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EFFECT OF ENERGY PARAMETERS OF MICROPLASMA POWDER SURFACING MODES ON SUSCEPTIBILITY OF NICKEL ALLOY ZhS32 TO CRACK FORMATION

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Presented is a technological experience of the E.O. Paton Electric Welding Institute in area of development of surfacing technologies for serial repair of blade flanges of aircraft GTE of nickel heat-resistant alloys ZhS26 and ZhS32 with oriented crystallization based on microplasma powder surfacing. It is shown that heat input value in a single-layer or multilayer surfacing using up to 40 A welding current can uniquely determine susceptibility to crack formation in «base–deposited metal» joints. A range of values of total heat input was determined. They can be used to predict absence or presence of cracks (hot or reheating cracks) with high probability. 18 Ref., 7 Figures.

Keywords: *nickel heat-resistant alloys, microplasma powder surfacing, weldability, crack formation susceptibility, effective heat power of arc, heat input, total heat input*

Nickel heat-resistant alloys ZhS26 and ZhS32 with oriented and single-crystal structure, containing 60 vol.% and more of strengthening γ'-phase are used in a series of current aircraft engines as a material of cast blades of high- and middle-pressure turbines (HPT and MPT) [1, 2]. Their sealing and antivibration elements working under more than 900 °C temperature wear and damage in process of operation most of all. Due to significant cost of the blades development of technology of their flange repair has been very relevant for long period of time [3–9] at extension of aircraft engine life.

Earlier these nickel heat-resistant alloys due to high content of strengthening γ'-phase were considered unweldable because of high susceptibility to hot crack formation in application of filler material similar on composition to base metal and level of high-temperature strength.

Appearance of hot cracks in the deposited metal and HAZ of the base metal with austenite structure is caused by exceeding a level of deformations, developing in a welded joint at cooling or under outside effect, and metal ductility in its specific zone [10]. Young's elasticity modulus in alloy ZhS32 at T = 20–1100 °C reduces from 140 to 90 GPa and thermal coefficient of linear expansion α rises in $(1.1–2.4)\cdot 10^{-5}$ 1/°C interval [11]. Due to known proportionality of solid body deformation in process of heating to $E\alpha T$ product [12] it can be assumed that the high values of rate of tensile deformations growth in cooling of welded joint including ZhS32 alloy are caused by respective combination of indicated physical-mechanical properties of this material at high temperature. It is considered that one of the most efficient techniques for prevention of crack appearance in fusion welding of nickel heat-resistant alloys is reduction of heat input in the product [13] that in most cases is reached by limitation of welding current intensity.

E.O. Paton Electric Welding Institute has developed a process of microplasma powder surfacing of ZhS32 alloy, which is currently used for serial repair of the blades of alloys ZhS26 and ZhS32 [5–9].

Peculiarity of this process is on-line control of welding current in 2–35 A range, surfacing rate in 0.2–3.0 m/h range and amount of filler powder in 0.5–5.0 g/min range depending on thickness of deposited blade flange and required bead section [5–9]. Necessary section of the deposited bead is determined by depth of wear or damage of blade flange (Figure 1) and can be provided per one [5–7] or several [8, 9] layers of repair surfacing.

In earlier published works [5–6] the main attention was paid on registration of separate modes of microplasma surfacing, at which in alloys ZhS26 and ZhS32 their susceptibility to crack formation in fusion welding and further heat treatment didn't appear.

Mastering of multilayer surfacing of alloy ZhS32 is very relevant in recent time due to expansion of a range of repaired parts and increase of zone of service

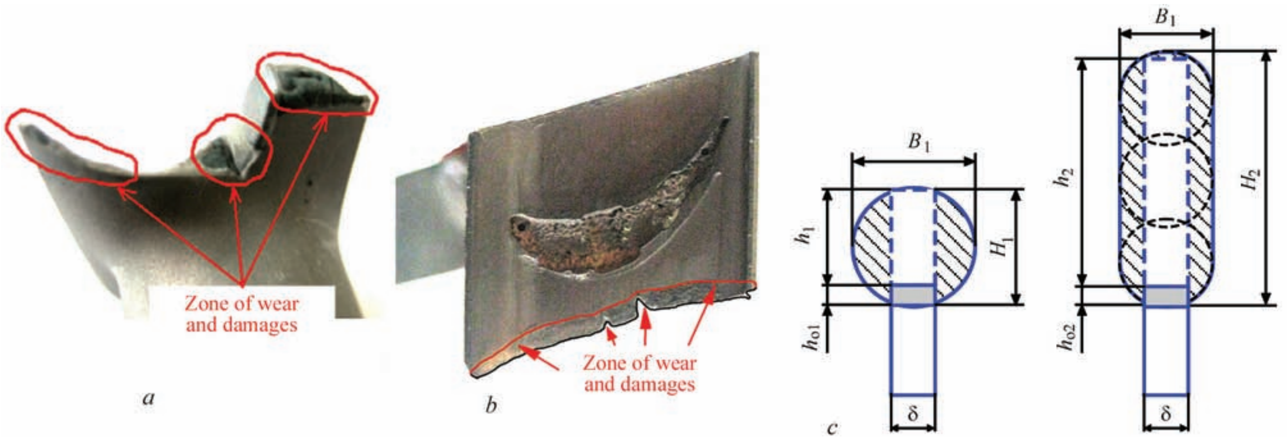

Figure 1. Appearance of wear removed zone and damages on blade flanges of aircraft GTE (*a*, *b*) and scheme of distribution of base and deposited metal in cross-sections of bead at their single-layer ($h_1 \le 4$ mm) and multilayer ($h_1 > 4$ mm) repair surfacing (*c*) (δ is the thickness of blade flanges; h_{o1}, h_{o2} are the depth of base metal penetration; H_1; H_2 are the height of deposited bead; h_1, h_2 are efficient height of deposited bead; B_1, B_2 are the width of deposited bead

damages [8, 9]. In this connection, aim of the present paper is evaluation of process ranges of modes of microplasma powder surfacing from point of view of crack formation resistance in «base–deposited metal» welded joint of ZhS26-ZhS32 and ZhS32-ZhS32-systems. The cracks can be hot as a result of fusion welding as well as appearing at their further heat treatment.

Series of leading foreign researchers characterize the welding processes on location of areas susceptible and unsusceptible to crack formation in corresponding welded joints of nickel heat-resistant alloys depending on value of heat input and welding rate [14]. The attempts of such an analysis for investigated alloys and process of microplasma powder surfacing have not been made yet.

In our case the following was taken as analyzed total indices of its modes:

- effective heat power of arc $q_{\text{heat s.}}$ characterizing specific power of heat flow of the microplasma arc in anode per unit of time, and first of all, depending on value of welding current intensity [5, 15];
- heat inputs in the product, characterizing average amount of heat introduced per 1 mm of length of deposited bead and, in particular, caused by duration of weld pool existence in molten state [16, 17].

In single-layer surfacing they correspond to heat input $q_{\text{heat s.}}/\nu$ (taking into account effective efficiency of the product); and in multilayer surfacing they are determined by sum of heat inputs in deposition of each layer $\Sigma Q_\Sigma/L$.

The results were received in process of adjustment and mastering of commercial technologies for of microplasma powder surfacing repair of the flanges of blades of ZhS26 and ZhS32 alloys with up to 3–6 thou. h of running, in particular, in aircraft engine D18T [6, 7]. At that in this case of multilayer surfacing no intermediate heat treatments were used for welding stresses relaxation after deposition of each layer or due to technological requirements they were limited by 1050 °C mode (2.5 h) [6, 7]. At that, solubility of γ'-phase in ZhS32 alloy does not exceed 50 % [18] at such modes of heat treatment. Therefore, it is assumed that they do not have significant relaxation effect on accumulated welding stresses and deformations in contrast to $\gamma + \gamma' \rightarrow \gamma \rightarrow \gamma + \gamma'$-transformation in process of homogenization of nickel heat-resistant alloys ZhS26 and ZhS32.

Statistical data on the modes of microplasma powder surfacing were collected in course of registration of its electric parameters and their further treatment using procedure of work [16]. Averaged energy indices of surfacing modes [15, 16], namely effective heat power of arc $q_{\text{heat s.}}$ and heat input $q_{\text{heat s.}}/\nu$, were determined in 5–40 A range. Used procedure through $q_{\text{heat s.}}(I)$ dependence allowed taking into account pulse modes of welding current with different pulse shape and time of pulse duration as well as level of constriction of microplasma arc, caused by diameters of plasma and focusing nozzle channels of the microplasmatron and composition of shielding gas in Ar + (0–10) % H_2 system. At that, the analysis was made for the process of surfacing (Figure 2) of directly pilot and pilot-commercial batches of GTE aircraft blades (Figure 3) or the process of deposition of the samples in form of narrow substrate [15] of up to 5 mm width, simulating real modes of repair of blade flanges (Figure 4). In some cases (see Figure 4, *a*) such samples were later on used for evaluation of level of heat resistance of «base–deposited metal» welded joint of alloy ZhS32 [6].

Analyzed values of heat inputs in the product in the studied welded joints were correlated with process strength on criterion of crack formation susceptibility

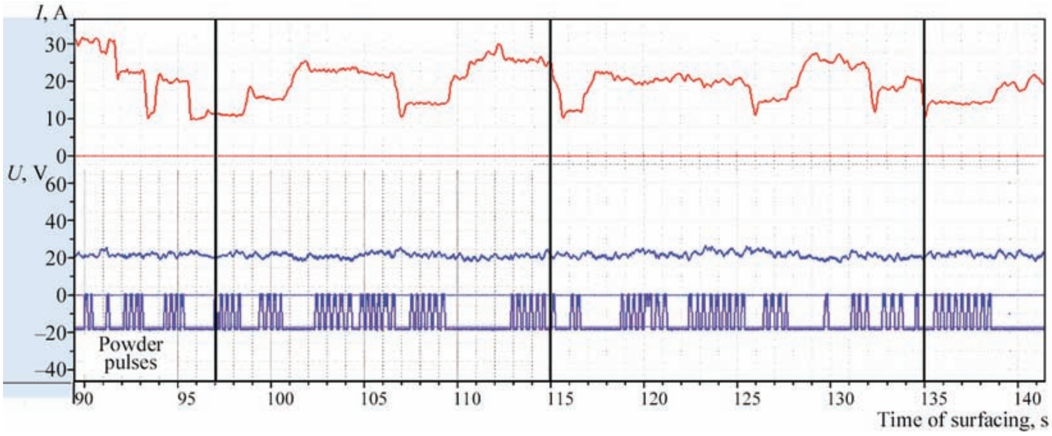

Figure 2. Fragments of registration of parameters of surfacing mode in flange surface of upper platform of MPT blade of ZhS26 alloy

Figure 3. Appearance of aircraft GTE blades, repaired with microplasma powder surfacing of ZhS32 alloy: *a* — HPT blade, alloy ZhS32, engine D18T [6]; *b* — MPT blade, alloy ZhS26, engine D18T [7]; *c* — shroudless HPT blade with inner gas-cooled cavity [8]

in «base–deposited metal» joint of nickel heat-resistant ZhS26–ZhS32 and ZhS32–ZhS32 alloy systems. Failures of the process strength of respective joint did not appear in process of fusion welding and their further heat treatment (Figure 5) or under some conditions appeared with high probability in form of macro- and microcracks in fusion welding and/or further heat treatment of the deposited parts (Figure 6). Macrocracks were detected visually or using penetrant testing, microcracks were found applying metallographic analysis of longitudinal cross-sections of «base–deposited metal» joint at ×50–200 magnification.

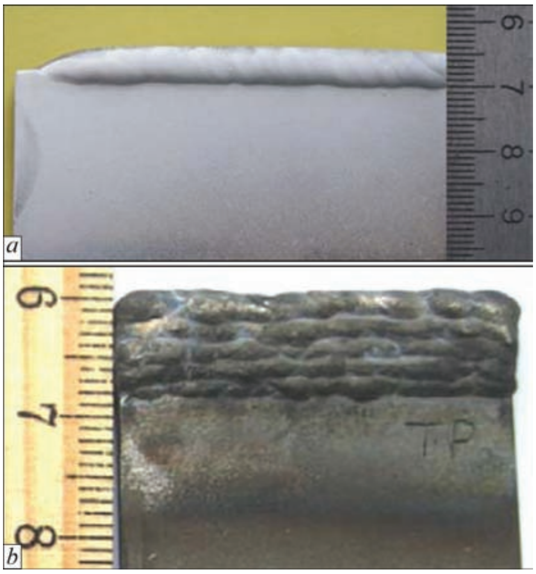

Figure 4. Appearance of samples of ZhS32 alloy simulating repair surfacing of blade flanges of aircraft GTE: *a* — single-layer surfacing on 3.5 mm narrow substrate width; *b* — five-layer surfacing on 2.5 mm narrow substrate width

Statistical analysis showed that in microplasma powder surfacing the value of effective heat power of arc in a range less than 650 W and, respectively, the value of welding current up to 30–40 A inclusively can not be uniquely considered as a process parameter completely determining crack formation susceptibili-

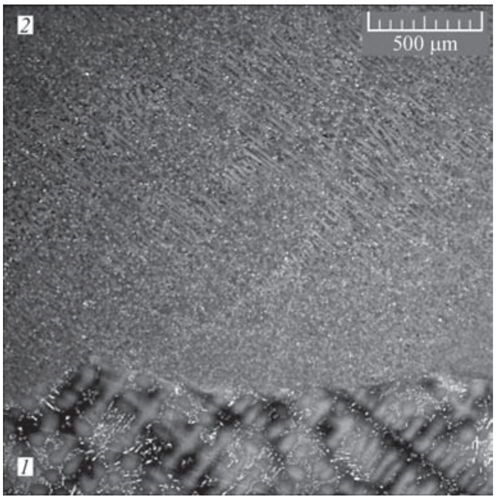

Figure 5. Example of sound microstructure of «base (*1*) — deposited (*2*) metal» joint of ZhS32-ZhS32 system, area of fusion line, REM

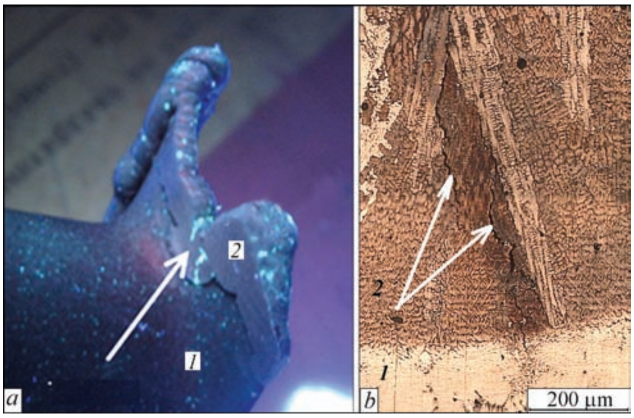

Figure 6. Examples of appearance of macro- and microcracks (indicated by arrows) in «base (*1*) — deposited (*2*) metal» joint, detected in process of adjustment of technology of microplasma powder surfacing of MPT blade of aircraft engine D18T (alloy ZhS26): *a* — at penetrant testing; *b* — at metallographic testing (optical microscopy)

ty in «base–deposited metal» joints, made on narrow substrate of 1–5 mm width. Failures of the process strength in $q_{\text{heat s.}}$ = 150–450 W value range as well as obtaining of respective welded joints without crack formation at $q_{\text{heat s.}} \approx 600$ W are possible.

At the same time, the value of total heat inputs $\Sigma Q_\Sigma/L$ (Figure 7) can sufficiently uniquely characterize the possibility of crack formation in studied «base–deposited metal» joints of ZhS26–ZhS32 and ZhS32–ZhS32 system. Boundary between the zones, in which the process strength of corresponding joints is provided with high probability or does not provided, lies depending on narrow substrate width δ = 1–5 mm at $\Sigma Q_\Sigma/L$ = 3200–4200 J/mm. In future work, a level of maximum allowable heat inputs for serial repair shall be additionally specified depending on a level of effect of serial of the process factors, namely state of the base metal; height of deposited bead and number of its layers; initial temperature of the joint before deposition of the next layer and others.

It was experimentally determined that in cooling the rate of tensile deformations growth in heat-affected zone of the deposited bead, as a rule, does not exceed the critical values of maximum allowable deformation for alloys ZhS26 and ZhS32. The bead is deposited using single-layer and multilayer microplasma powder surfacing on narrow substrate of 1–5 mm width in a process range of parameters characterized by $I \leq 40$ A, $q_{\text{heat s.}} \leq 650$ W and $\Sigma Q_\Sigma/L \leq$ ≤ 3000–4000 J/mm.

Thus, it is shown that the effective heat power of arc and value of welding current in up to 40 A range play smaller role, than it was supposed earlier, from point of view of demonstration of susceptibility of the studied nickel heat-resistant alloys with oriented crystallization to crack formation in fusion welding. In particular, this fact is proved by the possibility of performance of sound deposits at variation of welding current intensity in 2–3 times in course of sufficiently long period of time (see Figure 2). It is more reasonable to assume that effect of current intensity and effective heat power of arc develop indirectly via the value of total heat inputs together with surfacing rate and amount of deposited metal layers.

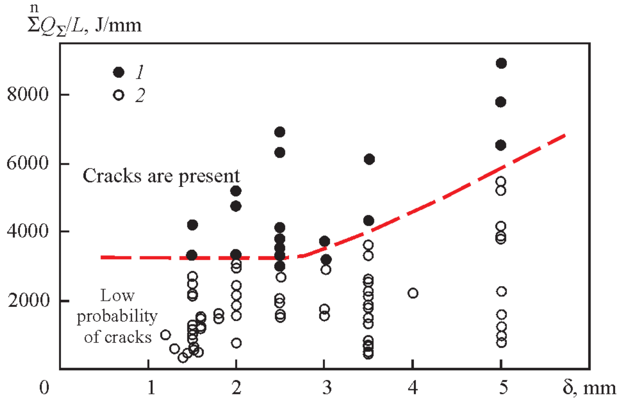

Figure 7. Dependence of obviousness (*1*) and non-obviousness (*2*) of susceptibility to crack formation in «base-deposited metal» joint of ZhS26-ZhS32 and ZhS32-ZhS32 systems on value of total heat inputs $\Sigma Q_\Sigma/L$ and width of narrow substrate δ

Conclusions

1. A process range of energy parameters of surfacing modes, used for repair of blade flanges of aircraft GTE and providing absence of hot cracks or reheating cracks, was analyzed for conditions of microplasma powder surfacing on narrow 1–5 mm substrate of nickel heat-resistant alloy ZhS32 of limited weldability.

2. For the first time, a boundary was set between process ranges of surfacing modes, where absence or presence of cracks, including hot ones in process of fusion welding, is observed. Its position depending on width of narrow substrate is characterized by value of total heat input 3200–4200 J/mm.

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