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Distortion control in 20MnCr5 bevel gears after liquid nitriding process to maintain precision dimensions

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ABSTRACT. Robotic and automotive gears are generally very high precision components with limitations in tolerances. Bevel gears are more widely used and dimensionally very close tolerance components that need stability without any backlash or distortion for smooth and trouble free functions. Nitriding is carried out to enhance wear resistance of the surface. The aim of this paper is to reduce the distortion in liquid nitriding process, though plasma nitriding is preferred for high precision components. Various trials were conducted to optimize the process parameters, considering pre dimensional setting for nominal nitriding layer growth. Surface cleaning, suitable fixtures and stress relieving operations were also done to optimize the process. Micro structural analysis and Vickers hardness testing were carried out for analyzing the phase changes, variation in surface hardness and case depth. CNC gear testing machine was used for determining the distortion level. The presence of white layer was found for about 10-15µm in the case depth of 250± 3.5µm showing an average surface hardness of 670 HV. Hence the economical liquid nitriding process was successfully used for producing high hardness and wear resistant coating over 20MnCr5 material with less distortion and reduced secondary grinding process for dimensional control.

1. Introduction

Bevel Gears are used in the Robotic and automotive gear boxes to transmit drive from a drive shaft to a driven shaft which requires a very close dimensional accuracy for high precision assembly. Secondary machining process is involved to maintain dimensional accuracy for a perfect assembly [1-5]. During secondary processes, grinding will also be employed, which makes production delay by consuming huge time and does not satisfy the requirement of close tolerances. To avoid the above mentioned problem, a new process to be developed for high precision gear part without further grinding in order to reduce the rejections and loss. Since bevel gears are exposed to high torque and high speed operations hardening process is inevitable, a strategic structure was formed to capitalize this process to maintain the required tolerance levels [6]. The durability of the gears is important for high torque operations hence alloy steels are most preferred [3,7]. 20MnCr5 alloy steels are preferred for the production of bevel gears [6]. Case-hardening or surface hardening process is carried for all types of gears. This process of hardening the surface of a metal object while allowing the metal deeper underneath to remain soft, thus forming a thin layer of harder metal at the surface. There are various types of case hardening process available to improve the hardness of the material they are flame and induction hardening, carburizing, cyaniding, carbo nitriding, ferritic nitro carburizing and nitriding.

Nitriding is a heat treating process that diffuses nitrogen into the surface of a metal to create a case-hardened surface this process involves with ferritic region in low temperature (550°C) which is below

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the transformation temperature [1,8,9]. These processes are commonly used on low-carbon, low-alloy steels. Nitriding is used in gear manufacturing units widely because of high dimension stability offered to the gears and no further secondary process requirement. Nitriding can be done as liquid, gas and Plasma method. 20MnCr5 is a case hardening steel having low carbon and low alloying elements which is widely used for high precision gears for the purpose of core toughness and surface wear resistivity through case hardening process. For gears lead, profile and run out parameters are important and hence examination of these is important. Surface hardness and case depth should be ensured for gears for reliable operation.

2. Material and Methods

The selected material 20MnCr5 alloy steel with the chemical composition given in Table 1, is exposed to liquid nitriding process to determine the distortion free feasible nitriding process parameter combinations. The results will lead to successful solution to avoid further grinding process after nitriding in bevel gears.

Table 1. Chemical Composition of 20MnCr5 steel

Elements	C	Si	Mn	P	S	Cr	Fe
Wt.%	0.17-0.22	0.40 max	1.10-1.40	0.025 max	0.035 max	1.00-1.30	Balance

Bevel gears are properly processed in CNC gear manufacturing machine maintained with proper pre dimensions determined towards nominal nitriding growth. Surface cleaning reagents are used to remove the surface impurities like oil, grease, corrosion products and dust particles. Pre heating process carried out at 350 ˚C for two hrs. Liquid nitriding process was conducted in several trials to optimize the process parameters like bath strength, temperature and soaking time. Post washing is done with green solutions Bio cleaning for the surfaces is followed by nitriding process. Hardness testing, microstructural analysis and case depth measurements were done by metallurgical microscopes. Future-tech image analyser (FM800) is used for dimensional measurements and GMS Gleason-350 CNC gear testing machine are used to observe the cumulative dimensional parameters like lead, profile and run out.

2.1. Nitriding

Bevel gears are processed as per the required dimensions (7th quality) and tolerances (±10μm) with 20MnCr5 steel. The dimensions of the final component has been inspected, ensured and were exposed to liquid nitriding with various trial combinations of temperatures from 540℃ to 560˚C for 2 to 4 hrs duration under the potentiality of 18 to 20 percent strength of liquid bath to obtain feasible results. 20MnCr5 material bevel gears are liquid nitrided under the three range of process combinations are given as, (i) constant temperature at 560℃ and 18 percent potentiality with variable soaking time from 2 to 4 hrs durations, (ii) constant soaking time 3 hrs and bath strength 18 percent under variable temperature 540 ˚C to 560 °C, and (iii) the other trials done with variable potentiality from 18 to 20 percent strength with constant temperature 560 ˚C for 3 hrs constant soaking time. The liquid nitriding process was carried out in pit type salt bath nitriding furnace at Eppinger tooling Asia Private Limited with components proper loading and jigging in to the Furnace. The nitrided samples as shown in Figure 1 had been cleaned by bio cleaning system to remove the surface residues. The dimensional inspection has been carried out in computerized gear tester (Gleason 350 GMS) to identify the distortion due to nitriding. The observed dimensions and gear teeth parameters has been noted and compared with initial readings.

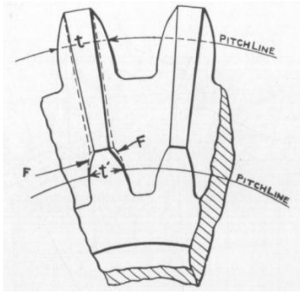

Figure 1. (a) 20MnCr5 bevel gear component after nitriding; (b) Bevel gear tooth profile

2.2. Testing and characterization

Future tech FM-800 model Micro Hardness tester was used to determine the hardness and case depth. Micro Hardness was determined using diamond indentor with a load of 500 gm with dwell time for 20 seconds. Case depth, white layer thickness, surface hardness and distortion level are characterized to ensure nitriding parameters. Nitrided gears with all the three process parameter combinations have been cut into small pieces and polished to get mirror like finish. The polished sample has been etched in 3% Nital for 15 seconds. Microscopic examination has been carried out in optical microscope to study the micro structure of all the nitrided samples. Case depth obtained in various nitriding processes have been analyzed recorded. The white layer measurement has been carried out since the white layer is the major reason for the dimensional distortion. Longitudinal deviation in dimension of gear tooth is called Lead error. Flank error - both left and right flank deviations are called profile error. These errors including profile errors are measured using Gleason 350 GMS gear testing machine.

3. Results and Discussion

Table 2 shows that the measured dimensions and distortion values observed in the nitride samples with varying combinations of critical nitriding parameters.

Table 2. Consolidated dimensional/distortion and metallurgical results of the nitride samples.

Process	**Based on Temperature (2 hrs with 18% potentiality)**			**Based on Time (540°C with 18% potentiality)**			**Based on Bath Strength (560°C for 2hrs)**		
	540°C	550°C	560°C	2 hrs	3 hrs	4 hrs	18%	19%	20%
Avg. Surf. Hardness ±10 (HV @ 0.5kgf)	530	595	783	535	770	789	770	786	850
Case Depth(0.25 +/- 0.10 mm)	0.05	0.14	0.20	0.08	0.22	0.29	0.19	0.23	0.32
White Layer (µm)	3.5	6	11.5	3.5	11	21	105	11.5	21
Distortion Level(mm)	0.0075	0.0075	0.0085	0.0030	0.0075	0.0480	0.0090	0.0090	0.0480
Lead (mm)	0.008	0.007	0.011	0.001	0.005	0.025	0.008	0.008	0.029
Profile (mm)	0.005	0.006	0.009	0.003	0.009	0.040	0.011	0.012	0.043
Run out (mm)	0.010	0.011	0.012	0.001	0.004	0.054	0.013	0.013	0.057

From the results shown in Figure 2, it is observed that the bevel gear is having less distortion in combination of temperature 560°C in 3 hrs soaking time under 18 percent bath strength over the other process parameters. The low temperature and lower soaking time nitriding is having moderate distortion than the above combination.

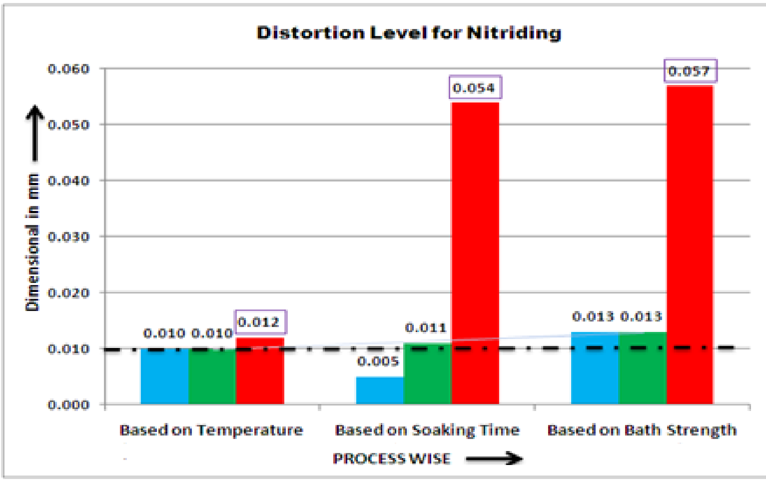

Figure 2. Comparison of Distortion level in different processes

From the results obtained as shown in Figure 3, it was observed that very high surface hardness and case depth was obtained in long soaking period than other nitriding processes, specified hardness was obtained in the combination of 560°C , 3 hrs soaking and 18 percent bath strength.. The low hardness observed in less soaking time.

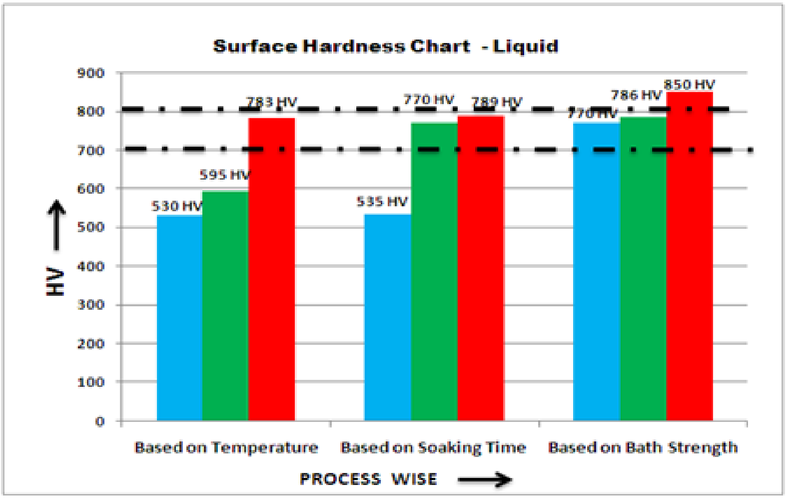

Figure 3. Surface hardness analysis

Microstructural analysis of the samples shown in Figure 4 reveals the martensite formation with retained austenite in all the samples. It is found that homogeneous distribution of martensite needles were observed in all the conditions/processes.

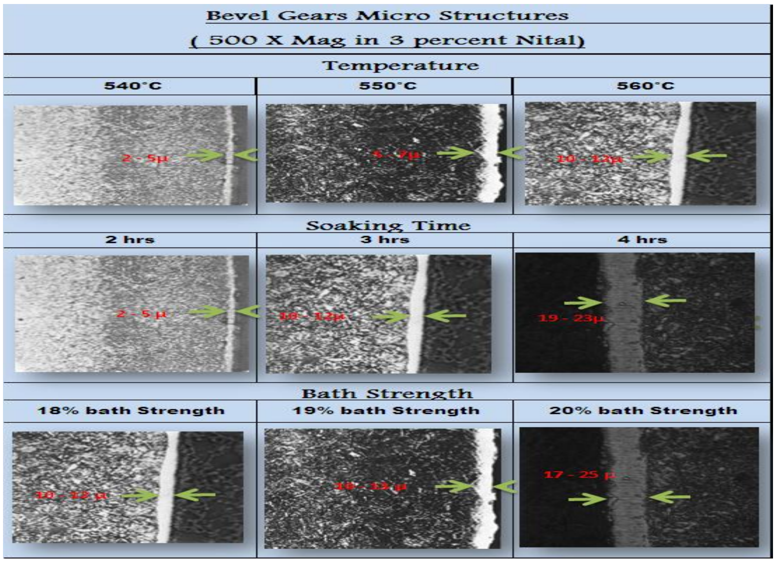

Figure 4. Microstructure of nitrided components with varying parmeters.

White layer is varied in the combination of temperature, soaking time and bath strength variations as shown in the figures 4, 5 and table 2.

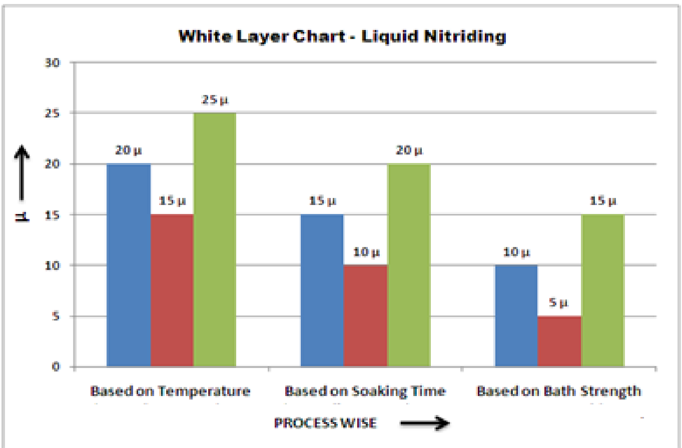

Figure 5. Analysis of white layer formation

The case depth, hardness and distortion in gear profiles are found very high in higher soaking time as well as higher bath strength combinations than the moderate nitriding process. Specified case depth obtained 560°C , 3 hrs soaking and 18 percent bath strength refer Figures 6 and 7.

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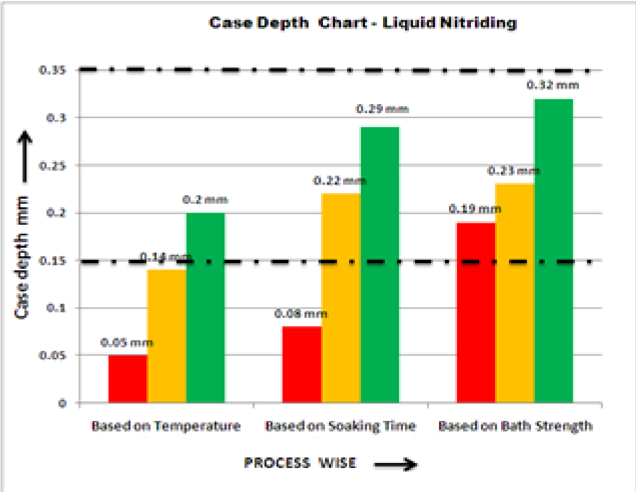

Figure 6. Case depths in various trials

As per AGMA Standard, the tooth profile errors like runout, Lead and profile error are to be measured. The eccentricity of the datum circle relative to the datum axis, wobble of the gear blank relative to the datum axis of rotation, tooth alignment variation are measured.

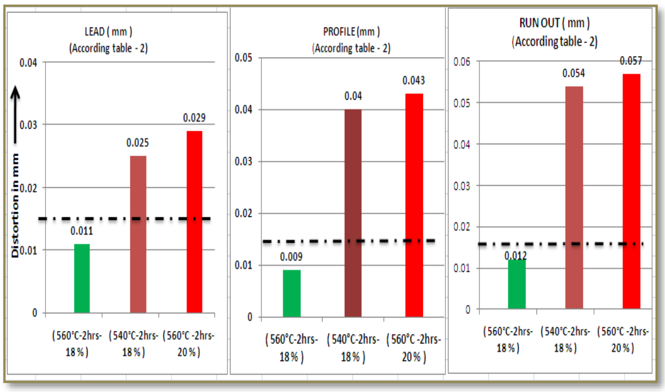

Figure 7. Variation in Lead, Profile and Run out in the gear profile dimensions

Above results show a small variation in gear profile dimensions. However this small variation could led to more wear and tear in the components during sliding each other. Hence it is necessary to analyze the effect of different process parameters. The surface nitrogen concentration and increase in time of contact increased diffusion efficiency and hardness along with nitrogen. Though the % carbon is relatively less than the required amount of 0.30% for complete transformation to martensite, presence of Mn and Cr promote the formation of matensite along with diffused Nitrogen.

4. Conclusions

Surface hardening of high precision automotive bevel gears made of 20MnCr5 alloy steel are carried out using liquid nitriding process with the combinations process parameters. Three different combinations of liquid nitriding process with temperature (540-560˚C), soaking time (2-4hrs)and liquid bath strength from 18-20% potentiality was success fully done. Characterization of the microstructure and variation in the level of distortion are studied to eliminate further grinding process after nitriding. The 4 hrs soaking time and 20% bath strength are inducing the high distortion up to 57 microns than requirement of below 10 microns. Higher surface hardness of about 790 – 850 HV is observed in the above conditions. Lower soaking time and the bath strength have resulted in the surface hardness of about 480 – 535 HV as well as minimum distortion level. Formation of white layer (FeN compound layer) on the surfaces is observed too high in 4 hrs of soaking time at 560°C under 18 percent bath strength. Hence, it is observed that the liquid nitriding at 560°C under 18 percent liquid bath strength for 3 hrs soaking time is reliable process parameter combination to get better metallurgical properties with limited distortion level. The selected nitrided samples were assembled in the main assembly without further grinding process. Additionally, the pre-dimensional concept introduced before nitriding process considering the nitride layer growth of about 5–10 microns. It was also successful to control and maintain the bevel gear dimensional tolerances.

5. References

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