WAYS OF DETERIORATING THE BALLS WITH STRUCTURAL GRADIENT FROM THE VALVES USED IN THE OIL EXTRACTION INDUSTRY

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Abstract: Valves (formed from ball and seat) equip pumps with pistons and ensure the movement of the petroleum from the deposit to the surface. The balls must withstand the complex erosive-abrasive wear determined by the corrosive environments, while having a resistance to micro cutting and micro fatigue as good as possible. In the case of extraction through underground combustion the effect of high temperatures will also occur. Several experimental batches of balls with structural gradient were made using different extremely hard alloys. An analysis, using finite elements, of the tension states which occur during the process was performed and the life span of the balls was estimated. We present the analysis of the ways of deterioration caused not only by usage in the process but also by the manufacturing defects of balls with structural gradient. The complex analyses that were performed to determine the causes and the mechanisms of deterioration are presented and technological ways to improve the life span are proposed.

Key words: oil extracting pump, valves, balls, wear, extremely hard alloys, stresses, fracture, fatigue, FEM, CAD, life span.

1. INTRODUCTION

Valves (made from balls and seats) equip P-type and TB-type piston pumps (Fig. 1) and according to the stroke, ascending/ descending, ensures fluid movement (oil) to the surface of the deposit. In this hydraulic circuit for oil extraction, the balls have a major role. They are designed to resist the thermo-mechanical state specific to the extraction (oil type, depth of extraction, technology used, the composition of extracted material) and the complex erosive-abrasive wear in corrosive environments combined with the best possible resistance to micro cutting, micro-fatigue and, in the case of extraction through underground combustion, the effect of high temperatures also occurs.

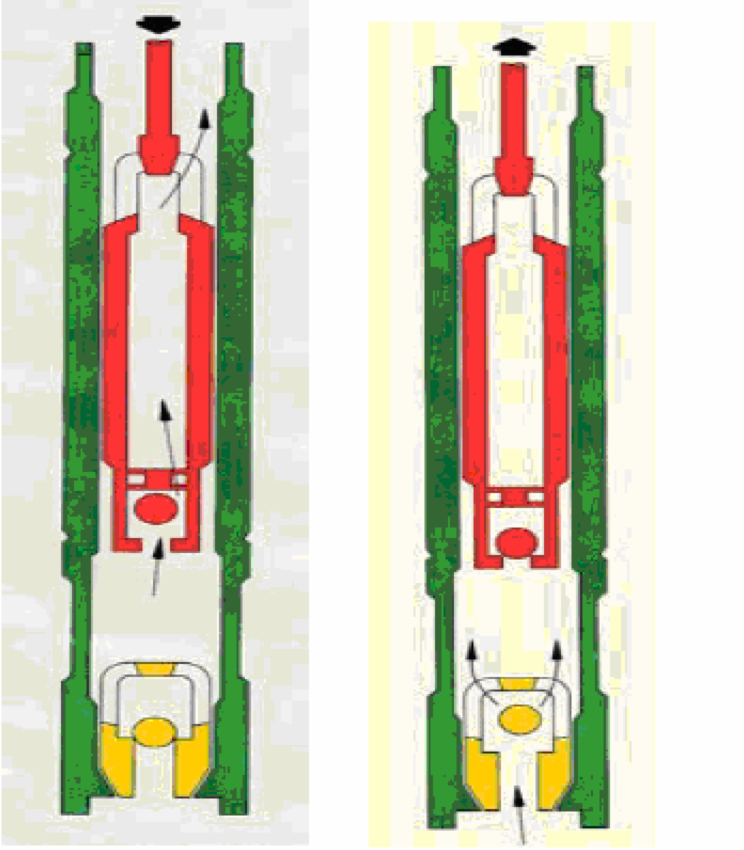

Figure 1. P-type and TB-type piston pumps

Based on the operating conditions mentioned, the balls are made in accordance with API 11AX standards [1] from the materials: martensitic stainless steel, cobalt alloys and simple composite materials WC-Co and WC-Ni.

The ball wear phenomenon begins when the balls are lifted off the seats under the high entrance pressure of the fluid. The fluid passing through the valve consists of a mixture of oil, acid gases such as H_2S, salt water, various acids and sand in suspension derived from the productive layer [2, 3]. This phenomenon continues at each pump and the phenomenon of fatigue occurs. The ball can rotate so the position of the wear is random. The seat's position is fixed and a wear phenomenon that occurs in an area worsens with each pump. In the moment the valve is closing (it makes contact between ball and seat) the wear area is positioned in the contact area, allowing abrasive fluid to leak and the wear is more pronounced due to the increased speed.

2. TYPES OF BALLS EXAMINED

Balls were analyzed with different degrees of deterioration that were produced [4] by the following technological procedures:

a. Balls made by powder metallurgy method from sintered metallic carbides (WC-Co);

These balls are made of tungsten carbides witch Co matrix. Hydrostatic pressing and the sintering is followed by mechanical processing in order to get balls with dimensions and tolerances required by the project. Hot isostatic pressing [5] adds substantial improvements in the mechanical characteristics as well as a properly cost. As we will see from the analysis of the thermo-mechanical demands, an improvement of mechanical characteristics does not necessarily increase the life of application, superficial wear being the main reason to stop using the balls.

b. Reconditioned balls. These balls are produced using mechanical processes to remove traces of wear and defects of the outer layer. If the size obtained is in the lower dimensional range, it can be used as such. Before starting reconditioning, balls have to be inspected through non-destructive methods to determine the depth of the defects. If these defects will remain in the ball with reduced dimensions, the reconditioning situation should be analyzed carefully and generally it was proposed to give up these balls. If the amount of material removed is relatively small and an economic calculation shows that reconditioning is efficient, a layer of material can be added through powder metallurgy technologies. The layer can be of a material more resistant to wear, thus increasing the duration of use. The technology is in course of being implemented. This technology is demanding from the viewpoint of compatibility between the two materials both in the fabrication phase and in the usage phase (ex: tensions brought in the contact layer due to differences between the thermal expansion coefficients etc.).

c. Balls made by specific powder metallurgy technologies from two or more types of virgin powder. This technology was developed and is in the experimental stage. Although it is more expensive, it can give remarkable results because it combines specific features of two materials (mechanical resistance and wear resistance). But the effects that may occur both in production and in use due to the different characteristics of the materials and especially the effects of diffusion between the two materials have to be analyzed. The important problems that were solved are the concentricity of the two layers and the constant thickness of the outer layer. Another solved problem is the outer layer grip.

d. Balls made by powder metallurgy technology from two or more kinds of powder from which at least one of them is recovered. It is a technology similar to that previously presented and it is in the experimental stage. The great advantage is the recovery of materials. Several adverse effects can occur (pores, cracks, large grains, micro-cracks in grains etc). These defects can be removed through carefully respected technology. The problems of concentricity of the two layers and the adherence are of the outer layer are important aspects to be taken into account.

In figure no. 2 is presented a ball made in multi-layer system from two types of material. Inside there is a ball made of WC-12% Co and outside a layer of WC-Co12% Ni. This ball was made through our own technology.

3. TYPES OF DEFECTS CAUSED BY MANUFACTURING PROCESS OF THE BALL / SEAT VALVE AND MODES OF DAMAGE THAT CAN OCCUR USING

Analysis of possible defects is important in order to achieve a model that together with the macro and micro fractographic analyses allow choosing the best manufacturing solutions [2, 3, 5-7]. In reality, two or more deterioration mechanisms act, the superposition effect being a reduction, sometimes drastically, of the life span. In case of superposition, micro cracks and removal of material by erosion, no matter the cause of their production, can evolve rapidly joining and reaching the critical size. In these cases, the growth rate of defects is relatively high, typical of materials with brittle behavior. The tri-axial stress state and the tension deviator especially (with component stretching) is the one that leads to the sudden increase of cracks. Depending on tension levels and the way it is stressed, mechanisms of deterioration typical to fatigue can also occur.

Damage to the ball and valve’s seat is statistically constant. In practice the ball rotates so that a range of deterioration mechanisms act in different places on the surface of the ball. On the valve’s seat the mechanisms of deterioration are localized and therefore they produce more intense effects.

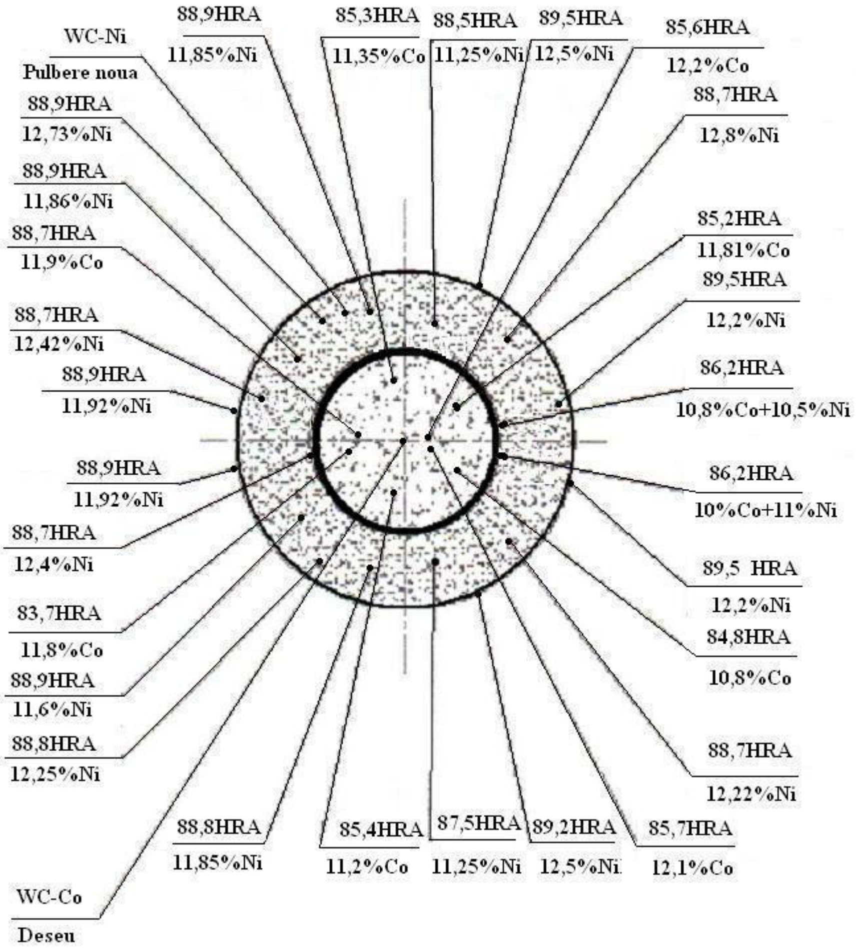

Figure 2. Ball made in multi-layer system

The main identified damage mechanisms are:

a. Wear due to abrasive content of the fluid which is carried by the pump.

The extracted oil contains a number of solid abrasive materials (ex. sand). These granules, many of which have sharp edges produce a phenomenon of abrasion. Small scratches get worse during operation and produce a preferential flow of the fluid. In this case an accelerated wear with undesirable effects on the sealing ability of the ball-valve seat assembly occurs. The phenomenon can occur both on the ball and on the valve’s seat. The type of material chosen for manufacturing the two components has a major influence on the life of the assembly. The decommissioning of the whole assembly or of a component is made when it is no longer possible to ensure the sealing. Note that areas with accentuated wear contain micro-cracks. In the corresponding situation of a state with thermo mechanical tensions, these micro-cracks can join or increase, stable or unstable.

The most dangerous situation occurs when the "scratch/ lack of material" on the ball and/ or the seat is in the sealing area of the ball/ seat assembly valve. In this case the fluid that leaves the little channel has a much higher speed than if the seal is opened. Abrasive materials in the fluid have a greater effect in the case of flowing through the little channel with high speed. Deterioration is also increased by the superposition of corrosion and abrasion produced by abrasive fluid flow with stress effect due to the contact in the sealing area. In this case cracks/ wear open and the aggressive/ corrosive/ abrasive environment increases the depth of deterioration. The most possible situation is produced by exposing the tungsten carbide crystal so much that it is pulled from the remaining binder. In the first phase, the tungsten carbide crystal has an abrasive effect on the adjacent area.

Figure 3 shows the abrasion areas more or less pronounced.

Figure 3. The valve (ball and seat) of piston pump for oil extraction

b. Damage caused by hard material grains that are retained between the ball and the valve's seat when closing the seal. In this case, two phenomena can occur:

b.1.by compressing a granule of hard material (sand grains, grains of WC-Co ball ripped from the ball/ seat assembly, for example) it presses locally in the ball and seat and can cause a local material deformation, the appearance of cracks etc. This very small deterioration can evolve over time due to wear effects described previously;

b.2. the intensification of the phenomenon described in section 1 in the case when complete sealing cannot be achieved. In this case the space through which fluid can flow is very small and symmetrically misaligned. Flow velocity increases greatly and as a consequence wear is more pronounced.

c. Deterioration through chemical corrosion due to the H_2S present in the oil. Generally sintered carbides resist relatively well to chemical corrosion by hydrogen sulfide but the overlapping effects of other types of deterioration and this phenomenon can produce a decrease in the life span of the sealing valve assembly. However the phenomenon is highly dependent on the concentration of H_2S, temperature and water content of the fluid. The phenomenon is statistically constant over the ball's surface and the valve's seat surface for the area exposed to corrosion.

d. Deterioration caused by the shock that occurs at the contact between the ball and the valve's seat when closing the valve. If the closure is made with a shock, the state of tension caused by this can accentuate the degradation phenomena produced by the growth and unification of micro-cracks. In the case of contact between ball/ seat valve, two situations can be discussed:

d.1. deterioration to the balls may be much lower because the ball can rotate so that the line of contact between the two components of the valve may be different during successive closures;

d.2. damage caused to the valve's seat can lead to a permanent deformation which under certain conditions can lead to the apparition and development of cracks.

In both cases the critical situation occurs when in the wear area close to the hertzian contact between the two bodies there are defects of pre-critical dimensions.

e. Damage caused by defects introduced by the using of improper procedures of powder metallurgy (these defects are due to applied technologies and can be removed either by strictly following the procedures or through an effective control before delivering the valve's components and by eliminating the defective parts:

e.1. the appearance of a separation surface (poor sintering between layers of manufactured when the ball is made using multilayer technology). This type of defects can be detected by using CND so that the balls with manufacturing defects are not introduced into use (Fig. 4); Pores occur due to the poor preparation of the contact surfaces which allow the occurrence and capture of gases (generally produced when the temperature rises).

e.2. uneven thickness of the layers from different materials. This type of defect can occur both during the pressing operation and during the sintering operation. The uneven thickness of a layer during the thermo-mechanical stress can lead to misaligned symmetrical tension states with local components of significant value;

e.3. the appearance of cracks, pores, large grain areas which are initiators of micro/ macro cracks that may occur either because of inadequate powders (especially when using recovered powders) or the improper technologies during the course of fabrication;

Figure 4. Defect of the ball made by the breaking of the outer layer

e.4. pressing a layer of powder over a processed body in the case of reconditioned balls is difficult, requiring special devices. Even in this case, providing a hydrostatic pressing is difficult, leading to different compacting values. During sintering different compaction leads to different densities of the sintered and therefore to uneven properties of the balls with negative influence on the life span.

f. Deterioration by separating the bodies in two or more pieces, deterioration of fragile type produced by already existing cracks which rapidly grow to critical size when the sudden rupture occurs (Fig. 4 and 5).

g. Damage caused by differential expansion that occurs in the case of multilayer balls. If layers have different physical and mechanical characteristics, they lead to dilatations/ different strains at the interface between layers. If the sintering is not appropriate and at the interface contact defects or other types of defects occur (sintering or training) these tensions, due to different dilatations/ distortions, can lead to the growth of defects in a dangerous way (Fig. 5). The lack of adherence can also be explained by the low temperature that does not allow the partial melting of the inner piece (solid) and the diffusion between the layers of different materials.

Figure 5. Defect of the ball made by the breaking of the outer layer and a piece of initial ball

4. ANALYSIS OF DEFORMATION AND STRESS STATES IN THE BALL SUPPORT ASSEMBLY

For the finite element analysis of the tensions and strains states produced by loads that occur during the usage of the subassembly in the process [8, 9] a 3D model was developed with Autodesk Inventor (Figure 6). For reasons of symmetry of the model and the loads, only one quarter of the sub-assembly was modeled. The finite element analysis was performed using ANSYS.

The analysis was performed for stationary conditions. The shock that occurs at the contact between the ball and the valve’s seat and the fatigue phenomenon were not taken into consideration.

The analysis of a sub-assembly composed from a ball made from one material. The model is presented in the figure 6.

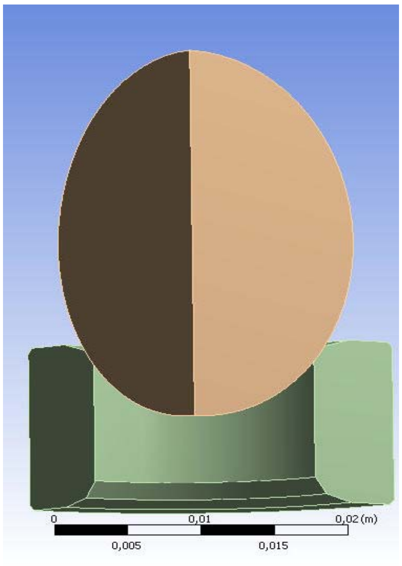

Figure 6. The 3D model of the valve (ball and seat)

The model was meshed into finite elements. In areas of interest, the meshing was refined. The model of the subassembly meshed into finite elements is presented in the figure 7.

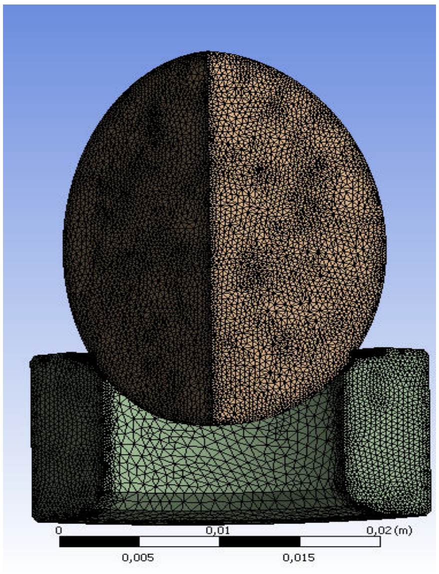

Figure 7. The meshing of 3D model of the valve (ball and seat)

The state of equivalent tensions calculated according to the von Mises criterion is shown in the figure 8 and 9.

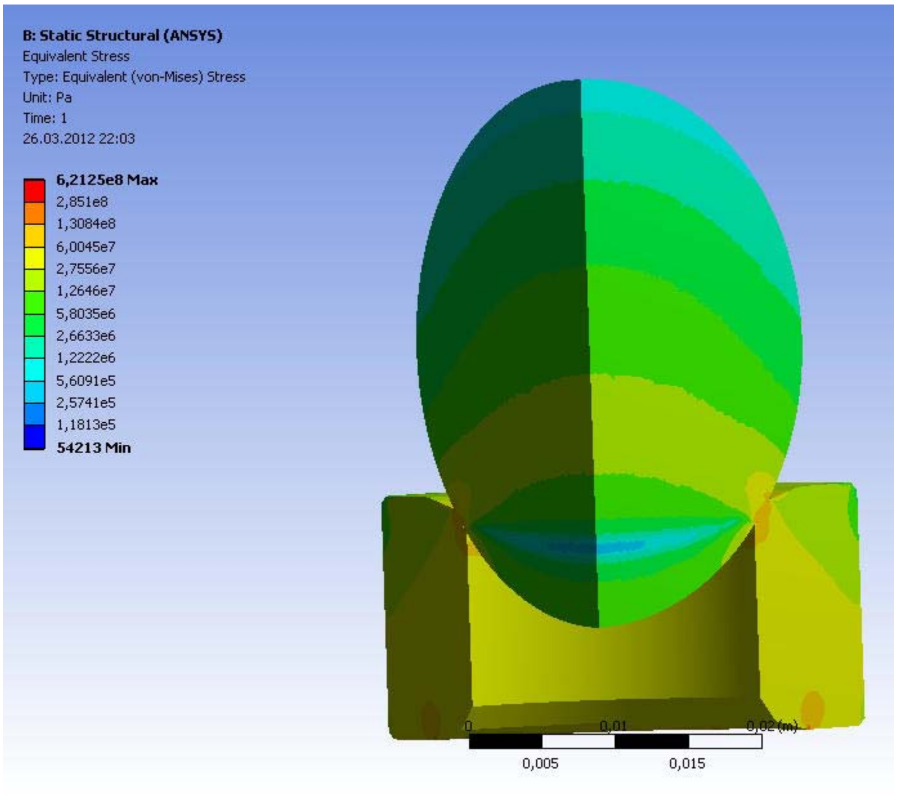

Figure 8. The state of equivalent tensions (with von Mises criterion)

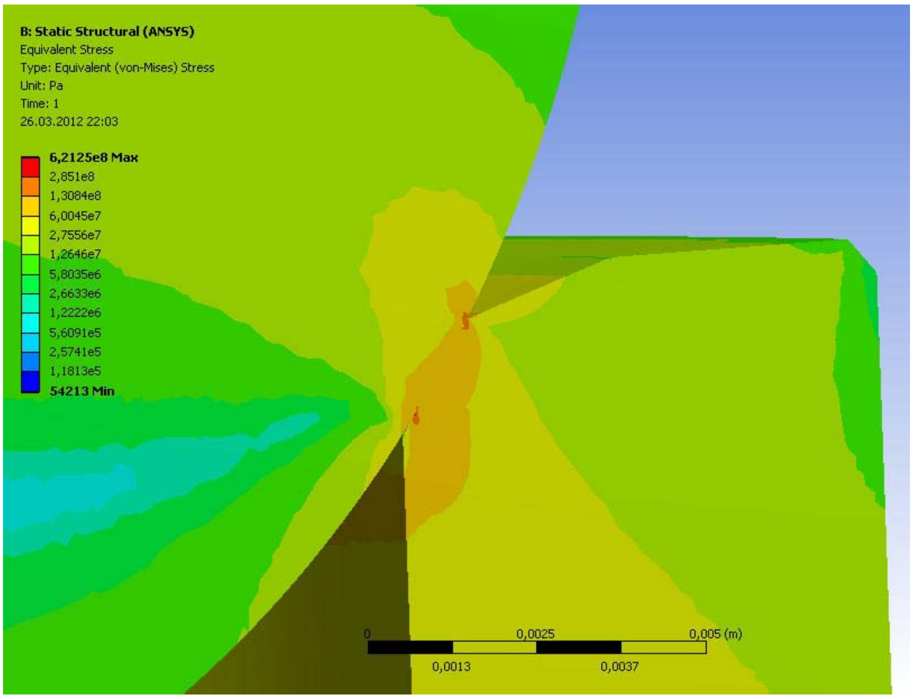

Figure 9. The state of equivalent tensions (with von Mises criterion)

5. CONCLUSIONS

After analyzing the deteriorated balls and the theoretical considerations for determining the tension states, the following conclusions are reached:

5.1. The state of thermo-mechanical stress is not the main cause by deterioration even to a large number of cycles, when both the balls and their seats don't present defects or at least they are smaller than the critical size specific to the solicitation area;

5.2. The main cause of deterioration is the wear phenomenon that no longer allows the correct closing and because of this loss of fluid occurs, so the pumping is ineffective;

5.3. Serious deteriorations can still occur due to wear phenomena or internal defects produced in the manufacturing process which, combined with the thermo-mechanical state of stress can lead to breakage of the valve's components;

5.4. Manufacturing balls with several layers can bring a considerable increase in terms of resistance to wear but it can also introduce new types of defects if the manufacturing technology is not properly applied. The manufacturing of multilayer balls is a complex process that does not require special preparation and sintering conditions.

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