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DEVELOPMENT OF THE TECHNOLOGY OF RECONDITIONING THE SEALING ELEMENT OF NOZZLE BLADE SECTOR FROM DIFFICULT-TO-WELD HIGH-TEMPERATURE NICKEL ALLOY OF ZhS6 TYPE BY MICROPLASMA POWDER SURFACING

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In order to ensure the technological strength at reconditioning of the side sealing element of a sector of nozzle blades from ZhS6K alloy with the required deposition volume of 7–13 cm^3, a less heat-resistant material with sufficient deformability was selected. At microplasma powder surfacing it is characterized by the following level of values of short-time strength relative to the deposited metal ZhS6K: 0.7–0.8 at 20 °C; 0.5–0.55 at 1000 °C. Compared to the known technological solutions based on filler materials of IN625 type, it allowed increasing the level of deposited metal high-temperature strength by practically 2 times at 1000 °C at effective limitation of high-temperature ductility $\varepsilon_{1000\,°C} \leq 1.0$–1.5 %. Proceeding from the described materials science studies, PWI developed a new repair technology of microplasma powder surfacing that has successfully passed experimental-practical trials at SE «Lutsk Repair Plant «Motor». 10 Ref., 2 Tables, 5 Figures.

Keywords: high-temperature nickel alloy ZhS6K, microplasma powder surfacing of 7–13 cm^3 volume, deformability, technological strength, short-time strength values, repair technology

It is known [1] that after operation for more than 700 h the relative quantity of damaged parts rises significantly in one of the modern bypass gas turbine engines with an afterburner. A typical representative of such parts is the sector of nozzle blades (SNB) of a high-pressure turbine (HPT) from high-temperature nickel alloy (HTNA) ZhS6K (Figure 1, *a* and Table 1), which belongs to the group of stator parts. One of the main types of operational damage of this SNB are thermal fatigue cracks, making it impossible to apply the currently available reconditioning technologies using methods based on fusion welding and brazing, (Figure 1, *b*) and loss or damage of the design shape of a large number of sections of the side sealing element, as a result of corrosion-erosion damage at high temperatures (Figure 1, *c*). Cutting out such defects requires practically complete removal of the material of HPT SNB side sealing element (Figure 1, *d*).

Design-technological analysis of a typical repair cutting out of HPT SNB side sealing element (Figure 2, *a*, *b*) showed the need for deposition of large volumes of HTNA — v_d = 7–13 cm^3, depending on the number of its damaged sections. Use of IN625 type alloys without dispersion strengthening by γ′-phase as the deposited metal for the side sealing element (see Table 1) for this SNB was considered unpractical, because of the risk of loosing the spatial stability of the reconditioned structural element as a result of a reduced high-temperature strength and increased ductility of such a material in operation at $T \geq \geq 1000$ °C. It should be noted that the authors of this work are unaware of any previous examples of application of repair technologies of aviation GTE parts with such an increase of the volume of deposition of HTNA with a high content of strengthening γ′-phase. Analysis of publications in the post-Soviet space showed

Table 1. Content of the main alloying elements in nickel alloys ZhS6K and IN625, wt.%

Alloy	C	Cr	Ni	Co	Al	Ti	Mo	W	Nb	Ta	Re	Fe	B
ZhS6K	0.13–0.2	9.5–12.0	Base	4.0–5.5	5.0–6.0	2.5–3.2	3.5–4.8	4.5–5.5	1.4–1.8	<2.0	<0.4	<0.4	< 0.02
IN625	0.10 max	20.0–23.0	Same	1.0 max	0.4 max	0.4 max	8.0–10.0	–	3.15–4.15		–	5.0 max	–

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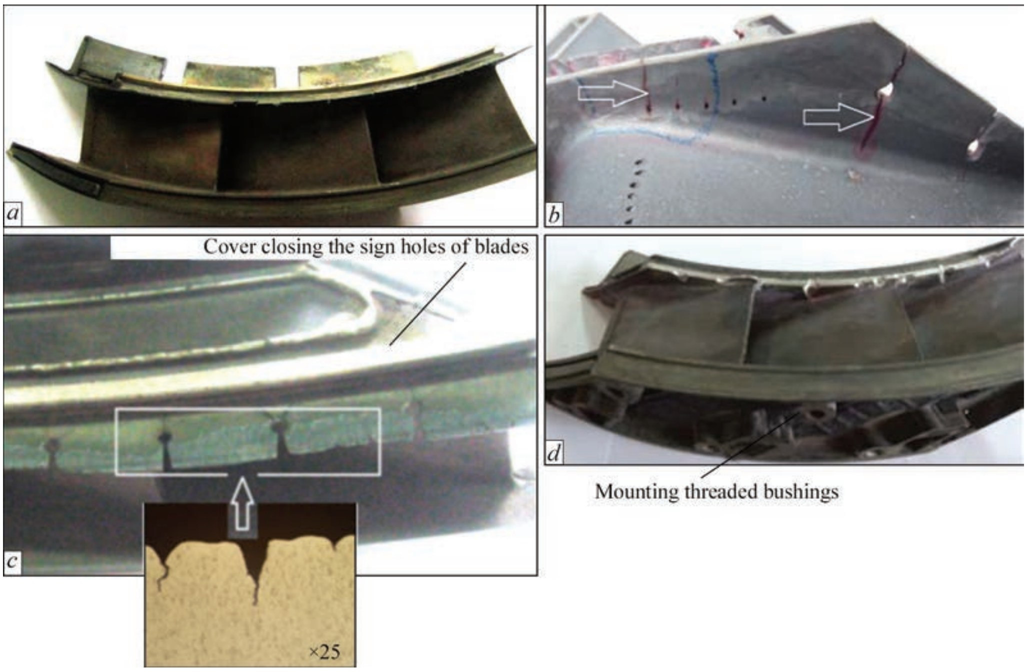

Figure 1. Appearance of HPT SNB from ZhS6K alloy (*a*), its operating damage (*b*, *c*) and cutting out of defects on the side sealing element (*d*)

Figure 2. Characteristics of the required cross-section of the deposited bead at restoration of HPT SNB side sealing element from ZhS6K alloy (*a*) and appearance of its surface restored by multilayer MPPS after liquid-penetrant testing (*b*, *c*)

that operational damage of nozzles from HTNA of ZhS32 type was repaired using practically the technologies of microplasma powder surfacing (MPPS) and laser-plasma surfacing with v_d of up to 2 cm^3, for instance, [2–5].

A priority task at development of the technology for restoration of the side sealing element of the above HPT SNB was evaluation of cracking susceptibility for a typical structure of ZhS6K alloy deposited by MPPS method (Figure 3) at successive increase of its volume in the direction of the respective increase of height *H* and length *L* of the deposited bead, in order to ensure the technological strength of such a welded joint (see Figure 2, *b*) in as-deposited condition.

Table 2. Results of static tensile testing of ZhS6K deposited metal in as-deposited condition (without heat-treatment)

Number, type	T_{test}, °C	$\sigma_{0.2}$, MPa	σ_t, MPa	ε, %
1	20	1004	1004	0.5
2	900	639	641	0.8
3	1000	377	386.5	0.65
4	1100	–	256	0.1

Similar to previous work [6], devoted to assessment of cracking susceptibility of ZhS32 alloy at MPPS, respective evaluations in terms of determination of the main indices of total heat input into the product were conducted also for the deposited ZhS6K metal (Figure 4). It was established that no cracks form in the «base metal–deposited metal» welded joint of ZhS6 type alloy under the conditions of typical MPPS applications for restoration of blade shroud platforms ($L \approx 35$–40 mm; $H \leq 5$ mm; $v_d \leq 2.0$ cm^3). However, already at increase of bead length above $L = 100$ mm during multilayer deposition of more than 5–7 mm height ($v_d > 4$–6 cm^3), the susceptibility to reheat cracking begins to be manifested in the deposited metal of ZhS6K alloy in most cases. Their appearance is due to the cumulative action of two factors: formation of residual longitudinal stresses [7] and established low deformability of the formed deposited ZhS6K metal (Table 2). Thus, the impossibility of ensuring the technological strength at application of ZhS6K alloy as deposited metal is established for the conditions of restoration of HPT SNB side sealing

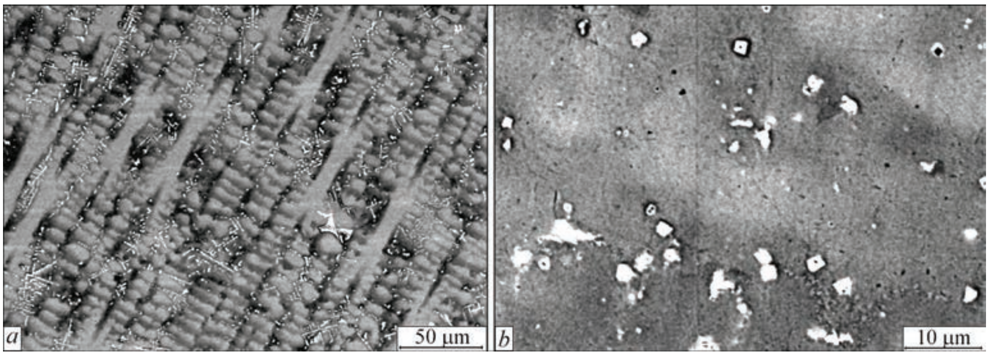

Figure 3. Microstructural features of ZhS6K deposited metal in as-deposited condition, scanning electron microscopy

element by multilayer MPPS, because of low deformability of the alloy during surfacing.

Periodical increase of deformability of ZhS6K deposited metal (to the level of $\varepsilon_{1000\,^\circ C}$ = 5.8–7.2 % [7]) by conducting vacuum heat treatment at the homogenization temperature could not be implemented in this HPT SNB, because of the design-technological limitations by the heat treatment temperature. They were due to the presence of brazed joints in it (sign hole cover, mounting threaded bushings), made using Vpr11-40N braze alloy. The temperature of such a brazed joint formation is much lower than that of ZhS6K alloy homogenization [8].

In view of impossibility of ensuring the technological strength at restoration of the side sealing element of HPT SNB at application of deposited metal of ZhS6K alloy, a decision was taken to apply deposited metal of reduced high-temperature strength. Static tensile testing of witness-samples of such deposited metal (Figure 5), conducted in servohydraulic machine MTS-810 by the procedure of [9], showed that the following level of short-term strength values is achieved compared to ZhS6K deposited metal: 0.7–0.8 at 20 °C and 0.5–0.55 at 1000 °C.

Compared to existing/known technology solutions that envisage application of filler materials of IN625 type with high-temperature strength $\sigma_{t\ 1000\,^\circ C} \approx$ ≈ 110 MPa, the new technological approach, in addition to stable provision of technological strength of multilayer MPPS of volume v_d = 7–13 cm^3, allowed increasing the level of high-temperature strength of the deposited metal practically 2 times at 1000 °C and in addition effectively limited its high-temperature ductility $\varepsilon_{1000\,^\circ C} \leq$ 1.0–1.5 %. Considering the known level of service loads of this HPT SNB (≈ 20 MPa [1]), the assessed values of high-temperature strength of the deposited metal allow prediction of the presence of the required set of functional properties for its restored side sealing element, in particular spatial stability, necessary to ensure reliable operation in modern aircraft GTE of RD-33 type.

Proceeding from the materials of the conducted investigations, repair of a test batch of the above HPT SNB from ZhS6K alloy was conducted for Lutsk Repair Plant «Motor» by the technology developed at PWI (see Figure 2, *c*) and respective technological instructions were developed.

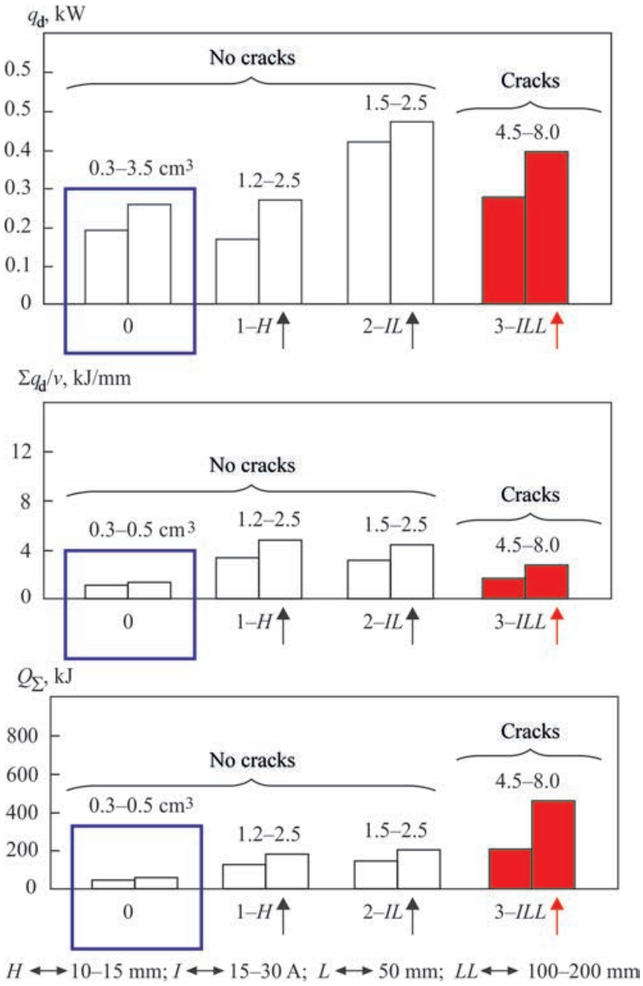

Figure 4. Analysis of the regularities of ensuring the technological strength in ZhS6K deposited metal, depending on a number of indices of the amount of heat input into the product (q_d — efficiency of microplasma arc; $\Sigma q_d/v$ — sum of heat inputs of all the deposition layers; Q_Σ — total heat input into the product) and its volume. Technological variant «0» corresponds to the conditions of MPPS of shroud platforms of HPT blades, described in the text: *H* — 10–15 mm; *I* — 15–30 A; *L* — 50 mm; *LL* — 100–200 mm

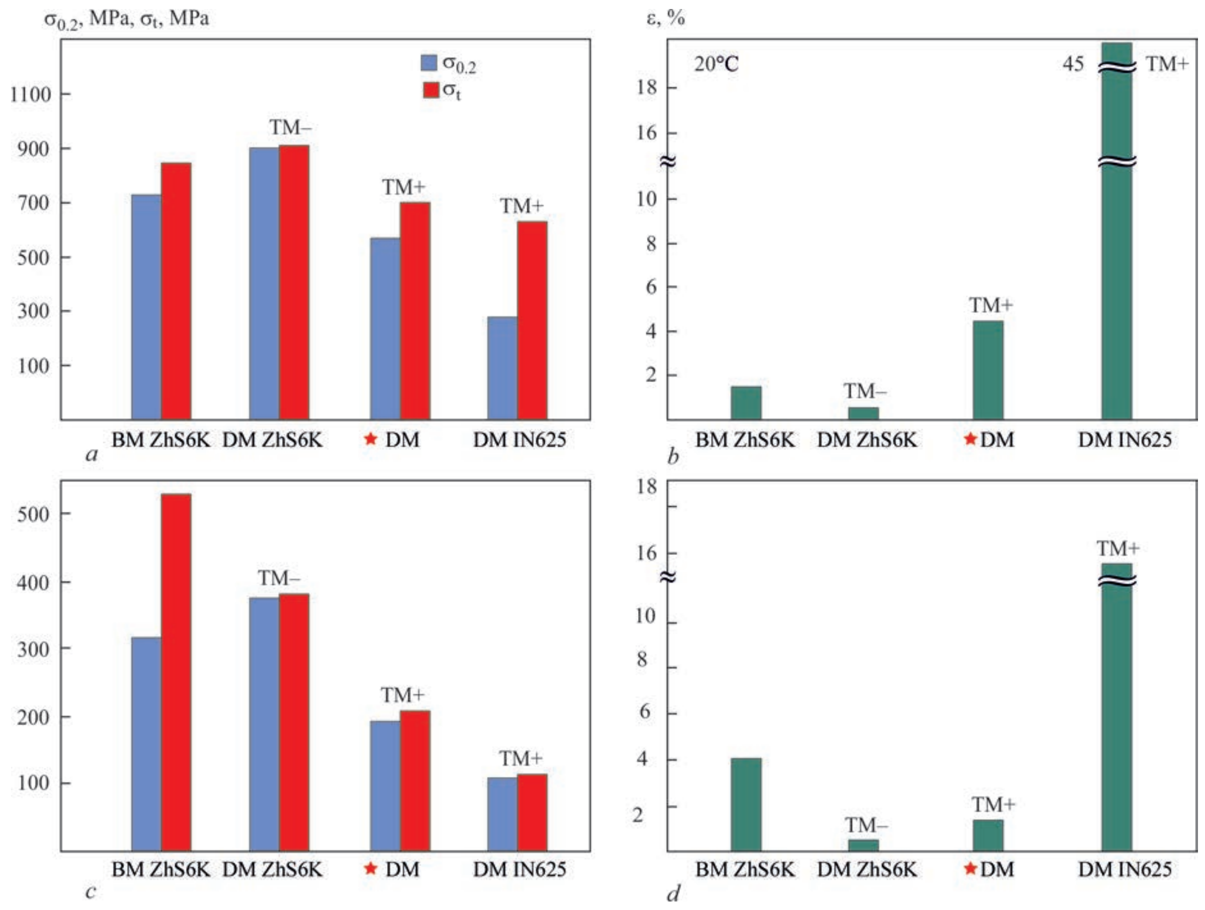

Figure 5. Analysis of short-time mechanical properties of different variants of deposited metal and regularities of ensuring its technological strength at restoration of HPT SNB side sealing element (BM —base metal; DM — deposited metal; ★DM — selected system of deposited metal; TS+ and TM– — technological strength is or is not achieved, respectively). Short-time mechanical properties of ZhS6K base metal are given by the data of [10]: *a*, *b* — 20; *c*, *d* —1000 °C; (*d* — ×25)

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