APPLICATION OF VANADIZING PROCESS FOR TOOLS AND DIES

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ABSTRACT: A hard vanadium carbide layer formed by diffusion process has excellent properties such as very high abrasion and adhesion resistance and good tribo-chemical properties. Because of these advantages it is used for different applications in the production of tools and dies. A vanadium carbide layer with 3500 HV protects the surface of tools or dies of abrasion when processing different materials which contain abrasive particles. A very stabile vanadium carbide layer also protects die casting moulds from reactive molten aluminium. Some results of the application of vanadized tools and dies are presented.

Key words: vanadising, carbide layer, duplex process

1. INTRODUCTION

The life time of machine elements and tools is an important factor in production, particularly in large batch and sophisticated productions. For a large number of years, considerable efforts have been put into attempts to increase wear resistance and service life by using different technological procedures. Attempts have been made in the direction of the application of higher quality materials and adequate heat treatment, and in the direction of the application of different procedures of modification and coating of surfaces in order to increase durability. Surface layers differ from the treated base material with respect to the chemical composition, microstructure, crystal lattice and other physical and chemical properties which result in different properties in exploitation. Among the surface modification and coating procedures, the treatment of chromium plating and the thermo-chemical treatment (surface cementation, boriding, nitriding, ionitriding, etc.) are applied most often, and lately, it has been the case with the physical vapour deposition – PVD – procedures (TiN, TiCN, TiAIN, CrN). In addition to one-layer coating (e.g. TiN) and multi-layer coating (TiCN, Al_2O_3, TiN), duplex processes, such as ion nitriding + PVD TiN, are also applied.
Using PVD processes, thin and hard layers are formed on high precision tools since the preceding heat treatment has been carried out at the temperatures which are higher than the temperatures at which the PVD processes are carried out. For some time now, concurrently with the PVD processes, diffusion coating processes have also been applied. These processes have their origin in the Toyota Diffusion Process [1] and in several patents [2, 3] and they have some technical and economic advantages over the PVD processes, but also some limitations in application. The advantages of diffusion coating processes are that they generate layers of greater thickness and greater hardness, as well as of superior tribological properties, abrasion and tribocorrosion in particular. A drawback or a limiting factor of this process is the application on parts with close dimensional tolerances. As the process is performed at high temperatures causing a change in the microstructure of the substrate, the consequence is that dimensions are changed and a layer is generated on the machine element surface. Thus, dimensional changes are bigger than with the application of PVD processes. The basic difference between diffusion formation of carbide layers and

coating processes is in that, in the diffusion formation of carbide layers, the substrate is the most important factor affecting the carbide layer formation, as shown in Figure 1.

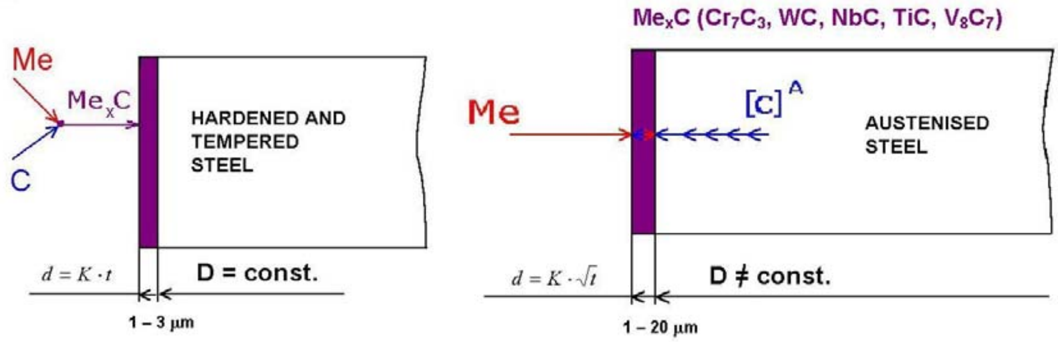

Figure 1. Schematic presentation of the basic difference between the processes of coating and diffusion carbide layer formation

2. DIFFUSION FORMATION OF CARBIDE LAYERS

Diffusion formation of a carbide layer on the surface of steel has a growing application in industry. This is due to the fact that relatively low investment costs for equipment are needed in order to enable the carrying out of the process and to obtain carbide layers of high hardness (from 3200 to 3800 HV) and of high abrasion and tribocorrosion resistance. The process is most often carried out in a salt bath of an appropriate composition, with the addition of one of carbide-forming elements (V, Cr, Nb, W, Ti). A carbide-forming element (e.g. vanadium, V) reacts on the surface of steel with carbon (C), which is at high temperatures of the process (≈ 1000°C) atomically dissolved in austenite, thus forming a very stable V_8C_7 carbide or some other carbide (NbC, Cr_7C_3, WC, TiC) [4, 5]. The carbide layer grows on the surface in the diffusion process of carbon from the surface layer of steel towards the carbide layer, and through it to a newly forming surface where it reacts with the carbide-forming element. Concurrently, a smaller amount of the carbide-forming element diffuses through the forming carbide layer into the surface layer of steel. In addition to high temperature, the rate of carbide layer formation is greatly affected by the chemical composition of steel, see Figure 2 presenting the processing of two different steel types under the same conditions of the process. The figure shows the difference in the microstructures of the surface layers of the processed steels. This is a consequence of partial de-carburization during the process in which a large amount of carbon is used as shown in the qualitative microanalysis (Figure 2) [6]. Previous research established the pattern of carbide layer formation process which takes into account the effects of carbon and alloying elements on the carbide layer formation [7-9]. Experimental results obtained at the same time confirmed the developed mathematical modes of the pattern, and a computer program, enabling the determination of technological parameters of the vanadising process in order to achieve a required thickness of the layer for a chosen steel type, was also developed.

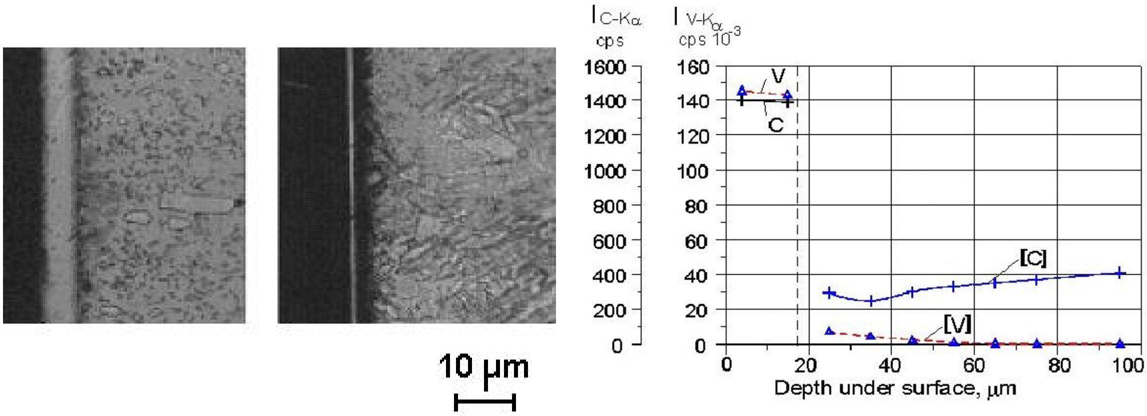

Figure 2. Metallographic cross-sections of different steels vanadised in the same conditions and the qualitative microanalysis of partial de-carburization beneath the carbide layer

3. DUPLEX PROCEDURE

Due to specific kinetics of the vanadium carbide layer formation, a difference in the content of carbon and a change in the microstructure of the surface layer of steel occur as a consequence of de-carburization during the process in which a large amount of carbon is used. As a result, this area exhibits a harmful effect of reduced hardness and reduced loading capabilities of the surface in loading conditions. To compensate for this, a duplex process has been developed. In the duplex process, the previously performed carburization prevents the partial de-carburization which occurs with conventional procedures of diffusion formation of carbide layers. A computer program has been developed for the specific calculation of the carbon required for the subsequent formation of a carbide layer of a required thickness and for the calculation of technological parameters of carburizing in gas atmospheres most commonly used. Figure 3 presents the interface of the program for the calculation of technological parameters of previously performed carburization in order to achieve a vanadium carbide layer of an adequate thickness [5].

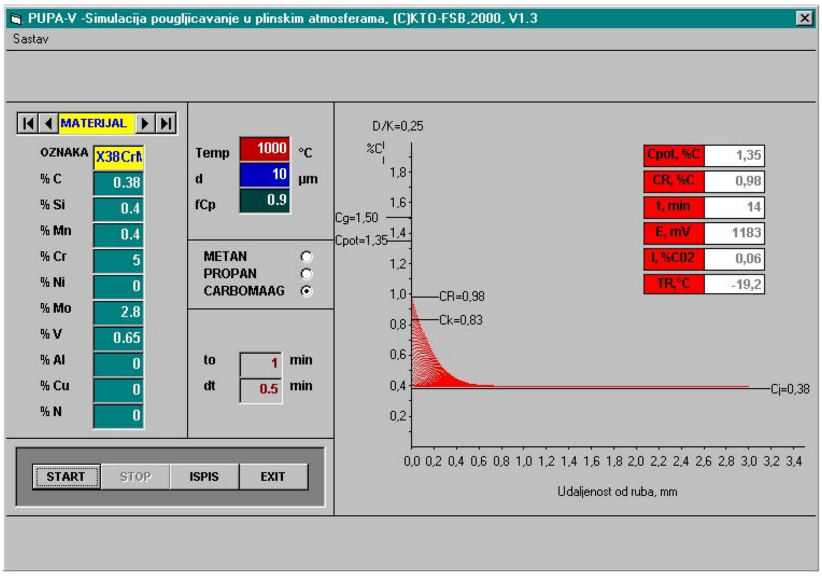

Figure 3. Program interface for the calculation of pre-carburisation parameters for the introducing of carbon required for the formation of a carbide layer of required thickness (10 μm)

In the next step, the duplex process has been extended in the way that during carburization a significantly larger amount of carbon than needed for the carbide layer formation is introduced. A result of the application of the second version of the program is shown in Figure 4.

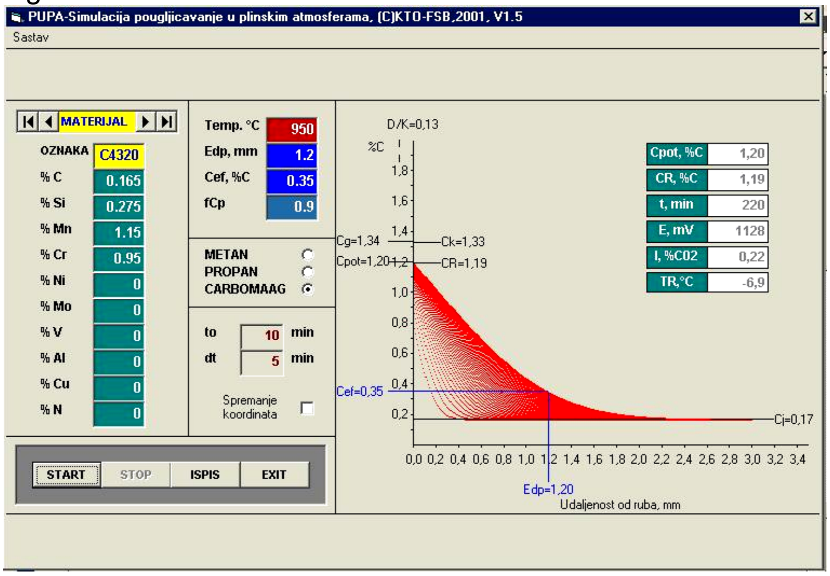

Figure 4. Program interface for the calculation of pre-carburisation parameters for a higher introducing of carbon than required for the formation of a carbide layer

In the second phase of the duplex process, the carbide layer formation process, only a small amount of carbon introduced by carburisation is used, while the remaining amount of carbon remains beneath the carbide layer and, in subsequent hardening, produces a hard martensite layer, i.e. a case-hardened layer. This layer is harder than the base steel and is a good sub-layer for an even harder carbide layer, as shown in Figure 5.

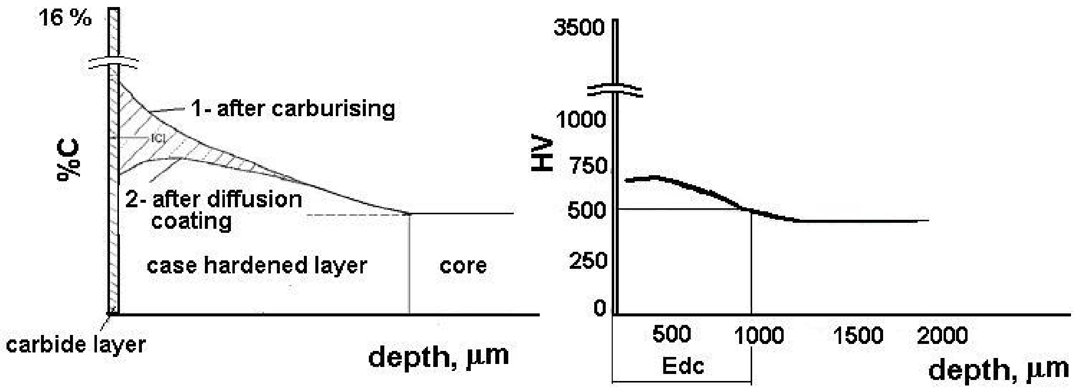

Figure 5. Changes of carbon concentration in the process of duplex layer formation (carburising+diffusion carbide layer formation) and micro-hardness distribution

By the introduction of pre-carburization, three advantages over standard procedures of diffusion formation of carbide layers are achieved: a harmful phenomenon of partial de-carburization which occurs with standard processes of diffusion formation of carbide layers is eliminated; due to higher accumulation of carbon, the rate of carbide layer formation is increased; and, an additional hard sub-layer is obtained. These advantages over the existing processes of diffusion formation of carbide layers are of major importance, and the original contribution of the idea was confirmed by the European Patent Office which accepted the patent [10].

4. APPLICATIONS OF VANADISING PROCESS

Vanadium carbide, $V_8 C_7$ has a cubic lattice of high hardness (from 3200 to 3800 HV) with very good tribological properties. Abrasion resistance is very high because the vanadium carbide layer carbide layer is harder than most hard mineral materials. Tribocorrosive adhesion resistance is very high as the layer is very stable and chemically resistant to aggressive agents (NaOH, HCl, etc.). High hardness of the carbide layer indicates that the layer is brittle and therefore the resistance to the surface fatigue is reduced. A strong metallurgical bound between the carbide layer and the base material (steel substrate) gives a good adhesibility of the surface layer to the substrate. Even a considerably greater thickness of hard surface layers of 5-20 µm, in comparison with the thickness of PVD layers of 1-3 µm, can be achieved. The industrial application of diffusion vanadising on a larger scale started in Japan (Toyota Diffusion Process) and then has spread to other industrially developed countries due to excellent tribological properties of vanadium carbide surface layers. The application of vanadising on structural elements and tools in different branches of engineering contributes to a significant increase in their durability in exploitation. The application of vanadising on the manufacture of tools has produced excellent results with numerous tool types which are subjected to the adhesive and tribo-chemical wear mechanism in their exploitation. For the abrasive wear mechanism, vanadising is the right choice for treating the parts of tools that are exposed to wear by hard abrasive particles. Surface layers of vanadium carbide extend the tool life by several times. A typical example are tools parts for powder compacting and extruder worms. Regarding the adhesive wear mechanism, vanadising is applied to the tools for metal forming processes such as extrusion, forging and drawing. As far as the tribocorrosive wear mechanism is concerned, the vanadium carbide surface layer efficiently protects the tools used in very aggressive media, even in HCl and HNO_3. The carbide layer is particularly useful in reactive soldering for the tool parts for aluminium die casting. The process has a broad range of applications, from feeding attachments to the forming of punches and dies, and provides a considerable performance improvement. The largest industrial application is punches for piercing and extrusion. The application on various die steels is also evident. In many cases, vanadium carbide has been coated on cold work die steel and high speed steel. However, vanadium carbide on cemented carbide dies is also utilized with a notable improvement of die life. The ability to change from cemented carbide to cold work die steel or high speed steel, and from high speed steel to cold work die steel, has been realized in various punches and dies. The process is also successfully utilized in the forging of stainless steel, ball bearing steel and non-ferrous metals. Dies used in the warm forging of stainless steel are also treated by this process. The vanadium carbide coating is continuously applied even for hot forging dies. Life time increases of several times over are not uncommon due to the elimination of galling problems. As a result, a great saving on die consumption has been achieved in industry. Additional advantages, other than savings on die consumption, were in some cases far greater.

5. CONCLUSION

Diffusion formation of hard carbide layers offers a new possibility in tool processing which increases wear resistance considerably, thus enabling a longer life in exploitation and consequently a more economic application. Different thermochemical processes produce different surface layers with adequate properties for specific applications. On the basis of the knowledge of the basic physical process pattern, an adequate thermochemical treatment process has to be chosen for adequate exploitation conditions. With diffusion formation of hard carbide layers, the choice of substrate, i.e. steel, is of major importance. In addition, due to high temperatures of the process, dimensions are changed because of subsequent hardening and additionally due to formation of a carbide layer. In the cases of close dimensional tolerances, a trial treatment needs to be performed in order to correct dimensions in the way as to compensate for the changes of dimensions during the forming of hard carbide layers. Processes of diffusion formation of carbide layers cannot replace the PVD process when it comes to cutting tools, milling cutters and reamers, which require close dimensional tolerances. The results obtained in the previous research and technological improvements of the duplex process, together with the developed computer programs, have contributed to the improvement of the original process of carbide layer formation.

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