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The impact of material selection on mechanical properties and durability of exhaust valve faces of a ship engine, after operation in real conditions

Abstract
Two alloys were used in order to extend the service life of marine engine exhaust valve head. Layers of cobalt base alloys on the valve faces were produced by laser cladding. After a certain period of service, one of the valves was severely damaged. This research indicated that proper material selection can influence the duration of the service life and operational safety of marine engines.
Key words: cobalt alloy, laser cladding, exhaust valve

Introduction

Proper selection of materials for specific applications is a key issue ensuring the correct and long-term use of machine parts and installations. Special difficulties arise when a structural element is affected by complex conditions, such as:
- variable mechanical loads, especially of fatigue nature,
- friction wear processes
-high temperatures
- aggressive work environment.
Such a set of material requirements is found in cases marine engines exhaust valves operating under heavy load.
Operating factors having the greatest impact on the technical condition of the exhaust valves of the marine engines are primarily [10,11,12]:

- combustion process which (due to incorrect injection timing or poor fuel quality) accelerates the wear of valve components exposed to exhaust gases;
- valve clearance too small clearance value can lead, in a short time, to burning the valve seat, while too high clearance leads, in turn, to long-term mechanical punching of the seat;
- the cooling quality of the valve seat, its deterioration will shorten the service life of both the seat and the head of exhaust valve;

It has been confirmed that steel valves intended for such products do not meet the requirements. Therefore, the face area subjected to the most intense loads of various types –is surfaced with various materials, especially cobalt and nickel based alloys [1,2,3,5,8]. These materials are required to have, above all, high corrosion resistance in the exhaust environment and resistance to wear (high hardness under operating conditions) [4,6,7]. Despite the usage of such solutions, various types of damage listed below may occur:

- loss of tightness caused by corrosion pits because of erosive exhaust fumes (Fig. 1b),
- over burning of the valve head edges caused by the flow of extremely hot gases through leaks (Fig. 1a),
- cracks, scratches and splinters caused by fatigue of the face layer (Fig. 1c).

Typical materials used for hard-surfaced surfaces are nickel-based alloys or Stellite, Deloro, Triballoy type cobalt.

Tab. 1 Guidelines for the selection of alloys [9]

resistance	alloy	mechanical wear	corrosion resistance	high temperature resistance
XXXX –excellent	Stellite	XXX	XXX	XXXX
XXX- very good	Deloro	XXX	XX	XX
XX- satisfactory	Triballoy	XXX	XXX	XXXX

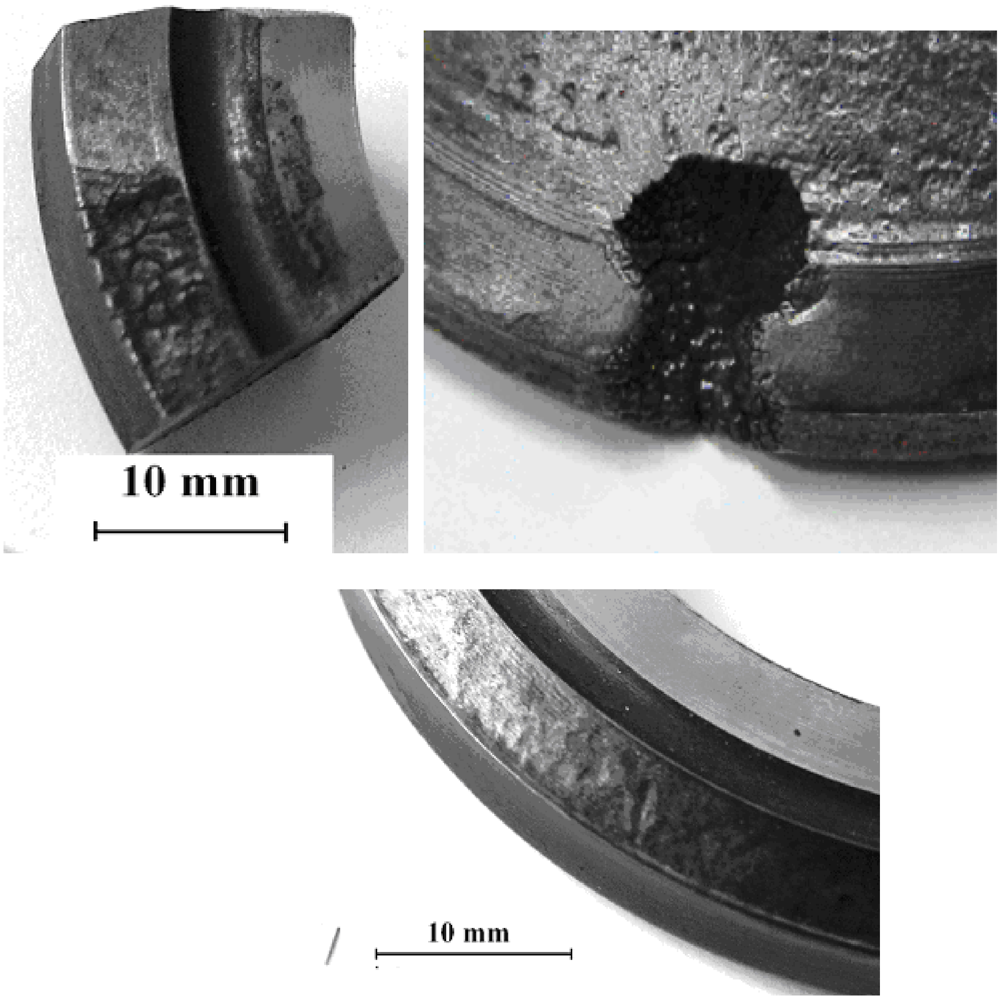

Fig. 1. Examples of damaged exhaust valve of the marine engine: a) - corrosion of the face - "pavement", b) - destruction of the face and substrate due to valve leaks - irreparable; c) - face wear – repairable

This paper presents the behaviour of the clad layers on the faces of the exhaust valve made of two alloys operating in real conditions, during normal work on a ship. In both cases, laser welding was performed using the HPDL ROFIN DL020 laser. The process parameters are specified in Table 2.

Tab. 2. Technological conditions of laser powder welding with HPDL ROFIN DL020 laser

Layer parameters	laser power [kW]	Welding speed [m/min]	The intensity of powder feed [g/min]	Bead thickness [mm]	Bead widness [mm]
1 layer – 2 beads	1,0-1,2	0,20	5,0	1,0-1,2	5,5-6,0
2 i 3 layer – 2 beads	1,1-1,2	0,20	5,0	1,3-1,5	6,0-6,5

Two cobalt base alloys, stellite 12 and stellite 21 enriched with tungsten were used to make the clad layers. These materials are characterized by high resistance to abrasion and corrosive conditions [13]. During cladding and operation, under the influence of thermal processes, the chemical composition of pads changes in relation to the composition of the powder used for welding. After the operation period, the chemical composition (in% by mass) of the pads was as follows:

Cladding layer marked L12: Co- 35,30, Fe- 31,83; Cr 23,12; W- 5,79; Si- 2,49; Ni-0,6; Mo-0,01;
Cladding layer marked N: Co -38,9, Cr -24,13; Ni -10,43; W - 8,75; Fe- 7,64; Mo- 7,56; Si-2,59;

Valves with faces covered with layers have been installed in the engine on the ship “Dar Młodzieży”. AL 20/24 engine has the following parameters: in-line engine, 8-cyliners; cylinder diameter 200 mm; piston stroke 240 mm; swept capacity 7540 cm^3; nominal rotational speed 720/750 rev/min or 900/1000 rev/min; 136kW/Cyl.

During operation, it turned out that after 2000 hours of service, the N valve was completely destroyed.

Fig. 2. N valve after 2000 hours of operation

The L12 valve after 3000 hours of operation did not show any significant signs of wear or damage.

Fig.3. L12 valve after 3000 hours of operation. Magnification 10x

Detailed investigations were carried out on the face surfaces of both valves and microstructures on the cross-section of the analyzed valves. In addition, hardness measurements were carried out to assess the degree of material degradation.

Metallographic examinations

A scanning electron microscope (SEM) was used for metallographic examinations which allowed the analysis of the valve face surfaces and microstructures on the cross-sections perpendicular to the face surface. Fig. 4 shows the surface condition of the N valve after service. Significant differences of the appearance of the valve face surface were observed. It also indicates different properties of the material in different area of the face which is not accessible.

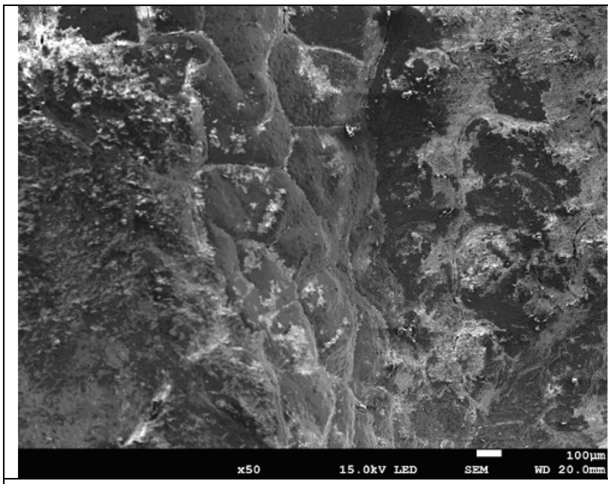	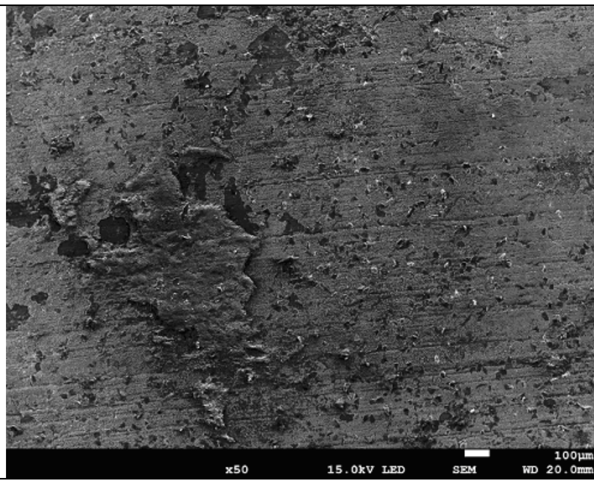
Fig.4a. N valve destroyed during operation – face surface	*Fig.4b. N valve destroyed during operation – face surface in different area*

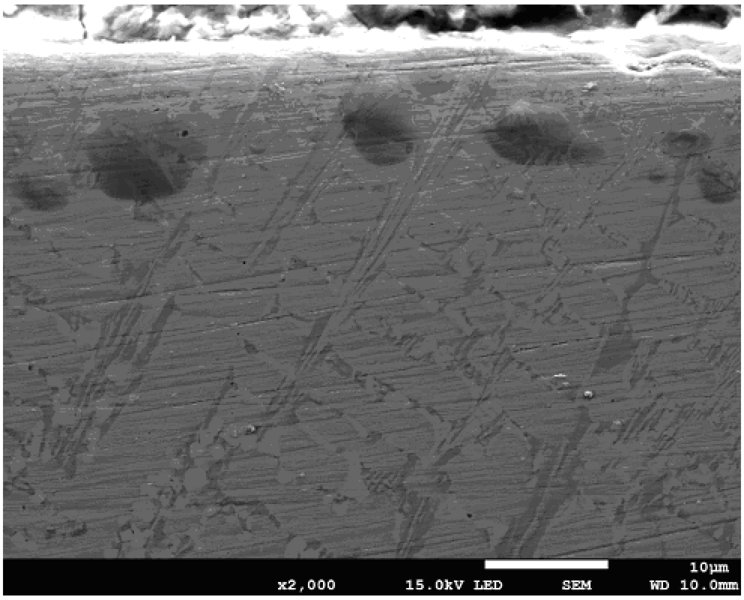

Fig.5. N valve destroyed during operation. Microstructure on the cross-section, close to the face surface

SEM-EDAX analysis in the cross-section, near the surface of the destroyed valve showed the presence of a dendritic structure with numerous precipitates characterized by a high content of molybdenum, nickel and chromium. Possible Phase P.

The L12 valve, undamaged after 3000 hours of operation, was tested the same way. Throughout the operation the valve functioned without any problems. It was dismounted and inspected. Despite the proper operation of the engine throughout the entire test period, the contact surface of the outlet valve face has been slightly degraded.

Fig. 6. L12 valve face after operation – scale

Observation of the face surface showed the presence of crumbling scale and areas of the exposed metal surface. In fig. 6 a multilayer scale with a tendency to crack and delaminate is visible. However, the largest layer thickness did not exceed 60 μm (fig. 6).

Fig. 7. L12 valve face after operation – plastic deformation

SEM observation of the cladding layer cross-section does not shows any significant changes in relation to the microstructure of the starting material. However, the presence of the scale on the face surface indicates changes in chemical composition resulting from diffusion processes. It may cause changes in material hardness.

Hardness measurement

The hardness measurement in the cross-section of the cladding face layer after the operation period was carried out. Due to the technology of applying the layer, the hardness measurement was carried out according to developed scheme shown in fig. 8.

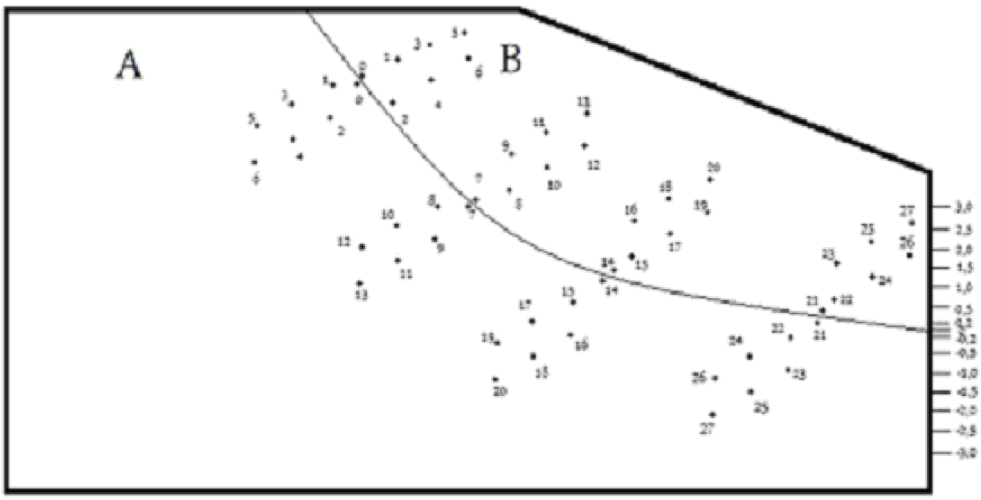

Fig.8. Positions of hardness measurement points on the cross-section of the cladded layer and the substrate; a –steel base, B - cladding layer

Due to the heterogeneous structure of the material four measurement series were made, the mean hardness value and the confidence interval were determined. The results are shown in fig. 9÷13.

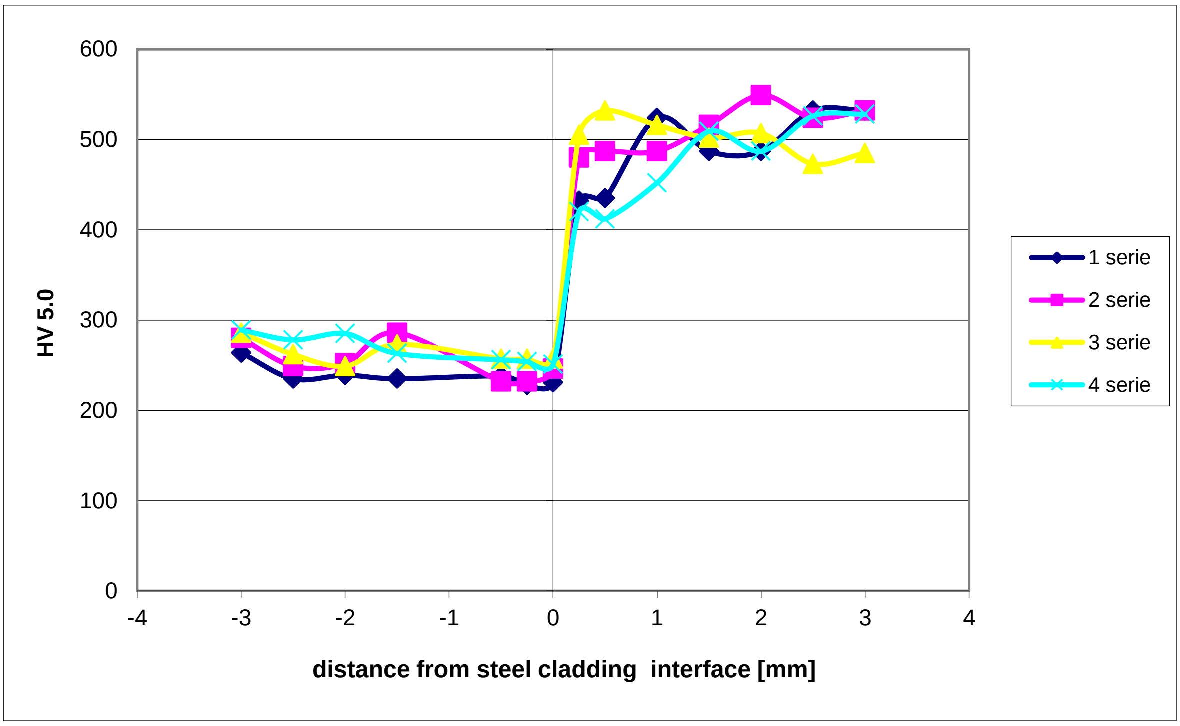

Fig.9. Results of HV5 hardness measurements for face cladding and steel base of L12 valve after 3000 hours operation - 4 series

distance from steel cladding interface [mm]

Fig.10. Statistical analysis of hardness measurements for L12 valve after 3000 hours of operation

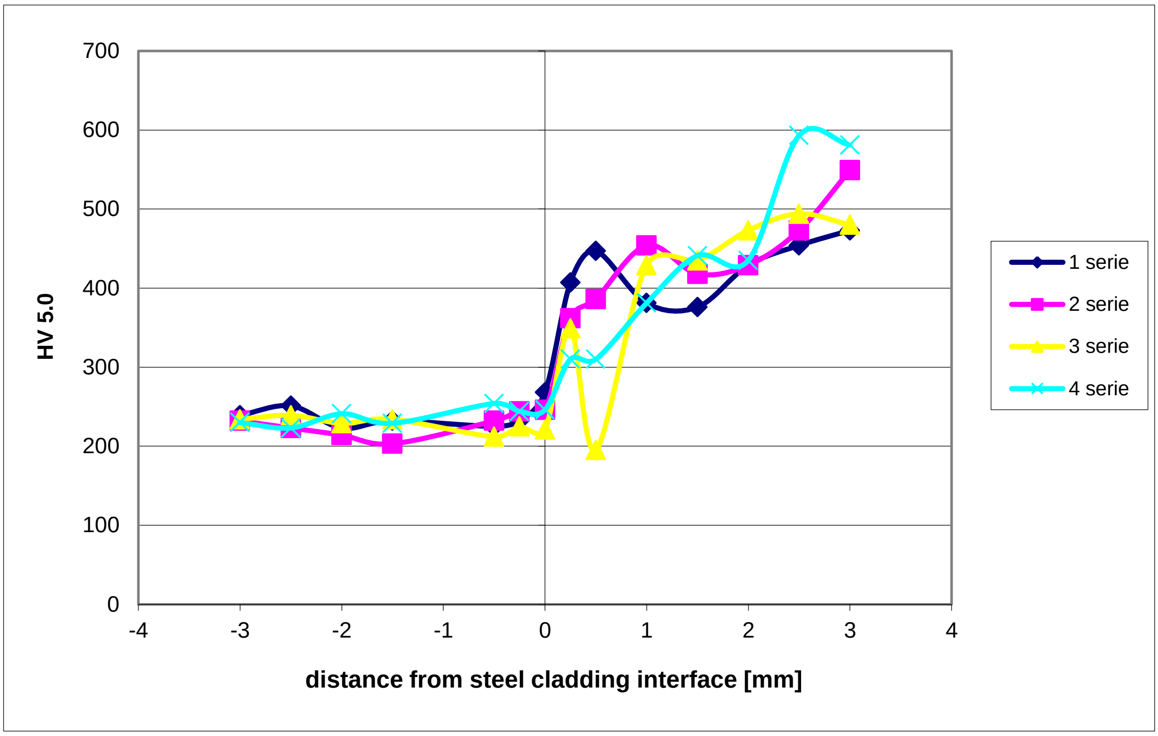

Fig.11. Results of HV5 hardness measurements for face cladding and steel base of N valve after 2000 hours operation - 4 series

distance from steel cladding interface [mm]

Fig.12. Statistical analysis of hardness measurements for N valve after operation for 2000 hours

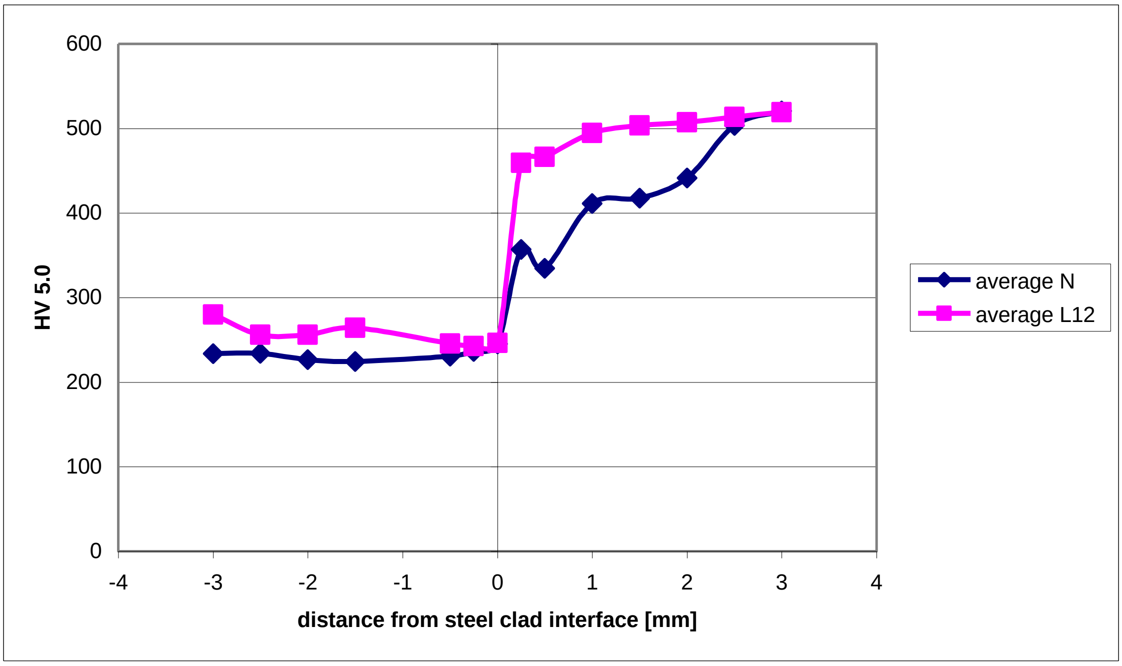

Fig.13. Comparison of average values of hardness of the faces claddings N i L12

Conclusions

- The cladding process provided both clad layers on the valve faces with a correct structure, typical for cladding process.
- The analysis showed that not every stellite type cobalt alloy can be used in harsh conditions that are observed at the valve outlet of the ship engine. The cladded layer made of the powder with higher amount of Ni proved to be less resistant for real exposure conditions.
- Differences in the chemical composition of alloys led to the creation of the layers of different hardness of N and L12 valve which could affect the durability of the faces
- It is also important to consider the possible mechanical factor i.e. - the valve is a grinding-in valve. This would imply irregular wear of the seat in the undamaged area of the N valve. Improper valve fitting in combination with imprecisely selected material led to premature valve failure

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