MECHANICAL AND PHYSICAL PROPERTIES OF CARBON S-PHASE ON STAINLESS STEEL, PRODUCED BY CARBON SUPERSATURATION[1]

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Abstract

While the excellent corrosion resistance of austenitic stainless steels has resulted in wide commercial application of these materials, poor tribological behaviour, especially low abrasive / adhesive wear resistance and a tendency for fretting, has prevented the use of these materials in applications where both corrosion and wear resistance are required. For more than 20 years, the Kolsterising® process has offered a solution to the industry; enhanced wear properties and unaltered corrosion resistance. Suitable for austenitic and duplex stainless steels and nickel base alloys, this thermo-chemical diffusion process enriches the austenitic surface with carbon, forming a carbon supersaturated layer or carbon S-phase while avoiding the carbide precipitation that causes sensitization. This paper compares the properties of treated and untreated austenitic stainless steels. Results show improvement in wear resistance and fatigue life with Kolsterising®, while corrosion resistance is unaffected.

Keywords: Stainless steel; Carbon supersaturation; Kolsterising.

PROPRIEDADES MECÂNICAS E FÍSICAS DE FASE CARBONO S EM AÇOS INOXIDÁVEIS AUSTENÍTICOS, PRODUZIDO POR SUPERSATURAÇÃO DE CARBONO

Resumo

Enquanto a excelente resistência à corrosão dos aços inoxidáveis austeníticos tem resultado em grande aplicação comercial destes materiais, um comportamento tribológico sofrível, especialmente a baixa resistência ao desgaste abrasivo/adesivo, e uma forte tendência à “fretting”, tem limitado o uso destes materiais em aplicações nos quais ambas, resistência à corrosão e desgaste são exigidos. Por mais de 20 anos, o processo Kolsterising® tem oferecido uma solução para a industria, aumentando as propriedades a desgaste sem alterar a resistência à corrosão. Adequado para aços inoxidáveis austeníticos e duplex, e também ligas à base de níquel, este processo de difusão termo-química enriquece a superfície austenítica com Carbono, formando uma camada supersaturada em carbono ou fase Carbono S, e ao mesmo tempo evita a precipitação de carbonetos que causa o fenômeno de sensitização. Este artigo compara as propriedades de aços inoxidáveis austeníticos tratados e não tratados pelo processo. Os resultados mostram aumento da resistência ao desgaste e aumento do limite de fadiga com o Kolsterizing®, enquanto a resistência à corrosão permanece inalterada.

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1 INTRODUCTION

Austenitic stainless steels are widely used in the chemical and food processing industries, as well as for medical instruments and pharmaceutical equipments, owing to their excellent corrosion resistance. However, their hardness and wear resistance are relatively low, limiting their applications in the manufacturing of mechanical parts for engineering equipment and machines, where also their tribological behaviour is important. A major drawback of austenitic stainless steel is the poor wear resistance during sliding due to the high tendency to suffer severe wear by galling. Many attempts have therefore been made in the past decade to develop surface engineering techniques to improve the wear resistance of austenitic stainless steels without deteriorating their corrosion resistance.[1,2] The Kolsterising® process is an industrial surface hardening technique,[3] permitting to improve surface hardness and wear resistance of austenitic stainless steels. This process involves low temperature diffusion of carbon into the surface of the austenitic stainless steels, without the formation of chromium carbides; therefore it usually does not have any negative effect on the corrosion behaviour.

The aim of this work is:

- To show the tribological and corrosion behaviors of an austenitic stainless steel AISI 316L submitted to the Kolsterising® process, as measured in proper tests
- To present the latter applications in the Food & Beverage industry

2 EXPERIMENTAL PROCEDURE

The material used in the experimental investigations was AISI 316L in solution annealed condition, unless otherwise cited in the respective test conditions.

Table 1. Nominal chemical composition (wt%) of AISI 316L[1]

C	Cr	Mn	Ni	Mo	P	S	Si	Fe
0,03	17	2	12	2,5	0,045	0,03	1	rest

The tests compare untreated and treated specimens to show the influence on the properties of austenitic stainless steel. The Kolsterising® treatment was carried out by Bodycote Hardiff BV.

The micro structural characterization was carried out by means of optical, scanning electron microscopes (OM, SEM) and X-Ray diffraction on specimens prepared using standard metallographic techniques.

Hardness tests were conducted using a standard micro hardness tester with a load of 50 grams. The 50 gram load was chosen in order to measure the hardness of the relatively shallow case without any influence from the underlying softer material. The case depth hardness curve was measured on a cross section with a Knoop test.[1]

Fatigue test was carried out according to ISO 12107 Rotating bending fatigue test.[3]

Taber Abraser test according to ASTM 1978 was used to determine the wear resistance against abrasive wear by measuring the weight loss of the specimens.

The corrosion behaviour is investigated by measuring the pitting corrosion potential in 3%NaCl solution to compare the pitting corrosion behaviour of treated samples versus untreated.

3 RESULTS AND DISCUSSION

3.1 Microstructure

During the Kolsterising® process, carbon diffuses into the surface, dissolves interstitially in the FCC matrix, causing a distortion of the FCC cell (Fig. 2). In the microstructure (Fig. 1), the structure of the diffusion zone is more difficult to etch than the base austenitic structure.

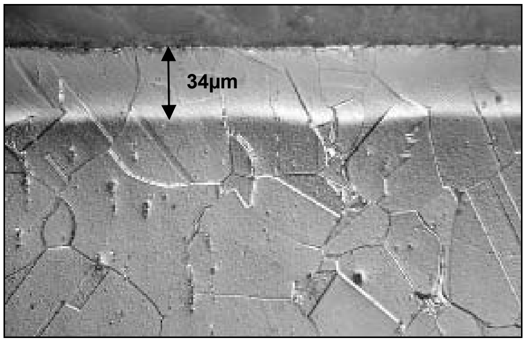

Figure 1. Microstructure of a Kolsterised 316L.

After standard V2A etching, the diffusion zone appears white. The grain boundaries are still visible, continuing from the diffusion zone into the base structure. Due to the low process temperatures involved, no chromium carbides are formed in the expanded austenite S-phase. The diffusion zone varies, depending on material and process type. During Kolsterising® the S-phase is supersaturated with carbon. This phase is described in the literature as “expanded austenite”.[4,5,6] The term expanded austenite is used based on the appearance of the atoms arrangement in the crystal lattice. Solution of carbon (or nitrogen) causes an expansion of the FCC lattice, where carbon atoms are positioned in the octahedral interstices of the FCC lattice (Fig. 2).

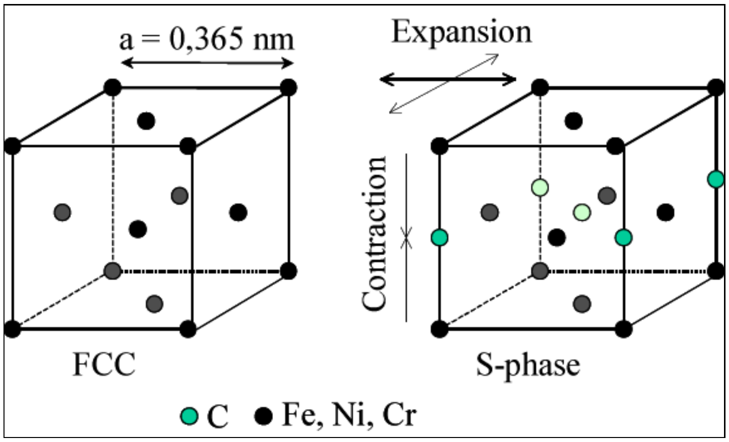

Figure 2. Model of expanded austenite.

The expansion of the cubic cell can be proven with x-ray diffraction (XRD).[7] The results in the literature state a shift in the characteristic Bragg-angels towards lower values (Fig. 3).

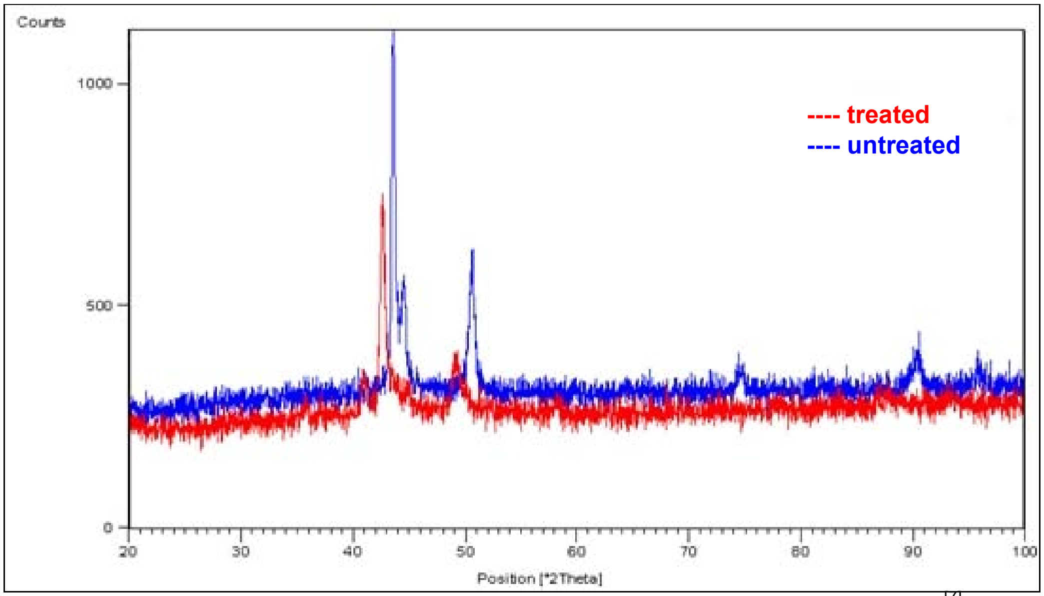

Figure 3. X-ray diffraction of AISI 316L Kolsterised (red) and untreated (blue).[7]

The solid solution hardening effect with carbon is related to a build up of compressive stresses in the surface and a consequent increase of hardness up to 1200 HK. The S-phase is a metastable phase and will decompose to chromium carbides when thermally annealed at extended time period and too high of a temperature. The driving force for this “migration” is assigned to different concentration gradient i.e. diffusion.

3.2 Hardness

The hardness increase is caused by compressive stresses, Fig. 4.

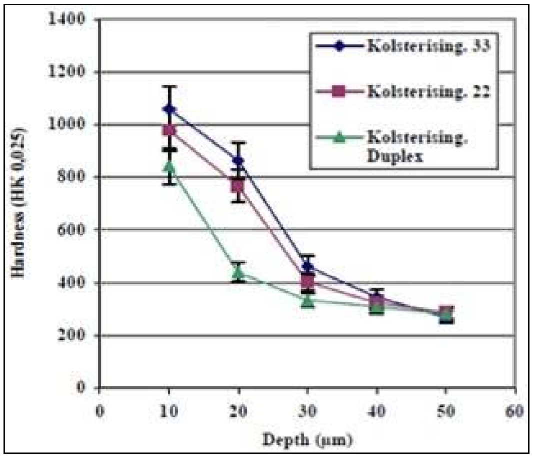

Figure 4. Graphic representation of hardness curves.

The hardness curve shows a typical profile of a diffusion zone. On the surface, the hardness increases to about 850–1100 HK0.025, - depending on the process and the material – going inwards the hardness drops continuously until the hardness of the base material is reached.

3.3 Fatigue Strength

The fatigue strength was tested with a rotating bending fatigue test. The influence of the surface alteration, by Kolsterising can be seen in Fig. 5, the Wöhler curve. The fatigue strength increases from 360 MPa to about 520 MPa. During the test a strong temperature increase on the Kolsterised part was detected. Stabilizing the temperature of the sample at room temperature increased the fatigue strength to 620 MPa.

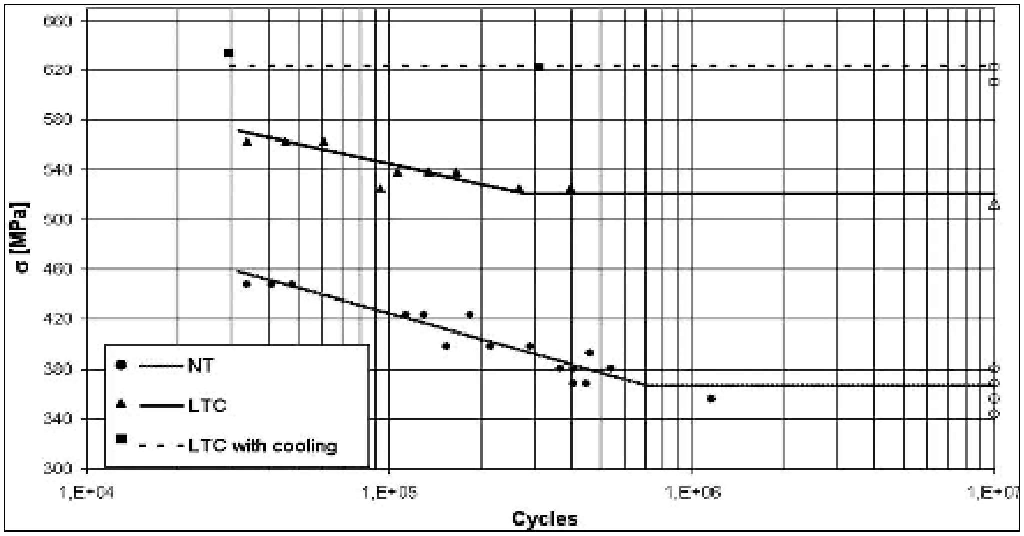

Figure 5. Fatigue life curves of the AISI316L: untreated (NT), low temperature carburised (LTC) and LTC with cooling during the test.[6]

3.4 Wear Test

The Taber Abraser test was carried out according to ASTM 1978 using H10 Taber wheel.

Fig. 6 shows the results of the Taber Abraser test on untreated and treated samples with the weight loss as a function of cycles. Treating the austenitic stainless steel (1.4404) reduces the weight loss by about 50 % compared to the untreated sample, but it does not eliminate the abrasive wear.

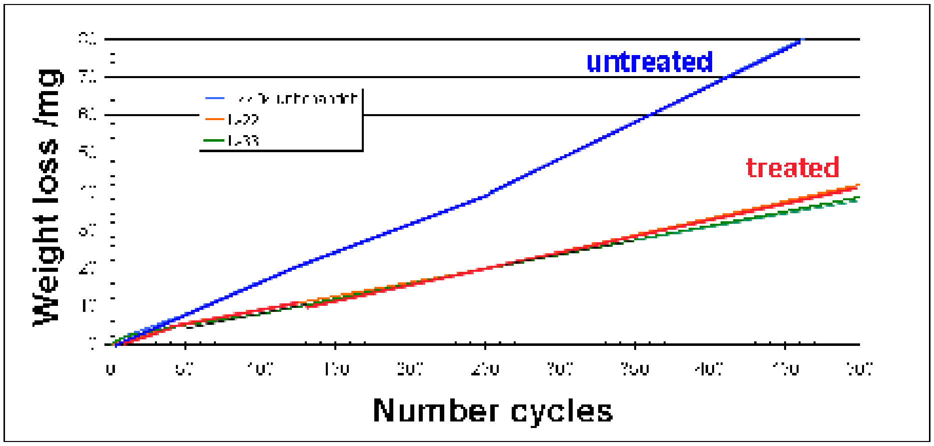

Figure 6. Weight loss in Taber Abraser test.

3.5 Corrosion Behavior

A standard potentiostatic measurement was used to determine the current density vs. electropotential curve of treated and untreated samples using a platinated Titanium counterelectrode and standard Ag/AgCl for reference (Fig. 7). In this test a certain potential (mV) is applied to the parts, the current flow (mA/cm²) is then measured. In this test a 3% sodium chloride solution, similar to seawater, was used to determine the pitting potential.

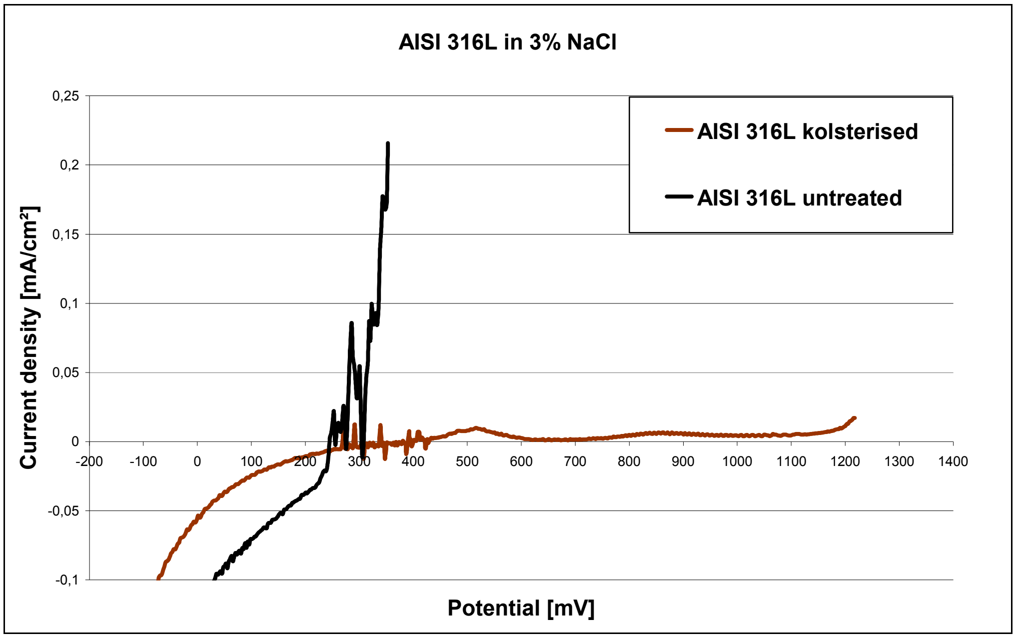

Figure 7. Potentiostatic measurement.

In a passive behaviour no current flow is detectable, but in sodium chloride pitting corrosion, a certain electric potential (pitting potential) is induced and when a current flow is detected, it is an indication that the passive behaviour has destabilised locally and pitting corrosion has begun. The higher the potential level, the more stable the material is against pitting. Comparing untreated and Kolsterised specimens, pitting corrosion started around 350 mV in the untreated sample. For the Kolsterised sample, no current was measured and no critical pitting potential could be determined. The condition of the base material (delta ferrite, deformation martensite) and the surface preparation must be taken into consideration when corrosion resistance is of particular importance for the application. Both affect the corrosion behavior of the material, especially in the Kolsterised state.

4 APPLICATION

The combination of increased wear resistance and fatigue resistance while the corrosion resistance and non-magnetic behaviour of austenitic stainless steels are not affected has already resulted in numerous applications. Examples are ferrules for tube fittings. The ferrule should cut into stainless steel tubing to provide mechanical strength to the fitting connection. Therefore, the cutting edge of the ferrule should be significantly harder than the tube.

Another area of application is the pump industry. In machines for food filling the use of Kolsterised metal-to-metal (i.e. without O-rings) piston-type dosing pump components has resulted in a more than ten-fold increase of the lifetime. The absence of non-metallic seals (e.g. O-rings) has an added advantage. It reduces maintenance and improves the hygienic conditions. Other successful pump applications relate to gear, screw and centrifugal pumps.

The treatment provides a solution whenever high corrosion resistance is required and lubrication is not allowed.

Further applications can be found in all industries where stainless steels are used, e.g. the oil and gas industry, pharmaceutical and chemical industry. Also, consumer goods benefit from the technical advantages such as watch parts. In general, the treatment can be beneficial for austenitic stainless steel components which are subject to wear (friction, erosion, abrasion), prone to galling and corrosive conditions. In view of the relatively small thickness of the hardened case and the modest hardness of the underlying base material, the resistance against heavy macroscopic impact wear is limited. In such applications the hardened case cannot prevent the deformation of the base material. On the other hand, the combination of a high hardness and high ductility of the case provides excellent resistance against microscopic impact wear mechanisms like cavitation.

5 CONCLUSION

Kolsterising causes the formation of the S-phase which leads to an increase and improvement of various mechanical and physical properties.

Kolsterising can be used in all cases where the following combinations of often incompatible characteristics are required:

- Corrosion resistance and resistance against galling;
- High hardness and high ductility;
- High fatigue strength and corrosion resistance;
- High hardness and non-magnetic properties;
- Improved polishability of austenitic stainless steel.

Kolsterising is used in a wide variety of industries such as food and beverage, medical, chemical and automotive industry.

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