IMPROVING OF SHEARING BLADES LIFE

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In the paper, design and implementation of a method for increase of shearing blades life are described. Blades for shearing of a reinforcing grip bar are made of tool steel 55WCrV8 (19 733 according to Czech Standard). Plasma nitriding method, which allows higher surface hardness while maintaining a ductile core, was chosen as an optimal method increasing blades life. A scratch pattern and a hardness measurement of initial and modified samples confirmed improvement in blade surface hardness to a value of 64 HRC.

KEYWORDS

shearing, shearing blade, lifetime, plasma nitriding

1 INTRODUCTION

Increasing requirements for strength and durability of metal forming tools are reflected in seek new ways of their treatment. For parting of a reinforcing steel, shearing blades with dimensions 1000 × 200 × 60 mm are used. These blades are made of tool steel 55WCrV8 (19 733 according to Czech Standard). Shearing blades, which are hardened to 48 HRC, are suitable for shearing of the reinforcing grip bar with diameter of 32 mm and with strength of up to 650 MPa. A new requirement is shearing of material with diameter of 75 mm with using higher strength steel, namely up to 1 100 MPa. In the shearing process, at a temperature from 30 °C to 150 °C, rapid blunting of blades is evident. Increase of the surface hardness of blades while maintaining toughness of their central section seems to be a suitable solution of this problem.

2 POSSIBILITIES TO INCREASE SHEARING BLADES LIFE

In the case of shearing tools, surface layers are weared, which means changing of quality of functional surfaces or changing of a tool geometry. Main mechanisms include adhesive and abrasive wear.

Adhesive wear is a result of creation of micro-welds caused by high pressure and high temperature between opposing asperities on rubbing surfaces of counterbodies and their subsequent breach. This form of wear can be found between chemically related materials and materials with metallically pure contact surfaces. Adhesion can be reduced by using a lubricant that creates a protective film between the tool and sheared material.

Abrasive wear is caused by rubbing action of hard material particles acting on a softer material or by cropping of fragments from the tool surface. It is characterized by a gradual loss of the tool material. External impurities and impurities contained in the lubricant also make for abrasive wear. The resistance of the material to abrasive wear is called as its abradability. The abradability is directly related to the hardness. But, higher values of the abradability cause risk of a brittle fracture, which is demonstrated by fracture of the whole blade or by blade chipping.

Because of this reason, improving of abradability of tool active parts, while keeping a toughness of the material core, is necessary. This concept can be achieved by a number of modifications of functional tools parts, i.e. shearing edges buttering and surface treatment leading to hardness increase. For example, this can be achieved by creation of a thin layer (in the order of microns) from different material on the tool surface. A hard chrome plating method falls into this category. Newer creating technologies of thin layers are known as coating methods and they include chemical vapor deposition (CVD) or physical vapor deposition (PVD). PVD method can be subdivided into sputtering, vapor deposition and ion implantation.

Another possibility is a chemical-thermal treatment, wherein the part surface is saturated with a suitable chemical element (C, N, Bo, Cr) up to a depth of several mm. Advantageous property changes can be achieved by changing of the chemical composition of the surface layer, e.g. the hardness, the wear resistance or a thermal load resistance. Chemical-thermal treatments are divided according to element, which is used for the surface saturation. The most significant methods are cementing (saturation with carbon), nitriding (saturation with nitrogen) and boriding (saturation with boron).

Basic parameters of selected methods are summarized in Tab. 1. A nitriding method seems to be optimal for surface treatment of shearing blades. A long time of process can be significantly shortened by using a plasma nitriding method.

Method	Process temperature [°C]	Process duration [hours]	Maximum layer thickness [mm]	Surface hardness [HV]
Chromating	50-55	15	0,004	800
CVD coating	700-1000	9	0,01	to 3400
PVD coating	350	5	0,0025	to 3200
Cementing	850-950	20	2	750
Nitriding	450-550	to 50	0,6	1200
Boriding	800-900	16	0,2	1000

Table 1. Basic parameters of selected coating methods

2.1 Plasma Nitriding Process

Classical nitriding process in gas is carried out in gas-tight furnace in an atmosphere of partially dissociated ammonia. Atomic nitrogen is formed by disintegration of ammonia molecules at elevated temperature in the furnace. Nitrogen atoms, that are formed on the steel surface, react with iron to form an absorbent surface layer with strong concentration of nitrides. These nitrides, which is bonded to the steel surface, are unstable at elevated temperature and they decay to lower components. Released nitrogen enters into the absorbent layer and it penetrates deeper into the surface. Disintegration of ammonia molecules on the surface of the steel, which has a catalyst effect, is much faster than disintegration of ammonia molecules in a gas phase in the furnace chamber. Furthermore, atoms of nitrogen, which are formed in the gas phase, recombine into the molecular state (N_2) before they reach the steel surface and they have no importance for the nitriding process. Therefore, the nitriding process in the gas furnace is performed by nitrogen atoms, which were formed by dissociation of ammonia molecules directly on a component surface. In the case of plasma (ion) nitriding, treated components are stored separately in a vacuum container (recipient). In an electrical circuit, this container is connected as an anode, whereas the nitrided material represents an cathode. Lower pressure of nitrogen and hydrogen mixture ($N_2 + H_2$) is kept in the container (recipient). [Hruby 1995], [Ptacek 2002]

For creation of an electric field, a DC power source with voltage of 400 to 1000 V is connected to the anode and the cathode. Electrical current and the pressure must be configured so as to match an area of anomalous discharge. The electric field then cause a movement of molecules, their collisions, and consequently dissociation and ionization of molecules. Nitrogen positive ions are accelerated towards to the cathode, i.e. to the surface of the nitrided component. Their velocity increase, which also means kinetic energy increase, is not linear. A sharp rise of velocity occurs near the component surface. The greatest intensity of dissociation and ionization is currently in this area (the area of the cathode voltage drop). Mentioned area is located at the same distance from the surface around the entire component regardless of the component shape or a distance from walls of the vacuum chamber. Therefore, the anomalous discharge has a flat shape and its shining corona follows the component surface. Without this feature, industrial use of glow discharge for diffusion heat treatment processes would not be possible. Particular processes occurring in the container and on the component surface are schematically shown in Fig. 1 [Hruby 1995], [Ptacek 2002].

1. In the container, N_2 molecules are cleaved into atomic nitrogen.
2. Nitrogen atoms are ionised and cations are attracted to the material.
3. When an impact of ions is realised, part of their kinetic energy is converted into heat and the component is warmed. Besides warming of the component, high velocity of the ion impact cause knocking-out of iron and other components from the material surface. This phenomenon is called the sputtering or the cathode sputtering and it is probably the most important action in the ion nitriding process.
4. Directly on the component surface, part of the nitrogen ions are combined with iron to form FeN.
5. In the nitriding atmosphere, iron atoms combine with nitrogen ions to form FeN. The surface layer with high nitrogen content is created by condensation of FeN.
6. FeN unstable nitrides are absorbed.
7. Unstable layer, which contains a large quantity of nitrides, disintegrates to stable components (FeN, $Fe_{2-4}N$, Feα). Part of released atomic nitrogen diffuses deeper into the part and it bonds with nitride-generating elements.

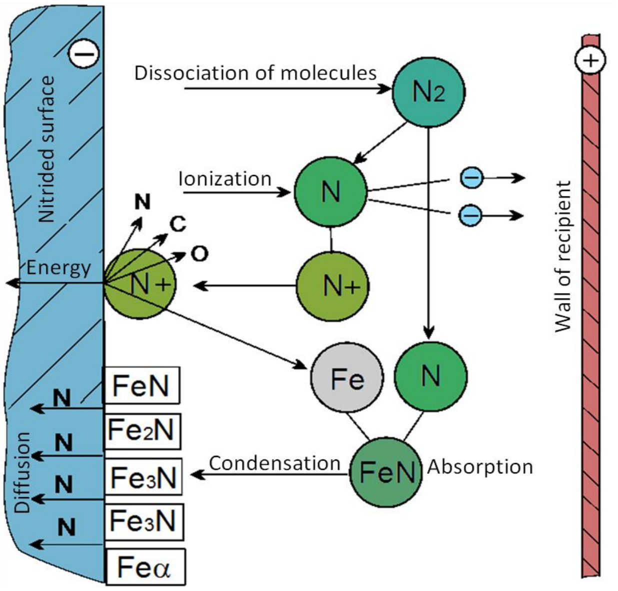


Figure 1. Schema of ion nitriding process

From the above, it is evident that ion nitriding reactions on the component surface, creating surface layer of nitrides, are realized under entirely different conditions than nitriding in an ammonia atmosphere of gas-tight furnaces. Formation of nitrides surface layer can be substantially controlled by choosing appropriate conditions (voltage, surface current density, pressure and composition of the atmosphere). Oxides dedusting cause an excellent passivation of the steel surface and thereby improving of nitriding conditions, especially for high alloyed steels. In contrast, surface depletion of dedusted carbon leads to suppression of carbon-nitridic mesh across grain boundaries. The resulting hardness and a microhardness depend on a time and a temperature of the nitriding process. In the case of low temperature and short time of nitriding, thin and hard layers are created. The surface hardness decreases by temperature increasing and time prolonging. However, decrease in hardness is milder towards the core.

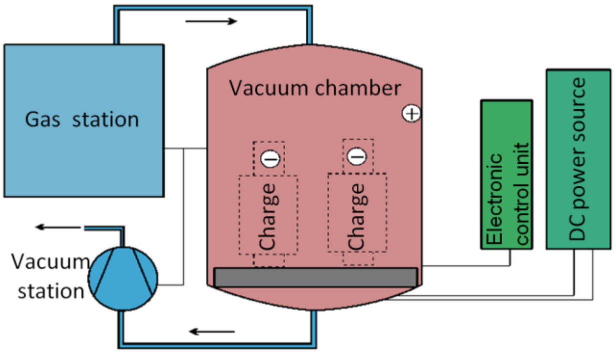


Figure 2. Schema of ion nitriding device

Basic parts of an ion nitriding unit are schematically shown in Fig. 2. The device consists of follows:

- The vacuum container (recipient), which is sometimes called the working chamber or the vacuum chamber. For formation of the electric field, two electrodes are inside of the vacuum container, i.e. the cathode and the anode. Cathodes are represented by workpieces, which are stored separately, whereas the anode is represented by an internal wall of the vacuum container.
- The vacuum station, which is interconnected with an inner space of the vacuum container. It reduces the pressure in the recipient to the initial value of 5 to 10 Pa. When the nitriding atmosphere is dosed, the vacuum system ensures the maintenance of the prescribed pressure. The pressure value is generally in the range from 100 to 800 Pa for the ionic nitriding of common workpieces.
- The DC power source, which gives DC voltage of 250 to 1000 V for striking and maintaining of a glow discharge. Its electric power is determined by the maximum cathode surface (charges and fixtures). Main parts of the power unit are: a transformer, a rectifier for current and voltage regulation and a device for discharge surface stabilization.
- The electronic control unit ensuring a process correctness according to set parameters. By using sensors, it protects devices and nitrided components to avoid damage by, for example, a temperature over range, an interruption of gas supply or cooling water, etc. The unit is equipped with a recording device that is directly connected to the computer and operators can control the whole process retroactively. In the case of failure, the device is automatically turned off and the unit sends an indication to the operator. After elimination of the failure, the device automatically switches to the nitriding temperature and the nitriding cycle continues without breach of the layer.

- The gas station which is used for preparation of the nitriding atmosphere with adding of other gasses, like hydrogen (argon) for a depassivation process or nitrogen for a rinsing. It is usually arranged as a separate part of the nitriding unit. When a larger number of nitriding containers are used, all containers are usually supplied by only one gas station due to economic and space advantages. the gas station mainly consists of pressure tanks with gases, pressure-reducing valves, devices for dissociation of ammonia, devices for cleaning and drying of gas, mixing devices and an eguipment for adjustment of the output pressure. The station allows supply of a standard H_2 mixture: $H_2 : N_2 = 3 : 1$, which is obtained by complete dissociation of ammonia. Furthermore, the mixture may be prepared from clean gases H_2, N_2, CH_2 and Ar.

3 EXPERIMENT

For an experimental verification of an ion nitriding effect for properties of the shearing blades, 2 samples with dimensions of 16 × 56 × 85 mm were extracted. One sample was subsequently nitrided. With respect to relatively low tempering temperature of steel 55WCrV8, the ion nitriding temperature was chosen at a lower limit. Thus, the nitriding process was performed at the temperature of 450°C for 15 hours. After the nitriding process, a sample surface, which is perpendicular to the tool face, was milled for the hardness measurement. Thereafter, a scratch patterns of both samples was created for evaluation of microstructures and thicknesses of nitrided layers.

Vickers hardness measurements were carried out on both samples by using diamond pyramid hardness testing machine Zwick 3212. Hardness HV10 was measured, where loading force of 98.1 N was applicated for 13 seconds. Diagonal lengths of indents were measured by using cooperation of a computer equipped with TestXpert software and a testing machine microscope. The measuring software shows digital microscopic photos in real time and it allows to determine indents dimensions using a coordinate cross. By a scale reading, the software can recalculate hardness values, which were then converted to Rockwell hardness values (HRC). The measuring station is shown in Fig. 3.

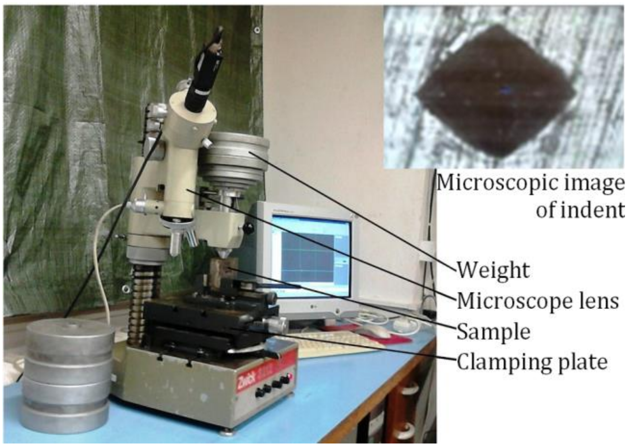
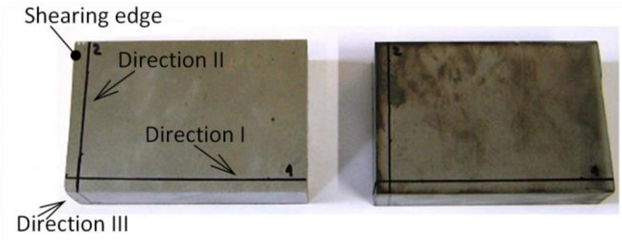


Figure 3. Hardness testing machine Zwick 3212

The hardness was measured for unmodified and nitrided sample, namely in three directions, see Fig. 4. Direction III corresponds to the tool face and it was used for determination of surface hardness. Direction II, which is parallel to the cutting edge, only serve to correction of the material inhomogeneity. Direction I shows behavior of material hardness in the sample volume.



a) unmodified sample b) nitrided sample

Figure 4. Samples for hardness investigation

Measured values of hardness are shown in Tab. 2 for unmodified sample and in Tab. 3 for nitrided sample. The dependence between hardness and distance from the shearing edge is then shown in Fig. 5.

The average of the measured values in the direction III was used as the surface hardness, i.e. hardness values at a distance of 0 mm for the direction I. Measurement in the direction II on the unmodified sample shows that hardness values along the shearing edge are in the range of 348 to 360 HV. Therefore, the material can be considered as very homogeneous. Possible deviations of all measurements may not be caused only by different material hardness, but also by poor surface that cause bad reading of indent dimensions.

Direction I [mm]	HV 10	HRC	Direction II [mm]	HV 10	Direction III [mm]	HV 10
0	759	57	5	360	1	733
2.5	415	42	10	353	3	773
7.5	353	36	15	358	5	736
12.5	369	38	20	360	7	766
22.5	366	38	25	351	9	789
32.5	371	38	30	354	11	785
42.5	361	37	35	348	13	759
52.5	359	37	40	357	15	739
62.5	364	37	45	357	-	-
72.5	368	38	50	354	-	-
82.5	373	38	-	-	-	-

Table 2. Hardness values for unmodified sample

Direction I [mm]	HV 10	HRC	Direction II [mm]	HV 10	Direction III [mm]	HV 10
0	967	68	5	368	1	993
2.5	431	44	10	360	3	978
7.5	391	40	15	359	5	1062
12.5	395	40	20	368	7	1078
22.5	390	40	25	362	9	957
32.5	392	40	30	363	11	854
42.5	383	39	35	358	13	897
52.5	382	39	40	357	15	920
62.5	384	39	45	362	-	-
72.5	381	39	50	356	-	-
82.5	384	39	-	-	-	-

Table 3. Hardness values for nitrided sample

Measured values from the direction I shows that the surface hardness was higher than the hardness of the core before the nitriding process. After nitriding, the surface hardness increased from 57 HRC to 68 HRC while the core hardness was changed from 37 HRC to 39 HRC. Therefore, it is possible to anticipate that the toughness of the material core was kept. the biggest increase in hardness is located in a 0.2 mm-thick layer just below the sample surface.

The initial surface hardness (57 HRC) fully corresponds to the expectable hardness after the heat treatment, i.e. tempering to 56 HRC. The surface hardness after the nitriding process (68 HRC or 967 HV) is higher than expected.

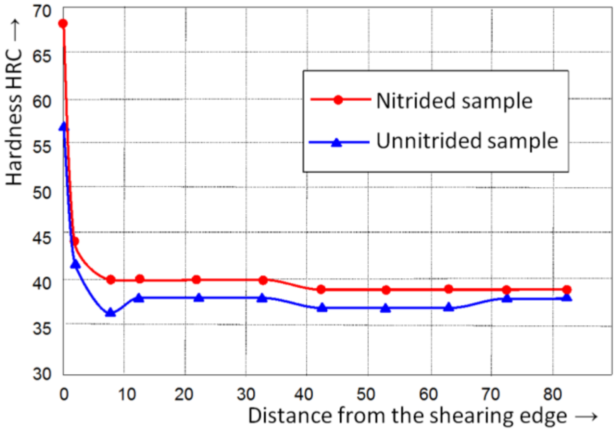


Figure 5. Hardness profile graph

The modified surface hardness is generally in the range of 58 to 64 HRC by using ion nitriding. Nitriding conditions or chromium and tungsten quantity in the material have an impact on this result. Both elements create a very hard carbides, although chromium has a negative effect to the depth of nitriding. This fact was reflected in determining of the nitrided layer depth, as described below.

The microstructure of the steel before and after the nitriding process and the thickness of the nitrided layer were next investigated parameters. In the case of nitriding at low temperatures can be expected that the fine-grained structure of the original material will be retained. The scratch pattern was performed in a perpendicular direction to the nitrided surface. Metallographic photographs of the nitrided and unnitrided shearing blade surfaces are shown in Fig. 6 and Fig. 7. Photographs were taken with a magnification of 400×.

It is evident that the material structure is really retained. The thickness of the diffusion layer is about 0.1 mm and it is represented by white color in the photo. The surface layer from which nitrides disintegrate and diffuse into the material, which is known as a nitrides hem or a white layer, is not clear in the scratch pattern. Either it is thinner than the threshold of recognizability due to lower temperature or it was completely suppressed by the atmosphere choice.

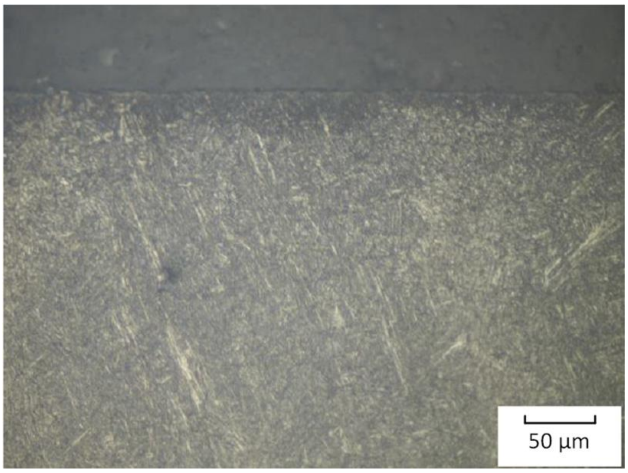


Figure 6. Metallographic photo of the unnitrided shearing blade surface

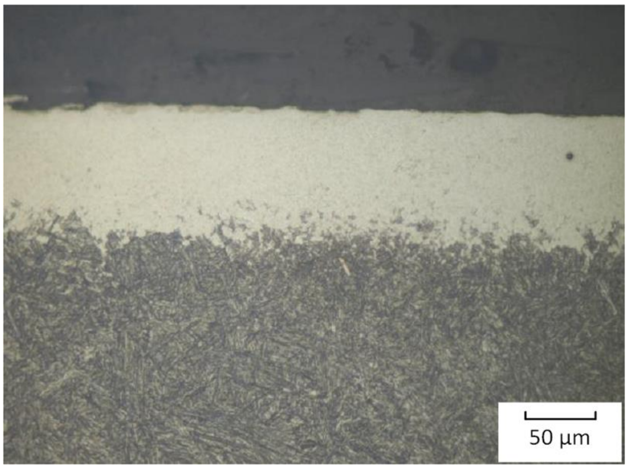


Figure 7. Metallographic photo of the nitrided shearing blade surface

4 CONCLUSIONS

In the case of shearing of the reinforcing grip bar, the plasma nitriding treatment was designed to increase the life of shearing blades which are made of tool steel 55WCrV8 (19 733 according to Czech Standard).

For verification of results of the selected method, two samples extracted from the blade were compared. One of them was left in the original condition and the second one was nitrided for 15 hours at the temperature of 450 °C. The visual inspection of scratch patterns confirmed the preservation of the original structure and the creation of approximately 0.1 mm thick layer on the nitrided sample. Hardness measurements showed an increase of surface hardness values from 57 HRC to 68 HRC while keeping the toughness of the material core. The measured values of hardness give a realistic assumption for increasing abradability of the surface and thus increasing the lifetime of shearing blades.

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