BEHAVIOUR OF THE EXHAUST VALVE CLADDING FACE UNDER THE SERVICE CONDITIONS

Wlodzimierz Konczewicz

Gdynia Maritime University, Department of Mechanical Engineering
Morska 83, 81-225 Gdynia, Poland
tel.:+48 058 6901564; fax: +48 058 6901399
e-mail: wlodekk@am.gdynia.pl

Hanna Smolenska

Gdansk University of Technology, Department of Materials Science and Engineering
Narutowicza 11/13, 80-952 Gdansk, Poland
tel.:+48 058 3472297, fax: +48 058 3471815
e-mail: hsmolens@pg.gda.pl

Abstract

During the ship engine operation one of the key problems is the exhaust valve durability. A special interest is in valve head face because this narrow part of the valve is responsible for tightness. Cobalt base laser cladding layer on the exhaust valve head face have been investigate under real service condition using the laboratory two-stroke diesel engine L22 for two years. During this time the engine was fuelling with both ordinary light fuel and biodiesel fuel. After removing from the valve head from the cylinder head the face surface were fully inspected optically. There were no damages and the surface was shining in the great deal however some dark "spots" on it. The samples made of the used valve head underwent microstructural investigation and hardness measurements. There were no observed substantial microstructural changes neither in the surface of the layer nor in the bulk of the clad. The decrease of the hardness numbers was observed but still clad layer presented higher hardness than steel base. This type of clad layer underwent intensive laboratory examinations which contained oxidation experiments at different temperatures and corrosion in exhaust gases and with the present service experiment this method of valve head hardfacing is suitable for practical applications.

Keywords: *exhaust valve, laser cladding, cobalt alloy, service wear*

1. Introduction

The high temperature and high pressure which are typical condition for heavy-duty diesel engines result in high stress and severe work condition for exhaust valves. Not only tensile, creep and fatigue properties are important but also excellent oxidation resistance and forgeability are recessive. The increasing demands which increasing the stress levels or temperature, changes in fuels and lubricants and possibility of repairing were the main reason for seeking new materials and technologies. The proper solution of all this demands should meet long-term durability of the valve elements. Surfacing the seat face with different techniques and different resisting materials can increase the durability of valves. Due to surface hardening the valve can be resistive to friction and corrosion wears at high temperature exhaust gases. The cobalt base alloys are commonly used for valve seat face surfacing because of their resistance for combustion products hot corrosion. They are a good choice because of their resistance to fatigue wear also. Various studies had been performed on the most commonly used hard facing materials, called stellites. Some of them emphasize the influence of carbide on abrasive wear resistance and some examine the influence of alloying elements [1,2,3,4,5].

In modern technology, hardening is often used to produce surface coatings protecting parts against different kinds of wear. Laser surface treatment has already been widely studied. Among surface treatments, laser cladding has proved to be an alternative to conventional techniques when wear and corrosion resistant surface are required. The laser cladding goes beyond not only producing the new layer but it also can be useful to repair worn components. This technique is characterised by an excellent metallurgical bonding between base material and a clad layer with little intermixing and low distortion.

2. Laser cladding of valve face

For the ship engine, the exhaust valve head are usually made of valve steel which are resistant for high temperature, wear and service environment. For this investigation also the steel forging valve was used. The steel was A-R-H10S2M which is corresponding with an X40CrSiMo10-2 steel. Before cladding the valve face underwent turning. Cladding was conducted with a high power diode laser HDPL ROFIN SINAR DL 020 with generated beam power of 2,5 kW. The powder was delivered straight to the melt pool. The parameters of the process are as follows: the laser power -1,0 kW, laser scanning rates - 0,2 m/min, powder feeding rate - 5,0 g/min, the layer thickness - 1,0 mm and width - 6mm. The subsequent laser tracks were overlapped by 30 %. The chemical composition of the powder, which was used for creating the clad layer, is presented at Table 1. The whole clad layer consisted of three sublayers with three tracks on each one.

Tab. 1. Chemical composition of the powder (in weight %)

elements							
C	Si	Cr	W	Ni	Mo	Fe	Co
1,55	1,21	28,8	4,9	2,2	<0,1	2,0	balance

After cladding, the surface was machined to obtain proper geometry. In order to conduct further investigation the valve was cut perpendicular to the cladding layer and was characterized by optical and scanning electron microscopy (SEM). Microhardness of the specimens was measured with PMT-3 hardness meter. The concentration and distribution of the alloying elements were determined using EDAX analysis. In deposited layers a typical surface welding solidification structures were observed (Fig. 1).

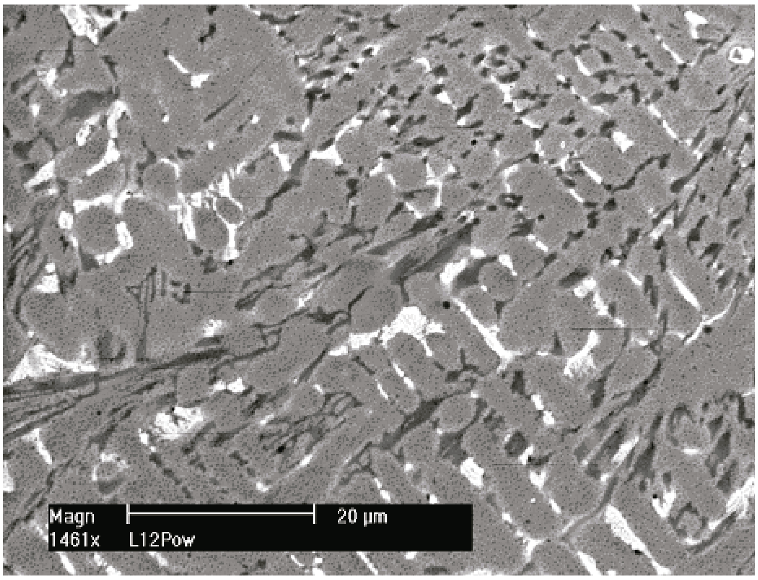


Fig. 1. SEM photograph of the cross section of the clad layer close to the surface. The grey regions are dendritic while light and dark domains and interdendritic regions, respectively

Microstructure of as-deposited layers consists of α-Co (Co-rich matrix) with a network of carbides and eutectics in the interdendritic regions. The carbides which were observed were identified as mainly $M_{12}C$ (Co_6W_6C) and $M_{23}C_6$ ($Cr_{23}C_6$). Carbides are the most important secondary phase in cobalt alloys and contribute significantly to alloy strengthening. Cross-section EDAX analysis of clad layers revealed that the matrix was enriched in chromium and tungsten while the eutectics were enriched in chromium, tungsten and silicon.

The Vickers number hardness obtained after laser cladding on the outer layers were variable in the range from 41HRC (402 HV30) to 46,5HRC (471 HV30) and were higher than average hardness original heat-treated steel, which was 283 HV30. However, this information, which is suitable for users, does not allow estimating how the presence of many tracks influence on clad layer properties. Micro-hardness across the clad, heat-affected zone and parent material was measured using a GOST 7865-86 microhardness tester. The test was carried out on the finely polished transversally sectioned surface at the load of 200 g for a loading time of 20 s. The hardness variations across the layer were the result of the non-homogeneous structure of the clad layer which was showed on the Fig. 1.

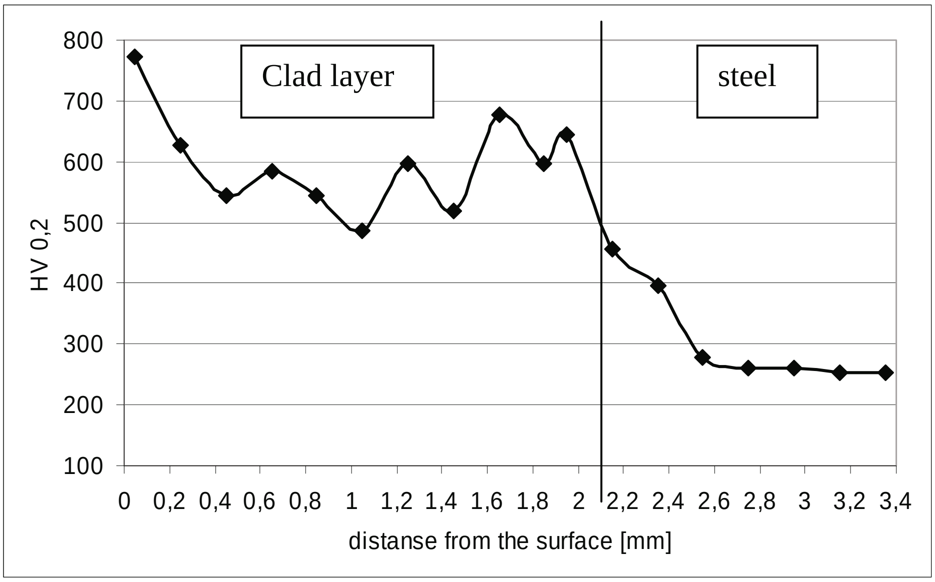


Fig. 2. Microhardness profile of cross-section specimen of the as clad valve face

3. Clad layer properties after service

In this part of the investigation the valve with a clad layer on the face was examined by real working conditions using the laboratory two-stroke diesel engine L22 for two years. The engine was fuelling with both ordinary light fuel and biodiesel fuel. After removing from the valve head from the cylinder head the face surface were fully inspected optically. There were no damages and the surface was shining in the great deal however some dark “spots” on it. On the Fig. 3 was presented valve head after removing and a new one and on the Fig. 4 typical picture of the face surface after service was presented. After cleaning and cutting off the steam the rest of the head were cut into the samples and prepared to the more detailing investigations. The first step was observation of the surface of the face with the special attention to the mentioned dark “spots”. To this task SEM microscope was used and the results were presented on the Figures 5 and 6.

The radial cross-section, prepared through the valve face surface, were ground and polished according to standard metallographic practise. The Leica Reichert MEF4M optical microscope (OP) and Environmental Scanning Electron Microscope Philips-FEI XL 30 ESEM were used to examine cross-section in unetched and etched conditions. The SEM images alloy to examine influence of the long time exposition on working conditions on the microstructure changes.

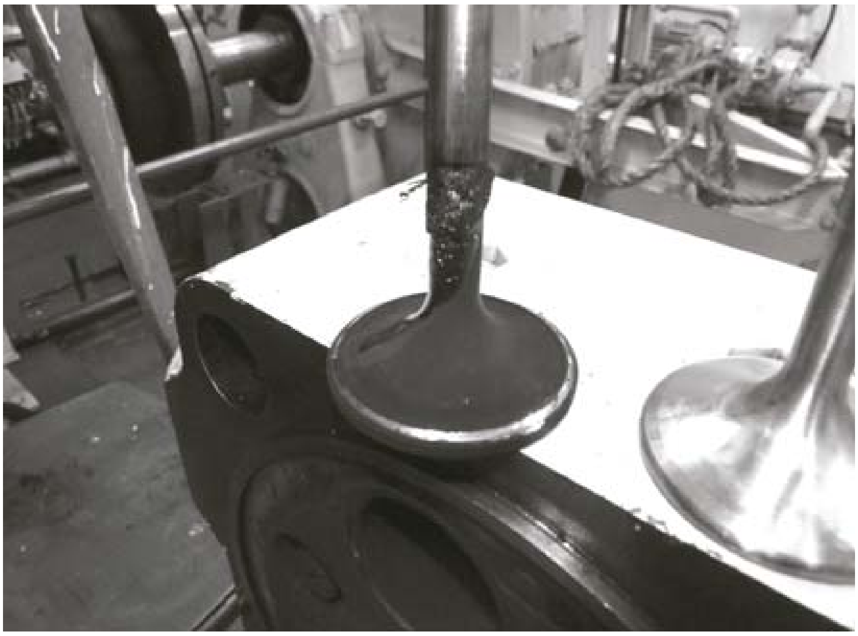


Fig. 3.The vale heads: after service (on left) and new one (on right)

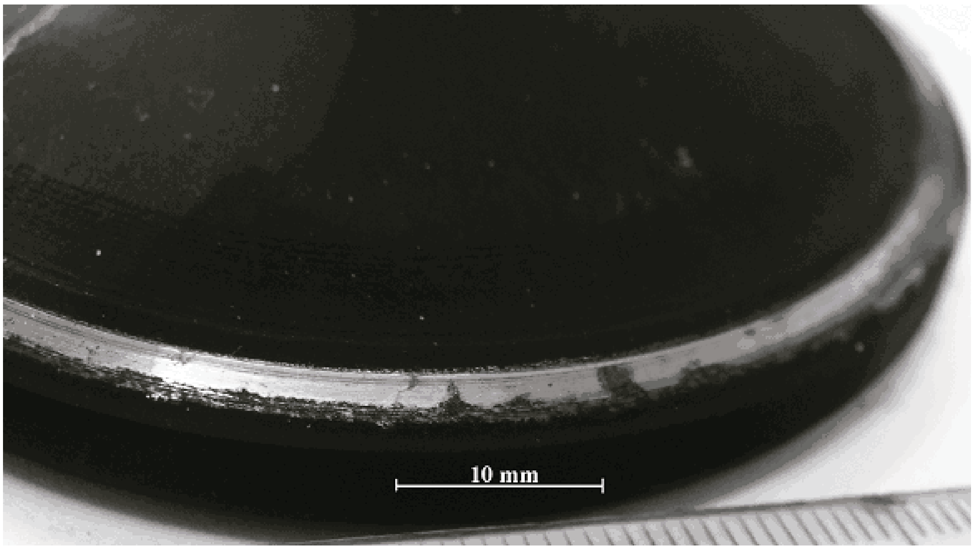


Fig. 4.The vale face after two years of service

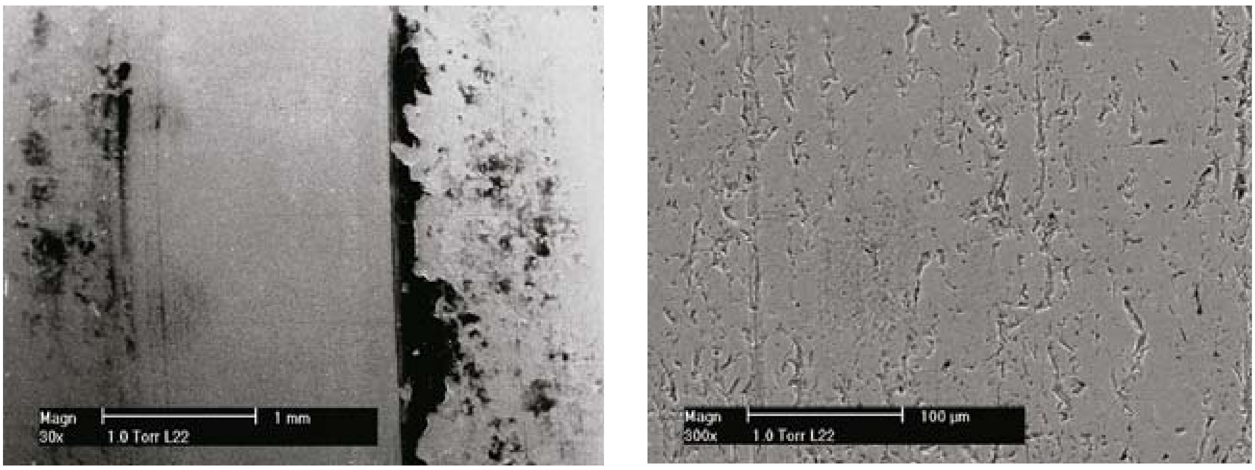
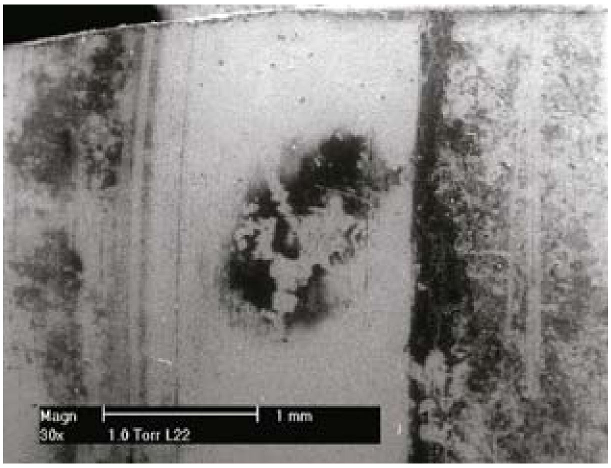


Fig. 5. SEM of the vale face after two years of service – shining region under different magnification



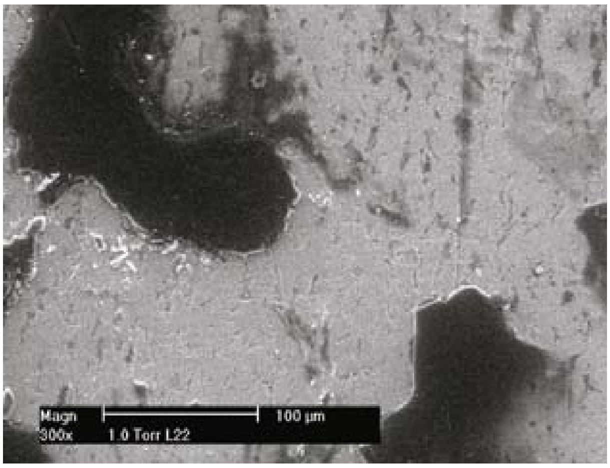


Fig. 6. SEM of the vale face after two years of service – dark "spot" region under different magnification

The OM and SEM observation of the face sample were conducted on the cross-sections, perpendicular to the face surface, were the second step of the layer examination. Fig. 7 presents result of SEM observation.

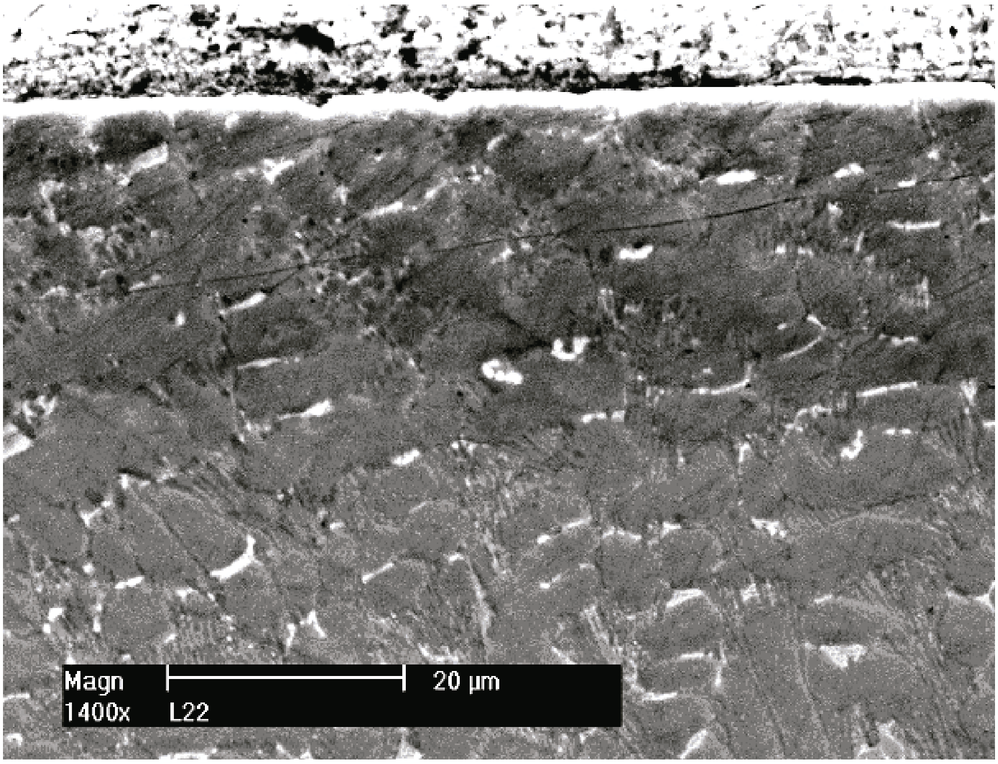


Fig. 7. SEM of the vale face after two years of service – cross-section

There were no observed differences in the clad layer microstructure in comparison with the as-clad structure (Fig. 1). The small amount of wear pits were found, however theirs depths were no more than 7 μm.

The microstructure observation were followed by hardness measurements which were carried on the same way as for as clad layer. Because of the high measured differences on hardness numbers, three microhardness profiles were obtained in order to improve the statistical significance of the data. The result of measurements and average values which were calculated was showed on the Fig. 8.

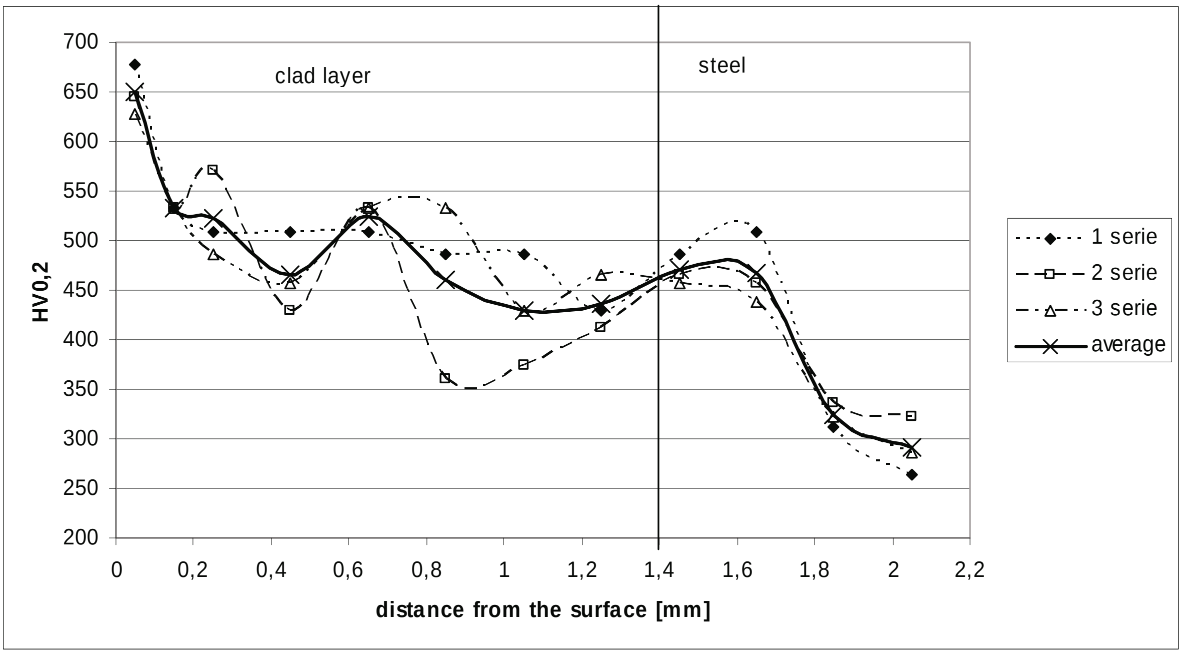


Fig. 8. Microhardness profile of cross-section specimen from the valve head after two years of service

The decrease of the hardness numbers was observed but still clad layer presented higher hardness than steel base. Also variation of the hardness across the layer was limited which was a result of the diffusion processes during the long tame of heat influence however this changes were not noticed in the microstructure.

4. Results

After two years of service, the face presented smooth, shinning surface with not numerous dark spots. The geometrical and roughness properties were found proper. The detail investigation reviled that wear processes took place. On the surface the evidences of pitting were observed. In this places the small amount of the metal were pull out and the spaces were partially fill up with the wear residuals (especially debris of the scale). Also the shinning part of the face presented the traces of the wear (Fig. 5, 6). The SEM examination of the cross-section specimens of the valve face allowed stating the minor changes in the microstructure of the bulk of the clad layer. After two years service hardness gradients are reduced as diffusion of elements from the substrate can occur. This type of clad layer underwent intensive laboratory examinations which contained oxidation experiments at different temperatures and corrosion in exhaust gases [6, 7, 8]. With the present service experiment this method of valve head hardfacing is suitable for practical applications. The next step of investigation will be evaluation of the valve behaviour during the service in the real working ship engine.

5. Conclusions

After performed investigations the following conclusions were established:

- Laser cladding is an effective material processing that produces a surface layer having good wear and corrosion properties with minimized dilution.
- The laser cladding technology with a cobalt base powder is a new good solution for building up valve head faces.
- Cobalt-based superalloys, with excellent high-temperature wear/corrosion resistance, are important industrial materials for cutlery, machine tools, and wear-resistant coatings. This

particular alloy has relatively high carbon content (1.55%) that is necessary for increasing the amount of carbides for higher hot hardness and wear resistance also enhanced inhibition to grain boundary sliding, dislocation movement, and grain growth.

- There is no need for a special preparatory operation before laser cladding.
- The obtained layers present good fusion bonding to the steel, lack of the cracks and porosity and little distortion of materials produced by this process.
- After two years of service no general failure was observed.

References

[1] De Mol Van Otterloo, J. L., De Hosson, J. Th. M., *Microstructural features and mechanical properties of cobalt-based laser coating;* Acta Materalia, vol. 45, no. 3, 1997.

[2] d`Oliveira, A. S. C., Vilar, R., Feder, C. G., *High temperature behaviour of plasma transferred arc and laser Co-based alloy coatings;* Applied Surface Science 201, 2002.

[3] d`Oliveira, A. S. C., da Silva, P. S. C. P., Vilar, R. M. C., *Microstructural features of consecutive layers of Stellite 6 deposited by laser cladding;* Surface and Coatings Technology 153, 2002.

[4] Elliott, P., *Choose materials for high-temperature environments*, Chemical Engineering Progress, 97, 2, pp. 75-85, 2001.

[5] Schlager, D., Theiler, C., Kohn, H., *Protection against high temperature corrosion with laser welded claddings, applied and tested on exhaust valve discs of large diesel engines burning heavy fuel oil*, Materials and Corrosion 53, pp. 103-110, 2002.

[6] Smoleńska, H., *The gas corrosion of the cobalt base layer at elevated temperature*, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 18, iss. ½, pp. 235-238, 2006.

[7] Smoleńska, H., Kończewicz, W., *Analiza własności napawanych laserowo powierzchni przylgni zaworów wylotowych silników okrętowych po korozji w powietrzu i gazach spalinowych,* Inżynieria Materiałowa, R. 27, nr 3/151, pp. 536-539, 2006.

[8] Kończewicz, W., Smoleńska, H., *The resistance investigation of the marine engine exchaust valve using the modelling chamber*, Journal of KONES: Powertrain and Transport, Vol. 15, nr 4, pp. 255-262, 2008.