THE INFLUENCE OF LASER PADDING PARAMETERS ON THE TRIBOLOGICAL PROPERTIES OF THE AL_2O_3 COATINGS

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Abstract

In this paper, the authors attempt to select the technological parameters of laser padding of spring steel. The coating material was prepared in the form of Al_2O_3 powder paste. Laser coated specimens were subjected to tribological tests of abrasion resistance, hardness, microstructure and elements distribution in the coating. The conducted tests indicate that the technology of laser padding with powder paste is feasible. Obtaining a coating with interesting properties depends on the selection of laser processing parameters.

Keywords: Laser padding, spring steel, laser treatment, ceramic coatings

1. INTRODUCTION

The operational durability of technical components used in machine building is an important feature regarding the wear and reliability of equipment and machine assemblies. Usually, these elements are subjected to heavy mechanical loads, tribological wear and fatigue processes during the operation [1]. The surface wear results in the deterioration of the object's functional properties. This may be due to various physical and chemical processes that accompany the operation. The wear mechanism, affecting the damage to machine parts, is complex and combines many related factors. The most important of them include [2,3]: the size and type of mechanical load, the slip speed of the rubbing surfaces, process temperature, hardness and structure of rubbing surfaces, roughness of working surfaces, corrosive environment, type of abrasive material, working surface friction coefficient, duration of the wear process.

The trends currently prevailing in the global technology market signal new design and manufacturing challenges. Hence the necessity to improve physical and mechanical properties in many materials and structural components of technical devices. Manufacturers use state-of-the-art materials all the time and use regenerative processes - in particular surface treatments such as laser padding. The purpose of the surface treatment is to cure the surface layer of structural elements by using abrasion-resistant metal alloys. The use of coatings on native materials allows to increase their operational durability [4]. This allows to reduce energy and material losses as well as to increase the quality of products. Surface treatment gives the opportunity to improve tribological properties (resistance to abrasive wear), resistance to mechanical loads, resistance to corrosive and erosive effects, resistance to temperatures and resistance to unfavorable working conditions. Surface treatment allows for the replacement of high-alloy steels with medium and low-alloy steels coated with the outer layer [5,6]. Padding is the process of covering the surface of components with layers of another metal or composites. It involves welding combined with the simultaneous melting of substrate. This treatment requires enormous accuracy and precision so that the coating layers adhere tightly and are free from cracks or pores. Laser padding is one of the methods of obtaining tribological coatings on the surface of the treated elements [7].

2. RESEARCH METHODOLOGY AND RESEARCH AND MEASUREMENT TOOLS

In order to carry out the laser padding process and perform tests on specimens with the obtained coatings, the following research and measurement tools and procedures were used:

1) The laser padding experiment was carried out on a TRUMPF TruFlow 6000 CO_2 laser with an installed mirror head generating a rectangular beam with dimensions of 20 x 2 mm.

2) During the padding process the temperature was measured by OTTRIS G5H monochrome pyrometer.
3) Microscopic examinations of the obtained surface quality were performed on the Hirox KH-8700 digital microscope, whereas structural studies on the Nicon Eclipse MA200 optical microscope.
4) The distribution of elements in the resulting coating was studied using a JEOL JSM-7100F scanning microscope.
5) The abrasion resistance test was conducted on the tribological T-07 tester with the following parameters: rotational speed of rubber disc (counter-specimens) V = 60 rpm, contact load F = 1510 G (14.8 N), test time t = 10 min (the test was performed in five 10 minute cycles).
6) Hardness was measured using the MMT-X3A microhardness tester, Vickers test was conducted with the following operating parameters: load F = 1000 G (9.8 N), dwell time t = 30 s, reading accuracy: 0.01 μm.

3. PREPARATION OF SPECIMENS AND ORGANIZATION OF THE PADDING STATION

Specimens made of 50 HF spring steel were prepared in the form of 30 x 30 x 5 mm cuboids. The chemical composition of steel is presented in **Table 1** (the steel type was identified by EDS analysis using the JEOL JSM-7100F and additionally the sulphur and carbon content was investigated by means of the CS230CH analyzer).

Table 1 Chemical composition of 50 HF steel according to PN-74/H-84032 standard [8]

Steel code	Percentage of elements (%)							
	C	Mn	Si	S max	P max	Cr	Ni max	V
50HF	0.46 - 0.54	0.50 - 0.80	0.15 - 0.40	0.03	0.03	0.8 - 1.1	0.40	0.10 - 0.20

The increase in the specimen surface was achieved by sandblasting with the EB90 electroround. The surface increase will improve the adhesive connection with the Al_2O_3 paste. A layer of Al_2O_3 paste with a thickness of 0.6 mm was applied to the prepared surface of the specimen. The specimens prepared in such a manner were placed in a specially designed operating holder. The holder was installed on the workbench of TRUMPF ThruFlow 6000 laser machine. The working station and process are presented in **Figure 1**.

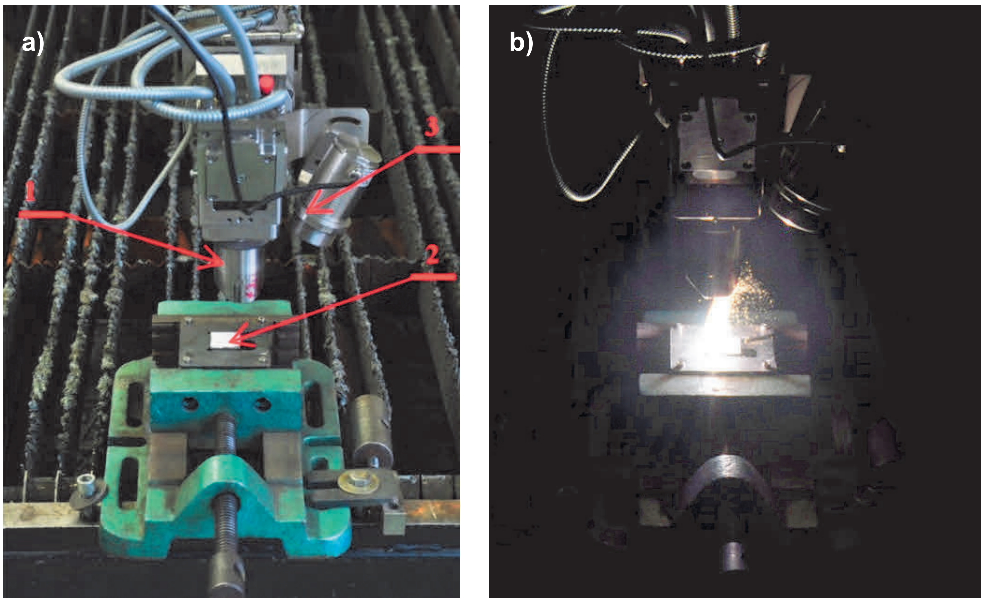

Figure 1 a) view of the laser welding station with the mounted specimen: 1 - reflecting laser head, 2 - specimen with the applied Al_2O_3 paste, 3 - OPTRIS G5H optical pyrometer; b) the laser padding process

The laser padding experiment was carried out for the following laser parameters:

- Specimen a): power: 4500 W, speed: 1000 mm/min, measured surface temperature ~1500 °C
- Specimen b): power: 6000 W, speed: 1000 mm/min, measured surface temperature ~1800 °C

After the laser padding a microscopic evaluation of the specimen surface was performed, the crystal structure was examined, the distribution of elements in the coating was determined, the tribological test was carried out on the T-07 tester and the microhardness was measured.

4. EXAMINATION OF THE OBTAINED COATINGS

One of the first and basic studies is focused on assessing the quality of the obtained coating by macroscopic evaluation. The obtained coatings are homogeneous, but the surface waviness is visible. Microscopic examinations revealed pores in both cases as shown in **Figure 2** and **Figure 3**. The surface porosity of the a) specimen is considerable, and the pores have a size of 80 - 300 microns. The surface of the b) specimen also has pores, but they are not so numerous and their size is insignificant in comparison with the a) specimen.

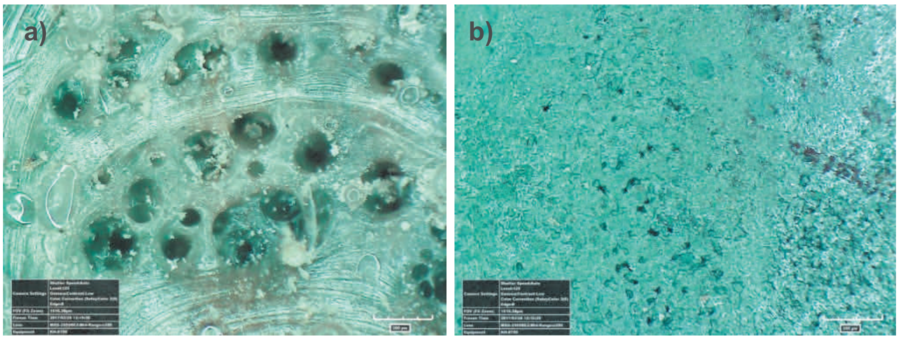

Figure 2 Coating surfaces at x200 magnification, specimen a), specimen b)

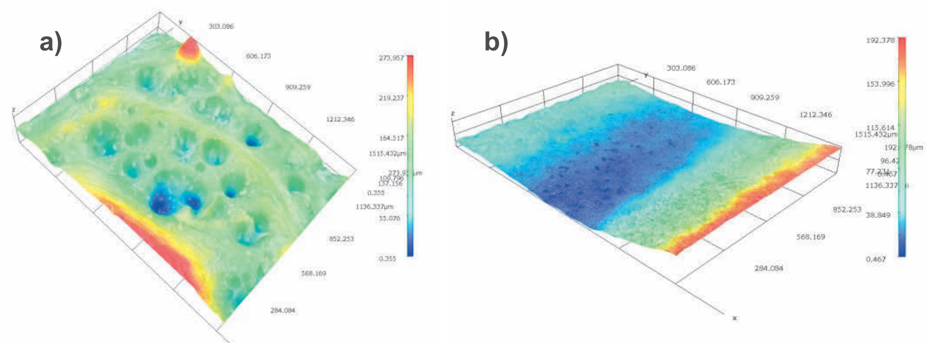

Figure 3 Surface topography of the obtained coatings, specimen a), specimen b)

The analysis of the steel structure after the laser padding process is extremely important. It permits the identification of the phase changes occurring during padding and provides the fundamental knowledge about the material properties. A fragment of the test specimen was polished and digested with the nital reagent (Mi1Fe). The examination revealed a fine-grained ferritic-pearlitic structure as the starting structure of spring steel.

Based on the observation of the microstructure, it can be concluded that both specimens have structures similar to each other - **Figure 4**. The differences are insignificant and refer only to the depth of the HAZ. For both specimens, a clearly applied coating can be observed on the surface. Under the coating in the HAZ an idiomorphic ferrite (plate) can be found, which indicates too high temperature in this zone. Generally, such structures are characterized by brittleness. Under this structure in the HAZ one can observe a coarse ferritic-pearlitic structure with a native material underneath - a fine-grained ferritic-pearlitic structure. In order to homogenize the structure some heat treatment after the padding process should be planned. What is primarily undesirable is the structure of plate ferrite, which can affect the elastic properties of steel.

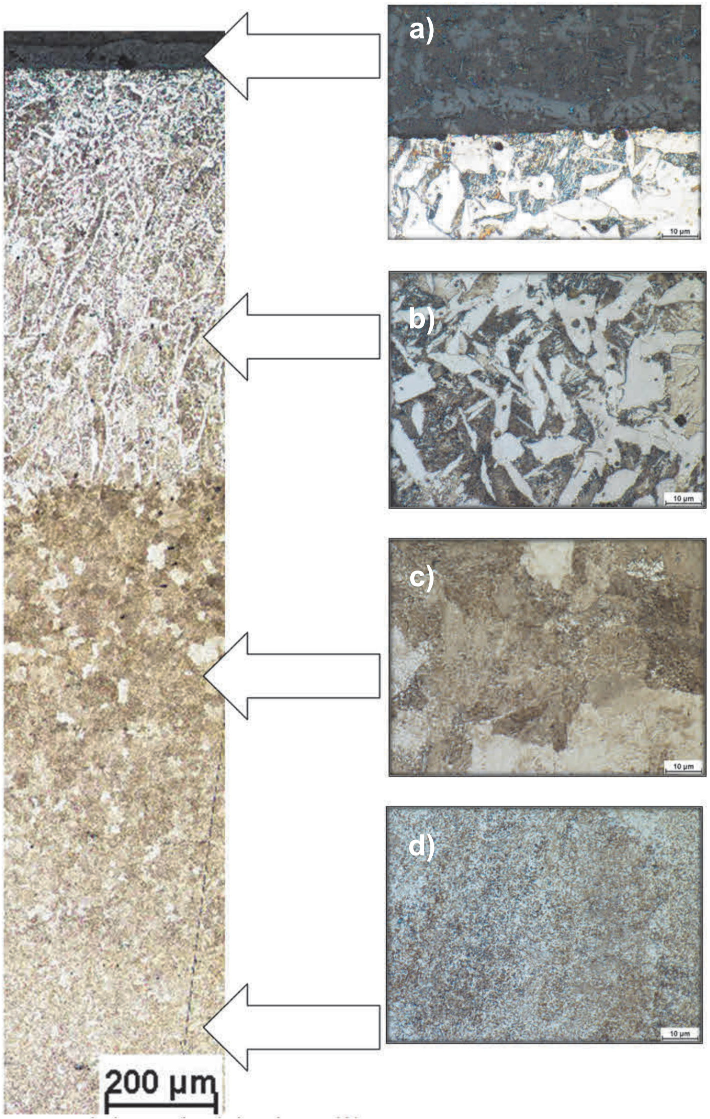

Figure 4 Structure of specimen with the magnification of the characteristic zones after laser padding: a) Fusion line. Above - Al_2O_3 coating (thickness about 50 μm), below 50HF steel - plate ferrite, b) Heat-affected zone (HAZ) (thickness about 600 μm) - idiomorphic ferrite (plate), c) HAZ (thickness about 400 μm) - ferritic-pearlitic structure, grain expansion, d) Native material, fine-grained ferritic-pearlitic structure.

It is possible to clearly determine whether the Al_2O_3 coating was formed on the surface of the specimens by making X-ray qualitative and quantitative phase analysis. Unfortunately, the authors do not have access to the X-ray analyzer. Therefore, the content of particular elements in the presumed coatings and immediately underneath were analyzed quantitatively. The element distribution analysis at the specimen surface and theoretical calculations of each element percentage will provide basis for the hypothetical considerations whether the Al_2O_3 coating was formed on the surface of the specimen [9]. The element distribution in the relevant specimen coating parts was analyzed accordingly. The graphs were prepared for specimen a). **Figure 5** shows the view of the measurement path of the density distribution of elements and graphs of the distribution of particular elements: oxygen, aluminum and iron.

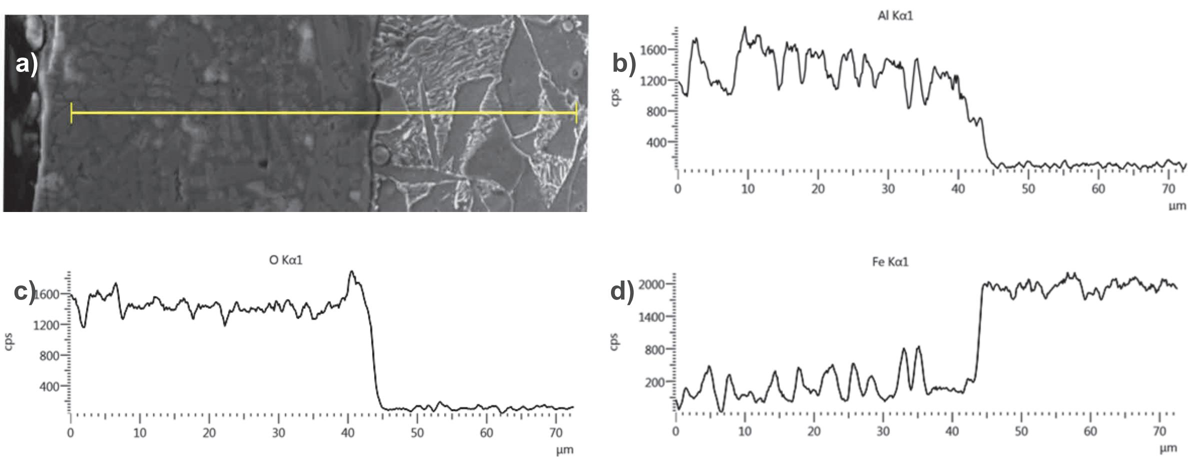

Figure 5 a) The measurement path of the density distribution of selected elements. On the left one can see the coating and the native material underneath. Density distribution of aluminum along the measurement path: b) aluminum, c) oxygen, d) iron.

Based on the analysis of the graph presenting the density distribution of aluminum and oxygen in the specimen, it can be assumed that in this case the Al_2O_3 coating was formed. Due to the above, the different elements in the coating were identified quantitatively. **Table 2** presents the results of the percentage share analysis.

Table 2 Percentage distribution of elements in the investigated coating.

	O	Al	Si	Ca	Cr	Mn	Fe	Total
Avarage distribution	43.50	39.25	1.13	0.95	0.77	2.03	6.88	100.00

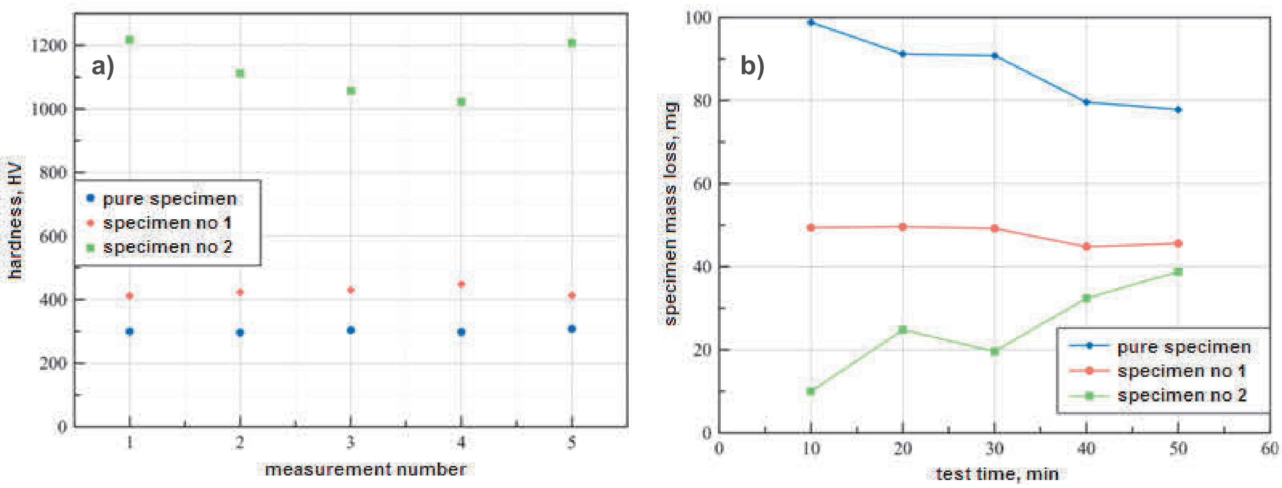

Figure 6 a) distribution of microhardness on the specimen surface, b) Mass loss after abrasion resistance test (tribological tester T-07)

Based on the calculations [9] it is assumed that it is highly likely that the an Al_2O_3 coating was in fact formed. To determine the tribological properties, the hardness was measured and an abrasive wear test was carried out. The results of testing specimens with the formed coatings were compared with the results obtained for a non-cladded specimen (reference specimen) - **Figure 6**.

5. CONCLUSIONS

Both specimens are characterized by a longitudinally wavy surface on which there is a noticeable white coating presumably with Al_2O_3. The direction of the observed waviness coincides with the direction of the laser beam shift. Most probably, the inequality geometry is related to the unevenness of the beam's power distribution along its length (multi-mode beam). Microscopic analysis revealed the occurrence of numerous pores on the surface. Their size was estimated at between 80 and 300 micrometers. The expanding gases in the padding pores of caused a significant detachment of the coating from the surface of the specimen. The remaining amount has been remelted and is characterized by a glassy appearance and porosity. The reason for the formation of the pores could be too much aeration of the Al_2O_3 paste which, being mixed with an organic binder, absorbed a large amount of gases. The paste did not contain stabilizers in the form of e.g. titanium oxide. After laser padding of the specimens, an increase in the hardness of their surface was observed. With the laser operation parameters of P = 4500 W and v = 1000 mm/min, the hardness increased approx. four times compared to the hardness of the reference specimen. It is a significant increase. With a laser power of 6000 W and the same feed speed of the laser head, the hardness increased slightly, hence the conclusion that in order to obtain a satisfactory effect, the appropriate parameters should be selected for laser padding.

Summing up:

1) The tests showed that the technology of laser padding of Al_2O_3 coatings is feasible.
2) Obtaining the coating with the interesting properties depends on the appropriate selection of laser processing parameters and the type and sequence of thermal treatment.
3) During the investigation it was demonstrated that the Al_2O_3 coating significantly increases the durability of the components.
4) Observed surface porosity unfortunately renders the technology commercially unviable. Further attempts should be made to make the surface geometrically homogeneous.
5) It is suggested that the coating should be stabilized by adding approximately three percent of TiO_2 to the Al_2O_3 paste.

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