New method for high density Powder Metal parts

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Abstract

In order for Powder Metal (PM) to increase market share there are two factors that have a significant influence. The two factors are strength and cost There are methods on the market such as Surface Densification by rolling, shot peening, powder forging and some other proprietary methods that will increase strength but the common denominator for all methods are increased cost and sometimes other draw backs. In this paper a method for Hot Isostatic Pressing (HIP) of PM parts is presented. The container needed for HIP of PM parts is very costly and impossible to make in the shape of a gear wheel. This paper will demonstrate a method for HIP:ing gears and components in PM without a container thus eliminating a big part of the cost for the HIP process. The strength benefits will be demonstrated as well as the cost situation for HIP:ing of a gear to full density.

Introduction

Commercial Hot isostatic pressing has been a technology developed in the early1960's (1). The aim was, and still is, to simultaneously apply heat and pressure that eliminates internal voids and microporosity through a combination of plastic deformation, creep, and diffusion bonding; this process primarily improves fatigue resistance of the component but in many cases it will also increase ductility, impact toughness and ultimate strength as well. (2,3)

This advantages of HIP compared to roll densification, densification by peening or extrusion densification are several fold; No tooling is required, no iterations, the process is commercially available with short lead times, typically a few days. The densification methods above all suffer from being selective and usable only for surfaces. It has also been shown that selective densification may act as stress riser (4) which is unfavorable.

During 2011 to 2013 a rally car was sponsored by Höganäs AB and competed with. What made this rally car special was the transmission where all gears had been replaced with PM gears. In order for the PM material to sustain the dynamic loads some form of densification was needed and the choice fell on HIP. The process steps involved were:

(Compaction of puck)-(Sinter 1120°C)-(Can)-(HIP)-(Machine gear)-(CQT)-(Grind)

The final result was a transmission that performed without failure for 3 seasons and was then decommissioned. Another example was a transmission in a SAE Baja car, see figure 1, where normal life of 8620 steel gears was 3 races, with the HIP:ed PM gears it was still running after 24 races 3 years later winning the competitions.

The idea that is patent pending was then to make a PM gear that was HIP:ed without can since the costly part of HIP is the welding of the can that is done manually using TIG and stainless -or mild steel sheet metal. The process would then be:

(Compaction of gear)-(Sinter)-(HIP)-(CQT)-(Grind)

A four step process that would give performance comparable to a good steel gear.

Figure 1. Redesigned HIP transmission made in sinter steel for a Baja vehicle

Another patent that is pending approval is a development of the HIP process for PM gears where sinter, HIP and CQT is done in the HIP vessel. That would shorten the process to 3 steps:

(Compaction of gear)-(Sinter,HIP,CQT)-(Grind)

The sinter process would be at 1120-1150 °C and HIP cycle at around 1000 °C . The carburizing step would take place at 1000 bar and temperature would also be 1000 °C which would give an extremely short soak time and over all short process making it cost competitive.

Requirements for Can-less HIP of PM parts

For the HIP process of PM parts with porosity a closed pore system is required. There are a few ways to accomplish this. Most of these ways requires extra processes that closes the pore system such as bagging the parts or glass slip casting systems. What is presented here is a method that eliminates extra pore closing processes. The trick lies in the material, lubricant and in the sintering. The alloying composition was found to be subordinate to particle size and sintering time/temperature. So in the experiments presented here only ASC100.29 and ASC300 standard grades were used. See table 1.

Powder Name:	ASC 100.29	ASC300
Chemical Properties:	Fe – 99.7%	Fe – 99.7%
Approx. particle size range % µm:		
+212	-	-
150-212	8	-
106-150	22	-
75-106	20	-
63-75		0,1
45-75	30	
45-63		9,9
0-45	20	90

Table 1. Materials used in test matrix

Graphite was admixed; 0.2% and 0.6% to investigate influence of a high carbon content. Some influence was found but negligible, the process works also for 0.6% C content. 0.6% Zink stearate was used as lubricant.

Number of teeth	z=18
Module	m_n=1.5875
Pressure angle	α=20°
Face width	b=10mm
Outside Diameter	OD=31.8mm

Table 1: Gear data

Table 2 defines the Gears used as test samples for the HIP process. Also sintering temperature and time and has been included in the study, see below. The gears were compacted net shape. The shrinkage during HIP was not uniform, more shrinkage was found in radial direction that in axial direction but results so far indicate that it should be predictable; measurements are ongoing to determine this. Further, heat treatment (CQT) will be done and the gears will be tested in bending. There is also a grinding allowance on the gear flanks (0.1mm) that will allow machining after heat treatment to compensate for distortions.

Results after HIP

After HIP:ing the porosity is reduced or eliminated. It is possible to get different amounts of residual porosity by lowering the sintering temperature if that should be desired. This will increase the size and number of the largest pores allowing the densification by HIP:ing to be less effective leaving some residual porosity, especially in the neutral zone. See figure 2 and 3. Sample denomination explained in table 3 below.

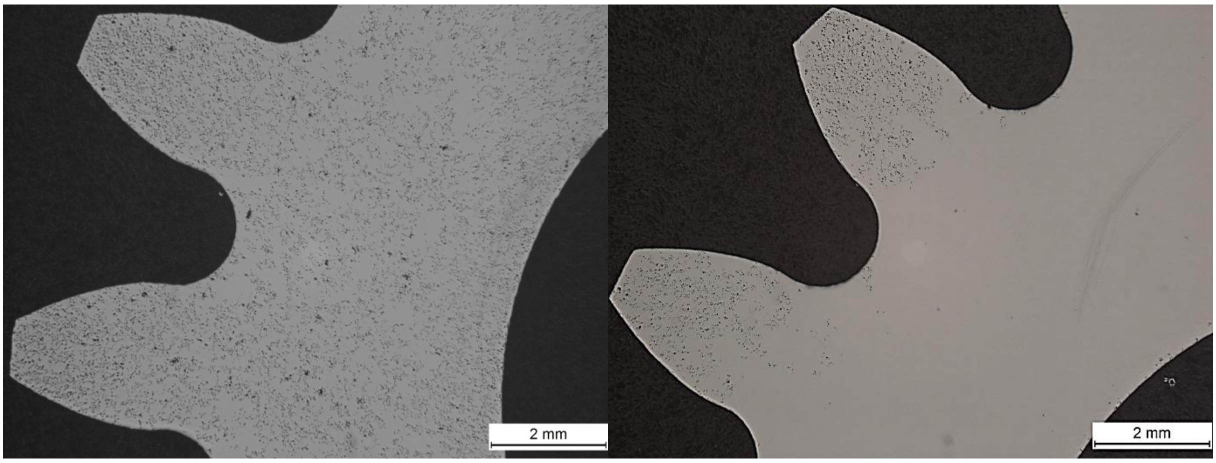

Figure 2. Left: Sample A14 *Right: Sample A16*

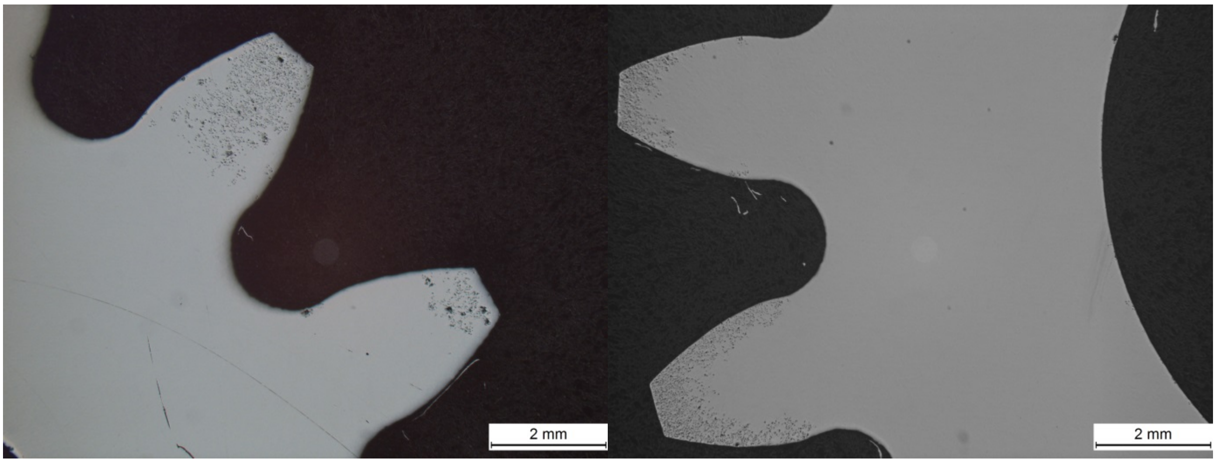

Figure 3 Left: Sample B14 *Right: Sample B16*

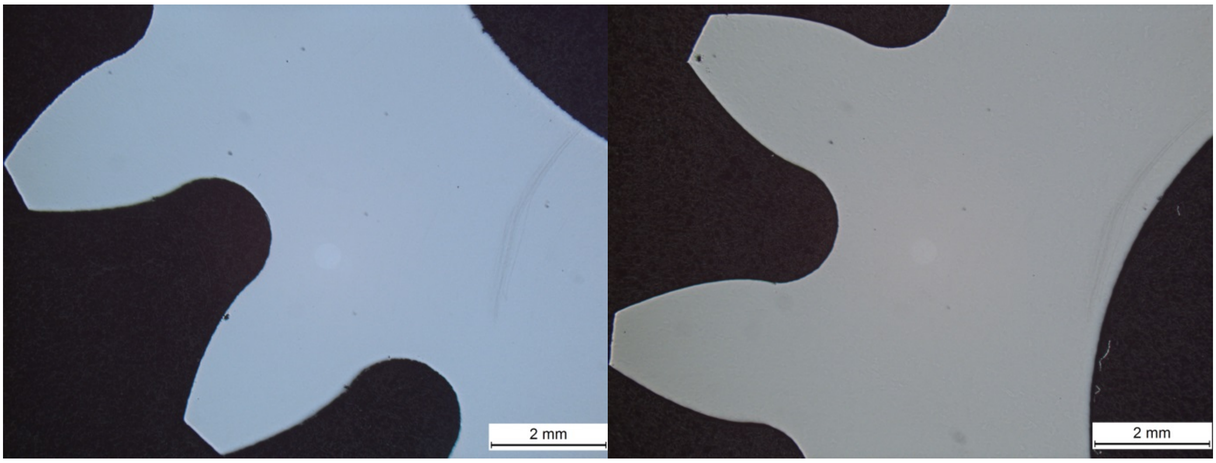

Figure 4. Left:Sample B17 *Right: Sample B18.*

In Figures 2,3 and 4 there is a variation of the material and sintering, see table 2.

Material	Sample	Tsint (°C)	tsint (min)	ρ_0(g/cc)	P_{sint}(g/cc)	P_{HIP}(g/cc)	ρ_{0rel}
100.29	A14	1180	60	7.40	7.42	7.65	98%
100.29	A16	1250	60	7.40	7.43	7.83	100%
300	B14	1180	60	7.40	7.43	7.87	100%
300	B16	1250	60	7.40	7.41	7.87	100%
300	B17	1300	30	7.40	7.45	7.88	100%
300	B18	1300	60	7.40	7.46	7.88	100%

Table 2

As can be seen from pictures 2-4 there is still some porosity in samples A14 and A16 despite 100% of theoretical density is achieved in A16 and for samples B16-B18 more that 100% percent of theoretical density is achieved (measured weight in air/water). But for the samples B16-B18 no pores where found, the black spots in the pictures are artifacts from metallography.

Impact on strength

HIP:ing is expected to give a significant improvement of the mechanical properties of PM steels. To investigate the strength test bars made from Astaloy 85Mo (Fe+0.85Mo) +0.3C were compacted, sintered, HIP:ed (no can) and finally case hardened. Both the fatigue strength and the transverse rupture strength were measured and compared to reference data for conventional PM as well as a standard case hardening steel.

Fatigue testing was done in plane bending on standard ISO 3928 test bars that were case carburized, using a load ratio of R=-1. The endurance limit was evaluated for two million cycles using the staircase method. The estimated fatigue strength of the HIP:ed test bars is 700 MPa.

Reference data generated on conventional case hardening steel SS2506 (Swedish standard, corresponding roughly to 20NiCrMoS2) on the same type of test bars tested in the same equipment show an endurance limit of 760 MPa. For a conventionally processed, case hardened Astaloy 85Mo at a density of 7.30 g/cm^3 the corresponding endurance limit is 450 MPa. Thus, the HIP:ed material shows a significant improvement in the fatigue strength compared to conventional PM, with properties close to the same level as wrought steel. The reference specimens were made in an earlier study. Case profiles and core hardness are different as well as surface roughness, which will influence the comparison.

It should be noted that the SS2506 test bars were machined to a surface roughness corresponding to that of a hobbed gear tooth root. The PM surface finish was that of a compacted, see figure 5, or compacted and HIP:ed material. Thus, in all cases a surface corresponding to what is expected in a gear root.

Also, further investigations are necessary to compare the defect content of a HIP:ed PM steel compared to a wrought steel to fully understand the behavior of the materials.

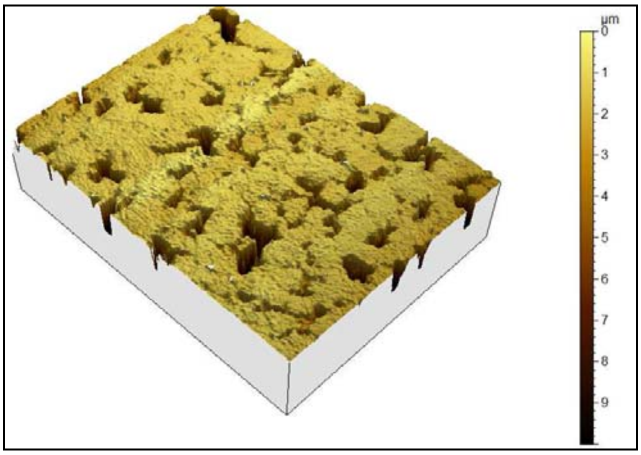

Figure 5. Sintered surface, press direction is parallel to the measured surface.

To compare static strength transverse rupture strength (TRS) was measured using three point bending. For the HIP:ed samples an average strength of 2100 MPa was found, which can be compared to around 1300 MPa for conventional PM (internal data from HAB). This corresponds to around 60% improvement after HIP, comparable to the improvement in fatigue strength. At this point there are no reference data for wrought steel for comparison.

The micro hardness curves for the HIP and reference material SS2506 can be found in figure 6 below.

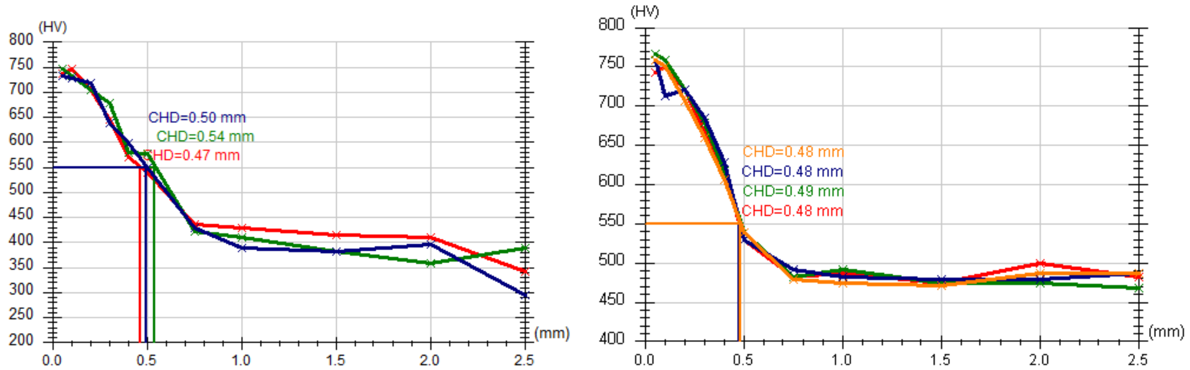

Figure 6. Left: Case profile for HIP FS bar *Right: Case profile for SS2506 FS bar*

Worth noticing in figure 6; there is a difference in core hardness where HIP-PM averages 350 HV0.1 and SS2506 averages 475 HV0.1. This helps to explain the difference in fatigue result. The relation between core hardness, base material carbon concentration, case depth and residual stress is very complex. In any case more data will be collected in the future to better quantify all advantages with HIP. At the time of writing there are only 5 data points from the HIP samples but more data points are being generated in the test rigs.

Conclusions

It has been showed in this paper that HIP:ing of PM gears or parts without can or any extra processes to seal the surface is possible. The requirement is that the surface pores do not let pressurized gas into the pore system but allows any gas inside the pores to be evacuated without creating cracks.

The method for obtaining this is a fine particle powder and high temperature sintering. Sintered density of 7.40 was obtained in single compaction and high temperature sintering. However density is not enough since a double compacted regular powder grade material also obtaining 7.45g/cc or above does not densify as easily using HIP. The success is also connected to the small pore size and that ties into material particle size and morphology as well the high temperature sintering giving pore rounding.

Evaluation of the mechanical properties shows a 60% improvement in both fatigue and TRS strength after HIP compared to conventional PM. Fatigue strength was also found to be on a level comparable to wrought steel.

The next generation of process equipment has also been presented where sintering, HIP and CQT can be done in one process enabling the highest performing gears to be made using sinter steel with a very short process chain that should be cost advantageous.

The cost for HIP when working with external supplier is based on how many kilograms of weight that is put in the HIP furnace. Today, provided that the baskets are packed by the buyer and shipped to the HIP:er, is around 1 Euro per kg.

References

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