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INCREASING TOOL STEEL SURFACE WEAR RESISTANCE BY SURFACE TREATMENT

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Abstract

The industry is imposing increasing wear and tear requirements on tools, which can no longer be satisfied with the development of base materials (tool steels). Surface treatment technologies can provide a solution as the surface of the working tool must be suitable. It can determine a relationship between the hardness, surface roughness and the abrasion resistance of various surface treatments and the coating technologies such as PVD as a result of tool steel surface layers. These relationships form the basis for tool selection and provide a theoretical basis for the design of surface technologies.

Keywords*: hardness, wear resistance, PVD process, surface treatment.*

1. Introduction

Tool steels can be graded according to their requirements such as high hardness, toughness, wear-resistance and other determining mechanical properties.

As the development of steels has its limitations, the aim has been to increase the hardness and wear resistance of the working surface.

The hardness and the abrasion resistance of the surface can be increased by conventional and modern methods. Various thermochemical processes (nitridation, cementation, boridation, etc.) have long been used to successfully increase the hardness and wear resistance of steels. Recent developments include surface treatments with PVD and CVD technology, where a thin, hard layer is built on the surface of the tool **[1, 2]**.

In the late XIXth century, thanks to advances in cutting technology, tools were used for high-speed cutting work, necessitating the need for improved tools and the development of high-speed steels.

The first high-speed steel type was registered in 1910 with the T1 mark, which was patented by Crucible Steel Co. Due to tungsten deficiency at that time, molybdenum was introduced, with which newer steel types were developed **[3, 4]**.

In the 1960s the rapid development of steels and the emergence of steels with increased strength also placed higher expectations on the market for tool materials. Tool manufacturers have therefore responded by applying surface treatment to the tool steels to meet the cutting requirements.

Traditional processes have also been significantly improved, but in addition, coating technologies (PVD, CVD, etc.) have also begun to spread. The coatings, in contrast to conventional surface treatment methods, were able to increase hardness and abrasion resistance up to 3–10 times. **Figure 1** shows the PVD coated tools.

2. Traditional surface hardening processes

The purpose of surface heat treatments (crusting processes) is to create a hard, abrasion-resistant surface crust while maintaining the toughness of the core material. The heating must take place very quickly, at a rate of a few 100 °C/s, so that the microstructure of the already refined material does not change. The most well-known of the conventional surface treatments in practice are surface hardening, insert hardening and nitriding **[5]**.

Figure 1. *Coated tools*

2.1. Surface hardening

Surface hardening consists of the heating and rapid cooling of the piece. The starting basal tissue is spheroidite created by heat treating. This ensures the toughness and strengths of the core.

Martensite gives the hardness and abrasion resistance of the bark. Martensitic transformation is when the cooling is so rapid that there is no time for diffusion, the transformation is not equilibrium.

The process is influenced by two opposite effects: due to rapid cooling, the gamma-alpha conversion constraint increases, but the overcooling results in a low temperature at which the rate of diffusion conversion decreases.

As a result of these two effects, the gamma-iron structure changes from an FKK lattice to a TKK lattice by tilting the atoms together at the same time.

However, since the carbon solubility of the TKK lattice is much lower, a supersaturated and tetragonal distorted form of the alpha lattice is created. This is called martensite, it gives the hardness of the surface layer.

Thus, the essence of surface hardening is that the heat treatment cycle is performed at such a rate that there is enough time in the crust for allotropic transformation and cooling from it, but the inside of the workpiece no longer has enough time for hardening. Significant stresses arise from temperature differences between the surface and the core.

These stresses can be reduced by annealing between 150-200 °C. Surface hardening can be performed in several ways, the processes can be grouped according to the energy sources:

- flame hardening,
- induction training,
- electron beam surface training and
- laser surface training.

Flame hardening can be used to create a larger bark thickness (1.5–12 mm). In induction hardening, the thickness of the treated layer can be controlled by varying the frequency of the alternating current [6, 7]. The higher the frequency, the thinner the layer that heats up, the hardened layer can have a thickness ranging from a few tenths of a mm to up to 10 mm). Induction heating achieves the required temperature significantly faster than conventional methods. In contrast to other hardening methods, the most fundamental difference is that the heat is generated in the workpiece itself by induced eddy currents [8, 9].

2.2. Carburizing

The peculiarity of the carburizing process is that the surface of the part to be treated is enriched with carbon and then hardened. The toughness of the workpiece is provided by the low carbon content of the steel, and the hardness of the surface is ensured by martensitic microstructure by the increased carbon content in the surface layer.

Thus, non-curable grades with low carbon content ($C < 0.25\%$) are used for proper toughness. The strength of the core is improved by alloying. However, due to the diffusion (cementation) of carbon into the surface, the carbon content of the shell can be increased to the same extent as that of tool steels, ($0.6\% < C < 1\%$) thus becoming hardenable.

If the piece is hardened after cementation, the core cannot harden due to its low C content, so it retains its tough properties. The bark will be hard and abrasion resistant depending on the carbon and other alloys and the workout.

The thickness of the carburized layer achieved by insert hardening is from a few tenths of a mm to approx. 2 mm. After depositing, a piece is subjected to a tempering heat treatment at 180-200 °C. With this treatment, a surface hardness of 55-65 HRC can be achieved.

2.3. Nitriding

Nitriding is a thermochemical treatment of steels aimed at enriching the surface with nitrogen by diffusion. The strength and toughness of the workpiece core is due to the refined (spheroidite) microstructure. The hardness of the surface layer is provided by nitride compounds formed by nitrogen with nitride-forming alloying elements (Al, Mo, Ti, V).

The nitridability therefore depends on the alloying elements. Since only the surface layer is treated by nitriding, the proper toughness and strength of the core is ensured by refining before nitriding. The nitriding is carried out in a nitrogen-releasing medium (most often ammonia). Nitrogen diffuses into the surface layer and form nitrides with alloys. The nitriding temperature is lower than the tempering temperature used to temper the steel. Nitridation achieves a higher surface hardness than insert hardening (1000–1200 HV), but a maximum crust thickness of 0.1–0.2 mm can be achieved [10, 11].

3. Modern surface treatment processes

Vapour phase coating methods can be divided into two main groups: Physical Vapor Deposition (PVD) and Chemical Vapor Deposition (CVD). These processes are classified as modern coating processes [11–13].

3.1. Physical Vapour Deposition (PVD)

In physical vapour deposition, the coating material is applied in atomic, molecular or ionic form to the surface of the component to be coated. The coating is applied from a solid, liquid or gaseous source. PVD processes are performed at relatively low temperatures (50 °C… 550 °C).

This means that the process does not modify the fabric structure of the sublayer substrate, which is advantageous in several respects [13, 14]. On the one hand, there is no allotropic transformation, so the resulting size change is avoided, and on the other hand, it is known that the alloys and the diffusion material to be coated dissolve differently in the modified microstructure.

It can also be used on hardened and hardened high-speed steel tools without the risk of softening. On cooling, more warping and more residual stresses could be expected, which is not advantageous due to the stability of the coating and also makes the design more difficult.

The hardness available depends on the chemical composition of the layer formed on the surface. Figure 2 shows the coating.

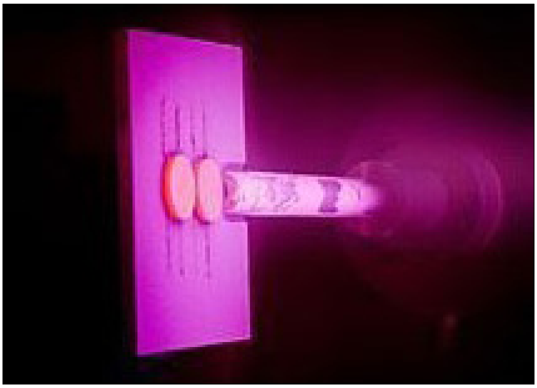

Figure 2. *PVD coating process*

3.2. Chemical Vapour Deposition (CVD)

Chemical vapour deposition is a similarly versatile process for applying any coating to metallic and non-metallic materials (e.g., carbon, silicon). Thus, compounds (nitrides, carbides, oxides) and many other materials can be applied by this method.

In the process, two or more gaseous compounds of suitable composition are introduced into a reactor furnace and reacted thermally, (conventional CVD) or otherwise (e.g., plasma or laser-induced CVD) near the surface of the object to be coated. resulting in thermochemical decomposition and further reactions.

The resulting reaction product condenses on the surface of the parts to form a solid coating, whereupon the gas phase by-product is formed. The process has a basic vacuum history for PVD, but the temperature is in the range of 600-1100 °C. Due to the high temperature pre-diffusion, it must meet the same test requirements for CVD and have a low porosity.

However, as long as the sintered carbide support material can withstand high temperatures without distortion, it is unavoidable for post-heat treatment (hardening and tempering) in the case of tool steels and a certain degree of deformation must be taken into account. Therefore, research on CVD processes today is also aimed at developing low temperature processes.

4. Conclusions

The expected surface hardness and wear resistance of parts and tools subjected to high wear can be achieved by the described methods or combinations thereof. Both traditional and modern surface processes are constantly being developed, which can further increase the life and efficient application of treated workpieces.

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