Chromium Alloyed Surface Densified PM Gears to Replace Conventional Machined Gears

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Surface densification is now a well-known technology for improving the performance of PM components. Chromium-alloyed powder grades have been developed in order to replace expensive alloying elements such as nickel and molybdenum with more cost beneficial chromium.
Astaloy CrL (Fe-1.5Cr-0.2Mo) is a material with excellent formability in the as-sintered state, high hardenability and high fatigue performance and is therefore selected as a candidate material for surface densified gears in this study. Helical gears for the fifth gear in a manual gearbox have been investigated in this study. The response to surface densification by radial rolling is investigated and compared to the behaviour of Astaloy 85 Mo. The result after case hardening is also compared for the two materials using low pressure carburising for the Astaloy CrL and conventional gas carburising for Astaloy 85 Mo. The implications of these results are discussed in terms of tooth root bending fatigue and service life.

Introduction

In the automotive industry gears are conventionally produced by machining of wrought steel. Machining of gears consumes a lot of material and requires many production steps, e.g. turning, hobbing and shaving. In order to decrease the waste of material and number of production steps, conventional gears can be replaced by gears made by PM in the case of medium performance requirements. In order to increase the performance of P/M gears so that they can be used for highly loaded applications surface densification can be used. The method to densify the surface of gears by rolling in order to improve the properties of gears is a well known technique since 20 years [1-6].

Powder that is prealloyed with chromium is a cost effective choice of material compared to materials that are alloyed with for example nickel and molybdenum. Previous papers have shown that molybdenum based materials in surface densified gears give properties comparable to solid steel [7]. The chromium alloyed materials has shown good bending fatigue properties [8]. This in combination with good formability in the as-sintered state and good hardenability indicates that high performance of surface densified gears can be achieved using chromium prealloyed materials.

In this paper a chromium prealloyed material is compared with a molybdenum prealloyed material regarding densification, hardenability and performance.

Experimental
The material used for the investigated gear is Astaloy CrL which is prealloyed with 1.5% Cr and 0.2% Mo and as reference material Astaloy 85 Mo prealloyed with 0.85% Mo is used. The microstructure of Astaloy CrL in as-sintered condition at low carbon levels is a mixture of ferrite and fine pearlite. The reference material Astaloy 85 Mo has a microstructure of ferrite and bainite. The combination of ferrite and pearlite has shown to have better formability than the combination of ferrite and bainite, which is important in order to get a good densified layer at the surface. Astaloy CrL also has good hardenability and is hence suitable for case hardening. Recent investigations [8] have shown that chromium containing materials gives excellent fatigue properties.

Two different materials were used and their compositions are displayed in Table 1. Cylinders (∅ 80 mm, height 26 mm) were compacted in a hydraulic press using a compaction pressure of 800 MPa. Material A was cold compacted while material B was warm compacted. The cold compacted cylinders were sintered at 1120°C for 30 min in a 90/10 mixture of nitrogen and hydrogen and the warm compacted at 1250°C for 30 min in the same atmosphere. The sintered cylinders were machined and surface densified by radial rolling. The densification was performed in a two-roll burnishing machine that is normally used for burnishing of wrought steel gears. The gear blank is fixed between two rolling tools that apply a force on the surface of the teeth so that a densification is performed on the gear flanks. Figure 1 gives an overview of the rolling operation. For more information about the rolling process see e.g. [9].

Figure 1: Rolling machine.

The green and sintered characteristics of the materials used are shown in Table 1. Material B has undergone a significant shrinkage during sintering.

Table 1: Characteristics of sintered blanks.

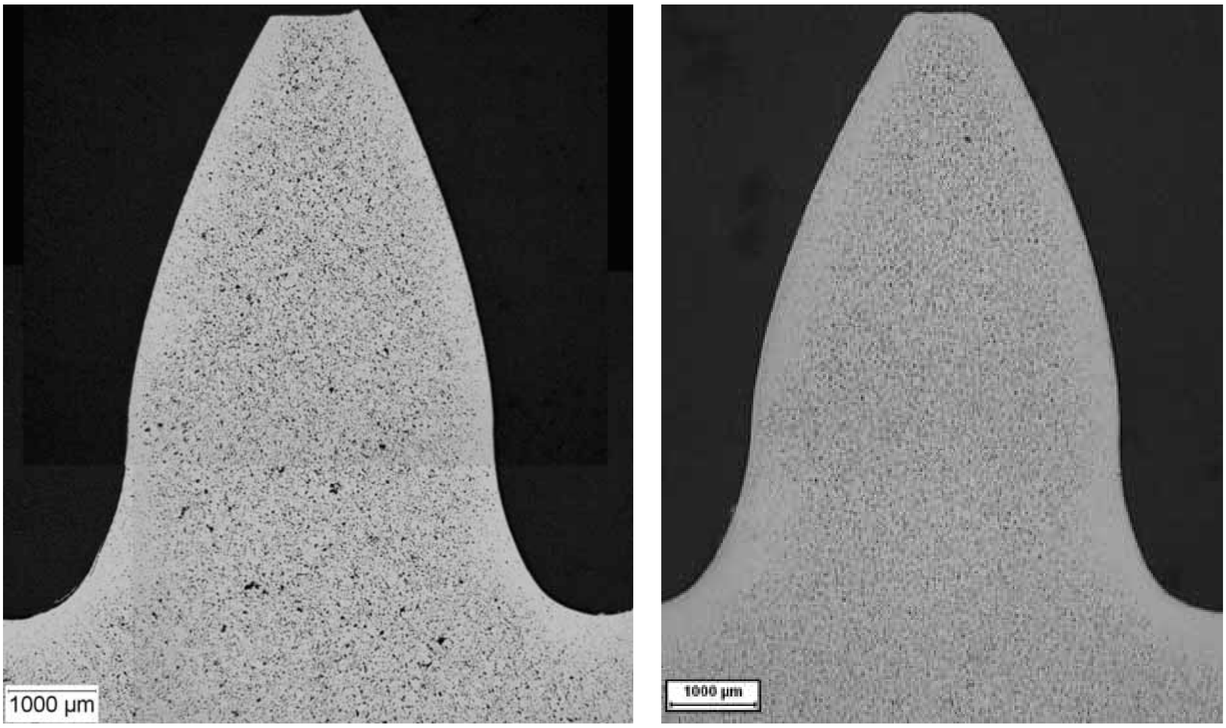
	Material	**Carbon (%)**	**Green Density (g/cm^3)**	**Sintered Density (g/cm^3)**	**Hardness (HV10)**
A	Astaloy 85Mo	0.20	7.10	7.10	120
B	Astaloy CrL	0.21	7.28	7.36	124

The heat treatment for the different materials after surface densification was not the same for both materials. Material A was gas carburised at 920 °C with a carbon potential of 0.8% followed by quenching in oil at 80 °C. Material B was low-pressure carburised at 960 °C using acetylene as carbon donor and quenched in nitrogen gas at a pressure of 10 bars. Both materials were tempered at 160 °C for 60 min.

Results

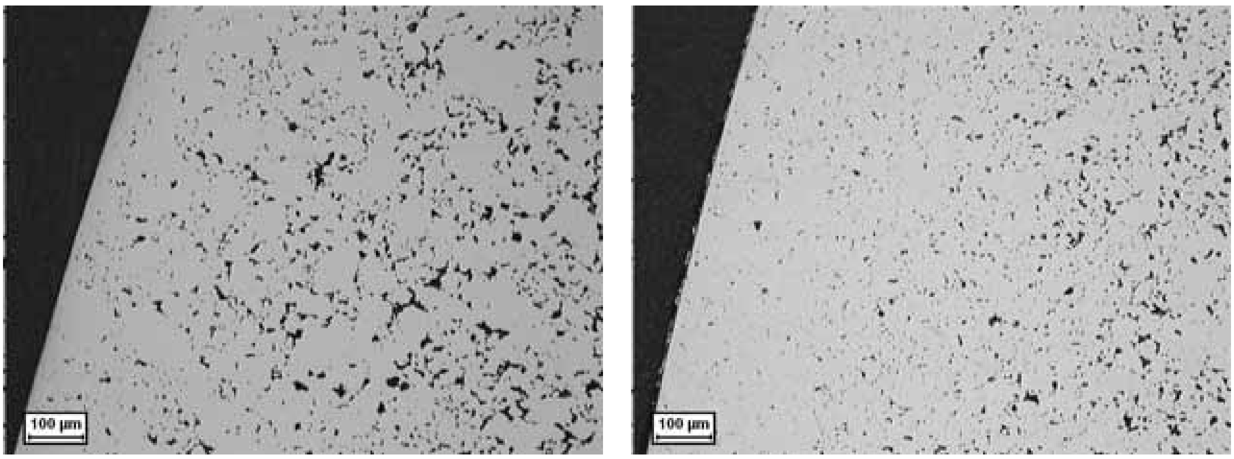
Densification

The result from the surface densification of teeth of the two materials is shown in Figure 2 and Figure 3. It can be seen that the best densification is achieved on material B. A porosity profile of the flank was measured by image analysis and is shown in Figure 4. The porosity profile consists of four different segments. Direct at the surface there is nearly full density and then the density decrease until about 0.05-0.1 mm shown as segment 1 in Figure 4. Further in to the tooth, in segment 2 is the density constant before it decreases again in segment 3 until it reaches the core density of the gear in segment 4. The depth of the second segment with constant density is 0.1 mm for material A, and 0.4 mm for material B see Figure 3 and Figure 4. The densification depth of material A is shorter compared to material B. On the flank a relative density of ~97% is obtained for a depth of ~0.2mm and ~0.5mm for material A and B respectively. The densification is better in the root compared to the flank for both materials.



a) Material A (Astaloy 85Mo) b) Material B (Astaloy CrL)

Figure 2: Densified gear tooth of material A and B



a) Material A (Astaloy 85Mo) b) Material B (Astaloy CrL)

Figure 3: Higher magnification of the densification on the flank.

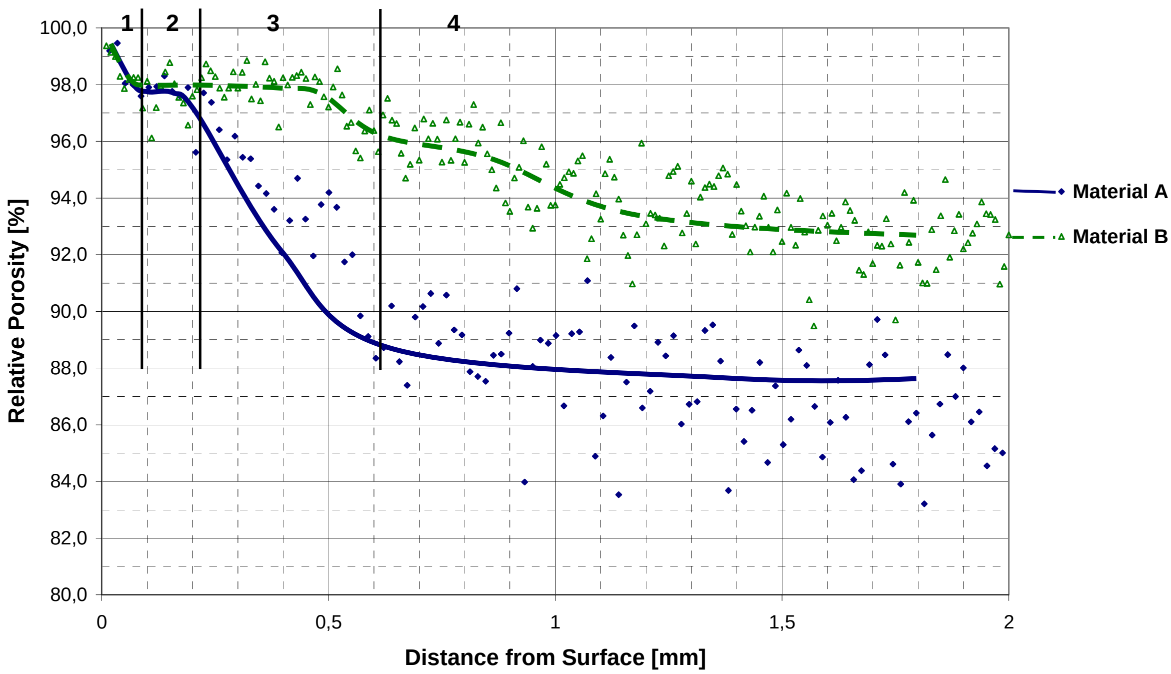


Figure 4: Density profile of the flank.

Heat treatment

The results from the case hardening are that material A has a case depth of 0.35 mm and a surface hardness of 900 $HV_{0.1}$. The case depth for material B is 0.6 mm with a surface hardness of 850 $HV_{0.1}$. Figure 5 shows the micro hardness profile of material A and B.

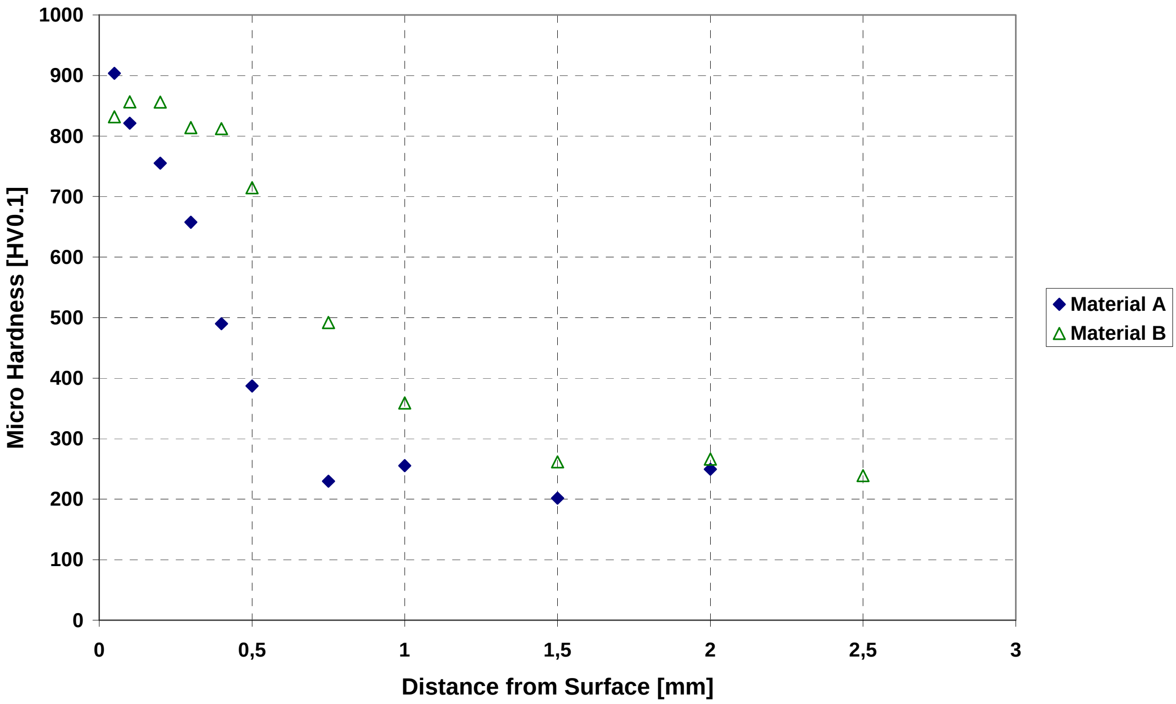
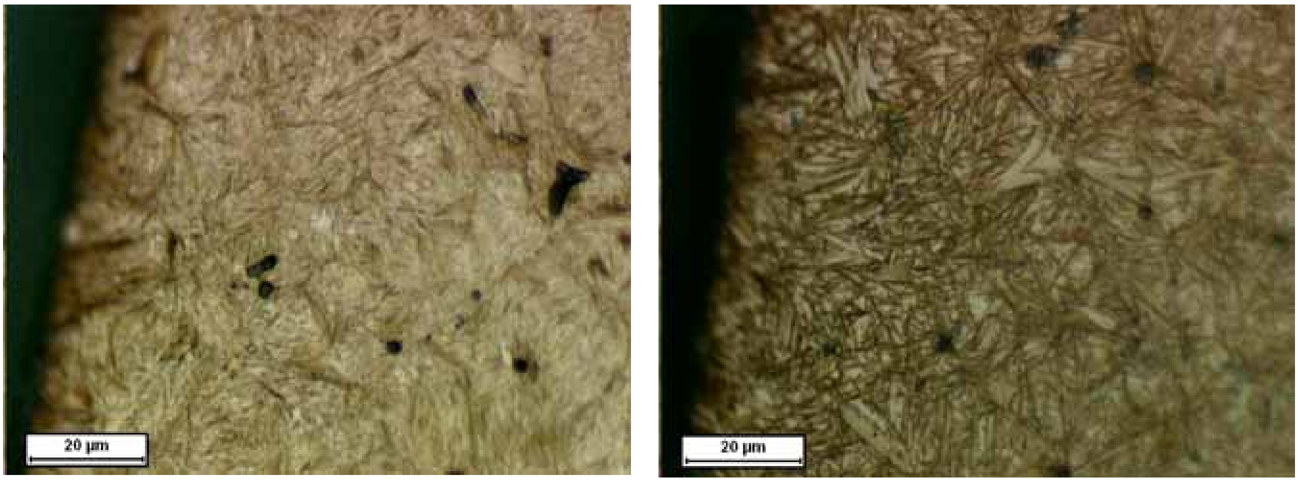


Figure 5: Hardness profile of material A and B.

The microstructure after the case hardening for material A is plate martensite at the surface and for material B plate martensite with a small amount of retained austenite. The microstructure at the surface for the different materials is displayed in Figure 6. In the core of the gears the microstructure is a mixture of bainite and lath martensite with low carbon content for both materials A and B.



a) Material A (Astaloy 85Mo) b) Material B (Astaloy CrL)

Figure 6: The micro structure at the surface of the flank a) Material A, b) Material B.

Discussion

Material B exhibit a deeper densification depth on the flank compared to material A. The part of the density profile where the density is constant (Figure 4, segment 2) is deeper and somewhat denser for material B compared to material A. This is due to that the microstructure of material B consists of ferrite and pearlite. These structures are easier to deform and therefore gives a better densification compared to material A that has a microstructure that consist of ferrite and bainite. The chromium material has a more favourable microstructure for densification compared to the reference material Astaloy 85Mo. The surface hardness in material B is in the same range as the surface hardness of material B ~850-900 $HV_{0.1}$. The case depth is 0.6 mm for material B and which is deeper than the case depth in material A that has a case depth of 0.35 mm. The target case depth is 0.3 mm as a minimum and 0.8 mm as a maximum according to ISO standard [10]. The maximum case depth is not as important as the minimum depth. This means that the case depth is within target for both materials. Both materials got a martensitic structure at the surface with plate martensite. In material B there is a small amount of retained austenite as well and according to ISO standard [10] is the maximum amount of retained austenite 25%. The amount of retained austenite in material B qualitative analysed is below 25% and this means that it will not influence negatively on the performance of the gear.

The tooth root bending fatigue test has been reported for material A in [7] and there it reached an endurance limit of 9.4kN and solid steel DIN16MnCr5 has an endurance limit of 10kN. Material B has a better densification and a hardness at the surface that is comparable with material A, this means that the tooth root bending fatigue is expected to be higher than material A. The amount of retained austenite is within specification for the highest quality grade, this means that the performance of material B is expected to be better than material A.

Conclusions

- Material B achieved a better densification compared to material A.

- The surface hardness of material B is comparable to material A (850-900 $HV_{0.1}$).

- With a better densification of material B compared to A and a comparable hardness at the surface material B is expected to meet the tooth root bending fatigue performance of solid steel.

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