

The effect of cold treatments on the lubricated wear of case hardened components

P. Stratton

Most studies on the effects of cold treatment on the wear of steels have been carried out on tool steels.

Although carburised components are also routinely cold treated at -70°C to remove excessive retained austenite, there are few data on how this treatment affects lubricated wear. Nor are there many reports on the effect of extended deep cold treatments at -196°C and below on the wear of carburised components, although these treatments are known to greatly improve the wear performance of tool steels. The results of wear testing on steels after a wide range of thermochemical treatments using a pin-on-disk technique have already been reported. The same testing technique was used to obtain comparable results after additional cold treatment. A carburising steel - 20MnCr5 - was carburised using typical industrial cycles and then subjected to a range of cold treatments. This paper reports the effects of these treatments on lubricated wear.

KEYWORDS:

Carburised steel, deep cold, lubricated wear, liquid nitrogen, liquid helium, nanocarbitides.

INTRODUCTION

Cold treatment for the transformation of retained austenite in the case of carburising steels has been used in industrial practice for decades [1]. Cooling the steel below the M_f temperature effectively converts any retained austenite to martensite increasing hardness. Such treatments are generally considered a remedial measure when imprecise control of the carburising process has led to the case carbon being too high. However, some manufactures do overcarburise and cold treat deliberately as they consider it improves wear. This type of treatment at -70°C was therefore included in the study reported here. The benefits of extended deep cold treatment treatments on tool steels have been widely reported [2]. Although some work on the effects of deep cold on carburising steels has been reported, the effect on wear was not determined [3]. A typical deep cold

treatment cycle was therefore applied to case carburised samples to see if the same effect occurred as in tool steels. Because it has been shown that the longer a steel is held at the deep cold treatment temperature - typically -196°C in liquid nitrogen - and the longer it is held there, the better the result, it was decided to include a longer and colder treatment in this study. The samples were cooled to -269°C for 168 hours in liquid helium. To ensure that the results were comparable to a previous study of the wear of thermochemically treated steels [4], the same test apparatus was used and the same test conditions applied. Some studies of the effects of deep cold treatment on carburised and bearing steels have shown that it results in a significant improvement in dry wear properties [5 - 7]. However, as most real world carburised components operate in lubricated conditions, those results are reported here.

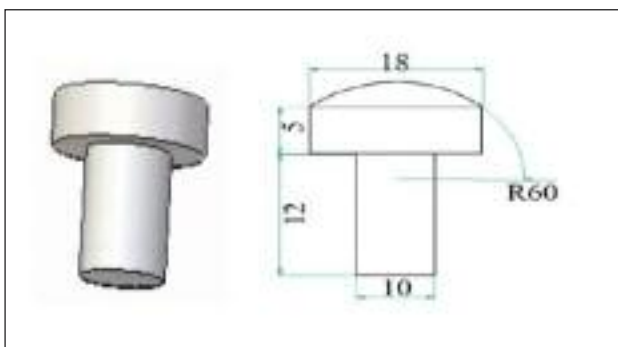


FIG. 1 *The wear test samples.*
Campioni per prove di usura.

Paul Stratton
Linde Gas, Huddersfield, UK

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EXPERIMENTAL

The samples (Figure 1) were manufactured from a typical carburising steel, 20MnCr5 with the analysis shown in Table 1. The heat treatment cycles were carried out at the Linde Gas laboratory in Unterschleißheim, Germany using an Ipsen TR25 sealed quench furnace (Figure 2). There were three carburising treatments followed by one of four post-carburising treatments (Table 2). Care was taken to ensure that the cold treatment followed the quench within one hour so that austenite stabilisation could not take place.

WEAR TESTING

Wear testing was carried out at Swerea IVF AB in Sweden. The pin-disk machine used for the tests is shown in Figure 3. The heat-treated test piece is attached to the vertical bar as shown,

%C	%Si	%Mn	%P	%S	%Cr
0.195	0.40	1.25	0.35	0.35	1.10

TAB. 1 *Sample analysis.*

Composizione dei campioni.



FIG. 2 *The Ipsen RT25-EM sealed quench furnace used for the heat treatment.*

Forno per il trattamento termico ("Ipsen RT25-EM sealed quench").

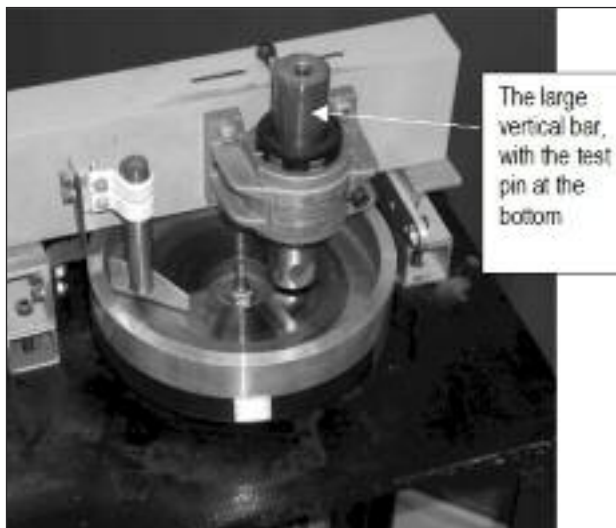


FIG. 3 *The Pin-Disk machine used for the wear testing.*

Apparecchiatura "Pin-Disk" utilizzata per i test di usura.

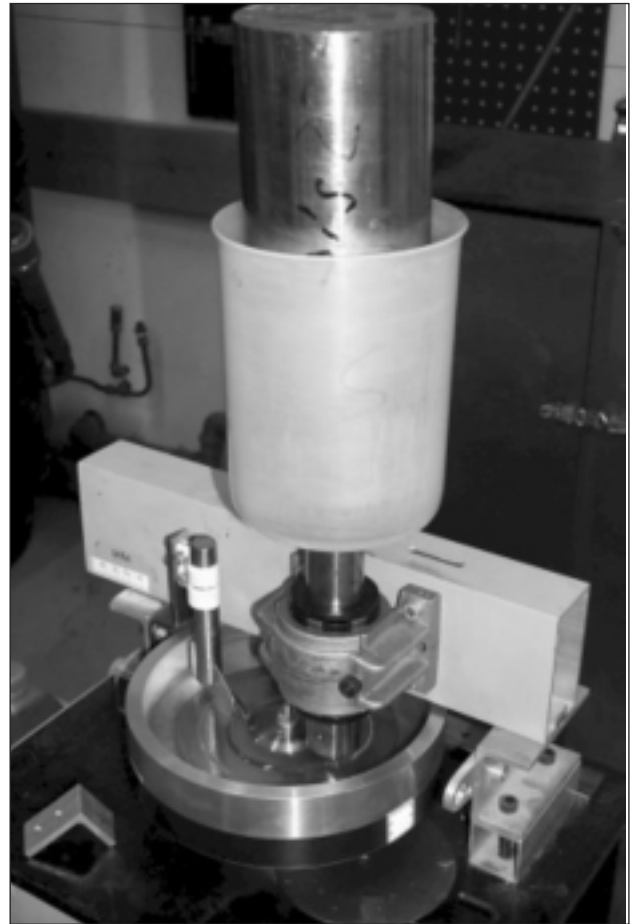


FIG. 4 *The wear test machine with 10 kg load for test under lubricated conditions.*

Apparecchiatura utilizzata per i test di usura, con carico 10 kg e in presenza di lubrificazione.

and remains stationary while the disk rotates. Loads can be applied to the top of the bar if required. In these tests a 10 kg load was used (Figure 4). The resultant pressure is very high initially; equivalent to approximately 100 N/mm² after 50 m sliding. The deflector plate on the opposite side of the disk ensures that the pin is constantly fed with lubricant.

The end of the large bar has a small angle against its length.

Carburising Treatments

Treatment	Conditions
1	Carburised to 0.8% carbon and a total case depth of 0.75 mm and direct oil quenched from 850°C
2	Carburised to 1.0% carbon and a total case depth of 0.75 mm direct oil quenched from 850°C
3	Carburised to 1.0% carbon and a total case depth of 0.75 mm, cooled out, reheated and oil quenched from 850°C

Cold Treatments

a	Temper at 150°C for one hour
b	Cool to -70°C for one hour then temper at 150°C for one hour
c	Cool to -196°C for 24 hours then temper at 150°C for one hour
d	Cool to -269°C for 168 hours then temper at 150°C for one hour

TAB. 2 *The heat and cold treatments.*

Dati dei diversi trattamenti termici a caldo e a bassa temperatura.

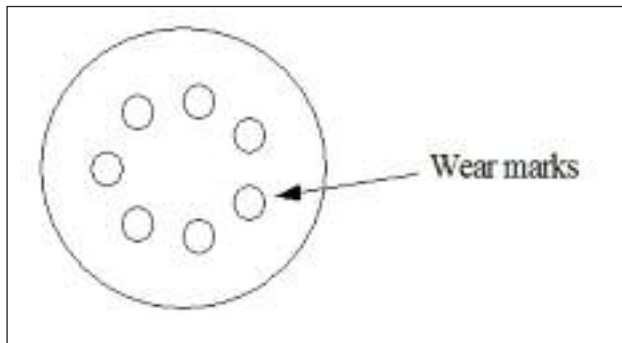


FIG. 5 *Wear marks at the end surface of the test pin.*

Impronte di usura sulla superficie finale dopo prova con "Pin-Disk".



FIG. 6 *The test pin with one large and one small wear mark.*

Provino di usura con una impronta larga e una piccola.

When the test pin is fixed in a hole at the end of the large bar the wear mark will not be in the centre, but at a circle between centre and the outer diameter as illustrated in Figure 5. Between each test, the test pin is turned a little and fixed again. This makes it possible to do six to twelve tests with each test pin. The wear mark diameter can be read with a microscope with a resolution of 0.01 mm.

The large horizontal grey beam in Figure 1 can be fixed in different positions so a new track on the horizontal wheel at different radius can be used for each test. In these tests only one disk was used so that all the results were comparable. The disk was made from a cold working tool steel hardened and tempered to 58RC. Its rotation speed was kept at the same sliding speed of 0.4 m/s for all the tests. The lubricant used was Castrol motor oil SLX OW-30, multigrade synthetic oil. After a fixed wear distance the large vertical bar with the pin fixed at its end was put under a microscope and the diameter of the wear mark was measured. The sample carrier was then replaced in the exactly same position and the test continued. Although it is possible to use the diameter of the wear mark (Figure 6) as the measure of wear, in this investigation the calculated wear volume was found to be more discriminating. Each sample was subjected to three tests and the results averaged.

METALLURGICAL EXAMINATION

Separate samples of the same dimensions as the wear test pieces were treated in each batch. Sections were prepared and examined for hardness profiles and microstructure. Near surface retained austenite was determined by x-ray diffraction.

RESULTS

Metallurgical

The hardness gradients for various cold treatments after case of carburising treatment 1 are shown in Figure 7. It can be seen that all the cold treatments resulted in a small increase in hardness near the surface due to the conversion of retained austenite to martensite. The total case depth was 0.65 mm and the effective case depth (to 550 HV) was 0.45 mm. The hardness gradients for carburising treatment 2 and 3 samples were very similar with the same total and effective case depths.

The retained austenite in the case of the samples after carburising and cold treatment is shown in Table 3.

The microstructures of the carburising treatment 2 before and after the cold treatments is shown in Figure 8. The reduction in retained austenite produced by the cold treatments can clearly be seen.

As may have been expected the microstructure of the near surface case of carburising treatment 2 exhibits some fine globular carbides (Figure 9) produced by the cool-out, reheat and quench treatment. The retained austenite was correspondingly lower than was produced by the direct quenched treatment (carburising treatment 2).

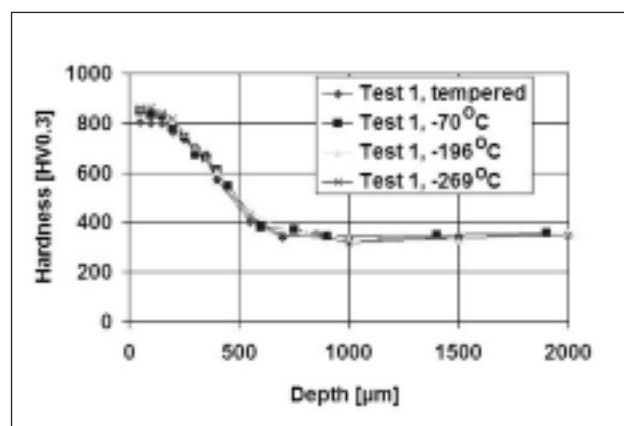


FIG. 7 *The case profiles for carburising treatment 1 after various cold treatments.*

Gradienti di durezza dopo cementazione con trattamento 1 ed esposizione a basse temperature.

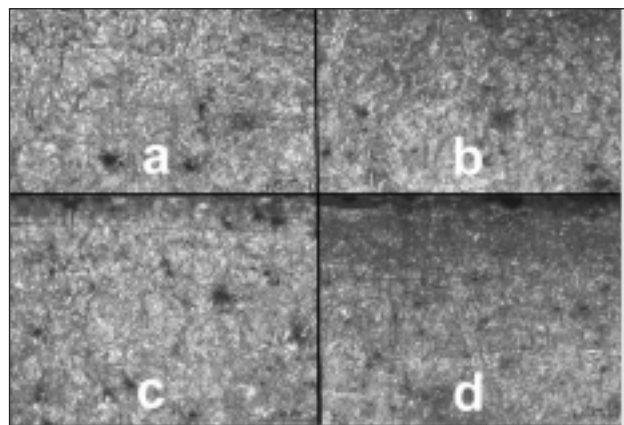


FIG. 8 *The microstructure of treatment 2 after cold treatments a, b, c and d.*

Microstrutture a seguito del trattamento 2 seguito dalle esposizioni alle basse temperature a, b, c, d.

	Carburising treatment 1	Carburising treatment 2	Carburising treatment 3
Tempered	9.1	31.0	6.4
-70 °C, tempered	3.3	13.5	4.1
-196°C, tempered	3.0	9.6	4.0
-269°C, tempered	2.6	8.3	2.9

TAB. 3 Retained austenite percentage for all the treatments at 50 m.

Percentuale di austenite residua a 50 m a seguito di tutti i trattamenti di cementazione.

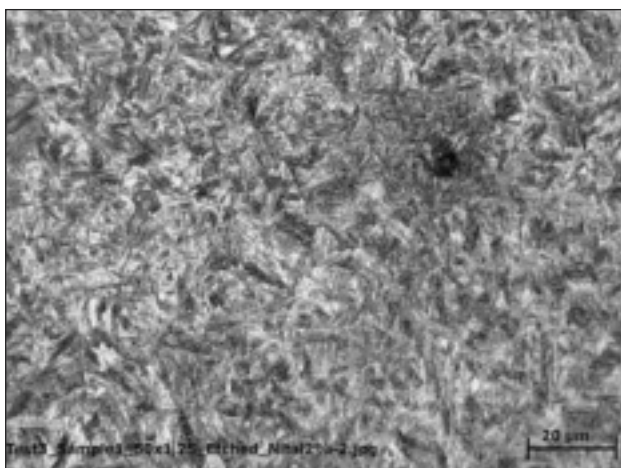


FIG. 9 The microstructure of carburising treatment 2 after reheat, quench and temper.

Microstruttura a seguito del trattamento 2 dopo riscaldamento, tempra e rinvenimento.

Wear

Although in most cases the three replicates used for each sample were very close, in a few instances there was a considerable deviation from the mean. In these cases an additional test was carried out. The results for each carburising treatment are shown in Figures 10 to 12.

It can be seen that the long term wear rates are established after approximately 5000 m sliding. It is this long term wear rate that is more important than the relative position of the wear curves as they are affected by the initial surface roughness in the region of the test, even though every effort was made to keep this constant. The long term wear rates for each treatment calculated for the wear between 5,000 and 20,000 m results are shown in Table 4.

DISCUSSION

The effect of cold treatment

For both carburising treatments 1 and 2, there is no significant reduction in wear after treatment at 70°C suggesting that reducing the retained austenite has only a small effect on lubricated wear. Further cooling to deep cold temperatures at -196°C might have been expected to improve wear in line with the results obtained on tool steels, due to the precipitation of nano-sized ϵ -carbides [8]. However, there is no large improvement for either carburising treatment, even though the lower temperature is associated with a further fall in retained austenite in both cases. There is a further reduction in retained austenite and wear when the temperature is reduced to 4K. There is a trend in all three treatments for wear to fall with increasingly low temperature treatment and associated retained austenite reduction. This is known to be more difficult for lower carbon cases and thus the very low temperature in deep cold treatments (c) and (d) convert more retained austenite [9].

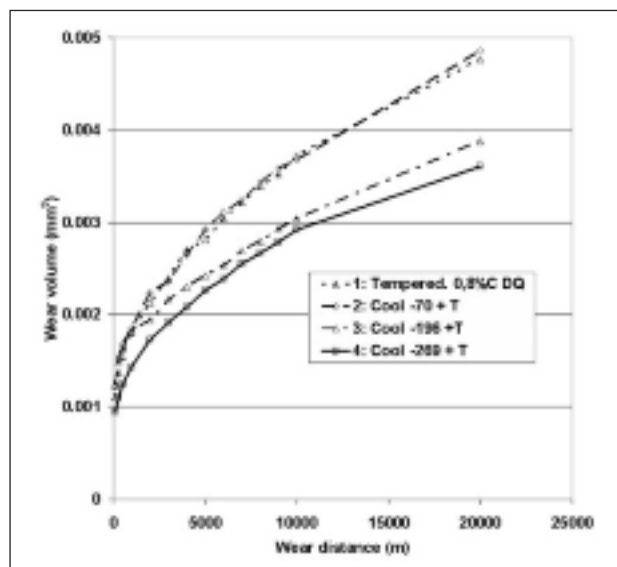


FIG. 10 The wear of samples carburised to 0.8% carbon and a case depth of 0.75 mm and direct oil quenched from 850°C after various cold treatments.

Usura dei provini cementati allo 0,8% di carbonio e una penetrazione di 0,75 mm con tempra diretta in olio da 850 °C seguita dalle varie esposizioni alle basse temperature.

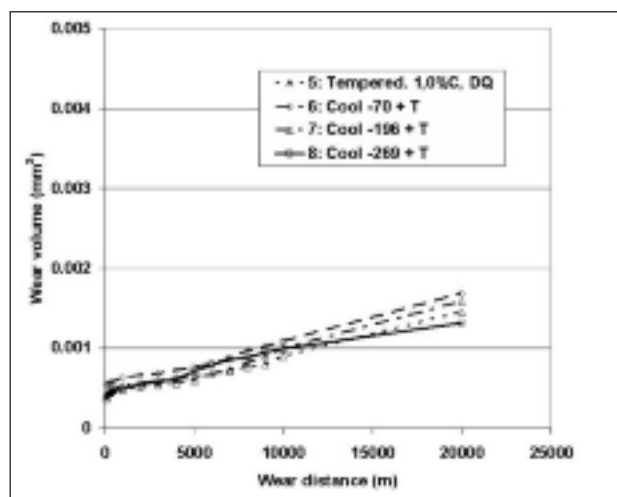


FIG. 11 The wear of samples carburised to 1.0% carbon and a case depth of 0.75 mm and direct oil quenched from 850°C after various cold treatments.

Usura dei provini cementati allo 1,0% di carbonio e una penetrazione di 0,75 mm con tempra diretta in olio da 850 °C seguita dalle varie esposizioni alle basse temperature.

	Carburising treatment 1	Carburising treatment 2	Carburising treatment 3
Tempered	130	57	84
-70 °C, tempered	129	61	157
-196°C, tempered	97	63	85
-269°C, tempered	89	39	55

Tab. 4 Mean wear rate 5000 to 20,000 m sliding ($\text{mm}^3/\text{m} \times 10^{-7}$).

Velocità medie di usura tra 5000 e 20000 m di scorrimento ($\text{mm}^3/\text{m} \times 10^{-7}$).

The results for carburising treatment 3 are more difficult to interpret. The cool-out, reheat and quench mean that, even though the surface carbon is 1.0%, there is less carbon in solution and there are some large carbides present. This combination produces a wear rate equivalent to an optimally carburised sample deep cold treated. However, the mechanism that effectively doubles the wear after treatment at -70°C is unknown. In this case all three replicates showed almost identical wear. There is also nothing unusual in the microstructure of the near surface to explain the effect, as can be seen from Figure 13. When compared with the microstructure illustrated in Figure 8, although the primary carbides seem to be larger, it is not obvious how cold treatment could cause their growth. This result seems to contradict the findings of M. Preciado et al. who suggest that the formation of carbides prior to deep cold treatment - by tempering in their case - enhanced wear resistance [6]. However, this may only be true in dry wear. Alternatively, the result for this sample is anomalous.

The effect of carburising treatment

For the purposes of this part of the discussion it will be assumed that the result for sample 2b is anomalous so as to avoid having to repeat the argument unnecessarily.

It is obvious that the carburising treatment has more effect on wear than the subsequent cold treatment. For 20MnCr5, increasing the carburising carbon potential from 0.8% to 1.0% effectively halves the wear rate no matter what the cold treatment. If this higher carbon potential is used and the part is cooled out and then reheated and quenched, half of the advantage of the higher carbon potential is lost.

Lubricated wear is not the only parameter that needs to be considered. It has also been shown that specimens with large amounts of retained austenite in the surface layers possess superior fatigue resistance to otherwise identical specimens that are more completely transformed [10]. However, it has also been shown that there is an improvement in contact fatigue resistance arising from cold treatment and the associated reduction of retained austenite at the surface [11]. This latter parameter is of greater importance in the performance of gears.

It is also known that the presence of retained austenite in the cases of carburised components that are to be subsequently ground is definitely detrimental because it causes severe grinding burns and cracking [12]. The higher the retained austenite, the worse the effect becomes. Reducing retained austenite in carburised gears must therefore be considered essential.

CONCLUSIONS

Although the carburising parameters have more effect on the wear performance of 20MnCr5 than cold treatment does, cold treatment decreases wear and improves other parameters that affect component life, particularly for gears. The colder the treatment, the more retained austenite is transformed and the better the wear.

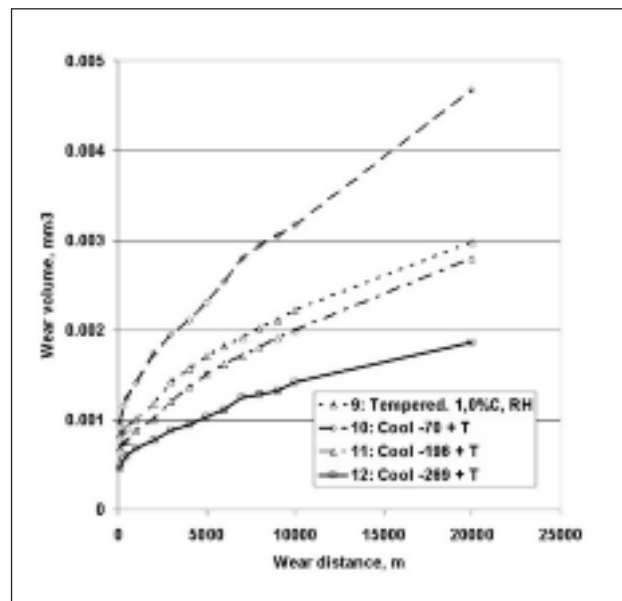


FIG. 12 The wear of samples carburised to 0.8% carbon and a case depth of 0.75 mm, cooled out and reheated before oil quench from 850°C after various cold treatments.

Usura dei provini cementati allo 0,8% di carbonio e una penetrazione di 0,75 mm raffreddati all'esterno e ritrattati prima della tempra in olio da 850°C seguita dalle varie esposizioni alle basse temperature.

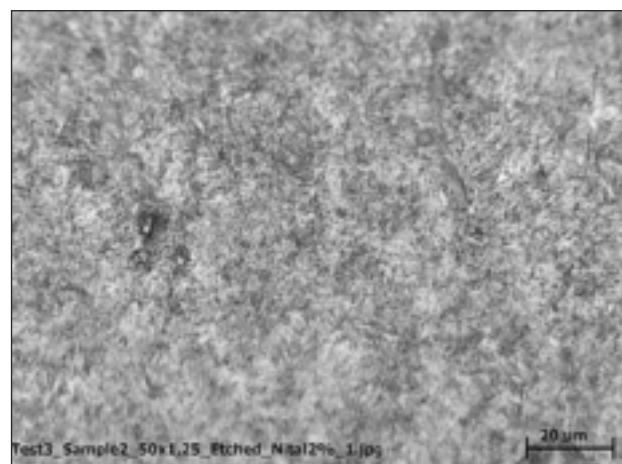


FIG. 13 The near surface microstructure of carburising treatment 3 after reheat, quench and deep cold treatment at -70°C.

Microstruttura vicina alla superficie del trattamento 3 dopo riscaldamento, tempra e trattamento profondo a -70°C.

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Abstract

Effetto dei trattamenti a basse temperature sull'usura di componenti cementati in presenza di lubrificazione

Parole chiave:
tribologia, usura, lubrificazione, acciaio

La maggior parte degli studi sugli effetti del trattamento a basse temperature sull'usura degli acciai sono stati effettuati su acciai per utensili. Anche se si verifica spesso che componenti dopo cementazione vengano abitualmente trattati a freddo a -70°C per rimuovere l'eccesso di austenite residua, vi sono pochi dati relativi a come questo trattamento influisca sull'usura in presenza di lubrificazione. E non vi è neppure molta letteratura sugli effetti di trattamenti profondi a freddo, a -196°C e oltre, relativi all'usura dei componenti cementati, anche se questi trattamenti sono noti in quanto in grado di migliorare notevolmente le prestazioni di usura degli acciai da utensile.

Sono già stati riportati molti risultati delle prove di usura su acciai, dopo un'ampia gamma di trattamenti termochimici, utilizzando una tecnica di "pin-on-disc". La stessa tecnica di prova è stata utilizzata per ottenere risultati comparabili, dopo ulteriori trattamenti a basse temperature. Un acciaio da cementazione - 20MnCr5- è stato carburato usando cicli industriali tipici ed è quindi stato sottoposto a una serie di trattamenti a freddo. Il presente documento riporta gli effetti di questi trattamenti sull'usura in presenza di lubrificazione.