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H. Smoleńska, W. Kończewicz[1]
Gdańsk University of Technology, Faculty of Mechanical Engineering, Department of Materials Science and Engineering, Gdansk, Poland
[1]Gdynia Maritime University, Department of Mechanical Engineering, Gdynia, Poland

FAILURE ANALYSIS OF THE EXHAUST VALVE FACE IN DIESEL MARINE ENGINE

ABSTRACT

The exhaust valve from marine diesel engine which was damaged after 2000 hours of service was investigated. In order to prolong the service time the valve face was cladded with cobalt base alloy using laser technique. After failure microstructural and chemical analyses reviled that cladding process was conducted improperly. The chemical composition of the clad layer was far from the designed one and what more completely inhomogeneous. As a result the valve presented different properties in different regions which led to premature failure.

Key words*: cobalt base alloy, laser cladding, wear*

INTRODUCTION

The contemporary ship diesel engines are subjected to high thermal and mechanical stresses. One of the crucial points of their structure is an exhaust valve exposed both to dynamic loads resulting from combustion pressures and variable high temperatures. Additionally, highly corrosive environment strongly influences the service life of the valves [1, 2]. Surfacing the valve face with different techniques and different resisting materials can increase the durability of valves. Due to surface hardening the valve face can be more resists to friction and corrosion wearing at high temperature exhaust gases [3, 4]. Exhaust valves tend to run hotter than intake valves and are subjected to the corrosive environment of combustion gases. Therefore, the exhaust valves and valve seats tend to require more expensive alloys based on Ni and Co [5]. The valve and seat insert must allow the inner side of the cylinder to be tightly sealed and the working fluid to be exchanged smoothly. During the operation, the valve face makes direct contact with the seat insert. The contact between the two faces causes wear of both faces reduces the sealing ability of the valve and seat insert [6].
An exhaust valve was taken from a diesel engine which was used in a main engine of the ship. This valve was categorized as a heavy-duty valve and the valve face was hardened of by the laser cladding. It failed after 2000 hours of service on board. The engine was examined after the failure of the valve head and there was no evidence of in piston, valve spring and exhaust piping deterioration. According to the foundation the

laser clad layer should be made of the cobalt base powder with high amount of chromium and tungsten. This type of hardening, in both meaning - method of cladding and chemical composition of powder, was examined earlier in laboratory conditions. In the laboratory the same type of engine was used and valve head with cladded face successfully survived three years of exposition.

RESULTS AND DISCUSSION

The substrate material of the valve head 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 melted 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 layer consisted of three sublayers with two tracks for each one. The subsequent tracks were overlapped by 30-40%. The mixture of argon and 5% H_2 was used as a carrier gas and this also shroud the melted region to prevent oxidation occurring during the process. The chemical composition of the powder, which should be used for creating the clad layer, is presented at table 1.

Table 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

The failed valve head was presented on fig.1. The part of the face and valve disk was completely destroyed while the rest of the valve head had no visible damages. Even the valve face was still shinning in the great deal.

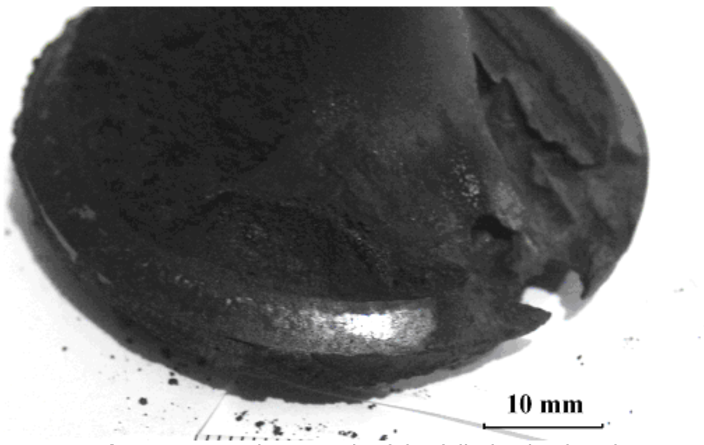

Fig. 1. Macro photograph of the failed valve head

Because such behaviour of the valve face was completely unexpected, the damaged valve undergone detailed examination. In order to conduct further investigation the valve was cut perpendicular to the cladding layer in two places: close to the damaged region and in the unspoiled region situated the far from the damaged part. The both samples were observed 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.
The results of the observation of the undamaged face were presented in Fig.2. The “dark” and “white” regions were noticed. The higher magnification of these “white” (Fig.2B) and “dark” places (Fig. 2C) allowed to state that the “dark” region were more intensive worn, even plastic deformed, than the “white” regions. Additionally the remains of the corrosion products were noticed in the “dark” region (Fig.2 D).

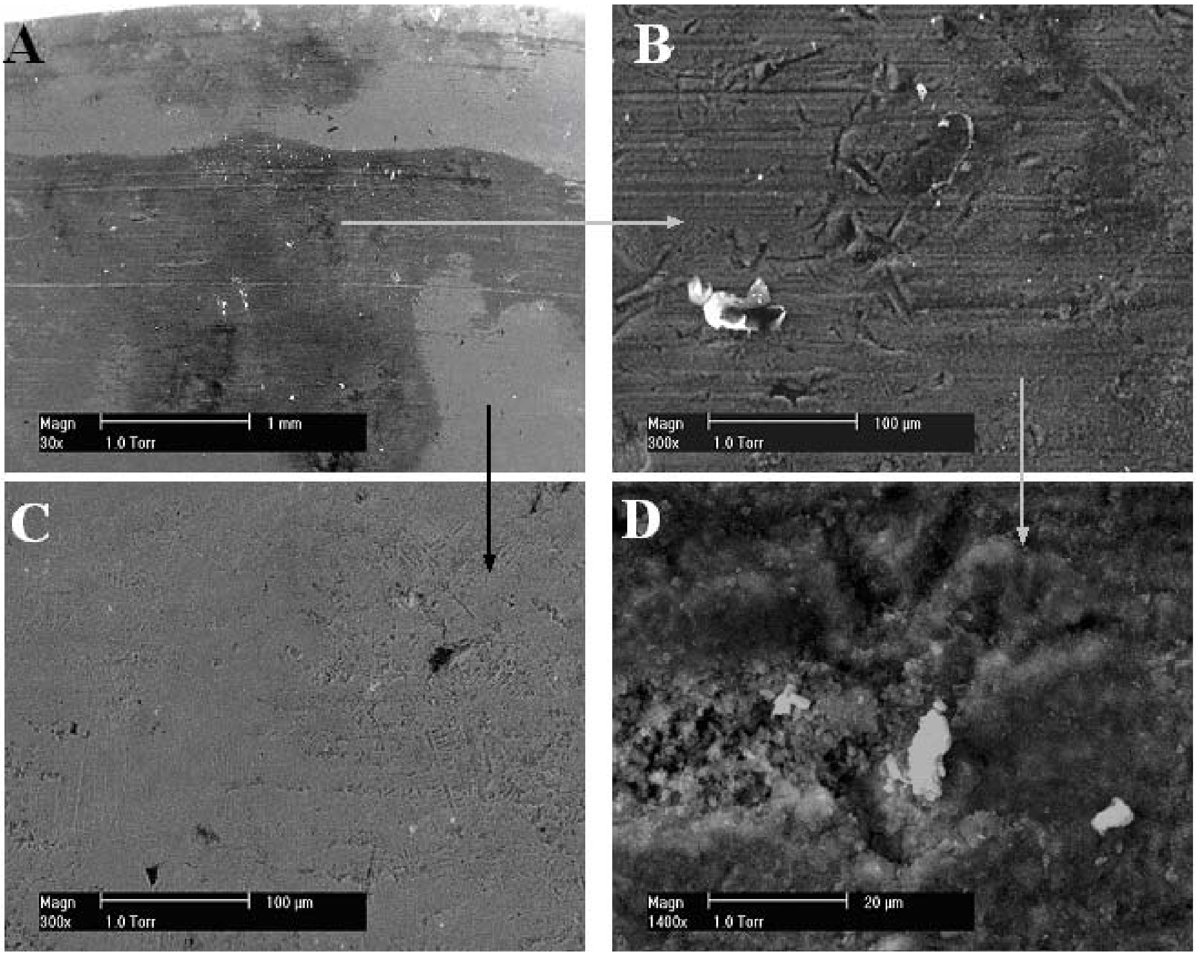

Fig. 2. SEM pictures of the undamaged face surface: A- the whole surface; B- higher magnification of the “dark” region; C- higher magnification of the “white” region; D- high magnification of the “dark” region

The radial cross-section, prepared through the valve face surface, were ground and polished according to standard metallographic practise. Fig. 3 shows the microstructure of the clad surface for the both samples. The photographs present typical dendritic structures however for the Fig. 3a additionally the undefined white precipitates are visible. Chemical analyses reviled differences in the composition of the clad layer. The results of EDS analyses are presented on fig. 4. The “damaged” region is enriched in most of the alloying elements (especially in molybdenum and nickel) while higher amounts of cobalt and silicon is noticed in undamaged region. Such a chemical composition is not conformable with the powder which should be applied according with the design.

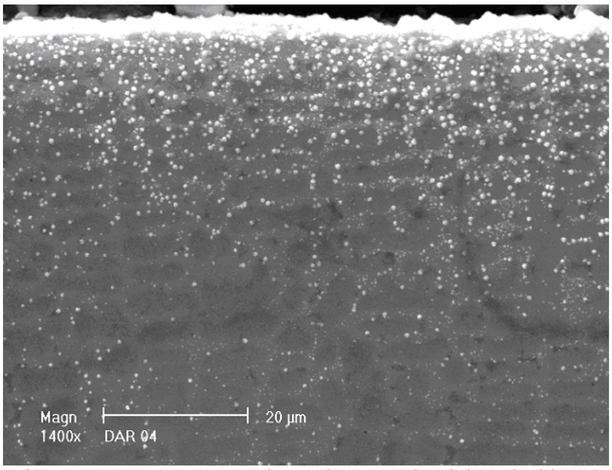

Fig. 3a. SEM cross-section micrograph of the clad layer surface, close to the damaged region (A)

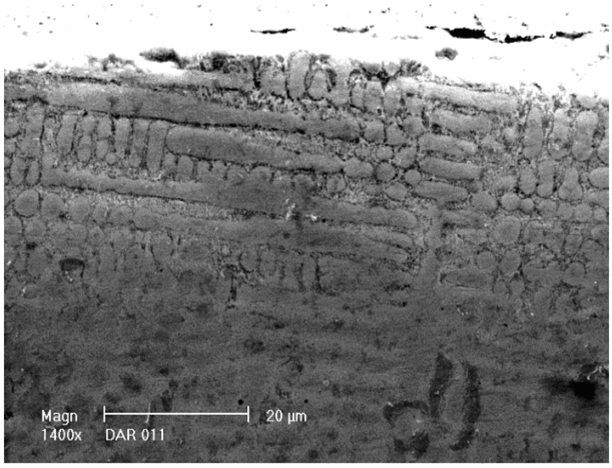

Fig. 3b. SEM cross-section micrograph of the clad layer surface from undamaged region (B)

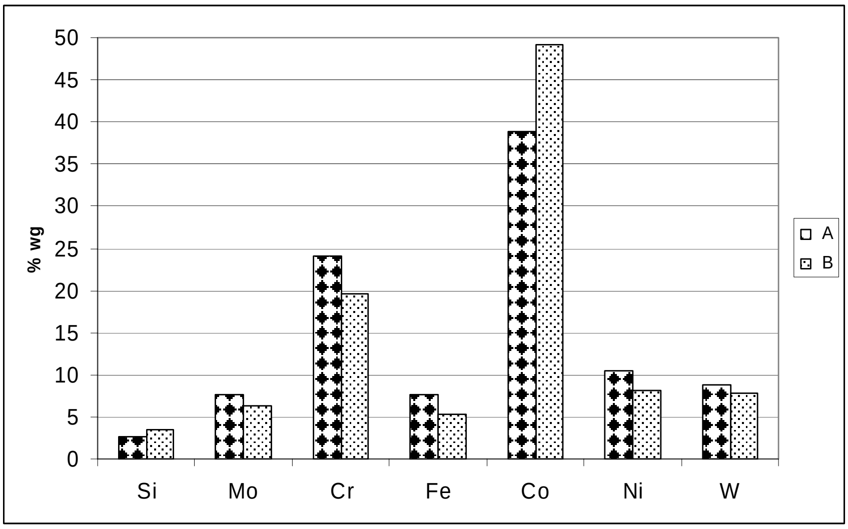

Fig. 4. Chemical analysis from the micro region situated close to the surface, on the cross-section of the clad, after service; A – close to the damaged region of the valve face, B – undamaged region of the valve face

Metalographical observation of the part of the clad situated deeper from the surface provided rather surprised picture of the microstructure. In the middle region of the clad both dendritic and globular structures are observed. Such a dual microsturcture was similar for all region of the valve (Fig. 5a and 5b). Also chemical composition of these regions is different how ever for undamaged part of the valve those differences aere less dramatic. Fig. 6 and 7 presents the results of the analysis.

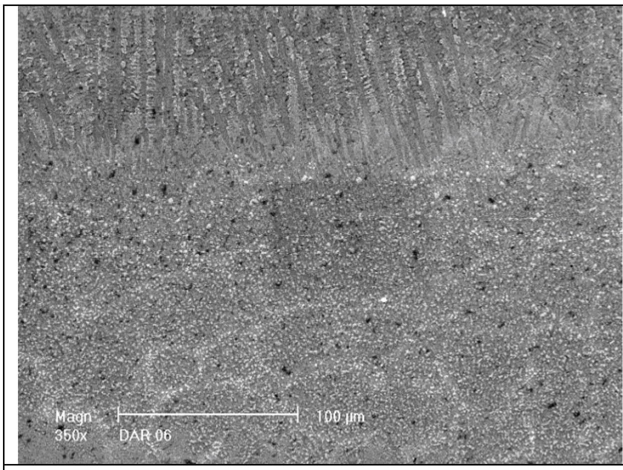

Fig. 5a. SEM cross-section micrograph in the middle of the clad layer, close to the damaged region (A)

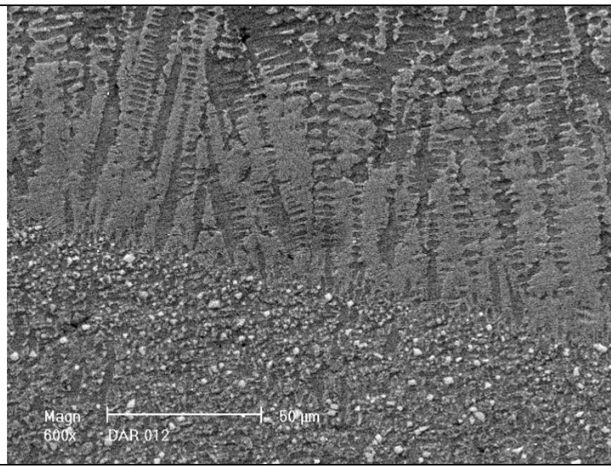

Fig. 5b. SEM cross-section micrograph in the middle of the clad layer from undamaged region (B)

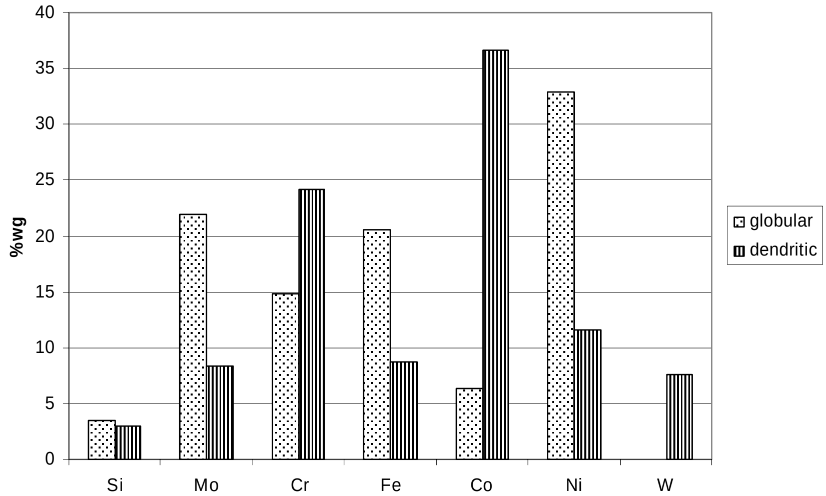

Fig. 6. Chemical analysis from the micro region situated in the middle of the clad, close to the damaged part (A) of the valve face, for globular and dendritic regions from the fig. 5a

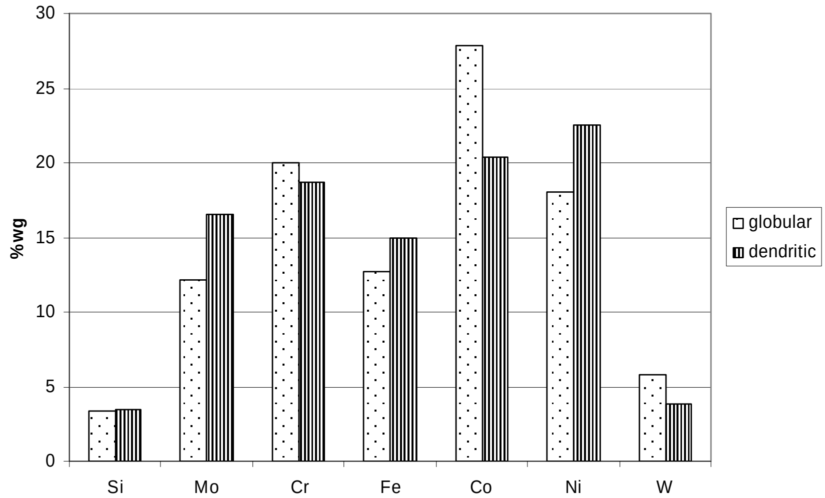

Fig. 7. Chemical analysis from the micro region situated in the middle of the clad, undamaged part (B) of the valve face for globular and dendritic regions from the fig. 5b

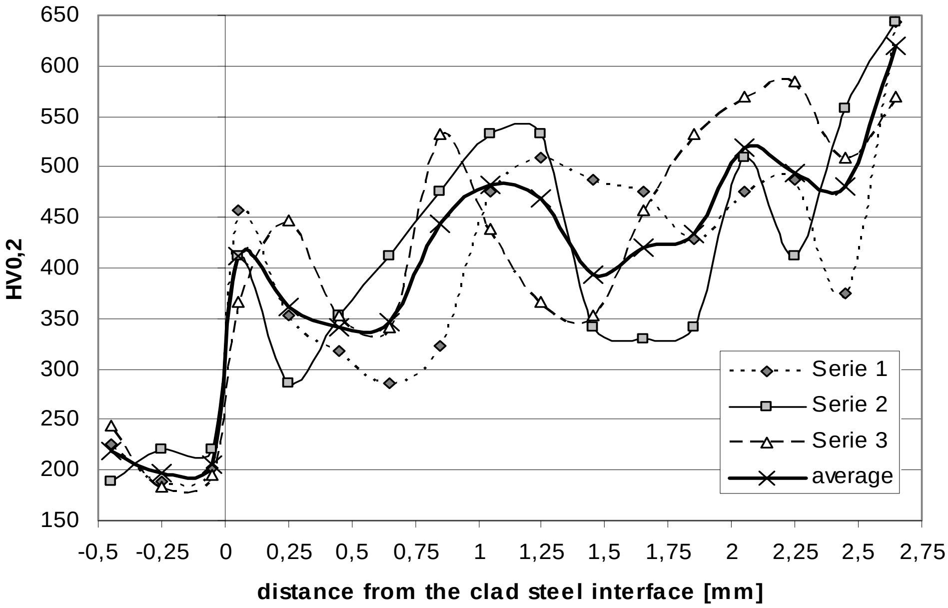

Fig. 8. Average hardness numbers for sample A (damaged region)

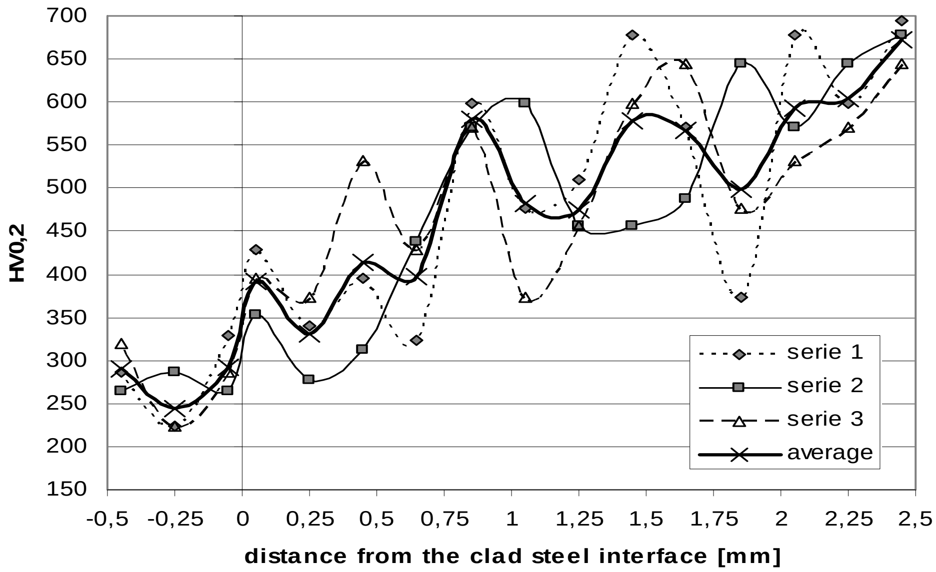

Fig. 9. Average hardness numbers in sample B (undamaged region)

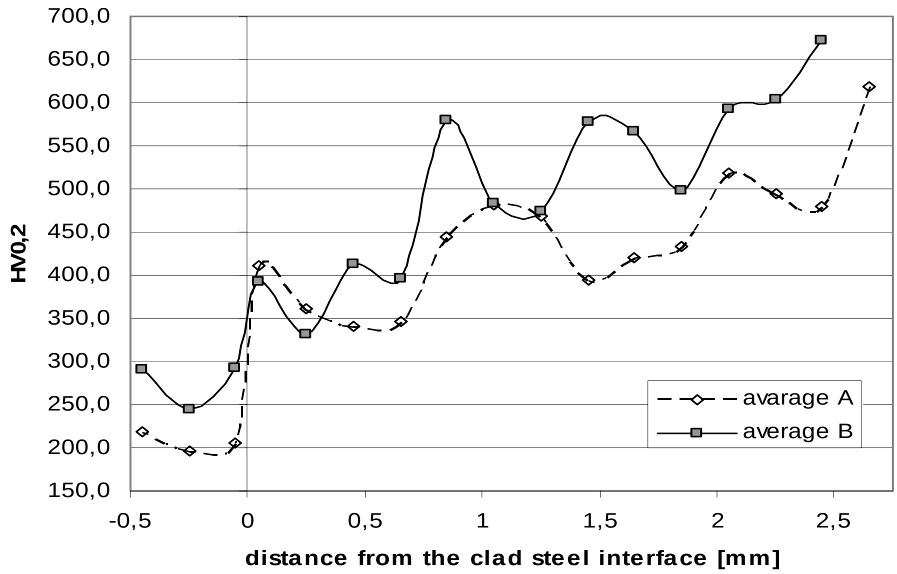

Fig. 10. Comparison of average numbers for A (damaged) and B (undamaged) region

Undamaged region presents higher hardness especially in the outer area of clad layer. It may result with the higher wear resistance and service time for this part of the valve face. How ever such huge differences in chemical composition, microstructure and mechanical properties are unacceptable for the safe reasons. Probably there were any disturbances during the cladding process which resulted with improper chemical composition (mixed powders) and improper microstructure (improper cladding parameters?). Generally producer did not keep regimes of the product engineering.

CONCLUSIONS

After performed investigations some conclusions may be established:

- The clad layer on the exhaust valve face did not accomplished designed properties completely.
- The mixed powders were used for producing the clad layer which was against designed conditions.
- Probably there were any disturbances during the cladding process which caused strong differences in layer structures.
- Such processes as valve face cladding should be performed by reliably producer in order to avoid such “surprises”.

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