Surface Hardening of Stainless Steels by Kolsterising

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Abstract

In many applications stainless steels need a hard and wear resistant surface. The common used austenitic stainless steels have excellent corrosion properties but very poor tribological characteristics. Depending on the demand of a high corrosion resistance there are only a few technologies to meet the necessary standard. A very successful process is the diffusion of carbon into the surface by the Kolsterising process which is done at very low temperatures so that no chromium carbides are precipitated. A high carbon content, dissolved in the lattice improves surface hardness and wear resistance by maintaining corrosion resistance. A surface hardness of over 1000 HV, a considerable improvement of wear resistance, an elimination of fretting (cold welding) and corrosion resistance in many hazardous environments are the results when Kolsterising is applied on austenitic stainless steels. Results of the influence of this hardening process on different properties of austenitic and duplex stainless steels are presented. Some examples for very successful applications of this surface treatment in different fields like automotive industry, medical industry, food processing and consumer industry are shown.

Keywords*: Austenitic stainless steels, surface hardening, Kolsterising, corrosion, tribology*

1 Introduction

Stainless steels find numerous applications in all areas of industrial production, for many of these applications high hardness and/or high wear resistance is required. Examples of such applications can be found in all areas, e.g. the process industry, food industry and although in the present-day automotive industry. Not only applications such as exhaust and fastening systems, but also linkage assemblies demand the superior tribological characteristics of stainless steels [1]. Austenitic molybdenum and ferritic chromium stainless steels as well as duplex steels are not hardenable like mild steels [1] and therefore it is difficult to meet these tribological requirements.

The classic coating/heat treatment techniques generally offer mediocre results at best, mostly due to the passive layer that stainless steels form under normal atmospheric conditions. This passive layer acts as a barrier to diffusion and prevents any diffusion processes from being able to adhere to the surface of the material. The common surface-hardening processes, for instance the traditional carburization, nitriding or boriding of a material, must be carried out at a very high temperature to high to avoid the formation of precipitates such as carbides, borides and nitrides. The presence of such precipitates can lead to a depletion of chrome in the affected surface material, which in turn compromises the corrosion-resistant properties of the material. In the last years various attempts have been performed to develop a specific process to carry out a lattice diffusion on the surface of a material without compromising the corrosion resistance. The most promising variants were executed in a temperature range underneath that where precipitates will be formed; that is, the material stays at low temperatures to prohibit the formation of precipitates containing chromium [1-3].

One of these processes, Kolsterising, was introduced to the market over 20 years ago and thus offers extensive experience in high-level tribological properties, such as cutter, tools in paper and food fabrication, beverage filling stations, regulating rods of turbochargers or valves in exhaust gas recirculation systems.

2 The Method

The process is described as the carburizing of a material surface at temperatures below 500°C and consists of a massive diffusion of carbon into the surface of a material, forcing the outer lattice structure on the surface into a distorted state (the so called expanded austenite) and in turn offering hardness values of up to 1200 HV (Figure 1). The diffusion layer depth varies between 20 µm and 40 µm. The process begins with the temporarily removal of the passive layer. This enables the diffusion of carbon at lower temperatures into the lattice structure on the surface of the material. After the process the passive layer, consisting of chromiumoxide/-hydroxide, spontaneously forms again at a special atmosphere. With this, Kolsterising offers a significant increase in surface hardness without compromising the corrosion resistance of the original material. By means of this treatment it is possible to obtain a surface hardness up to 1200 HV for austenitic stainless steel. The austenitic structure and the pertaining nonmagnetic character are not altered in the standard austenitic steel grades like AISI 316. All in all this process finds a wide range of applications with austenitic and austenitic-ferritic stainless steels.

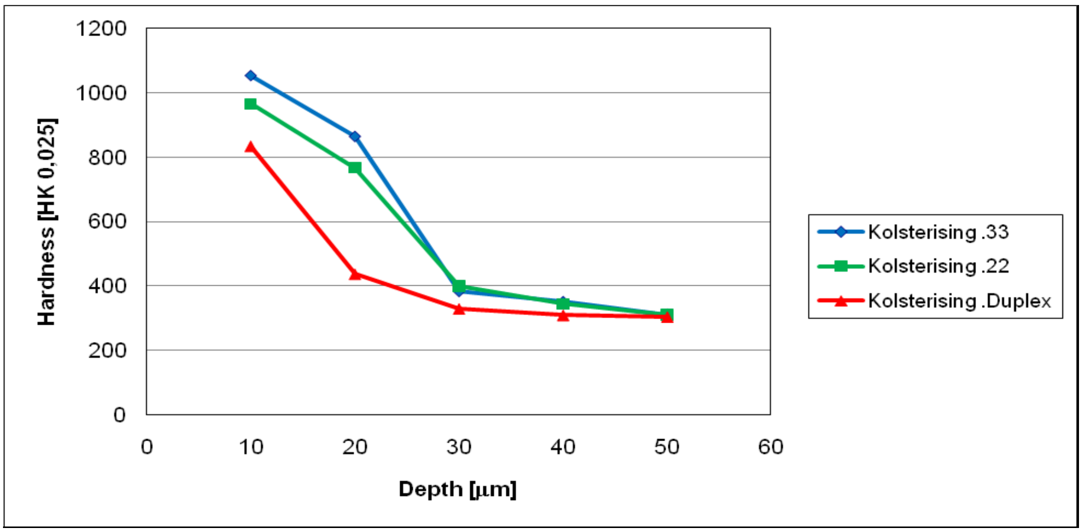

Figure 1: Hardness penetration, measured in Knoop of a kolsterised austenitic chromium-nickel-molybdenum stainless steel

The hardness curves show the typical characteristics of a diffusion profile with a high hardness on the surface and a gradual decrease in hardness going inwards (Figure 1). The thickness of the hardened zone is very uniform and adapts itself perfectly to the profile of a component (Figure 2), the original surface quality is maintained and the treatment does not cause any changes in size. The diffusion of carbon into the matrix (Figure 3) causes high compressive stresses and leads to this hardness increase. In Figure 3 the diffusion profile of carbon, measured with GDOES, shows a carbon content of up to 12 at.% compared to about 0 at.% in the base material. The diffusion layer is visible in the microstructure and can be identified as a "white layer", showing light etching characteristics. The grain boundaries can still be recognized in the hardened diffusion layer, even though the etching behaviour of this layer is different from that of the base material which is an indicator for a good corrosion resistance. The hardened lattice structure of the diffusion layer shows no signs of precipitates on the grain boundaries (Figure 4 and 5).

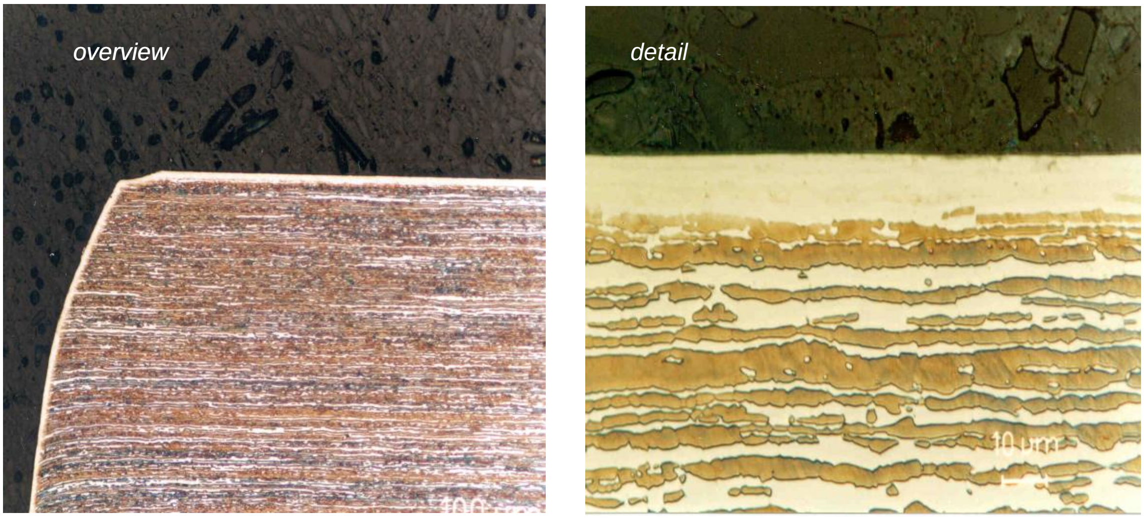

Figure 2: Micrographs of a cross section trough a Kolsterised sample (Duplex stainless steel X2CrNiMo22-5-2)

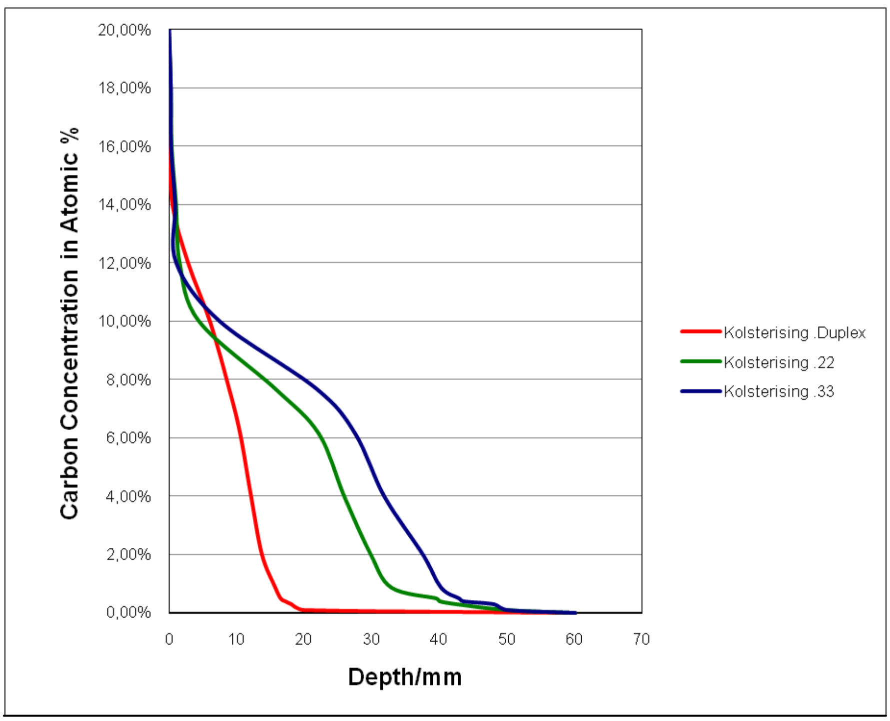

Figure 3: Concentration of carbon in Kolsterised stainless steels

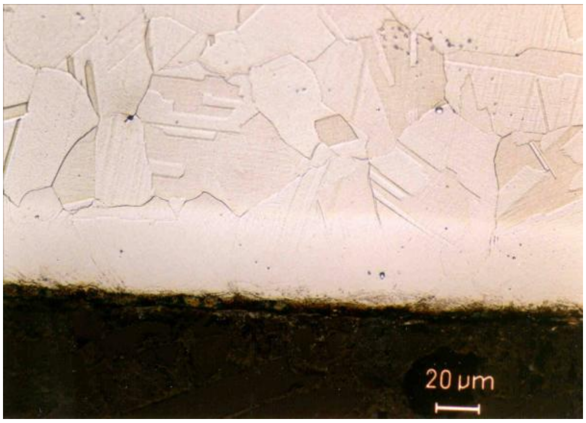

Figure 4: Microstructure in the hardened zone of stainless steel AISI 316L after Kolsterising

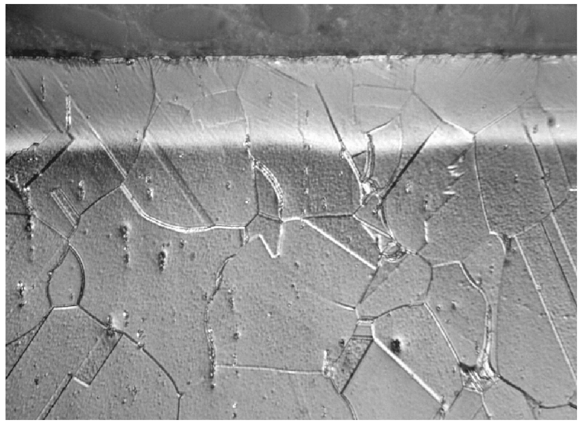

Figure 5: Microstructure in the hardened zone of stainless steel AISI 316L after Kolsterising. Light microscopy in angular light

Although the hardness increase is obtained through a distortion of the austenitic lattice structure, this expanded austenite is often referred in various literatures as the so called S-Phase [4]. The hardened zone at the topside of the material has outstandingly consistent properties and shows an impressive ductility. The process has nearly no influence on size or colour change of the material. Figure 5 shows clearly that the grain boundaries are free from any precipitations and that there is a difference in the etching behaviour depending on the amount of carbon in the lattice.

Tests with channels and blind holes showed, that the hardening effect can also be obtained in case of relatively unfavourable geometries (Figure 6). Even for a blind hole with a extremely unfavourable diameter/depth ratio the hardness penetration at the bottom of the hole is only a little smaller than at the surface.

Due to the high compressive stresses a small roughening effect in the range of 3-5 µm can be observed at a polished surface, this leads to a small decrease in the brightness of the surface (Figure 7).

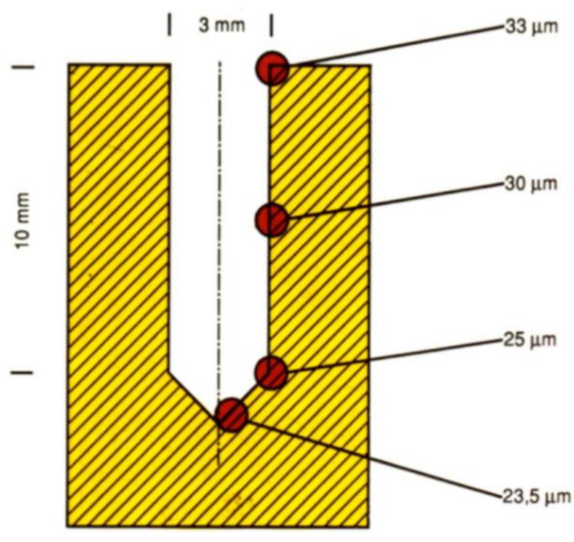

Figure 6: Hardness penetration in a blind hole

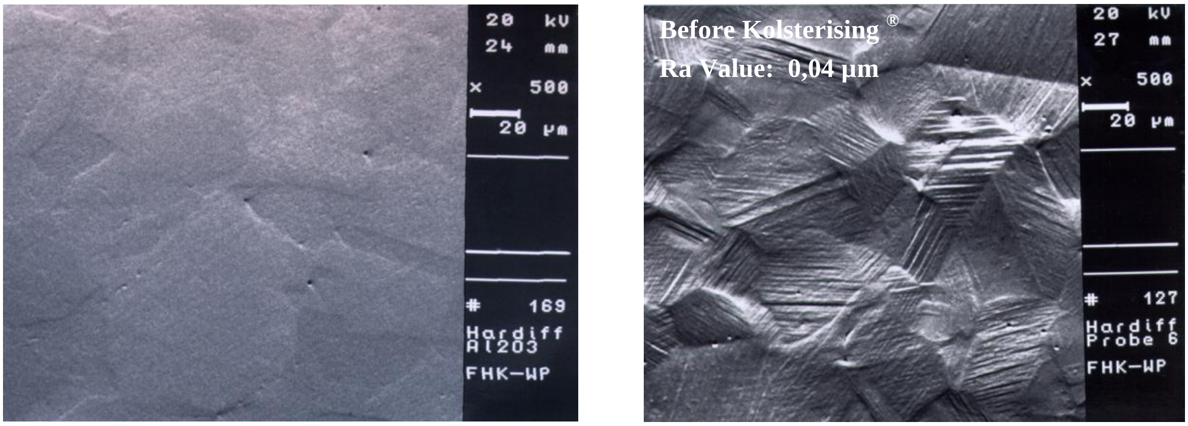

Figure 7: Compressive stresses lead to a small surface distortion

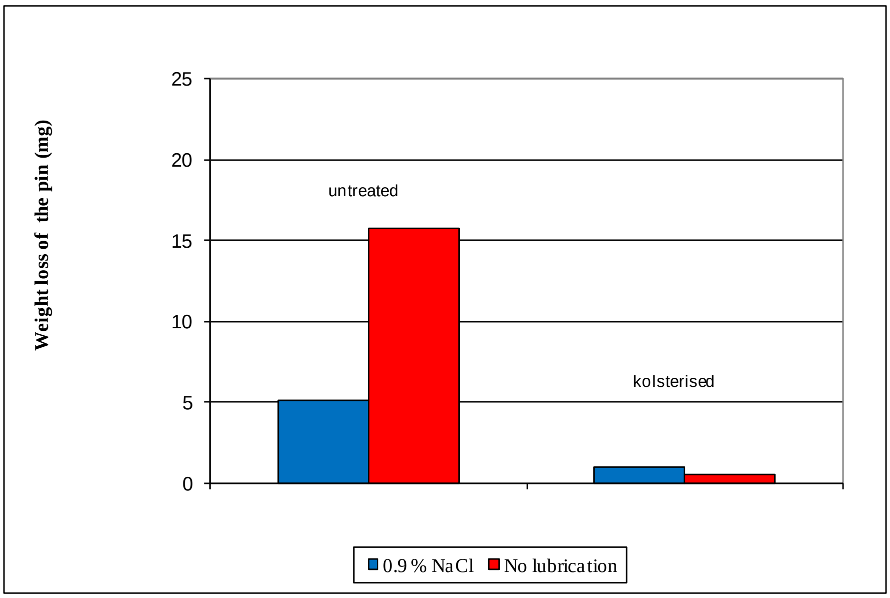

Figure 8: Weight loss in Pin-on-disc testing, Material X2CrNiMo18-15-3 (1.4435), rotational speed 36 rpm; pressing force 10 N, total frictional distance 720 m

3 Impact of Surface Hardening on Tribological Properties

For a lot of applications in the food or automotive industry, the tribological characteristics of the material also play an important role in addition to the corrosion resistance. As expected, the hardened surface of the component offers a clear improvement of both the wear resistance as well as the surface slip properties. To verify the impact of this process on the wear characteristics, extensive labor testing was carried out. The results clearly showed that the properties of numerous tribological systems are considerably improved due to Kolsterising.

The results of Pin-on-disc tests, carried out in both dry conditions as well as in a solution consisting of 0.9% NaCl, are shown in Figure 8. The hardened sample offers a clear improvement in wear resistance, improving the friction coefficient in dry conditions by a factor of ten.

Due to the lubricating effect of the salt solution, the difference between the Kolsterised and non-Kolsterised material in the solution is substantially reduced. Nevertheless the advantage of Kolsterising is conclusive, as it still offers an increase of the wear resistance by a factor of three.

These results are not necessarily directly transferable to other applications and tribological systems; these tests have been carried out in a controlled lab environment to produce general values for the corrosion and wear properties associated with this particular process. This by no means negates the results, however, one can clearly see that any contact between steels, particularly where the material is at risk to be "eaten away", is considerably improved with an increase of surface hardness.

4 Impact of Surface Hardening on the Mechanical Properties

As expected, the high compression stresses in the surface of the Kolsterised stainless steels lead to a clear improvement in the fatigue properties of these components (Figure 9).

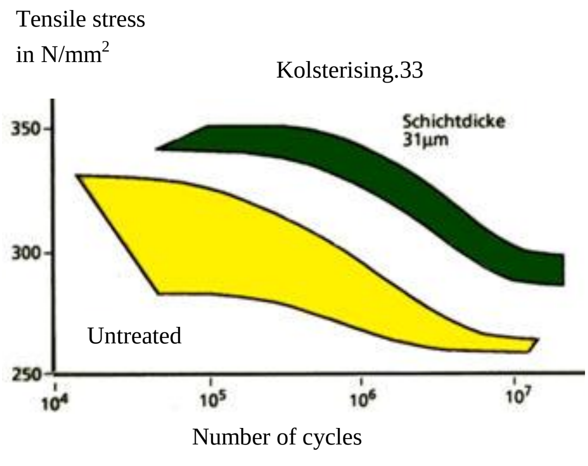

Figure 9: Rotated bending fatigue

The mechanical properties will only be influenced in tests in which the condition of the surface plays an important role, for example in fatigue tests or in testing very thin parts. Kolsterising gives no noticeable difference in both the tensile and impact values of standard specimen. In tests with uneven strain over the cross section, however, such as in bending tests, the benefit of the hardened surface was clearly recognized. Along with this, the fatigue strength of such austenitic stainless steels increases significantly with a hardened surface. For example, the surface hardening of a thin-walled component of austenitic steel can increase its fatigue strength by up to 40%.

None of the mechanical tests revealed any debonding effects such as for example flaking off of the hardened zone. At the convex side (tensile stresses) of a bend test specimen the hardened layer cracked, whereas at the concave side (compressive stresses) of the bend specimen the hardened zone piled up by means of a shear mechanism (Figure 10)

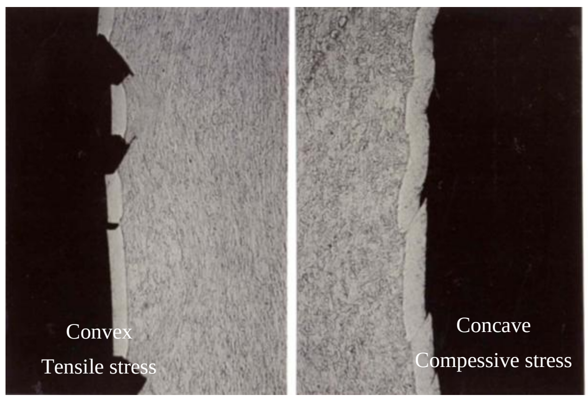

Figure 10: Behavior of the Kolsterised zone in a bending test (bending angle 60°, thickness 2mm, radius of mandrill 5mm)

5 Impact of Surface Hardening on the Corrosion Resistance

Corrosion resistance is of high importance when using stainless steels and any deterioration by a surface hardening is undesirable. In the analysis of the influence of Kolsterisation on properties of the material, the corrosion resistance of austenitic and austenitic-ferritic stainless steels showed predominantly no deterioration if the base material is in an optimized condition.

Figure 11 illustrates the impact of Kolsterising on the critical pitting temperature of an austenitic chromium-nickel-molybdenum steel in tests according to ASTM G48 standards, which implies a 10% iron chloride solution. The results show absolutely no degradation of the corrosion resistance caused by the heat treatment; quite on the contrary a slight improvement of these properties can be recognized by increasing the diffusion depth. As expected, the corrosion starts along the edges, and it can be shown that Kolsterising has seemingly improved the corrosive resistance. A plausible reason for this effect could be the chemical treatment of the cut edges during the Kolsterising process by finishing and cleaning techniques. By investigating the microstructure of the attacked specimen a side effect was detected: a corrosion attack was focused on the base material and the diffusion layer stayed intact (Figure 11). This can be observed by investigating the microstructure acc. the G-48 test.

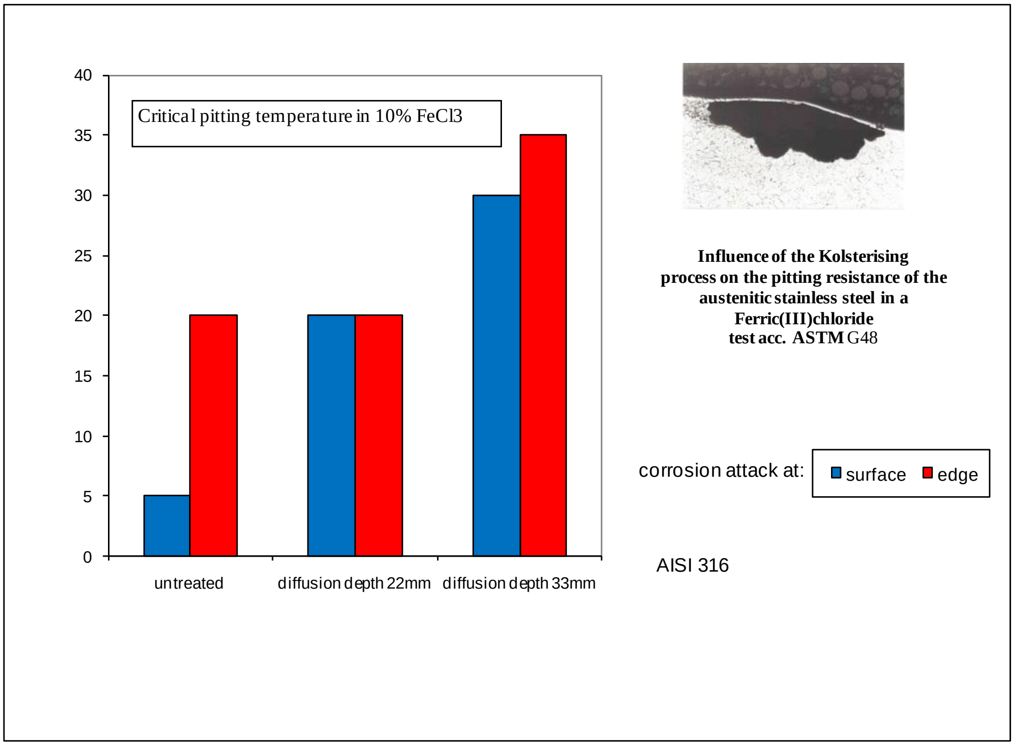

Figure 11: Impact of Kolsterising on the critical pitting temperature on an austenitic stainless steel in an iron chloride solution (compliant to ASTM G48)

Using electrical measurements to determine pitting resistance of Kolsterised versus non-hardened surfaces with various finish qualities it is shown that Kolsterising has no negative effect on the corrosion resistance properties of the material (Figure 12). Here it is not so much the surface hardness but rather the surface quality that is the deciding factor.

The improvement in pitting resistance could not only be seen in chlorinated solutions but also in solutions such as sodium hydroxide and sulfuric acid. Though it is not unusual when introducing internal compression forces onto the surface of a material, that there is a considerable improvement of resistance to stress crack formation on the Kolsterised probes.

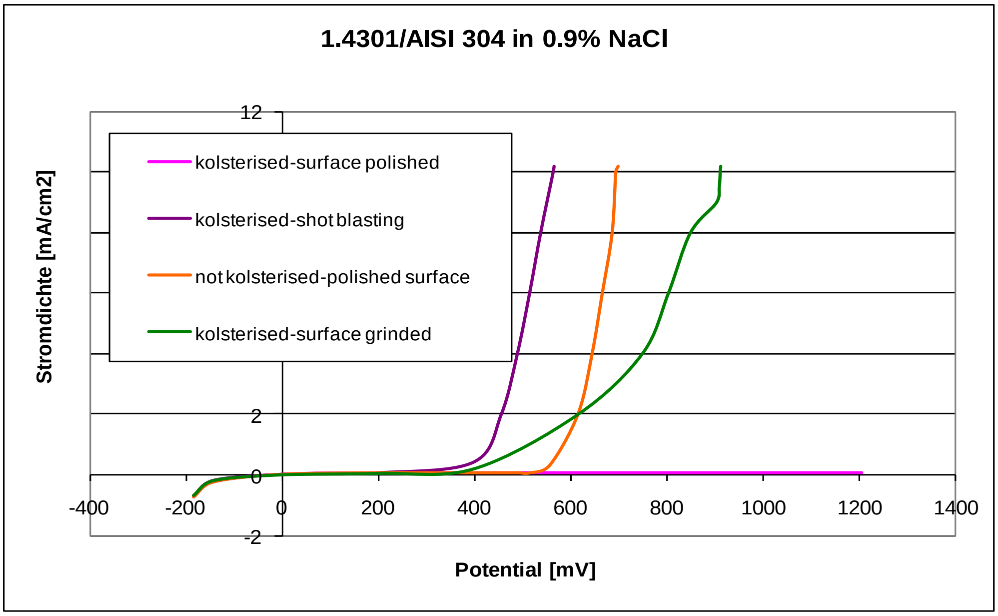

Figure 12: Current density-potential curves for various surface conditions of austenitic chromium-nickel steels

6 Examples for Application of Kolsterised Parts

The combination of increased wear and fatigue resistance with retention of corrosion resistance and non-magnetic properties of austenitic stainless steels has already resulted in a lot of applications in the last 20 years (Figure 13).

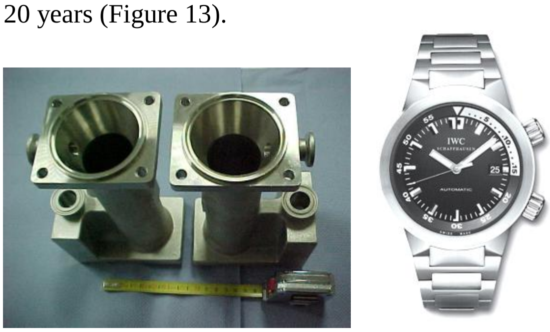

Figure 13: Examples for application of Kolsterizing

The application of the Kolsterising treatment often leads to remarkable benefits, for example in a high pressure homogenizer for which the application of the Kolsterising resulted in an extension of the service life by approximately a factor of 18. The treatment also enables closely tolerated sliding contacts, which introduces the possibility to omit the use of non-metallic seals. In the food industry this results in a more hygienic situation and less maintenance time.

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