ANALYSIS OF THE DAMAGE OF FUNCTIONAL BASED ON THE COBALT-RESISTANT ABRASION LAYERS

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Abstract

Cobalt-based alloys (e.g. Stellite) are often used on surfaces which are required for the high resistance to abrasion (sealing surfaces of the fittings, etc.). These surface layers are commonly applied to low alloyed steel Grade 22 or martensitic steel Grade 91 by welding techniques using. When using armatures with these layers in energetic plants (high pressure valves) have shown operating experience that occurs in damage to functional layers often. The typical damage is characterized by cracking and flaking (release) of the functional layer. This paper deals with the analysis of the causes of such damage to the surface layer of the ball valves (or their contact faces) after the low-cycle service application in superheated steam (550 °C/10 MPa). Layers were applied to the steel AISI 316. For this research were used methods of metallography, chemical and SEM analysis, phase and XRDA microanalysis, hardness and microhardness testing. It was found selective cracking in the areas of a specific phase composition. The subsequently release of material particles and other damage to the surface by these particles.

Keywords: Cobalt-based alloys, welding layers, damage, ball valve, microhardness

1. INTRODUCTION

Alloys based on cobalt-chromium (one of best known are materials Stellite) are used in a wide range of demanding applications. A high proportion of complex carbides, most frequently type M7C3, caused a high resistance to mechanical wear. Furthermore, these alloys are resistant to chemical and corrosion damage. The combination of cobalt and chromium also ensures high melting point, which allows for example application of the edges of cutting tools. Stellite alloys are non-magnetic, mostly resistant against high temperature excesses, resistant to cavity damage. There are many variations of Stellite high alloyed alloys containing a different combination of titanium, silicon, sulphur, phosphorus, molybdenum, manganese, chromium, carbon, boron, aluminium, iron and cobalt. According to the carbon content can be divided into: High Carbon - designed for high temperature applications and Low Carbon - with a higher content of chromium for increased corrosion resistance. The hardness of these alloys ranges between 40 HRC and 60 HRC. These values are useful for applications along with great toughness, but at the same time the problem during production, which is so demanding and uses precise casting, machining, grinding, cutting, etc. Stellite alloys are produced by a number of different procedures, including hot forging, powder metallurgy, welding of powder metal. Stellite alloys are used in the production of gears, disc and ball valves, valve seats, gun barrel, blades of turbines in power plants and Jet engines, in medicine to joint replacements and dental prostheses. Stellite layers are welded and surfaced by arc welding and laser cladding or plasma. Emitted plasma beam reaches high temperatures up to 16 000 K. The heating rate of this heat source is, therefore, very high a specific heat transferred into the basic material is a small. The result is a small affected zone, low deformation level, minimal smelting of basic material and very limited dilution. Due to the dispersed chromium and molybdenum carbides and consequently high hardness these material have a lower elongation. Some types (Stellite 12) are inclinable to pitting corrosion in seawater environs because of negative open-circuit potential. In practice, namely at the friction of two surfaces of mass objects, there are also problems with cracking and flaking of the surface layers of materials based on cobalt-chromium [1-7].

2. MATERIAL AND EXPERIMENTAL METHODS

The problem for research was a significant damage to the surface of the ball of the ball valves, after a very short operational exposition - approx. 12 months at approx. 50 cycles of changes the position. After this time, there were signs of leakage of valves and these have been dismounted. The valves worked in an environment of superheated steam at temperature 550 °C and pressure 10 MPa. There were three balls (with marking A, B, C) with a diameter of 72 mm (A, B) and 112 mm (C) and one piece valve seat E (**Fig. 1**). Basic material of balls was steel AISI 316, welding surface Stellite 6, at seat next P 91 vs. Stellite 721. Standardized chemical composition and hardness of both welded materials is in the **Table 1** [1, 3]. Surfacing was realized by OFW technique. After the surfacing is done finish and lapping surface. The declared thickness of the weld layer was approx. 3 mm.

Table 1 Standardized chemical composition and hardness of Stellite 6 and Stellite 712

Material	(wt. %)	Co	Cr	W	C	Mn	Ni, Fe	Mo, Si	HRC	HV
Stellite 6	Max.	bal.	31	5.5	1.4	1.0	< 3	1.5	45	490
	Min.		27	3.5	0,9				36	380
Stellite 712	Max.	65	34	2.5	3	1.25	Fe 0.3	Mo 19		
	Min.	40	27	1.5	0.5		Ni 3	Mo 3		

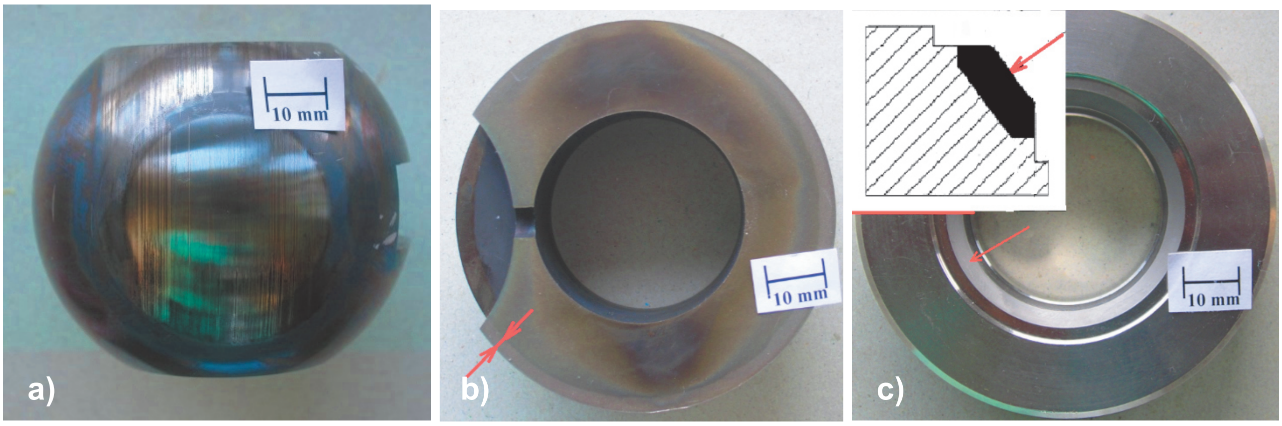

Fig. 1 Ball valves; a) - ball B - outlet side; b) - cross section of ball A cutting by electro-erosion method; c) - valve seat; Stellite welding layers are marked with red arrows

Due to the damage character has been done thorough documentation supplied parts of the ball valve with an emphasis on damaged areas by digital camera. These areas were also documented by optical stereomicroscope Olympus SZX12 at a magnification of up to 20 × whereas several types of damage were found, including posts that suggest that their rise was by separation (peeling) of upper part of welding layer (**Figs. 2a, 3a**), including probably initiation points. Most was the damage caused by erosion of the free particles (**Fig. 2d**), which is significant by grooves rise. In addition, were detected marks of foreign material adhesion on the ball surface also (**Figs. 2b, 3b**). In places the damage of lapped sealing surfaces were found to have marks of damage by flowing steam and erosion attack (**Fig. 2c**), that could be the cause of the detectable leakage of the valve.

Before the divide of balls of their entire surface penetration test was performed. Was used system PFINDER: AP 778/70 (cleaning); APENOL 1054 (penetrant); 870 (developer). Were detected only spot (small flat, mostly inconclusive) indications. And also the HRC hardness on the surface of spherical areas has been measured by rebound method with using of portable electronic metal hardness tester EQUOtip 2 and served rather as needed for setting the dividing parameters. For each ball hardness has been detected 36 HRC till 38 HRC. These values, however, may be misrepresented by the spherical geometry the measured area, which in addition, showed even the prescribed surface quality.

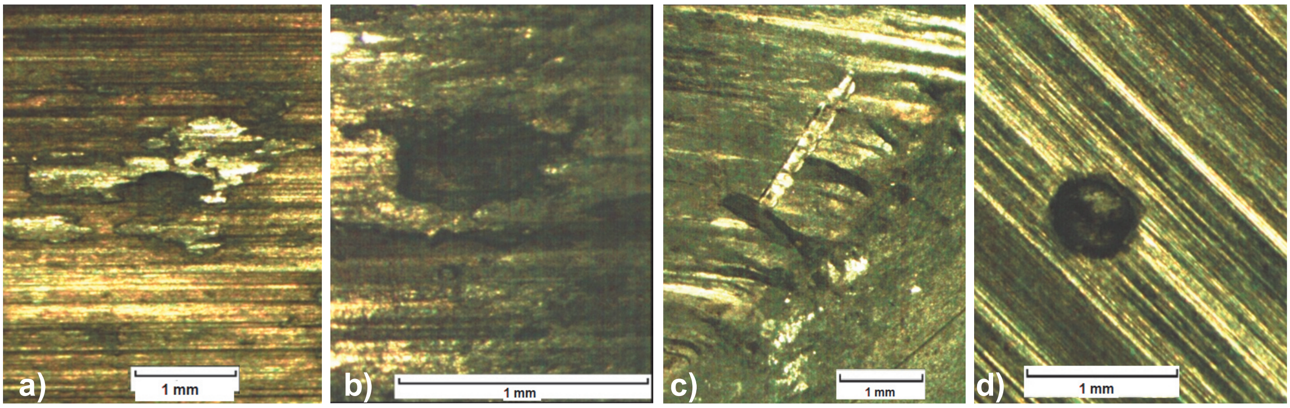

Fig. 2 Balls of ball valves - damage examples by stereomicroscope; a) - unstuck part; b) - adhesive particle; c) - damage by steam; d) - round depression

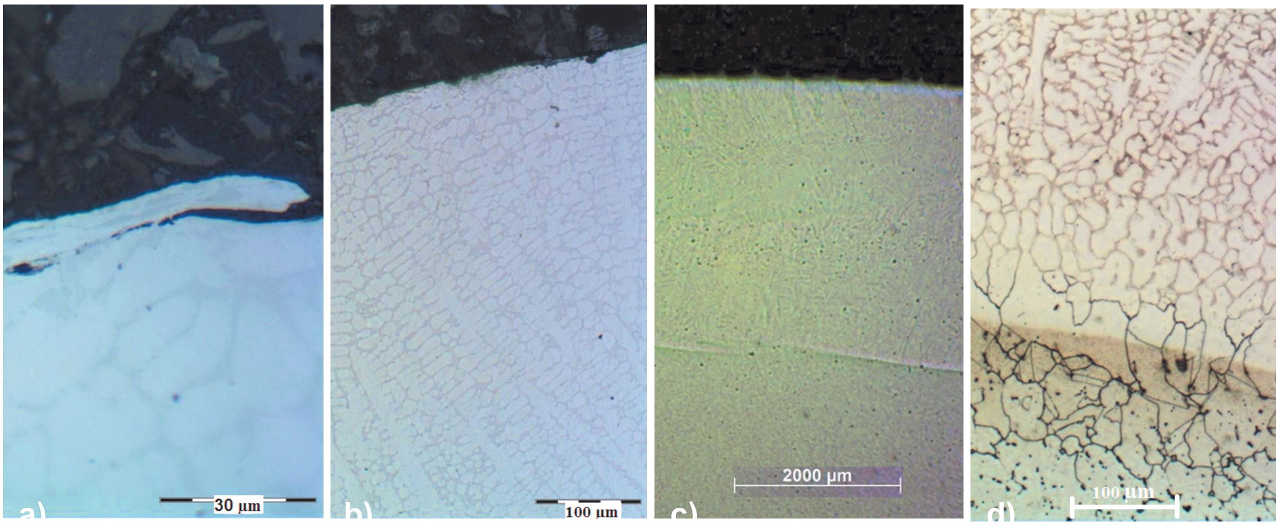

Fig. 3 Metallography of balls; a), b) - types of surface damage; c), d) - cross section of welding layer

Due to problems with the ball mounted housings and surfaces hardness, it was decided to cut the balls by the electro-erosive method (electro-erosive cutter CHMER EDM G32F). The newly established areas also documented photographically.

Metallographic evaluation was carried out on the chosen cross sections of balls A, B, C and seat E by optical microscope Olympus IX 70 on cross sections of damaged and undamaged areas in polished and etched state. Microstructure of basic material, welded layers (Stellite) and also sublayer was evaluated. Geometrical and oxide like character of damage of surface layer was observed.

For evaluation by scanning electron microscopy the electron microscope JEOL JSM - 6490LV with EDS analyser Inca x - act was used. Researched was working area of welding layer surface, and same cross-section as in optical metallography case. At selected locations of the damaged surface and transverse sections the microanalysis of chemical composition was made.

Microhardness by Vickers determined impact hammer LECO AMH 100 on transverse sections of welded layer of balls and seat. At first, through the entire thickness of the welded layer (equidistant lines of indentations) into the basic material - HV0.2, and secondly, for the visible structural components of both materials - HV0.01. Analysis of the chemical composition of the solid state phases were carried out with the use of the device Spectrometer ARL 9400 XP - THERMO ARL, for the analysis of phase composition Analyzer was XRD - difractometer Bruker AXS D8 used.

3. RESULTS AND DISCUSSION

The metallographical evaluation was found to be the thickness of the welding layer in the range of 2 till 3 mm, for all of the components equipped with surfacing (A-C, E). Metallographic analysis (**Fig. 3 c, d**) on the basic material expected standard austenitic microstructure with equiaxed grains, with a fairly homogeneous distribution of size. This one then connect in buttering layer, which gradually „ingrowing“ into the Stellite weld deposit. The microstructure of has the character of a cast "two-stage" structure with light dendritic formations (matrix) and interdendritic areas with darker contrast. Structure, with relatively high purity (micropurity), even with the occasional occurrence of particles based on carbides and nitrides is also characterized by a high „effort“ to the preferred orientation of dendrites, often perpendicular to the geometric centre of the sphere. On parts with the greatest degree of surface damage seems to be subsurface and surface layer volumic richer on dendritic phase. Are also evident damage with stripped layers character and "foreign" adhesion layers (perhaps with oxide-corrosion origin). In the evaluation of the damaged surface areas have been identified heterogeneities that are likely to arise when creating or finishing welded layer.

In the cross section of functional area of the valve seat was observed similar microstructure, as for balls. Only the thickness of the welding was somewhat less. An important finding is the fact that the place was found with significant damage (unstuck) of the surface layer with a unique initiation cracks in the area of eutectic interdendritic structure. It creates the significant large loose segments of the welded material, which may damage functional contact faces (**Fig. 4a**). From the fractographical viewpoint was in the valve seat confirmed the assumption that to cracking the brittle interdendritic eutectic structure occurs, see **Fig. 4b**. SEM analysis of valves seat more or less copies the others metallographic findings. In addition to the analysis of the basic phases were also detected by the minority particles of carbides and nitrides occurring in both phases (**Table 2**).

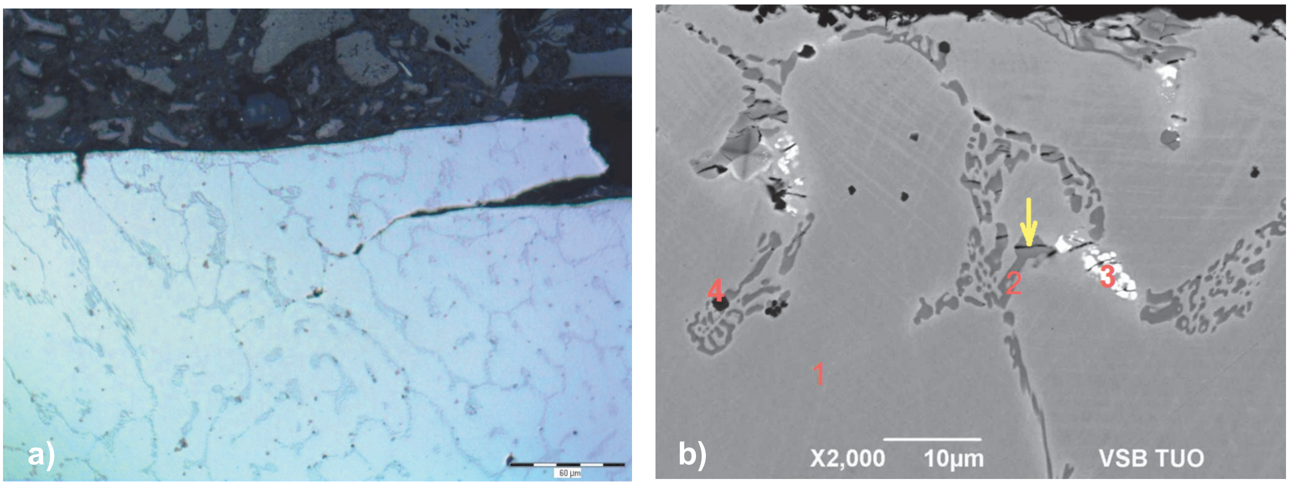

Fig. 4 Damage to the brittle structural components of seats welding layer, cracks in the eutectic phase; a) optical metallography; b) SEM analysis - the crack is marked with yellow arrow

Table 2 Chemical composition of structure components of welding layer - valve seat

Phase (wt.%)	N	Si	Ti	Cr	Mn	Fe	Co	Ni	Mo	W
1 matrix		1.2		23	0.65	24	43	4.1		3.4
2 eutectic				73		9.4	9.8		1.8	5.5
3 carbide		1.8		22		7.0	17	1.4	13	38
4 nitride	19	0.69	37	18	0.55	8.1	14	1.2		2.0

Evaluation of the surface showed the presence of "adhesion" units based on particular (complex) oxides of iron, chromium and cobalt plus depressions also (**Fig. 5a, b**). Their chemical composition is on the **Table 3**. SEM analysis of the composition of the welded material was confirmed standard chemical composition of

Stellite significantly diluted with iron (in comparison with the standards requirements) for dendritic formations a qualitatively similar, but quantitatively richer by chrome, composition of interdendritic eutectic structure, see **Fig. 5**. The look and composition of buttering layer documented **Fig. 6** and **Table 4**.

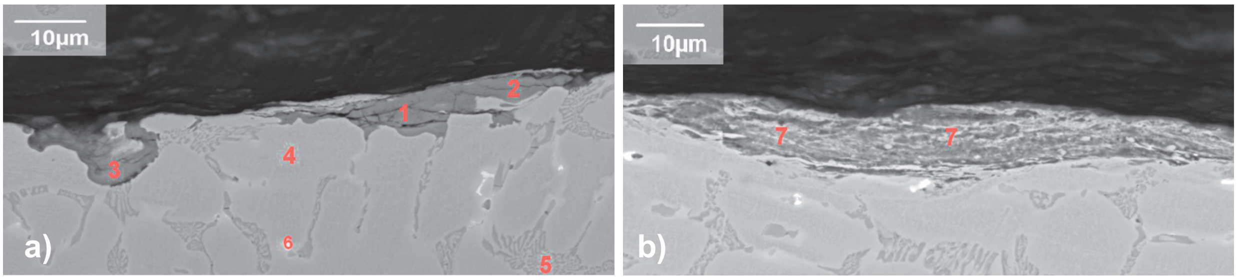

Fig. 5 Adhesive particles on the surface of Ball A

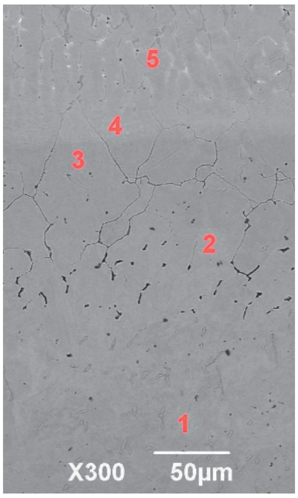

Fig. 6 The scheme of buttering layer

Table 3 Chemical composition of surface area - see **Fig. 5a, b**

Spectrum (wt.%)	O	Si	Cl	Cr	Mn	Fe	Co	Ni	Mo	W
1, 2	36		0.1	10	1.5	35	12	1.6	0.21	2.6
3	31		0.6	7.8	0.5	19	30.2	2.5	0.98	7.3
4		1.2		23	0.61	14	53	3.7	0.16	4.0
5		1.2		38	0.76	10	39	2.6	0.92	7.0
6		1.7		21	0.47	7	29	1.4	6.24	34
7	14	2.0	0.7	23	0.58	24	30	0.9	0.85	3.9

Table 4 Chemical composition of buttering layer neighbourhood

Spectrum (wt.%)	Si	Cr	Mn	Fe	Co	Ni	Mo	W
1, 2	0.79	18	1.5	67		10	2.2	
3	0.85	18	1.5	66		12	2.3	
4, 5	1.1	21	0.93	33	35	7	0.77	2.1

Measurement of microhardness in subsurface area of the working surface of the ball shows for values to around 580-620 $HV_{0.01}$. The average hardness of welding to a depth of 0.3 mm from a functional surface was 525 vs. 545 $HV_{0.2}$ for undamaged vs. a damaged surface (ball A), see **Fig. 7**.

Due to the nature of the problem and the geometry of the specimens the measurement of standard screening macro-hardness, e.g. HV30 was not done. From the measured results, however, can be concluded (with the support of the indicative measurement HRC), that the total hardness of the welding layers material corresponds to the standard requirements.

The welding layer of the valve seat was somewhat thinner (< 2 mm), however, they were detected in structural components with extreme hardness up to 1076 HV0.01 - by analogy with the ball C. Their presence greatly limited their ability to transfer of the deformation. On microstructure pictures (**Fig. 4**) and around indentations (**Fig. 7**) were noticeable cracks that extend across from these phases (on subsurface layer), connect with and finished at the open surface. From the character of the deformation damage in and around the indentations (movement of the slip bands) can be concluded on a very "intensive" stress-strain relations in the welded layer material, in particular eutectic phase (**Fig. 7**). Of course, this problem deserves further study [8, 9].

By volumetric analysis was analysed both the welding layer and the solid phase is removed from the inner surface of the valve cap, to demonstrate, that the source of the damage are or not releasing particles from the cap. The analysis showed the welding layer is diluted by underlying material (Fe, Ni). The particles on the surface of the cap should be oxide base (magnetite-hematite).

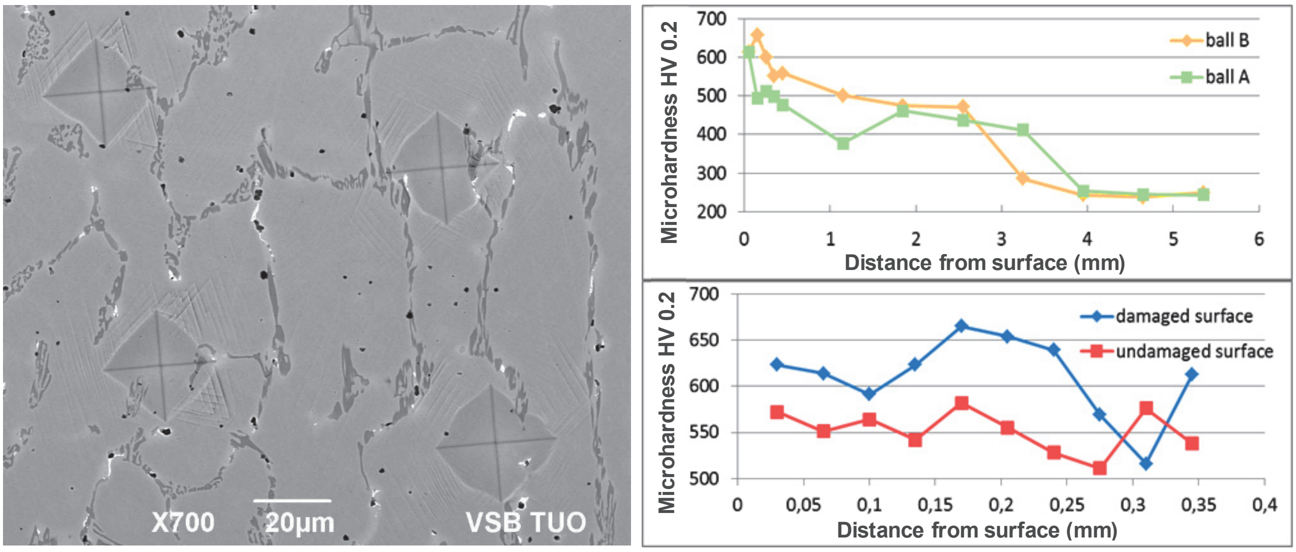

Fig. 7 Welding layer of valve seat - deformations near microindentations with cracks in eutectic phases (left); microhardness $HV_{0.2}$ of welding and buttering layer - comparison of ball A and B (above); hardness comparison of damaged and undamaged surface - ball A (below)

4. CONCLUSIONS

On the surface of the ball of the ball valves were found irregularly occurring abrasive materials damage of oxide layer and the welding surface itself. The damage was caused by particles of comparable hardness as the layer of Stellite on the sphere. Oxides or residues of P91 steel from which it is constructed surrounding the pipe, this did not cause damage (particles of oxides for lack of hardness, steel particles were not in the damaged places found). Damage was visually intense (more frequent) on the outlet side of the valve. Except most frequently grooves in the surface were detected traces of its own and secondary damage to the welding layers. In the case of functional layers occurred either extraction or sticking of welded material (according to the hardness of the materials that have been in contact).

On the lapping surface of were detected traces of damage by steam that may cause detectable leakage of valves. The character of the damage indicates that the cause of the damage to the surface of the ball valve has been part of the instability of the welding layers of the Stellite 721 or 6, i.e. more likely to be on the seat, and to a lesser extent also on the surface of the balls. For the layer was found its tearing along boundaries of the hardening phase (components had extremely high hardness and a minimum supply of plasticity). Spontaneous damage to the layer could be added by deformations of the chosen prime material - austenitic steel has a higher thermal expansion coefficient than steel P91 or Cr2, 5Mo1 that are for conditions of high-temperature exposition as a prime material recommended. These steels have up to 500 °C the similar thermal linear expansion coefficient. When in use the austenitic steel, the higher expansion of the underlying steel cannot be compensated for by deformation of welding-layers and this layer fails (convex/concave surfaces behave differently).

Other factors relating to the realization of the welding layers (dilution, cementation of interface, welding method, etc.) have not been directly observed, but cannot be underestimated.

Spontaneous instability of the welding layers is most likely influenced by the non-performance with the quality of created welding layers also. In the welds was found it is quite strong diluted of iron (about 14% Fe).

Weakened grains boundaries were detected between basic material and Stellite layer. The level of stress inside layer during production can be minimised by appropriate preheating of the treated subject.

For an observed welding of seat were found immixture of welding additional metals, which could be the cause of extreme local hardening through the carbide and intermetallic phases.

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