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# THE WEAR BEHAVIOUR OF ION IMPLANTED STEELS

Ion implantation can be regarded as an important process for modification of surface properties of different materials. For the last ten years the most papers for implantation in non-semiconductor materials are on the field of tribology. In Europe, USA and Japan many groups investigate the change in composition, friction, wear, corrosion ... with fundamental and application aspects. The most experiments on the improvement of wear resistance by ion implantation have been carried out using nitrogen ions. Nitrogen ions can be easily produced at high beam currents. The results of many practically tests on industrial tools and machine parts showed that soon the time is coming for modification of metal surface at the industry. First technical equipments we find today in the USA, in UK and in Japan /1-3/.
The implantation of nitrogen improves in the most cases the wear resistance and increases the surface hardness of steels. It was shown for different steels by different scientific groups. The hardening by nitrogen implantation is a function of the lattice structure. For fcc steels is the increasing of the wear resistance lower then for bcc steels.

The implantation of $N^+$ improves in the most cases the wear resistance and increases the surface hardness of steel. It was shown for different steels by different scientific groups. The implantation of nitrogen is a simple way and to date for practical applications the best way, but in the future other principles will introduce in the ion implantation technology, e.g. the simultaneously implantation of Ti and C or N ... But the basic principle is the same in all these cases the production of hard phases /in our exemple TiC or TiN/ in the surface region. It can be assumed that 3 different ways are possible to improve the wear resistance of a steel tool by implantation. In the first way we prepare a surface layer with lower friction coefficient. If the friction decreases in a tribological system the surface temperature during the sliding process will be lower and the oxidation rate of the steel surface will be reduced in this case. The chemical caused oxidative wear decreases. In the second way we can stabilize by implantation different metastable crystalline and amorphous phase or reduce the rate of phase transformation /e.g. the austenite/martensite-transformation by Sb-implantation/.

The whird way ist the typical and generally known way by interstitial and precipitation hardening. In the surface layer of a steel nitrided by nitrogen implantation the matrix structure coexistis with a very fine dispersion of nitrides and carbonitrides /about 1 to 10 mm/ and supersaturated solid solution of interstitial nitrogen formed during implantation. In analogy with the wear resistance or hardening obtained in conventional thermal nitriding, we can attribute these behefitial effects obtained by implantation to these very finely dispersed nitrides or carbonitrides. These very small precipitates have the ideal range of size to effectivily pin the dislocations by interacting more elastically with them and consequently impeding their motion in the near surface region. In the praxis it will be difficult to separate these tree ways because the wear is a very complex phenomen.

The implantation depth is below 100 µm, the wear resistent layer is some µm thick. During the wear process nitrogen ions are transported into the bulk material. This transport can be explained by the mobility of metastable N-dislocation and N-pointdefect complexes and by the increasing of the temperature during the sliding process /4/. The deformation of the surface during the sliding process leads to the formation of a dislocation network and a high vacancy density in the surface region. The dislocations migrate into the bulk, sideways and to the surface. The most of the implanted nitrogen is after the implantation in the elementar state and is able to migrate into the bulk according to the high defect structure. According to the implantation profile of nitrogen we have a steep N-concentration gradient and in consequent to the formation of the frictional energy into thermal energy a steep temperature gradient. We also have an attractive interaction between the nitrogen and the dislocations and vacancies. But it is not clear to date if the mobility of the mobile complexes is higher than the mobility of the interstitial nitrogen species.

In the following some of our results will be presented for the change of hardness and wear behaviour of 2 commercial steels types C100W1 and 90MnV8 obtained after implantation of different doses of $N^+$ at near room temperature. The chemical composition of the 2 steels is given in the following table. All experiments were done using carefully polished samples with a hardness of HRC=60 and a size of 20 x 20 $mm^2$ and 5 mm thickness.

The hardness was measured by a Vickers indenter and for the wear experiments a pin-on-disk arrangement was used. A fixed hardened bearing ball with 3 mm Ø served as pin with a definite load. The pin-ball slided on the polished disk with about 1m/s. In all cases the volume abrasion was investigated in relation to the sliding way of the bearing ball on the rotating disk. For C100W1 the nitrogen ions passed through a mass separator. Only the species $N^+$ were implanted into the steel surface. The abrasion tests were carried out with n-dodecane as a chemical inert lubricant. The results are

given in Figure 1. The load on the pin was allways 20 MPa. With increasing dose in the range from $10^{17}$ to 6 x $10^{17}$ $N^{+}/cm^{2}$ the wear rate was reduced significantly because of formation of various nitrides and carbonitrides phases and precipitates during $N^{+}$-implantation /5,6/. Doses higher than 6 x $10^{17}$ $N^{+}/cm^{2}$ lead to increase the wear rate. The measured microhardness showes the same behaviour /Figure 2/. The hardness increases with increasing $N^{+}$-dose in the range of $10^{17}$ to 6x$10^{17}$ $N^{+}/cm^{2}$.
In an other experiment the wear behaviour of the steel 90MnV8 was incestigated. Figure 3 showes the results of these experiments. In this case the implantation was carried out without mass separation. The species $N^{+}$ and $N_2^{+}$ were implanted simultaneously. However, the implanuation depth of the $N_2^{+}$ is only the half of that of the $N^{+}$ ions. The wear test were accomplished without lubrication. In this case the load of the fixed bearing ball was in all experiments only 0.1 MPa. The results are analogous to the data of the steel 0100W1. The wear resistance increases in the dose range from $10^{1+}$ to 6 x $10^{17}$ $N/cm^{2}$. After implantation of doses higher than 6 x $10^{17}$ $ions/cm^{2}$ the wear rate increases again.

In agreement with the results of many other research groups obtained for other steel types it was shown that the wear behaviour of the two inwestigated steels C1COW1 and 90MnV8 will be improved by the implantation of nitrogen ions in both cases with and without mass separation.

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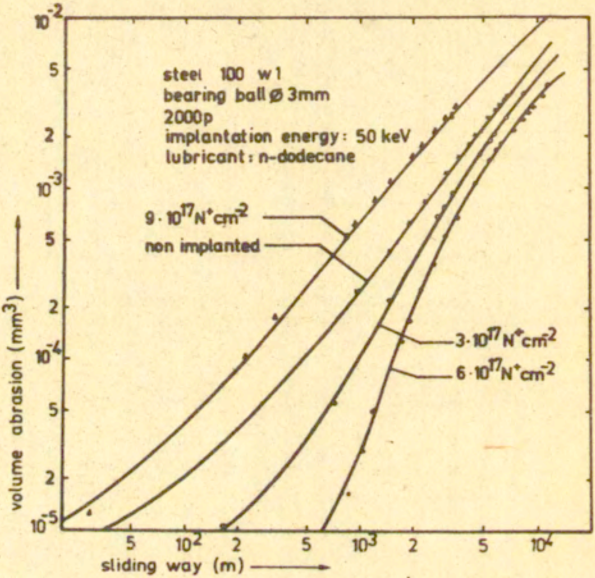
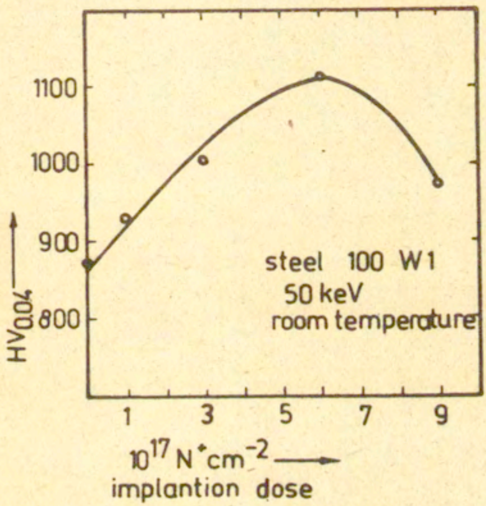
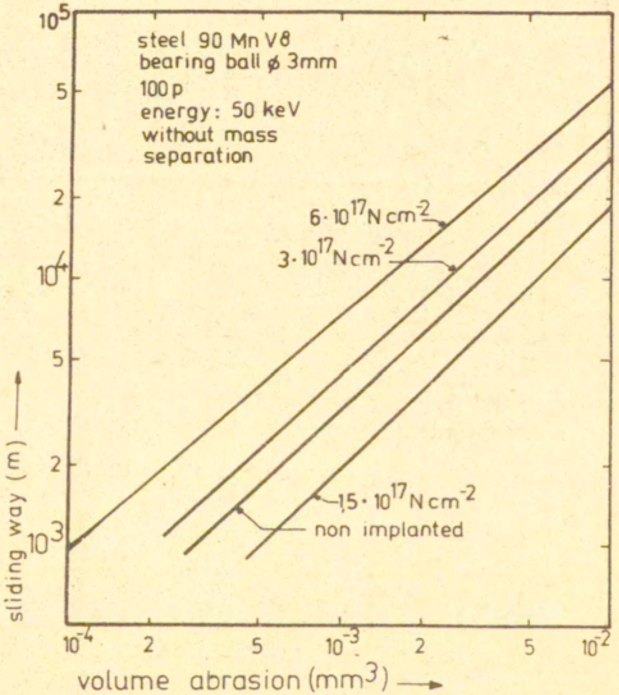



Rys. 1. Volume abrasion versus sliding way for the steel C100W1 with lubrication




Rys 2. Change of microhardness after implantation of different nitrogen doses for C100W1




Rys. 3. Volume abrasion in relation to the sliding way for the steel 90 MnV8 implanted with different doses of nitrogen