in table 2 and 3. Optimization effect achieved, is expected to contribute into MPWD process's successful application in Ukrainian aircraft repair industry, for increased operating time JS32 alloy GTE blades refurbishment, particularly with the use of multilayer deposition process.

CONCLUSION

HPT blade's bandage shelve MPWD process with current under 15 A has been observed from the point of heat input necessary to maintain the existence of single welding pool, at the same time providing technological6 strength of welding joint "substrate-deposited metal" of JS32 nickel superalloy.

Multiple technological factors, assisting to lower the amount of energy spend to form a basic part of deposited bead, have been stated and a new approach to optimize the process has been proposed.

REFERENCES

[1] V.A. Boguslayev, V.M. Muravchenko, P.D. Zhemanyuk, V.I. Kolesnikov "Technological providing of operating qualities for GTE parts. Turbine blades. Part II," Zaporizhia: «Motor Sich» JSC publ., 2003.

[2] G.I. Peichev, A.K. Shuryn, V.E. Zamkovoj, G.P. Kalashnykov, N.V. Andrejchenko, "Development and application of high-temperature wear-resistant alloy for GTE blade's bandage shelves," Technological Systems, vol.3, pp. 40–42, Mar. 2000.

[3] I.A. Peremylovsky "Strengthening turbine blade badnage shelves with heat-resistant alloys," I.A. Peremylovsky, I.A. Petrik. Gas turbine technologies, vol. 3, pp. 35-38, Mar. 2002.

[4] G.I. Peichev "Operation-worn construction elements of turbine JS-type alloy cast blade's bandage shelves refurbishment,"Aviation and space technics and technology, vol. 25, pp. 221-223, Aug. 2005.

[5] K.A. Yushchenko, V.S. Savchenko, A.V. Yarovitsyn, A.A. Nakonechny, G.F. Nastenko, V.E. Zamkovoj, O.S. Belozertsev, N.V. Andrejchenko "Development of the technology for repair microplasma powder cladding of flange platform faces of aircraft engine high-pressure turbine blades," The Paton Welding Journal, vol. 8, pp. 21-24, July 2010.

[6] Zhemanyuk P.D., Petrik I.A, Chigilejchik S.L. "Experience of introduction of the technology of reconditioning microplasma powder surfacing at repair of high-pressure turbine blades in batch production," The Paton Welding Journal, vol. 8, pp. 39-42, July 2015.

[7] S.V. Nerush, A.S. Yermolayev, A.M. Rogalev, S.A. Vasylenko "Research of high-pressure turbine first stage's JS32-VI alloy blade refurbishment technology with the use of atomized JS32-VI metal powder laser deposition," Digital scientific journal "VIAM proceedings", vol. 44, pp. 24-34, July 2016.

[8] Yushchenko K.A., Yarovitsyn A.V., Chervyakov N.O. "Effect of energy parameters of microplasma powder surfacing modes on susceptibility of nickel alloy ZhS32 to crack formation," The Paton Welding Journal, vol. 2, pp. 2-6, Feb. 2017.

[9] DuPont John N. Welding metallurgy and weldability of nickel-base alloys/ John N. DuPont, John C. Lippold, Samuel D. Kisser.– John Willey&Sons, Inc., Hoboken, New Jersey, 2009 – 455 p.

[10] N.N. Rykalin "Calculation of welding thermal processes," M.: Mashgiz, 1951 — 296 p.

[11] P.V. Gladkiy, E.F. Perepliotchikov, I.A. Ryabtsev "Plasma cladding," K.: «Ecotechnologiya», 2007. – 292 p.

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