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Laser powder surfacing of the Si-Mo spheroidal cast iron with nickel powder

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ABSTRACT

Purpose: Investigation results are presented of the effect of main parameters of laser powder surfacing of the Si-Mo spheroidal cast iron with the nickel based powder on quality and shape of padding welds and portion of the substrate material in the padding weld.
Design/methodology/approach: It was shown basing on investigation of the process of laser powder surfacing with the nickel based powder onto the spheroidal cast iron substrate that it is feasible to make high quality padding welds in the relatively wide range of parameters.
Findings: Investigation results presented in the paper were carried out to determine quality of padding welds applied by laser powder surfacing with the nickel based powder onto the alloy spheroidal cast iron and especially to determine the padding welds adhesion to the substrate.
Practical implications: It is possible to control the portion of the substrate material in the padding weld with high accuracy in a wide range from even a few per cent, by the relevant setting of the line energy of the laser beam and the powder feed rate.
Originality/value: The developed implant test makes the qualitative and quantitative assessment possible of the adhesion of the padding weld to the substrate, Table 5, Figs. 7 to 11. All padding welds made within the range of the optimum welding parameters demonstrated very good adhesion and the break, depending on the nickel padding weld thickness, occurred in the fusion area or by pulling part of the padding weld out.
Keywords: Welding; Cast iron; Powder laser surfacing; Padding weld

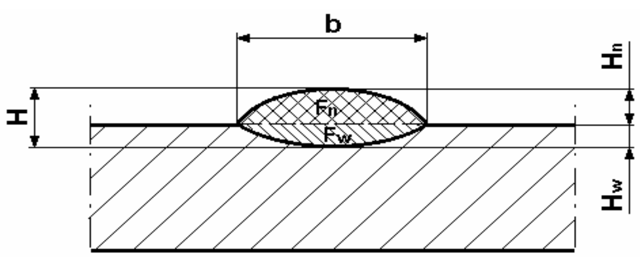
1. Introduction

Laser powder surfacing is one of the most modern technologies of developing surface layers with properties that cannot be obtained with the traditional welding technologies. Saying nothing of the still high cost of laser equipment, laser powder surfacing with the auxiliary material in the form of powder and/or wire yields the possibility of the very accurate control of the padding weld run shape, and - what is most important - control of the portion of the substrate material in the padding weld - U, Fig. 1.

The technologies and techniques of the laser powder surfacing of surface layers with the string and weave beads, including power surfacing of gradient layers was worked out[1-8]. The laser powder surfacing technique developed consists in parallel feeding of the auxiliary material from two separate powder feeders or from a powder feeder and wire feeder yields the possibility to develop surface layers with the nearly arbitrary chemical composition, from metal layers, through cermets and ceramic ones. The technique makes also possible, at the appropriate setting of the linear energy of the laser radiation beam, not only the accurate control of the chemical composition of surface layer, but also controlling the portion of the substrate material in the padding weld.

Laser powder surfacing makes controlling the substrate material portion in the padding weld possible in the very broad range from about 5.0% to 100%, in case of the surface layers alloying technique [1, 6, 7]. The excessive portion of the substrate material in the padding weld boosts surfacing costs; whereas, a very low portion makes it possible to obtain the required service properties in the first padding weld layer already. However, there is a threat of defects then like incomplete fusion or lack of penetration in the padding weld. Grey cast iron and spheroidal cast iron are the constructional materials especially difficult for power surfacing [1].

Investigation results presented in the paper were carried out to determine quality of padding welds applied by laser powder surfacing with the nickel based powder onto the alloy spheroidal cast iron and especially to determine the padding welds adhesion to the substrate.



$$U = \frac{F_w}{F_w + F_n} \cdot 100[\%]$$

Fig. 1. Portion of the substrate material in padding weld, where: $\mathbf{H_n}$ – padding weld height, **H** – padding weld thickness, $\mathbf{H_w}$ – fusion penetration depth, **b** – padding weld width,U - portion of substrate material in padding weld [%], $\mathbf{F_w}$ – fusion penetration surface area, $\mathbf{F_n}$ – padding weld surface area

2. Powder laser surfacing

The initial investigations of the laser powder surfacing of plates from the Si-Mo alloy spheroidal cast iron used in WSK RZESZÓW for the cast housings of gas turbines, Table 1, were carried out on the automatic stand equipped with the ISEL AUTOMATION numerically controlled table and the HPDL DL020 ROFIN SINAR high power diode laser, Fig. 2. The nickel based Castolin EuTroLoy 16223 powder, Table 2, was used as the auxiliary material for simulation of the technological conditions of rebuilding the casting defects areas of housings from the Si-Mo alloy spheroidal cast iron. This powder is designed for PTA plasma surfacing of corrosion- and oxidation at elevated temperatures resistant layers and is also abrasion wear resistant. The spherical shape of the powder with granularity in the 40-120 [µm] range ensures very stable and steady powder supply to the weld pool area, Fig. 3. The EuTroLoy 16223 nickel powder is recommended for surfacing the glass-moulds, dies, valves, guides, housings, etc., cast from the grey- and spheroidal cast iron [1].

Laser powder alloying tests with the EuTroLoy 16223 powder for the string beads were made on 30×30×8 [mm] plates cast from the GGG Si-Mo alloy spheroidal cast iron. Padding welding parameters were set within the recommended parameters range reported in [2, 4]: beam power 1.0 - 1.4 [kW], powder flow rate 4.0 - 8.0 [g/min], Tables 3 and 4. Other laser surfacing parameters were maintained at the constant level:

- surfacing feed rates 0.2 [m/min],
- shield gas - argon - flow rate - 8.0 [l/min],
- powder feed nozzle setting angle in respect to test piece surface - 45^0,
- beam focal length - 82 [mm],
- beam size - 1.8x6.8 [mm].

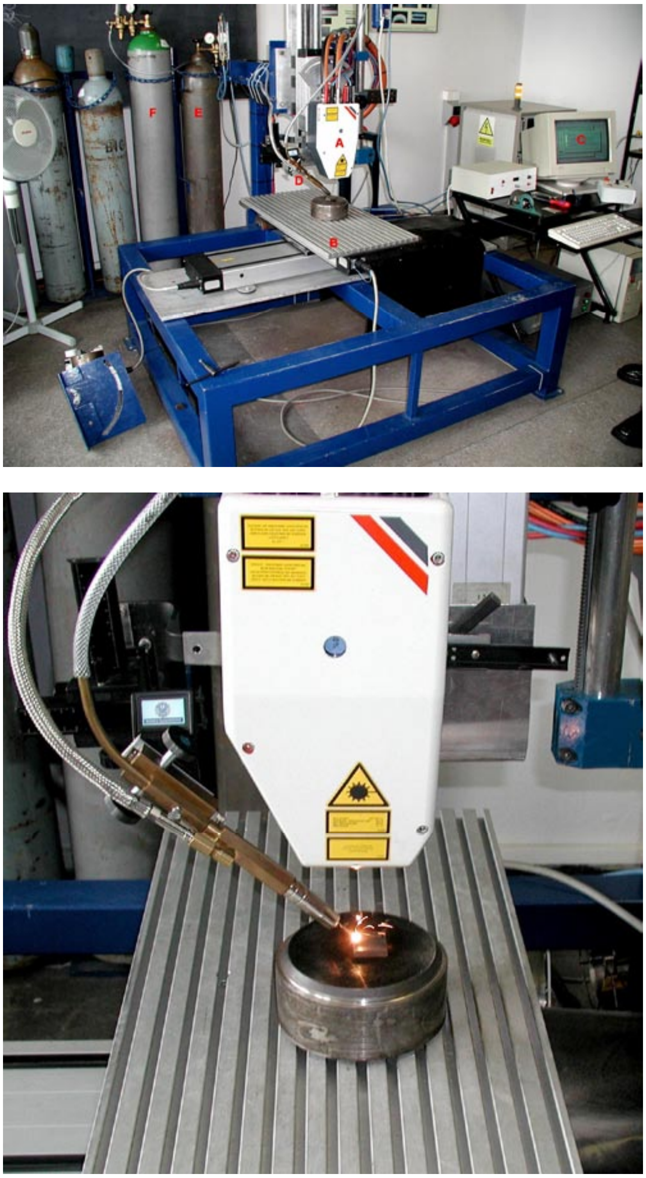


Fig. 2. Stand for laser surfacing and for the laser surfacing of the test plate: **A** – HPDL DL020 laser head, **B** – NC controlled table, **C** – control computer, **D** – concentric powder feed and shield gas nozzles, **E** – transport gas (argon) cylinder, **F** – shield gas (argon) cylinder

The surfacing string beads quality examinations, based on visual, penetration and ultrasonic inspection, Table 3, revealed no internal nor external defects. Metallographic examinations of the padding welds confirmed results of the non-destructive tests, Figs. 4 and 5. Calculations of the native material portion in the padding weld confirmed the possibility to control precisely the shape and quality of the laser padding welds, Table 4. The portion of the substrate material in the padding weld grows along tithe laser beam power increase and decrease of the powder feed rate. The portions within the range of 8.0% to 40% were obtained in case of the investigated padding welds. Regardless of the substrate material portion in the padding weld the homogeneous fusion penetration and no under-bead cracks were found, Fig. 5.

Table 1
Chemical composition of GGG Si-Mo spheroidal cast iron

Chemical composition [% mass]						
C	P	S	Si	Mn	Cr	Mo
3.6	0.05	0.015	3.0	0.15	0.04	0.8

Table 2
Chemical composition and properties of the powder weld deposit used in tests

Powder type	Weld deposit chemical composition [% mass]						Hardness [HRC]	Powder granularity [µm]
	Ni	Cr	Si	Fe	B	C		
EuTro-Loy 16223	85	7	3.1 max	3 max	1.3	0.3	31 ÷ 36	40 ÷120

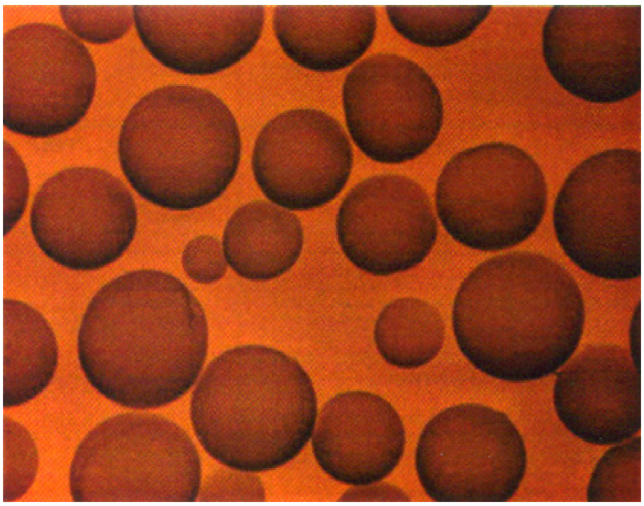


Fig. 3. Granules of EuTroLoy 16223 powder, magnification 300 ×

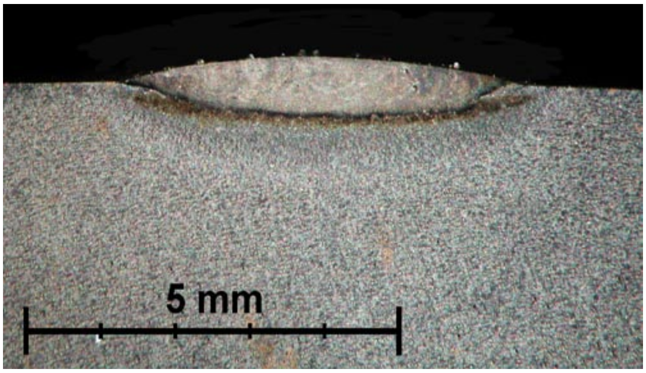


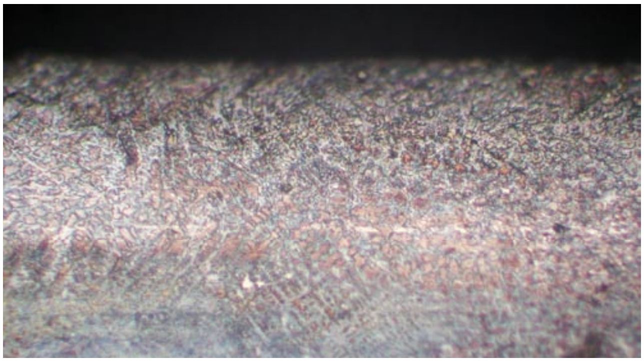
Fig.4 Padding weld macrostructure (No 4), laser beam power 1.2 [kW], powder flow rate 3. 8 [g/min], Tables 3 and 4

Table 3
Parameters of the laser powder surfacing with the HPDL ROFIN DL 020 laser of the string beads made on plates from the GGG Si-Mo spheroidal cast iron and view of the padding welds faces

Padding weld designation	Laser beam power [kW]	Powder feed rate [g/min]	Line energy, [kJ/cm]	View of the padding welds faces.
1	1.0	5.6	3.0	
2	1.2	5.6	3.6	
3	1.4	5.6	4.2	
4	1.2	3.8	3.6	
5	1.2	7.8	3.6	

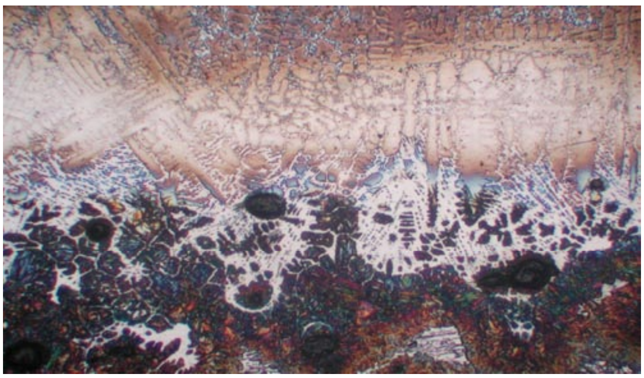
Table 4
Effect of laser powder surfacing parameters with the HPDL ROFIN DL 020 laser on the padding welds shape and portion of the substrate material in the padding weld, Table 3, Fig. 3

Weld ID	Padding weld width b [mm]	Padding weld thickness H [mm]	Padding weld height H_n [mm]	Fusion penetration depth H_w [mm]	Portion of the substrate material in padding weld U [%]
1	5.4	0.81	0.59	0.12	11.0
2	5.5	0.84	0.62	0.22	18.5
3	5.7	0.93	0.60	0.33	30.8
4	5.1	0.70	0.43	0.27	40.1
5	5.5	1.06	0.96	0.10	8.0



area below padding weld face

central padding weld area



fusion padding weld area

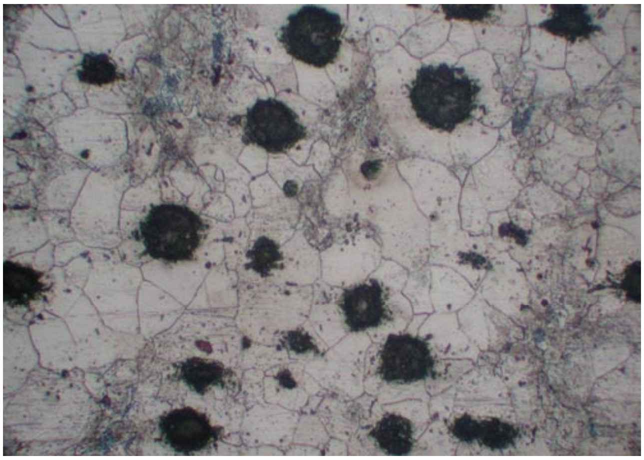


Fig. 5. Microstructure of padding weld No 2, Table 3, magnification 200 x

3. Tests of the padding welds adhesion to the substrate

The implant test, developed by the authors, was used to determine adhesion of the padding weld from nickel alloy to the alloy spheroidal cast iron substrate carried out within the optimum parameters range, Figs. 6 and 7. Plates with the dimensions of 30x30x8 [mm] with the 6.0 [mm] diameter hole and the precisely fitted pins were made from the GGG Si-Mi spheroidal alloy, Fig. 8. Six string beads were made on the implant test plates surfaces with the overlap of about 25-30%, Fig. 9. Breaking of the test pieces occurred in eight cases in the padding weld damaging thus the weld faces; whereas, in case of the remaining four implant tests the break occurred in the joint of the powder padding weld with the pin face surface, Table 6 and Fig. 10 and 11. Tests revealed the very good adhesion of the padding welds to the substrate. Breaks in the fusion zone, with the clear deformation of the padding weld metal over the pin surface occurred in pin test pieces with the big padding weld thickness at higher breaking stress than in case of pulling out of a part of the weld, Table 5, Fig. 11. The implant tests No I, III, IV, and VI were destroyed by shearing the padding weld - pulling out a part of the weld covering the pin surface, due to the smaller cross section area of the padding weld than the pin cross section area.

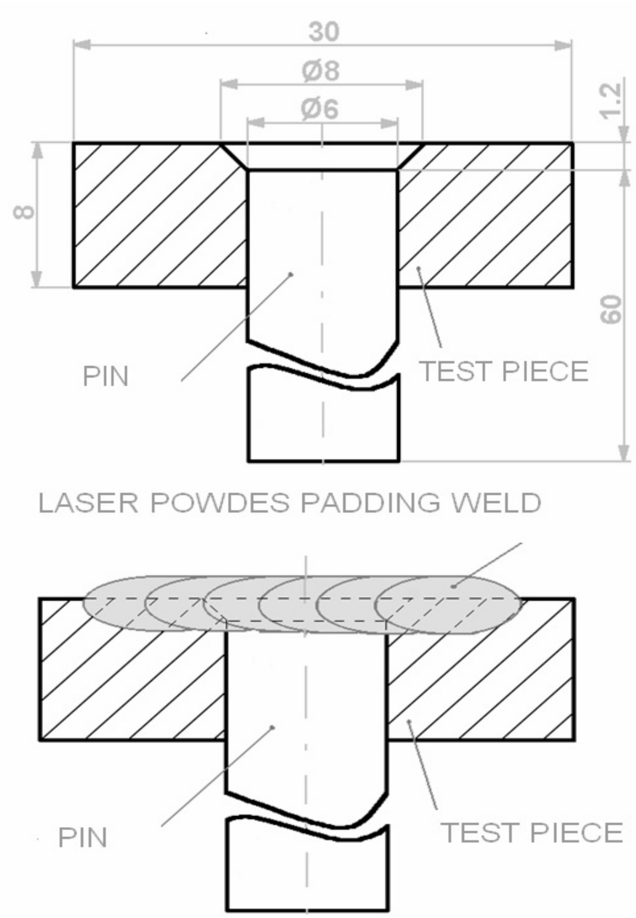


Fig. 6. Dimensions and view of the implant test after surfacing

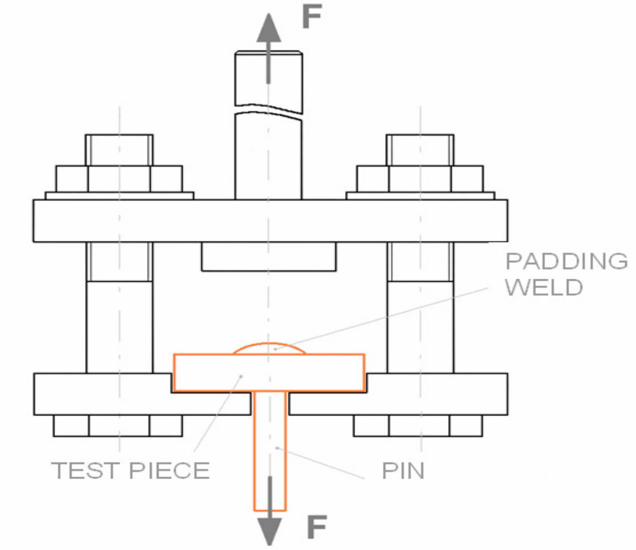


Fig. 7. View of the device for static tensile test of the pin test piece, Fig. 6

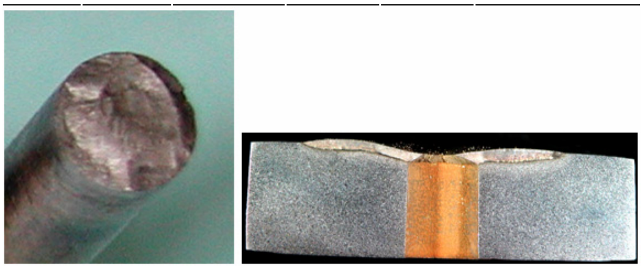
Fig. 8. Test pieces prepared for laser powder surfacing for adhesion tests of the padding weld to the substrate

Fig. 9. Pin test pieces after laser powder surfacing

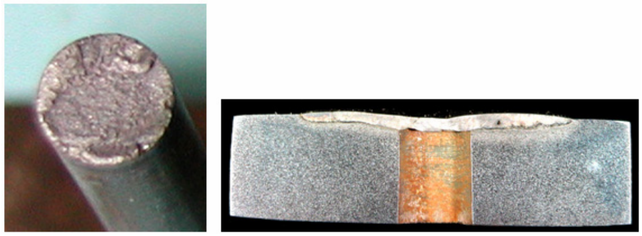
Fig. 10. Pin test pieces after adhesion test Holes visible in padding welds pulled out with the pin

Table 5
Effect of laser powder surfacing parameters on adhesion of padding welds to the substrate from the GGG Si-Mo alloy spheroidal cast iron, Figs. 10 and 11

Weld ID	Laser beam power [kW]	Powder feed rate [g/min]	Break force [kN]	Break stress [MPa]	Break area
I	1,2	3,8	4,45	157,5	Within padding weld
			4,4	155,7	Within padding weld
II	1,0	5,6	7,85	277,8	Within the area of padding weld fusion with the pin face surface
			7,9	279,5	Within the area of padding weld fusion with the pin face surface
III	1,2	5,6	7,3	258,3	Within padding weld
			7,0	247,7	Within padding weld
IV	1,4	5,6	6,65	235,3	Within padding weld
			6,1	215,8	Within padding weld
V	1,2	7,8	7,6	268,9	Within the area of padding weld fusion with the pin face surface
			7,8	276,0	Within the area of padding weld fusion with the pin face surface
VI	1,4	7,8	6,05	214,1	Within padding weld
			5,8	205,2	Within padding weld



test piece broken in the padding weld



test piece broken in the area of padding weld fusion with the pin face surface
Fig.11 . Pin face surfaces after adhesion test, Table 5

4. Summary

It was shown basing on investigation of the process of laser powder surfacing with the nickel based powder onto the spheroidal cast iron substrate that it is feasible to make high quality padding welds in the relatively wide range of parameters, Tables 3 and 4, Figs. 4 and 5. It is possible to control the portion of the substrate material in the padding weld with high accuracy in a wide range from even a few per cent, by the relevant setting of the line energy of the laser beam and the powder feed rate. The most significant effect has the powder feed rate.

The developed implant test makes the qualitative and quantitative assessment possible of the adhesion of the padding weld to the substrate, Table 5, Figs. 7 to 11. All padding welds made within the range of the optimum welding parameters demonstrated very good adhesion and the break, depending on the nickel padding weld thickness, occurred in the fusion area or by pulling part of the padding weld out, Figs. 10 and 11.

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