STUDY ON STRUCTURES AND PROPERTIES OF THE LASER CLADDING EXHAUST VALVE AFTER SERVICE

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Abstract

The cobalt base laser cladding layers which were built up on the exhaust valve head face of the heavy loaded marine diesel engine have been investigated. The valve head with cladded face were served successfully for 3000 hours in the engine of the Dar Młodzieży. After removing from the valve head from the cylinder head the face surface were fully inspected. The surface topography and roughness were evaluated. Microstructure on the cross section of the clad layer were analyzed using Scanning Electron Microscope (SEM) equipped with energy dispersive spectroscopy (EDS. Also microhardness of the clad layer was measured. The service conditions resulted with the formation of the scale which had different thickness and tended to cracking and spalling. The microstructure of the clad layers after service did not demonstrated serious degradation process. 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, long time exposition in laboratory engine and in the end 3000 hours successfully service on the ship. After such experience laser cladding cobalt base layers may be recommended as a useful solution for both prolongs of the service life and a method of the regeneration of the slightly used valve heads is suitable for practical applications.

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

1. Introduction

The exhaust valves are used in the heavy duty marine diesel engine and its function is to keep the combustion chamber pressure tight. These valves are used in higher temperature areas, require good performances in wear and, heat resistance. The exhaust valve is working over a long period of time under combined effects of thermal stress, mechanical stress and chemical corrosive stress. The valve face is subjected to high frequency impact, high temperature and erosion of thermal corrosion gases. The valve faces will be getting erosion and abrasive wear, even resulted in cracking of exhaust valve [1, 2]. High temperature decreases yield strength of materials, repeated cycle impact contact results in deformation and fatigue of materials, exhaust gas corrosion speeds up the extension of fatigue cracks and produces abrasive wear products. Such service conditions of the exhaust valve are very deteriorative for materials and could lead to the premature failure. What more for the last two decades it was noticed that the fuel oil quality deteriorated while marine diesel engine power ratings increase significantly. This has resulted in higher thermal loads and a more corrosive environment for an exhaust valve. For engines operating on heavy oil the most common form of valve failure is through the formation of a blow by channel on the valve face [3].

Contemporary the main preventing method in industrial application is to apply a special layer. This layer should provide proper thermal resistance, corrosive resistance and wear resistance on valve face. Also it would be useful to adopt this layer technique for rebuilding used valve faces. For this reason also good machinability is an important property.

There are some coating techniques such as thermal spray, plasma transformed arc (PTA), bead welding etc. All these techniques have advantages and disadvantages connected with quality and production cost. One of the newer industrially used methods is high power laser cladding. Laser aided deposition is a material additive based manufacturing process via metallurgically bonding the deposited material to the substrate. Due to its capability to bond various materials together, it becomes an attractive technology for part repair in small scale [4].

Cobalt base alloys have an excellent oxidation resistance and attractive mechanical properties (strength, toughness and creep resistance). These properties are connected with the microsturcture of the cladding layers. The first phase formed during cooling from the liquid state consists of cobalt-rich dendrites with a face-cubic (fcc) crystal structure. The remaining liquid is solidified by a eutectic reaction into an interdendritic, intimate lamellar mixture of the fcc phase, $M_{12}C$ (Co_6W_6C) and $M_{23}C_6$ ($Cr_{23}C_6$) eutectic carbides depending on alloy composition and cooling conditions. The enhanced hardness and wear of laser processed cobalt base hardfacing alloy coatings have been associated with the formation of these hard carbides in an austenitic matrix [5-7].

2. Experimental

In this work cobalt base clad layers were examined. They were produced on the face of the exhaust valve head from the marine diesel engine in order to prolong service time of this part. The substrate material was A-R-H10S2M (X40CrSiMo10-2) steel. 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 – 6 mm. The layer consisted of three sublayers with two tracks for each one. The subsequent tracks were overlapped by 30-40%. The powder was delivered straight to the melt pool. The chemical composition of the powder, which was used for creating the clad layer, is presented at Tab. 1.

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

elements							
C	Si	Cr	W	Ni	Mo	Fe	Co
1.55	1.21	29.7	9.0	2.0	0.01	1.7	balance

After cladding the layer underwent turning in order to obtain proper geometry. Prepared this way valve head was examined by real working conditions using the “Dar Młodzieży” diesel engine, type 8A20, for 3000 hours. After 3000 hours service, from the valve head was removed from the cylinder head the face surface were fully inspected optically. 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 natural surface of the face with the special attention to the mentioned roughness and deposits. Next, step it was analyses of face topography and changes in the morphology of the clad layer after service. The analytical techniques used to characterize the samples included optical microscopy, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and X-ray powder diffraction (XRD). SEM was conducted at accelerating voltages ranging from 15-30 kV in backscattered and secondary electron imaging modes.

For hardness measurement the GOST 7865-86 manual microhardness tester was used. The test was carried out on the finely polished transversally sectioned surface perpendicular to the surface of the layer, at the load of 200 g for a loading time of 20 s.

3. Results

There were no substantial damages and the surface however some roughness and deposits were observed on it. On the Fig. 1 typical picture of the face surface after service was presented.

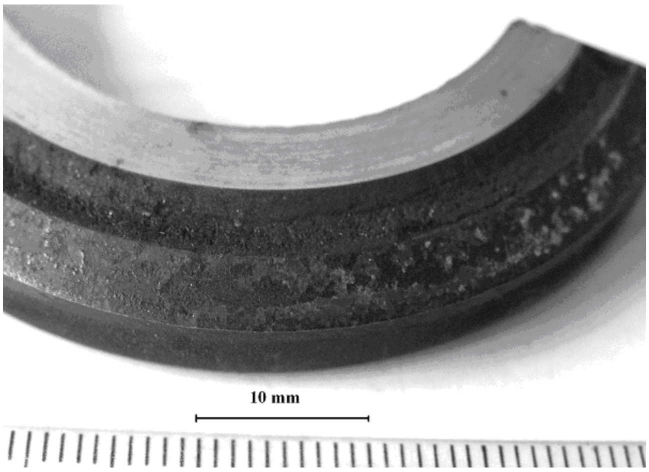

Fig. 1. The example the face surface after 3000 hours of service

The SEM microscope used for the analyse of the face surface condition and the results were presented on the Fig. 2 and 3. The face was covered with scale layer. This scale had different thickness and tended to cracking and spalling. Also the scale was not homogenous but consisted of many sublayers which were well illustrated on Fig. 3.

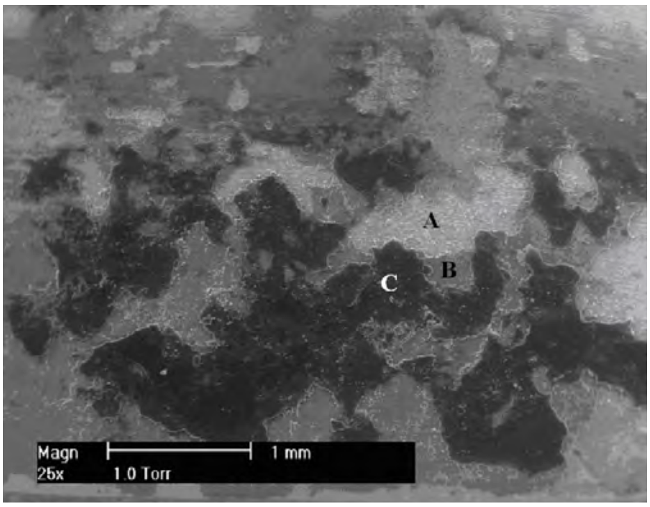

Fig. 2. The face surface topography after 3000 hours of service; A – almost clear metallic surface, B, C – scale layers

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 allow examining influence of the long time exposition, in working conditions, on the microstructure of the clad layer for the surface region and in the depth of the clad. Fig. 4 presented continuous and thick scale layer without visible

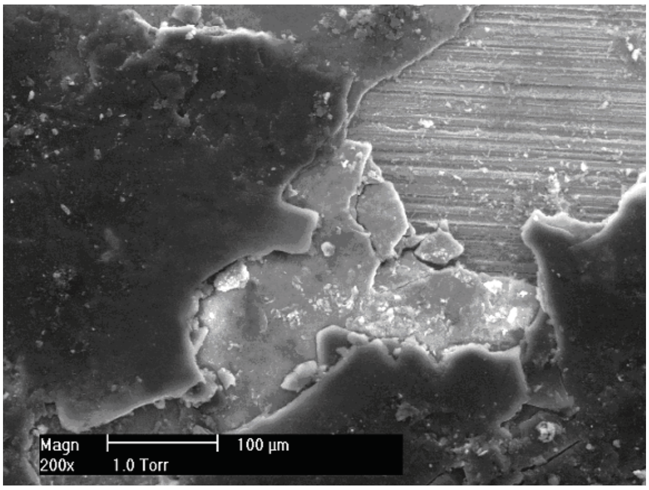

Fig. 3. A detail from the Fig. 2, showing the sublayers of the thin and thick oxides

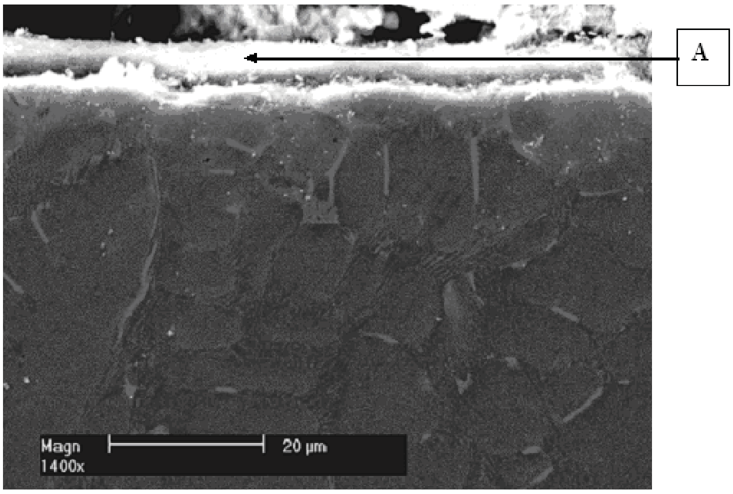

Fig. 4. The clad layer after 3000 hours service, morphology on the cross section, A – point of the EDS chemical analyse of the scale layer

defects. Its composition was quality described by EDS analyse and presented on Fig. 5. Under the scale there no essential changes in the bulk of the clad layer which still presented typical dendritic structure without any damages.

The long time service under elevated and variable temperature may cause more subtle changes in the microstructure, for example decomposition of the hard carbides. Analysis of the chemical composition of the different region of the clad layer reviled significant decrease in chromium content close to the surface just under the scale layer and increase of the iron content through the all clad thickness. The iron presence may be the result of the diffusion process from the steel base to the surface of the clad. Initial chromium content in powder was 29.7% while after service subsurface region contented only 23% of chromium which was steel enough to prevent the surface from the corrosion. The carbides are usually the main source of the chromium which is necessary to form chromium oxide on the surface and protect the layer form further oxidation and degradation. The better tool for valuation mechanical properties is the hardness measurement present more sensitive reaction on material changes during the heat treatment than microstructural analyzes [8]. Because of the high measured differences on hardness numbers, four microhardness profiles were obtained in order to improve the statistical significance of the data. The results of measurements and average values which were calculated were showed on the Fig. 6. Those measurements were compared with the microhardness results taken for the as clad layers. On the Fig. 6 the average values form five series of the measurement of as-clad layers were placed.

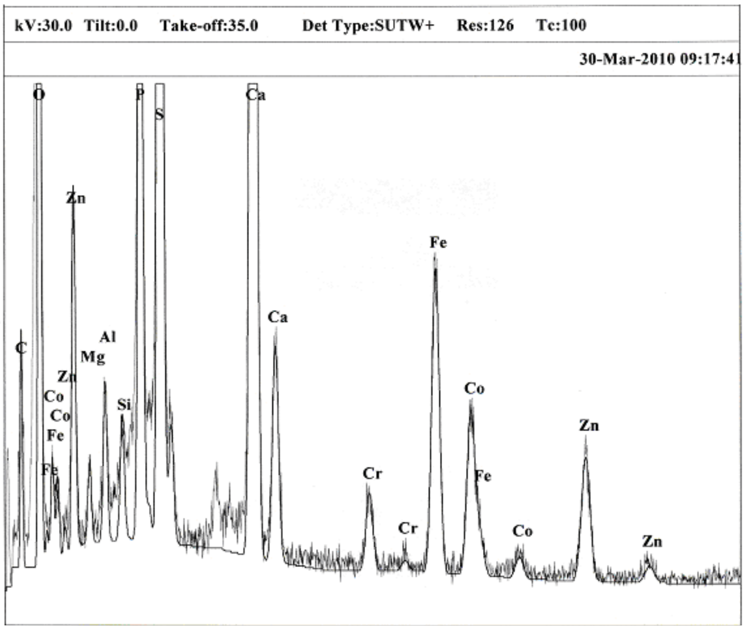

Fig. 5. The chemical composition of the scale which covered the face after 3000 hours of service. The measurement performed at point A (Fig. 4)

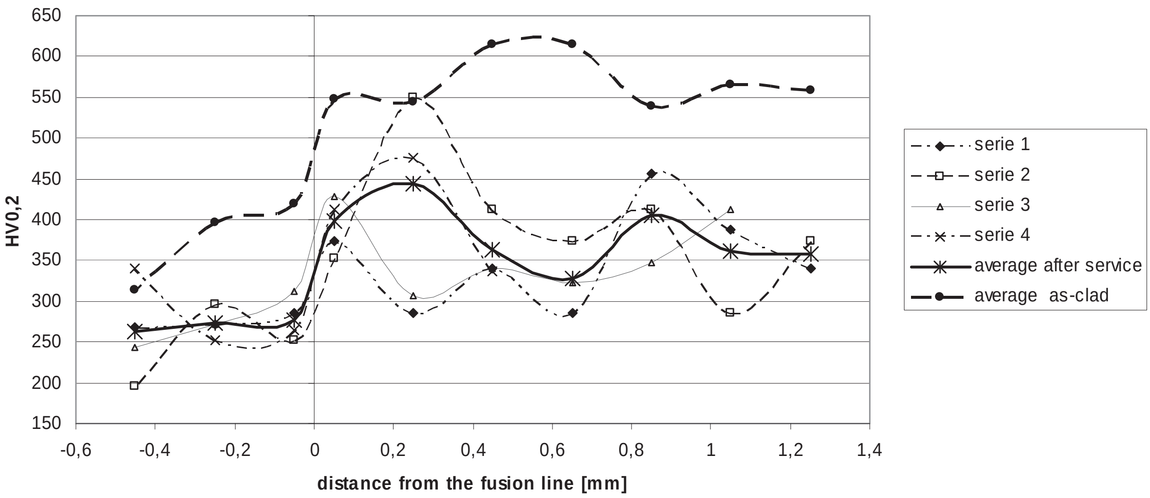

Fig. 6. The clad layer microhardness measurements: after 3000 hours of service and as-clad

The non-uniform hardness across the coating was a result of multilayer producing process and structure of this layer. The measured differences on hardness were affected by the dendrite structure and can also be attributed to the morphology of the carbides [9]. The influence of the long time service condition with a special attention to different temperatures and exhaust gases led to the changes in the hardness of the clad. The decrease of the hardness numbers was observed but still clad layer presented higher hardness than steel base.

4. Conclusions

This type of clad layer underwent intensive laboratory examinations which contained oxidation experiments at different temperatures [10] and corrosion in exhaust gases [11], long time exposition in laboratory engine [12] and in the end 3000 hours successfully service on the ship.

In this experiment cobalt base alloy was laser cladded in order to prolong the lifetime of the valve face or to repair used one. Two issues were important – evaluation of the method of hardening the valve face and choosing the best material for sever work conditions.

The clad layer which was prepared by laser cladding consisted of refined solidification structures and was characterized by increased hardness as compared to steel base. 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. Also very small dilution was observed. Also it was possible to produce layer with proper thickness so the turning to obtain a proper geometry led to small amount of scraps.

The presented results suggest that the cobalt base alloy which has excellent high-temperature wear/corrosion resistance is useful material for diesel engine exhaust valve. The composition analysis result of the tribochemical reaction product indicated that O, C, S, Ca were detected in addition to the clad-base metal of the valve. The scale, probable of oxide and sulfide generally, of different thickness was formed on the face surface. This scale tended to crack and spall when became thicker. But also this reaction product created the effect of preventing the wear on the valve faces. However, it increased the average R_{max}. There were any traces of internal corrosion of the layer. 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.

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