772. A study of selected properties in high dispersion padding welds produced in machine elements

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Abstract. This paper presents selected laboratory research results concerning the production of high dispersion padding welds that were made from Castolin EnDOtec DO390N P pulverized nanowire on acid resistant 0H18N9 steel using laser technology. The analysis of the microstructure showed a high dispersion of the micro- and nano-structure where the phase particles of large volume carbide (MC), $M_{23}(BC)$ boron carbides, and M_2B borides are distributed in the fine-grained iron matrix. The study found extensive differentiation of chemical composition in the micro-areas and extensive non-homogeneity of the microstructure due to repeated laser melting of the padding weld layer. Its surface hardness was 68-72 HRC and the cross-sectional microhardness was as high as 990 – 1100 HV0, 1.

Keywords: acid resistant steel, powder nanowire, laser padding weld, microstructure, chemical composition, microhardness.

Introduction

In industry, there is an increased intensity to search for modern solutions to reduce wear and produce more efficient regeneration of the elements of machines.

Most of wear processes begin on the surface of a product. The speed of slip, pressure, the roughness of the surface, the temperature of work, hardness, the ability to carry away heat and moisture, the type of motion and other factors connected with the natural environment are important to the machine elements which work together. The use of specially created coatings or outer layers is one of the most rational and effective methods of preventing wear [1]. This is now possible thanks to nanotechnology as an advanced, interdisciplinary field of science integrating the achievements of chemistry, physics and information technology. Nanotechnology enables the production of miniature products determined by the size of their elements, which are atoms and molecules. All technological operations are at the atomic or molecular level at scales below 200 nm [2].

Nanostructural materials require the precise location of atoms or their groups and control of the size and composition of produced grains or blocks, which results in searching for unique technological methods. These materials have mechanical, electrical, magnetic and optical properties different from conventional materials [3, 4].

In welding, there is also a tendency to create thin joints and put thin, precise weld coatings. The introduction of modern nanostructural wires or welding powders into the market enables precise padding welds. Presently, TiCN + Cu nanopowders are used in laser welding. Nanopowders enable a homogeneous padding weld of higher microhardness and expansion resistance [5]. The comparison of traditional laser welding and welding with TiCN + Cu nanopowder is shown in Fig. 1 [5].

Castolin EnDOtec DO * 390N welding nanowires and NanoAlloy XHD 6395N electrode have similar importance and properties. The use of nanowires reduces the consumption of binders by 37 %. Fig. 2 shows the microstructures of those binders as well as the standard composite material used in pad welding [6].

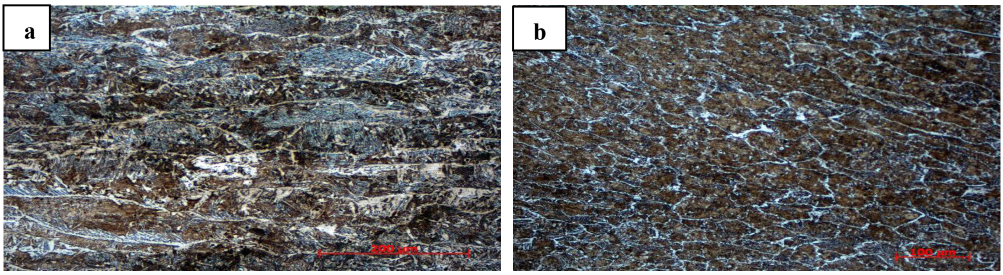

Fig. 1. The structure of the joint: a) after laser welding; b) after laser welding with the use of TiCN + Cu nanopowder [5]

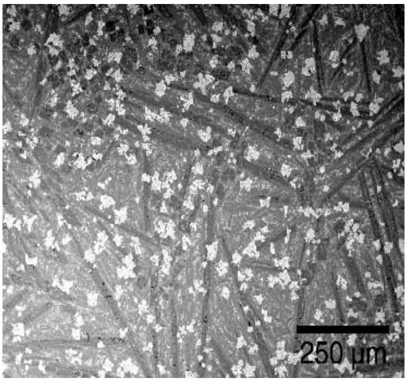

Fig. 2. Microstructure of EnDOtec TO * 390 padding wire [6]

The powders of this nanowire are built from the phases of carbides (MC) of large volume, the boron carbides $M_{23}(BC)$ and borides M_2B, evenly disposed in the fine-grained matrix of iron (Fig. 2) [6]. Standard composite materials used to pad layers resistant to wear by (e.g. abrasive) friction contain very hard wolfram carbides WC of irregular shapes, usually located in the Ni or Fe based matrix of lower hardness. While operating, carbides become gradually exposed, and in consequence, they chip or crack. This phenomenon is particularly common in the case of carbides of spheroidal shapes (Fig. 3) [6].

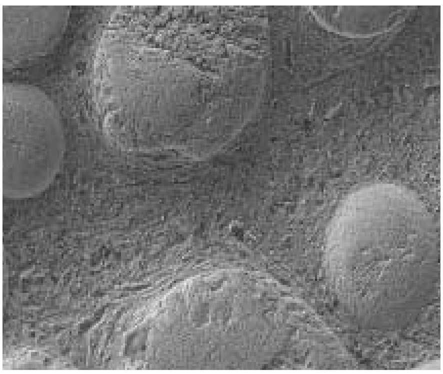

Fig. 3. Spheroidal carbides as components of standard padding materials [6]

As opposed to standard padding materials, a single layer of padding weld with the use of nanopowder wire is often enough to achieve the hardness of the surface up to 68-70 HRC in spite of the phenomenon of mixing materials, which is impossible to eliminate. The special nanostructure of the weld metal is exceptionally resistant to this kind of wear [6, 7, 8]. In the case of typical binders based on Ni and carbides, the same mixing of material results in a considerable decrease in the hardness of the weld metal and requires padding the next layers in order to obtain the required hardness [4, 5, 6, 7, 8].

Pilot studies

This article presents the results of pilot studies into nanostructural padding welds made with the laser technique. The Nd:YAG laser (Table 1), was used for the studies. The studies were conducted on 0H18N9 steel of the chemical composition presented in Table 2, and on additional nano-material used to pad welding (Table 3).

Table 1. Laser parameters

Laser wavelength	Operation mode	Laser pulse energy	Power rating	Maximum impulse power	Pulse frequency	Pulse time	Beam diameter
1064 nm	pulses	up to 100 J	200 W	12 kW	up to 20 Hz	0.5–20 ms	0.3 – 2.5 mm

Table 2. Chemical composition of materials used for padding according to EN 10025-2:2004

Native material	Material chemical composition										
	C	Mn	Si	P	S	Cr	Ni	Al	N	Mo	Cu
	max%	max%	max%	max%	max%	max%	max%	min%	%		
0H18N9	≤0.12	≤2.0	≤0.8	≤0.045	≤0.030	17.0-19.0	8.0-10.0	-	-	-	-

Table 3. Chemical composition of additional materials used for padding [4, 6]

Nanopowder	Fe + < 5 % C, < 2.0 % Si, < 5.0 % Mn, < 20.0 % Cr, < 10.0 % Mo, < 10.0 % Nb, < 10.0 % W, < 5.0 % B
Nanowire	71 HRC

The examination of the topography of the surface and the microstructure of selected welded joints were conducted with a stereoscopic, optical microscope and scanning electron microscope. The measurement of the microhardness of the native material and padding welds in characteristic zones was performed on a microhardness tester.

The tests were carried out with various parameters of processing, applying various energy thicknesses, laser impulse time, and a 50 % overlap (Table 4).

Table 4. Parameters of laser processing for four variants, 50% overlap

Processing variant	Parameters
a	One pass, 6 kW, 4 mili sec., 11 Hz, 24 J, 2997 J/cm^2
b	Two passes, 6 kW, 4 mili sec, 11 Hz, 24 J, 2997 J/cm^2
c	One pass, 3.1 kW, 4 mili sec., 24 J, 2997 J/cm^2
d	Two overlapping passes, 3.1 kW, 4 mili sec., 11 Hz, 24 J, 2997 J/cm^2

A high heating and melting speed of the materials, their large shrinkage and ultra-fast phase transitions also contributed significantly to the accumulation of local shear stresses and normal positive (tensile) stresses. The padding process was carried out cold without preheating the base material. Cooling after the padding weld was carried out in room-temperature air. To avoid future cracks, acid resistant steel should be preheated before padding.

As a result of double and triple laser remelting, a microstructure of very large dispersion, large inhomogeneity, and diverse chemical composition in microzones was obtained, which was not a positive result. When examining the quality of the padding weld in its cross-section, a good bond with the basis material was found; however, it unfortunately had numerous cracks, pores and shrink holes (Fig. 5).

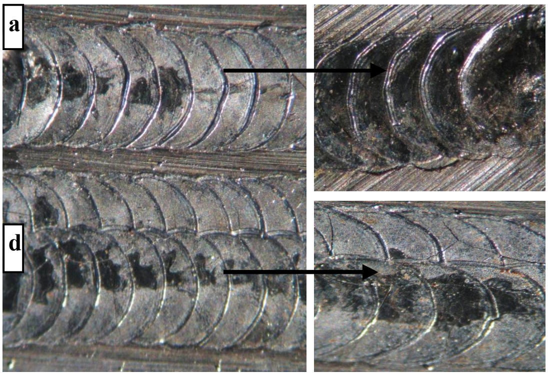

Fig. 4. Padding welding performed using laser technology with powder nanowire on 0H18N9 steel (variants "a", "d" presented in Table 4)

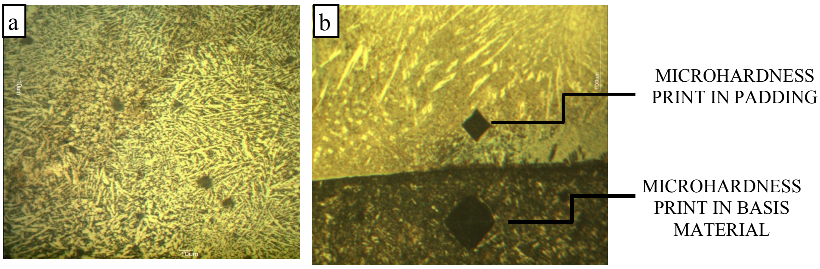

Fig. 5. Microstructure of the padding weld performed with the laser technique: a) zone of the padding weld material, b) penetration zone with the visible imprints of the microhardness tester at a load of 100G

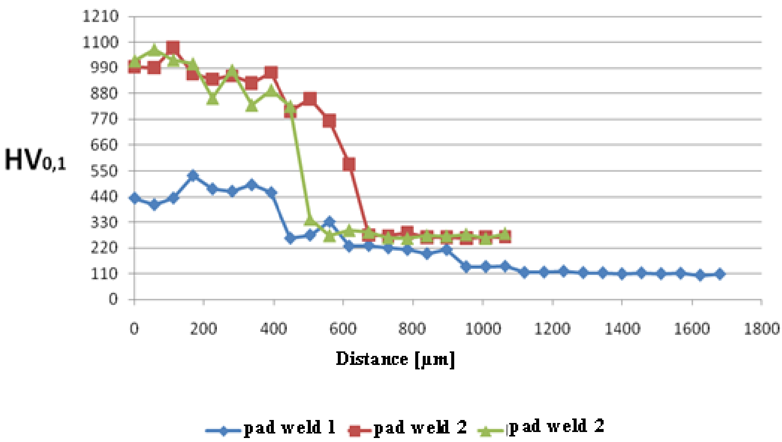

Fig. 6. Microhardness distribution in the cross-section of the padding weld created using the laser technique on 0H18N9 acid-resistant steel with the use of nanowire at various parameters of the process (from Table 3)

The microhardness distribution shows that, after laser padding acid resistant 0H18N9 steel with the use of powder nanowire, very high hardness of 990 - 1100 HV0.1 (Fig. 6) was obtained in the subsurface area of the padding weld for variants No. 2 and No. 3. In variant Number 1, a smaller microhardness of approx. 440 - 550 HV0.1 was obtained. In this variant, the padding material and native material gently moved (they probably mixed with each other). In variants 2 and 3, this distribution is completely different, i.e. one can see the clear border between the padding materials, the thickness of which varies from 450 µm to 750 µm, depending on a variant. The graphs of the microhardness distribution for variants 2 and 3 of laser padding in the penetration zone drops sharply, which proves that the padding weld mixes very little with the base and that there is a very large difference in microhardness values. The microhardness of the basis material is approx. 110 HV0.1, and the microhardness of the padding weld was as high as 1100 HV0.1 (Fig. 6).

Such high values of microhardness are probably the effects of the chemical composition and the nanocrystalic microstructure of the powder, which is the main component of the nanowire. Moreover, ultra fast processes of heating, melting and crystallisation occurring in laser padding also helped to produce such good effects. Unfortunately, as mentioned before, microcracks, which reduce the technical values of the padding welds, are serious drawbacks.

One can suppose that, if acid-resistant steel and nanowires of small diameters (0.6 – 0.8 mm) are first heated, it is possible to obtain precise micro- and macro-padding welds of very high technological values. Technological layers produced in this way can be applied in many elements of machines in order to significantly improve the tribological properties of their surface layers, especially their resistance to wear in the conditions of friction (including abrasive friction), erosion, etc.

Nanocrystalline microstructure has an essential influence on the increased resistance to wear in friction conditions. The atrophy of the oil film or the lack of lubricant are often causes of seizure processes influencing machine friction elements. Using precise laser micro-tooling (fibre laser with a Galvo head) oil micro-containers in the shape of “bowls” of approx. 90 µm in diameter and approx. 15 µm deep were formed in the surface zone of the padding weld (Fig. 7).

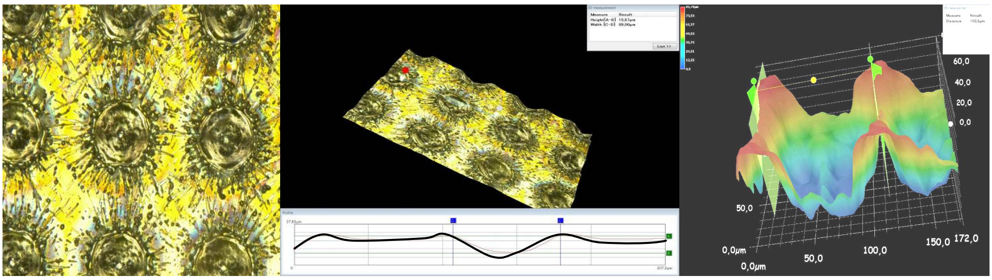

Fig. 7. The topography of nanocrystalline surface of the padding weld after laser texturing in order to form oil microcontainers essential in tribological processes

In the next laboratory studies of padding welds, the wear in friction will be examined with the use of modern tribological machines.

Conclusions

1. Pilot laboratory tests into producing high dispersal nanostructural padding welds on 0H18N9 stainless acid-resistant steel with the laser technique using nanowire as an additional material have proved that further tests are essential and that this technology has good perspectives for the future in production engineering and the regeneration of machine elements.

2. The chemical composition of the weld and the large thermal shock that occurred in the laser padding resulted in the production of numerous macro- and microcracks. In order to eliminate these cracks, 0H18N9 acid resistant steel should be heated up to the temperature of approx. 350 ^{o}C before the process of laser padding, and the steel should be cooled slowly after padding (approx. 50 ^{o}C / h).
3. After laser padding of 0H18N9 steel with nanowire, a very high hardness of the surface layer of the padding weld of 68-72 HRC was obtained. Additionally, microhardness in its cross-section was very high and equalled 990 - 1100 HV0.1. Probably, this high value of microhardness was also an effect of the chemical composition and nanocrystalline microstructure of the powder that was the main component of the nanowire.
4. The results are not satisfying because of numerous microcracks; therefore, further laboratory tests are needed to improve the technology of laser micro-padding with the use of nanowires. It can be assumed that, if acid-resistant steel and powder nanowires of small diameter (0.6 – 0.8 mm) are first heated, it is possible to obtain precise micro- and macro-padding welds of very high technological values. Technological layers produced in this way can be applied in many elements of machines in order to considerably improve tribological properties of their surface layers, especially their resistance to wear in friction, erosion, and cavitation conditions.
5. Using precise laser micro-tooling (fibre laser with a Galvo head), oil microcontainers in the shape of "bowls" of approx. 70 μm in diameter and approx. 15 μm deep with about 50 % of the surface filled were formed in the surface zone of the padding weld). As a result of ablative processing, characteristic microflow-outs and multidirectional extrusion of the liquid metal occurred due to a wave of pressure generated in the laser plasma at the laser impulse of approx. 100 ns.
6. Further laboratory studies of the padding welds are planned to test wear in friction conditions with the use of modern tribological machines.

Acknowledgements

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