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Technology of laser repair welding of nickel superalloy inner flaps of jet engine

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ABSTRACT

Purpose: of this paper: work out laser welding repair technology of cracked MIG 29 jet engine inner flaps made of cast nickel superalloy ŻS-3DK (ЖС-3ДК, Russian designation).
Design/methodology/approach: The study were based on the analysis of laser HPDL powder INCONEL 625 welding of nickel superalloy using wide range of welding parameters to provide highest quality repair welds.
Findings: Study of automatic welding technologies GTA, PTA and laser HPDL has shown that just laser welding can provide high quality repair welds. In order to establish the properties of welded joints repair cracks in the inner flap HPDL laser, studied the hardness, mechanical properties and erosive wear resistance.
Research limitations/implications: It was found that only laser HPDL welding can provide high quality repair welds.
Practical implications: The technology can be applied for repair cracked MIG 29 jet engine inner flaps.
Originality/value: Repairing cracked MIG 29 jet engine inner flaps.
Keywords: Welding; Nickel superalloy; Inner flaps; Jet engine; High Power Diode Laser (HPDL)

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1. Introduction

Jet engine parts of MIG 29 (NATO reporting name: Fulcrum) aircrafts are working in very complex environment under very strong mechanical fatigue loads, erosion, corrosion and friction wear at high temperatures. In order to ensure the highest durability of jet engine parts, they are mainly made of nickel superalloys, cobalt alloys and titanium alloys [5-7]. Because of very complex operational loading, jet engine parts a subjected different kind of wear, mainly in the form of cracks or loss of weight due to erosion or friction wear. Because of very high cost of jet engines parts maintenance companies decide to repair worn parts by application of modern high quality laser technology [1-5].

The main objective of present study is to work inner flaps made of cast nickel superalloy ŻS-3DK (ЖС-3ДК, Russian designation), the chemical composition corresponding to approximately RENE 95 (61% Ni, 8% Co, 14% Cr, 3.5% Mo, 3.5% W, 3.5% Nb, 2.5% Ti, 3.5% Al), Table 1. Inner flaps work in very complex operating conditions, with variable thermal and mechanical loads, erosion, corrosion, cavitation particularly under the influence of heated high temperature steam of gases at the engine exhaust. Superalloy RENE95 belongs to a group of precipitation-hardened nickel base alloys but due to their high content of alloying elements, especially the total content of titanium and aluminium (2.5% Ti + 3.5% Al), their weldability is very poor [5-7]. The most common defects of the inner flaps are cracks which starts at the edge of flap and develop through the thickness to the middle area of the inner flap, Fig. 1.

Fig. 1. View and macrostructure of a crack of jet engine inner flap made of nickel superalloy ZS-3DK (ЖС-3ДК)

2. Experimental

Preliminary study of automatic welding technologies GTA, PTA and laser HPDL has shown that just laser welding can provide high quality repair welds. Following studies are concentrated on selection welding technique and welding parameters to provide highest quality repair welds. Because cast structure of inner flap contains natural internal defects like porosity, nonmetallic inclusions, microcracks, it was decided to used high quality and very good weldability nickel alloy INCONEL 625 as the consumable material, Table 1. Second approach was directed to provide minimum welding stresses by application of low heat input parameters. Finally laser HPDL powder INCONEL 625 repair welding process has been developed providing very high quality process of repairing of inner flap cracks, Fig.2.

In the first stage of the study defined the field welding repair cracks inner flaps on flat specimens cut the flap was performed tests of stringer HPDL laser welding. Penetrant and metallographic examinations have shown that there is a wide range HPDL laser welding parameters for implementing high quality welds, without internal and external defects. In the next step performed model welds with different methods of joint preparation, in a wide range of process parameters, Table 2, Fig. 3.

Visual, penetrant and metallographic examinations of model repair cracks in welded joints of the inner flap, showed a high-quality welds without internal and external defects, despite poor weldability of nickel superalloy ZS-3DK (ЖС-3ДК), Table 2, Figs. 4 and 5. In the last stage of the study, developed using the technological process of laser welding repair cracks inner flap, Table 4, carried out the repair of damaged jet flap, Fig. 8.

In order to establish the properties of welded joints repair cracks in the inner flap HPDL laser, studied the hardness, mechanical properties and erosive wear resistance, Tables 3, 5 and 6, Figs. 7, 9. The results of measurements of HRC hardness face HPDL repair joints showed significantly lower hardness (48-49HRC) than base material - 55.6HRC. This is due to the fact used as additional material with nickel superalloy INCONEL 625, characterized by lower mechanical properties, but very good weldability. Microhardness measurements on cross-section have shown that all repair welds are characterized by hardness µHV0,5 at a similar level of 370-450 µHV0.5, Table 3, Fig. 7.

Studies of erosive wear resistance were conducted in accordance with ASTM G76 - Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement, Fig. 10. Abrasive particles of angular Al_2O_3 of nominal dimension - 50 [µm] are feed with the rate 2.0±0.5 [g/min] during the tests.

The abrasive particles velocity was kept in the range 70±2 [m/s] and stream of dry air is supplied with flow rate 8,0 [l/min]. The erosion tests were done during 10 [min], at erodent impact angle 30°, 45° and 60° and results are collected in Table 6.

Fig. 2. Laser HPDL surfacing experimental CNC stand

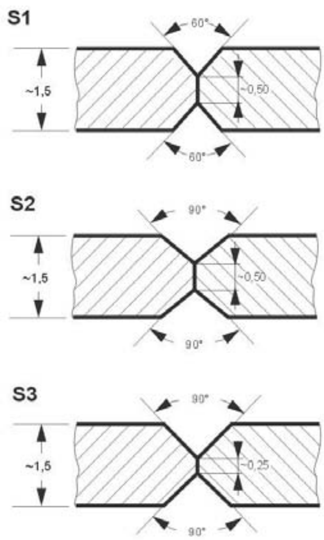


Fig. 3. Methods for preparation of model repair of welds inner flap of the nickel superalloy ZS-3DK (ЖС-3ДК), the HPDL laser welding process

Table 1.
The chemical composition of nickel superalloy ZS-3DK (ЖС-3ДК - Rene 95) and nickel superalloy powder INC 625

Type	Chemical composition [%wg.]										
	C	Ni	Cr	Fe	Mo	Al	Si	Mn	Ti	Co	W
ŻS-3DK (ЖС-3ДК)	0.07- 0.12	rest	11.0-15.0	< 2.0	3.5-5.0	4.0-4.8	< 0.4	< 0.4	2.5-3.5	5.0-10.0	3.5-5.0
Research at the IMŻ	0.03		11.55	0.11	4.13	3.68	0.04	< 0.001	2.55	9.58	4.18
EL-625*	0.0	rest	22.4	1.00	9.3	0.0	0.18	0.0	0.0	-	3.83

Remarks: *- powder with a particle size = 35-59 [μm]

Table 2.
Influence of joint preparation and HPDL welding process parameters on the quality of the model repair welds inner flap of the nickel superalloy ZS-3DK (ЖС-3ДК), Figs. 4, 5 and 6

<table>
<tr><th>Weld no</th><th>Joint preparation Fig. 3</th><th>Number of welds</th><th>Weld no</th><th>Laser beam power [W]</th><th>Travel speed [m/min]</th><th>Powder feed rate [g/min]</th><th>Quality of the weld*</th></tr>
<tr><td rowspan="2">ZL1</td><td rowspan="4">S3</td><td rowspan="10">2</td><td>1</td><td rowspan="4">400</td><td>0.2</td><td>3.0</td><td rowspan="2">PN, PS</td></tr>
<tr><td>2</td><td rowspan="5">0.3</td><td>4.0</td></tr>
<tr><td rowspan="2">ZL2</td><td>1</td><td rowspan="4">3.0</td><td rowspan="2">WJ</td></tr>
<tr><td>2</td></tr>
<tr><td rowspan="2">ZL3</td><td rowspan="2">S1</td><td>1</td><td>500</td><td rowspan="2">PN, PS</td></tr>
<tr><td>2</td><td rowspan="2">400</td></tr>
<tr><td rowspan="2">ZL4</td><td rowspan="4">S2</td><td>1</td><td rowspan="4">0.4</td><td rowspan="2">4.0</td><td rowspan="2">WJ</td></tr>
<tr><td>2</td><td>450</td></tr>
<tr><td rowspan="2">ZL5</td><td>1</td><td>500</td><td rowspan="2">5.0</td><td rowspan="2">WJ</td></tr>
<tr><td>2</td><td>550</td></tr>
</table>

Remarks: Focal length 82 [mm], laser beam spot - 1.8 × 6.8 [mm]. Dia. of powder feeding nozzle 2.0 [mm]. Shielding gas argon flow rate - 10.0 [l/min]
* - quality assessment of welds on the basis of metallographic, visual and penetration examinations: PN - cracks in the weld area, PS - cracks in the HAZ, WJ - no internal and external defects

Table 3.
Results of μHV0.5 micro hardness measurements on the cross-section of a model repair welds inner flap nickel superalloy ZS-3DK (ЖС-3ДК)

Weld no, Table 2	Layout of micro hardness measurements μHV0.5, Fig. 7							
ZL2	Microhardness measurements weld no 1							
	1	2	3	4	5	6	7	8
	460	448	402	408	452	441	408	409
	9	10	11	12	13	14	15	
	410	430	436	423	430	440	400	
	Microhardness measurements weld no 2							
	1	2	3	4	5	6	7	8
	450	435	398	374	400	411	382	378
	9	10	11	12	13	14	15	
	391	400	412	422	447	455	460	
ZL5	Microhardness measurements weld no 1							
	1	2	3	4	5	6	7	8
	387	390	394	373	381	387	399	408
	9	10	11	12	13	14	15	
	405	400	404	403	400	406	397	
	Microhardness measurements weld no 2							
	1	2	3	4	5	6	7	8
	398	400	404	416	417	386	388	398
	9	10	11	12	13	14	15	
	405	401	405	440	428	420	418	

Table 4.
The HPDL laser welding parameters the inner flaps of the nickel superalloy ŻS-3DK (ЖС-3ДК), Fig. 8

Joint preparation, Fig. 3	Number of welds	Weld no	Laser beam power [W]	Travel speed [m/min]	Powder feed rate [g/min]
S3	2	1	400	0.3	3.0
		2			
S2		1		0.4	4.0
		2	450		
		1	500		5.0
		2	550		

Remarks: Focal length 82 [mm], laser beam spot – 1.8 × 6.8 [mm]. Dia. of powder feeding nozzle 2.0 [mm]. Shielding gas argon flow rate – 10.0 [l/min]

Table 5.
Results of static tensile test and bending test of butt joint of the inner flap of the nickel superalloy RENE 95, HPDL laser welded, Fig. 9

Weld no	Break load F_m [kN]	Cross section area [mm]	R_m [MPa]	Area of break	Bending test [^{o}]		Remarks
					GL	GG	
RENE 95 - M1	25.8	14.7×1.5	1167.8	parent material	180	180	High quality
HPDL welded joint- L1	16.717	12.2×1.5	913.5	weld	-	-	-
HPDL welded joint - L2	16.099	12.2×1.5	879.7	parent material	-	-	-
HPDL welded joint - L1	-	20.8×1.5	-	-	-	180	High quality
HPDL welded joint- L2	-	21.8×1.5	-	-	180	-	High quality

Remarks: R_m of parent material RENE 95, $R_{0,2}$ = 1017.9 [MPa]

ZL2 ZL5

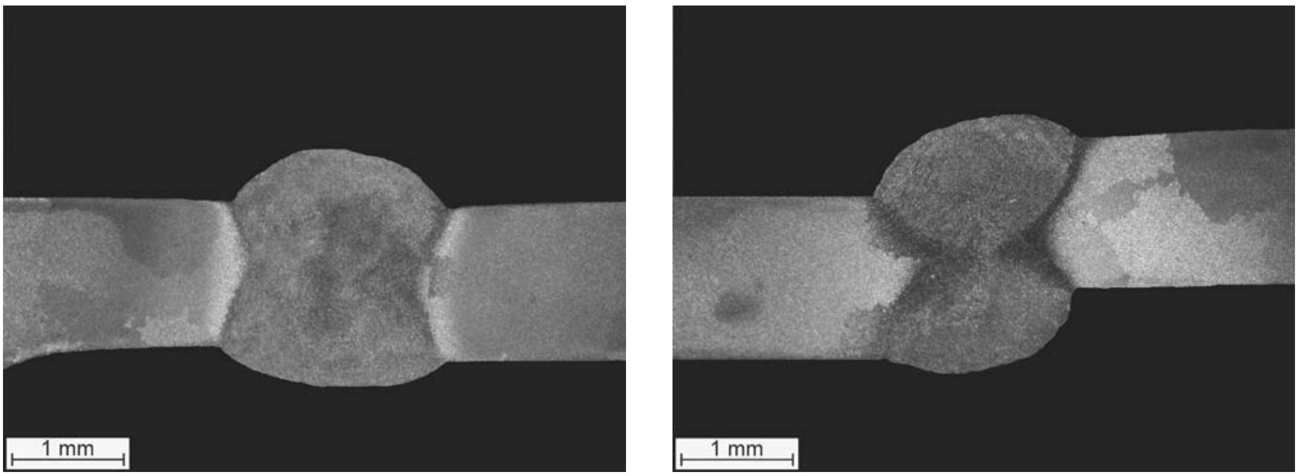


Fig. 4. Macrostructure model repair welds inner flap of nickel superalloy ZS-3DK (ЖС-3ДК), Table 2

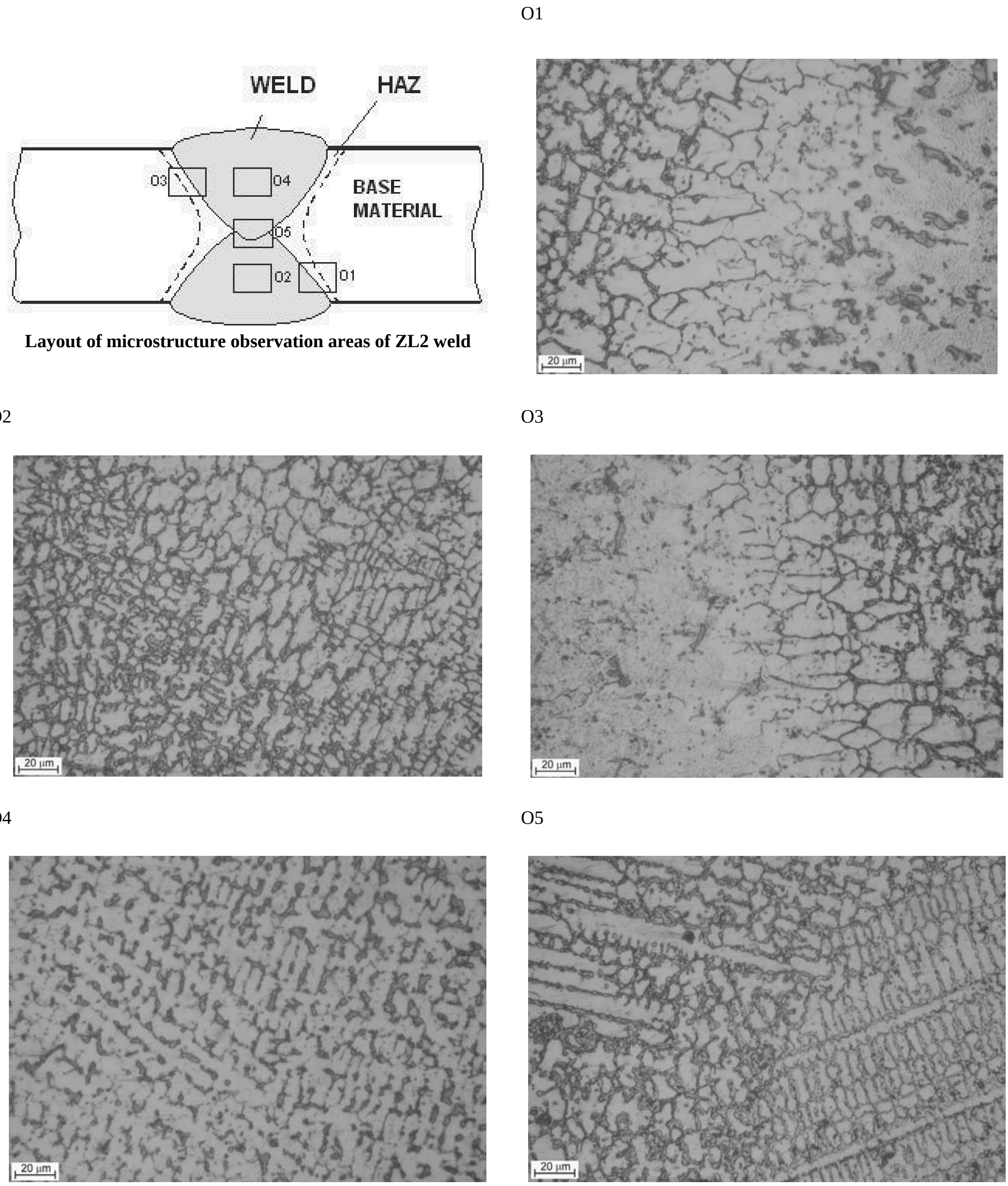
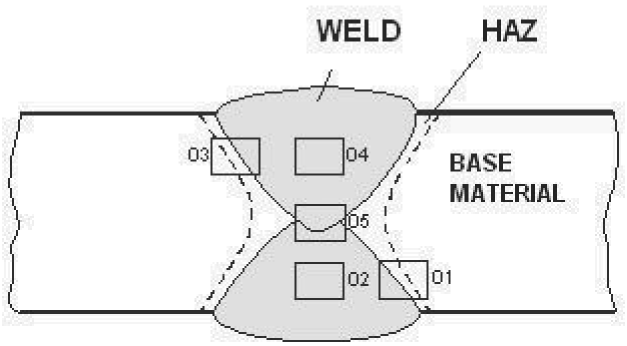
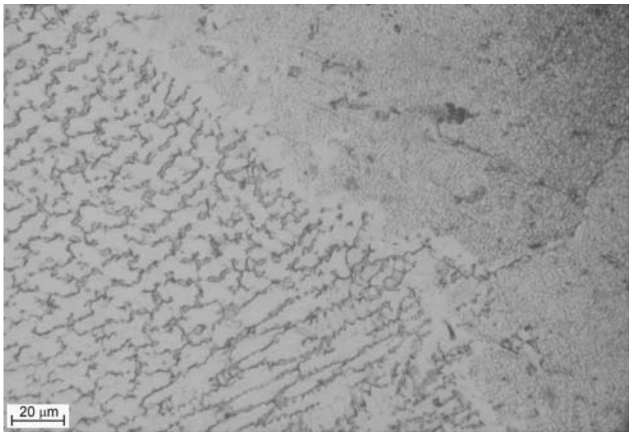


Fig. 5. Microstructure of a model repair ZL2 weld inner flap of nickel superalloy ZS-3DK (ЖС-3ДК), Table 2

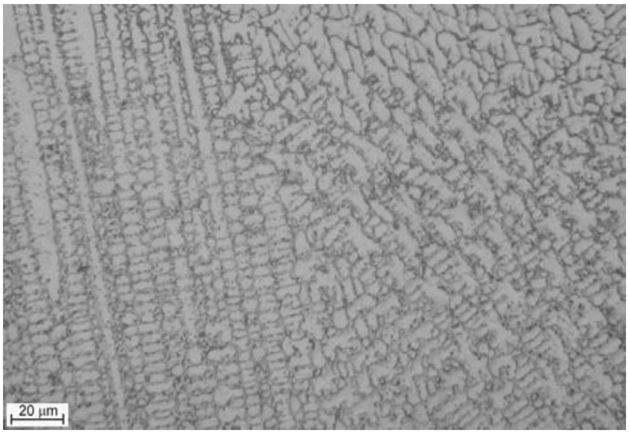


Layout of microstructure observation areas of ZL5 weld

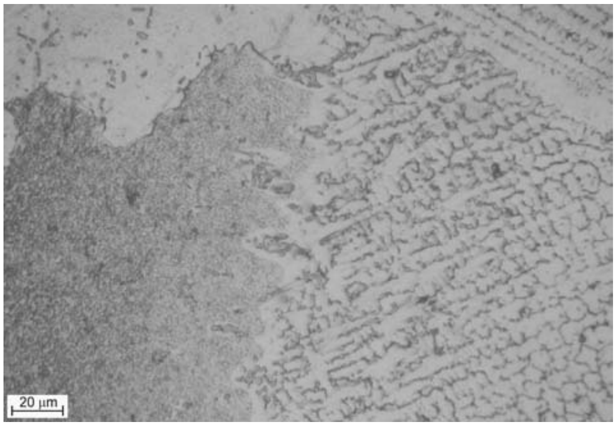
O1



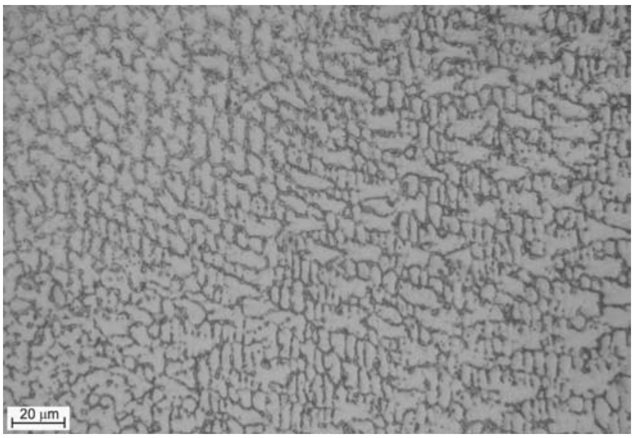
O2



O3



O4



O5

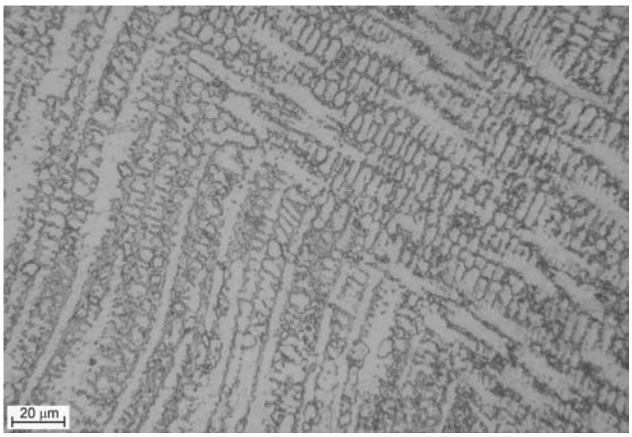


Fig. 6. Microstructure of a model repair ZL5 weld inner flap of nickel superalloy ZS-3DK (ЖС-3ДК), Table 2

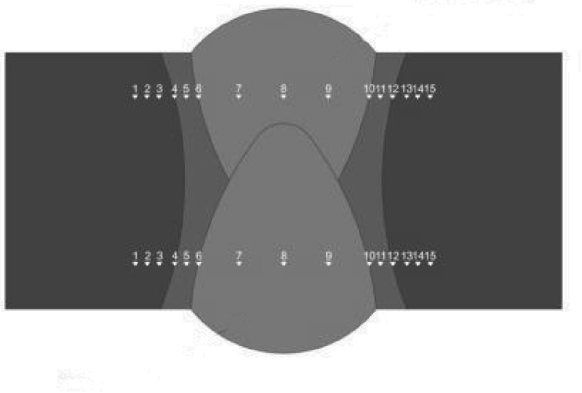


Fig. 7. Layout of micro hardness measurements on the cross section

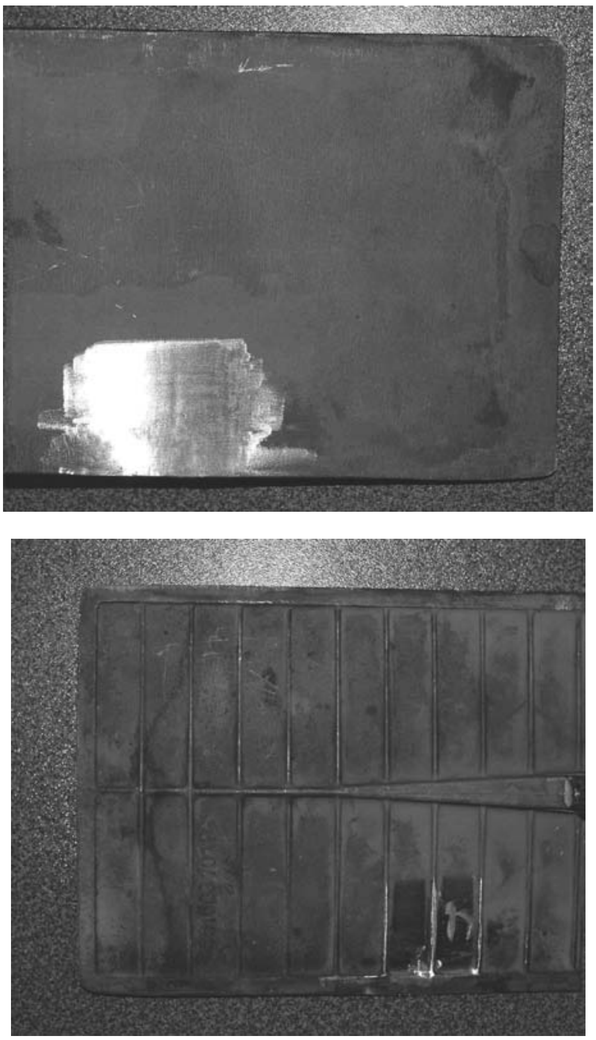
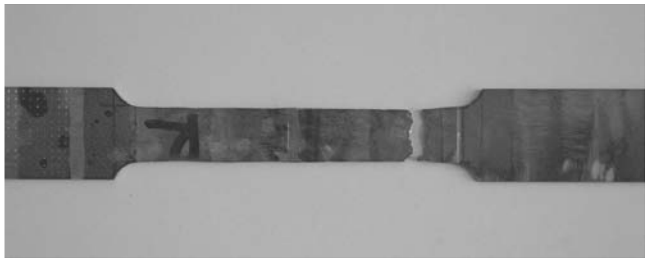
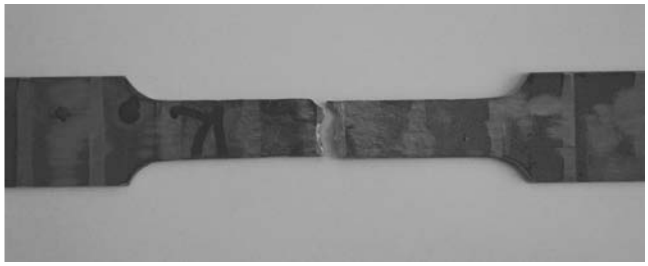


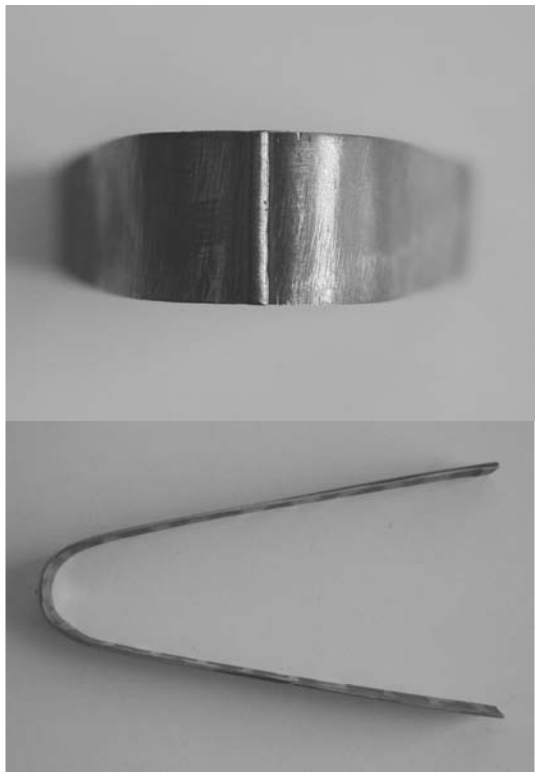
Fig. 8. View of a repaired crack from the inner flap of nickel superalloy ZS-3DK (ЖС-3ДК), using HPDL laser welding, Table 4



Break in the parent material



Break in the HAZ



Bending from the root of bead

Fig. 9. A view repaired butt joints of the inner flap the nickel superalloy RENE 95, HPDL welded after static tensile test and static bending test from the face and from the root

Table 6.
The results of erosive wear resistance of the inner flap of the nickel superalloy RENE 95 and repair cracks in welded joints

Test area	Impact angle	Weight of sample before testing [g]	Weight of sample after testing [g]	Erosion weight loss [g]	Average erosion weight loss [mg]
Parent material RENE 95 (ŻS-3DK)	60º	21.7998	21.7877	0.0121	12.35
		21.7606	21.7480	0.0126	
	45º	21.7877	21.7743	0.0134	13.4
		21.7480	21.7346	0.0134	
	30º	21.7743	21.7606	0.0137	14.15
		21.7346	21.7200	0.0146	
HPDL laser weld repair	60º	28.1598	28.1503	0.0095	9.8
		28.1503	28.1402	0.0101	
	45º	28.1796	28.1698	0.0098	9.9
		28.1698	28.1598	0.0100	
	30º	28.2029	28.1913	0.0116	11.65
		28.1913	28.1796	0.0117	

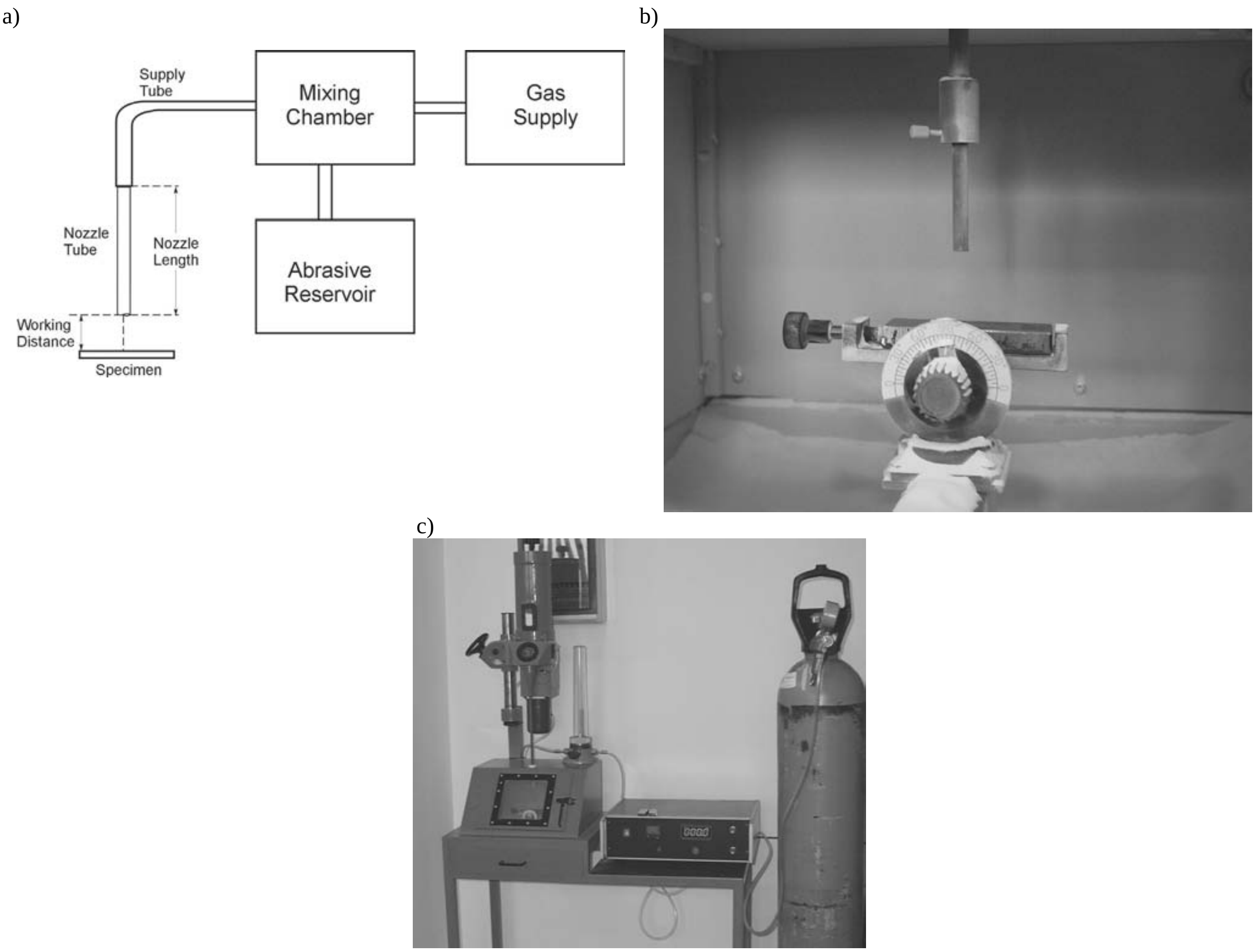


Fig. 10. Schematic diagram (a) and overview of standard ASTM G76-95 erosion tests apparatus (c). Specimen eroded at impact angle 90° (b)

3. Conclusions

Study of automatic welding technologies GTA, PTA and laser HPDL has shown that just laser welding can provide high quality repair welds. In order to establish the properties of welded joints repair cracks in the inner flap HPDL laser, studied the hardness, mechanical properties and erosive wear resistance.

Testing the mechanical properties of test joint plates taken from the inner flap, and HPDL laser welded with INCONEL 625 powder of the optimum welding parameters showed high mechanical properties of test joint. The high plastic properties of welded test joints by laser HPDL confirmed the static bending test from both the face and root side, in each case was 180° bending angle, Table 5, Fig. 9.

Results of erosion wear resistance testes conducted in accordance with ASTM G76 showed that all the repair welds are characterized by 22-35% higher erosion resistance than base material.

Summarizing the results of the study can be concluded that it is possible to repair the defects of inner flaps by HPDL laser welding with use in powder form INCONEL 625 nickel alloy as an additional material, Fig. 8.

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