

Fatigue Performance Improvements of Wheel Bearing Rolling Elements

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ABSTRACT

Wheel bearings are safety-critical automotive components. For this application, the steel rolling elements are subjected to fatigue failure and therefore play a key role in overall bearing fatigue life performance. This performance is influenced by metallurgical, mechanical, and physical properties obtained by precise manufacturing process parameters. These properties are continuously analyzed and are evolving at all bearing manufacturing companies. Last year, the Precision Bearing Components (PBC) Group of NN Inc., a global supplier of steel rolling elements for wheel bearings, developed a non-conventional heat treatment process for 100Cr6 (SAE 52100) rolling element steel for improved fatigue performance.

The results of wheel bearing rolling contact fatigue (RCF) tests showed the importance of rolling element dimensional stability. As retained austenite transformed to the martensite phase, rolling element volume increase occurred, leading to fatigue failure. The fatigue life of rolling elements is directly proportional to their dimensional stability.

As a result of the experimental tests, a project was initiated with the goal of increasing the dimensional stability of rolling elements, thereby enhancing RCF performance. The use of another conventional steel alloy not typically applied in automotive wheel bearing applications was the proposed solution. The goal of this new application package of rolling elements is to improve fatigue performance: in particular, sub-surface fatigue, as well as increased resistance to wear and stability at higher operating temperatures.

A subsequent evolution of the project will be to develop a non-conventional alloy grade for greater rolling element dimensional stability, resulting in an expected expansion of fatigue performance.

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INTRODUCTION

Rolling Element Failure Factors

The typical factors which influence the fatigue life of rolling elements within bearings are metallurgical, mechanical, and physical properties, considering the same application conditions.

Metallurgical Properties

First, the raw material must be free from impurities (e.g. Oxygen, Nitrogen and Hydrogen); previous studies confirmed that a micro-cleanliness improvement positively influences the fatigue performance of the rolling elements. Also, the subsurface stress status and the microstructure morphology of the rolling elements can largely influence the fatigue performances [1].

Mechanical Properties

Bearing steels, such as AISI 52100, in a typically quenched and tempered condition, are not particularly ductile [1]. This material is generally oil quenched at 850 °C temperature; then it is tempered in the range 150-250 °C. This results in a microstructure of lightly tempered martensite, primary carbides, and up to 12-17% retained austenite.

Hardness in the range 59-66 HRC has shown to be positively correlated with rolling contact fatigue life; greater hardness is associated with reduced wear on the surface. Nevertheless, without proper lubrication conditions, this correlation of wear against hardness fails due to the effects of heat generation on material removal [1].

Physical Properties - Dimensional Stability

Geometrical characteristics of rolling elements can induce vibrations in running conditions; this can reduce the fatigue life due to higher surface pitting phenomena.

During running the bearing elements are subjected to a dimensional variation which results in a non-constancy of the operating conditions.

Dimensional stability of the rolling elements is the capability to maintain its dimension along the life-cycle of the components. One of the goals of this study is to correlate dimensional stability with fatigue performances of rolling elements.

One of the key factors influencing dimensional stability is the retained austenite content of the AISI 52100 steel [2]. Sub-zero heat treatment performed after quenching markedly reduces the amount of not-stable retained austenite.

The second goal of this study is to correlate the influence of silicon and manganese on the fatigue performance of rolling elements directly related to dimensional stability. The presence of silicon in bearing steels improves the stability of the retained austenite [3].

METHODS AND TESTING CONDITIONS

For these tests, the fatigue performance of two types of bearing steels with different heat treatments were analyzed: 100Cr6, typically applied in wheel bearing applications requiring small and medium size rolling elements, and 100CrMnSi6-4, typically required in large rolling elements manufacturing due to its hardenability improvement. The chemical compositions of the steels are shown in the [Appendix A1](#).

Methods

The fatigue performances of the two materials have been evaluated by rig tests. Eight tests were performed for each material/heat treatment combination under identical conditions.

Rig tests are structured with an electrical motor that drives a rotating shaft on which the inner rings of two double row ball bearings are trapped. The rotary motion of the outer rings was prevented by using rings and an external fluted shell. The applied load is axial and is guaranteed by a pneumo-hydraulic pistons system. The temperature of the outer ring, the vibration of the system, and the applied load were controlled for the duration of the test using all the necessary transducers. Within each tested, first-generation wheel bearing, only one row was filled with balls due to the unidirectionality of the axial load. Lubrication was performed using mineral grease. To evaluate the performance of the ball, tests were focused on only one of the two bearings trapped on the shaft, on which the contact pressures were designed to be much higher.



Figure 1. Rig test bench

Test Conditions

The contact pressure on the tested balls were estimated in $3.88 \cdot 10^9$ Pa on the inner ring and $3.48 \cdot 10^9$ Pa on the outer ring. The rolling elements tested were balls of 11.112 mm diameter. The applied axial load was 34400 N throughout the duration of the experiment with a rotational speed of 690 rpm.

In order to reach ball failure, tests were stopped every 20 hours with the aim to assemble the same balls with new rings, cage, grease and in order to measure balls diameter variation.

Furthermore, the system is capable of prematurely stopping tests if temperature, vibration or load limits are exceeded. If one of these limits was reached, all components were analyzed and substituted, except for the balls; then, if a ball failure event was not verified, tests were resumed. The test stop thresholds set were 145 °C for temperature, 15 mm/s² for the vibrations, and 37500 N for axial load.

Test Balls Specifications

In the first phase of the study, two different heat treatments (Sample “A” and Sample “B”) on the 100Cr6 steel are compared in order to identify an improvement of dimensional stability of the material, which has repercussions on fatigue performance.

1) Raw Material

The tested balls were produced using 100Cr6 steel coils manufactured using ingot casting process route applying the premium material tolerances, typically required for wheel bearing rolling elements. All the dedicated inspections on raw material were performed in order to confirm quality.

2) Heat Treatment

Standard quenching was performed on both samples (850 °C, oil). Sample “A” was then tempered at 150 °C for two hours; sample “B” was subcooled at -70 °C for four hours and subsequently tempered at 220 °C for four hours ([Table 1](#)).

Table 1. Heat treatments

Heat Treatment		
	Sample “A”	Sample “B”
Quenching	850 °C - Oil	850 °C - Oil
Subcooling	Not performed	-70 °C - 4h
Tempering	150 °C - 2h	220 °C - 4h

3) Hardness

The Rockwell hardness profiles across the entire section of the two samples are shown in [figure 2](#). The mean hardness value for the subcooled sample is 3.7 HRC lower than the non-subcooled sample; this is the effect of the higher tempering temperature adopted.

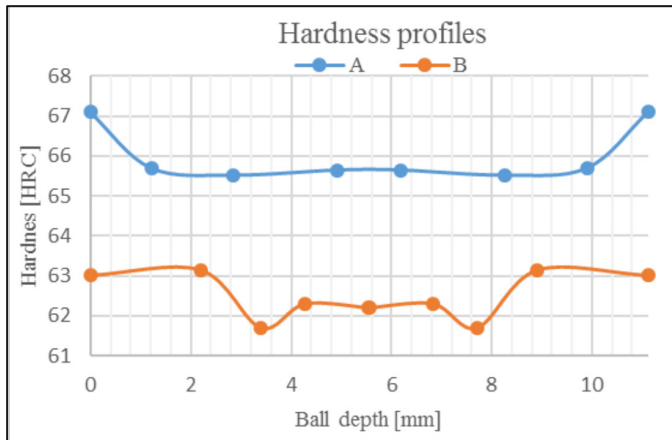


Figure 2. Hardness profiles

4) Retained Austenite

The amount of retained austenite was markedly reduced during the subcooling process. Table 2 shows the retained austenite value measured on 5 balls per sample (measurements performed on plate at about 2 mm depth) and, as expected, the average value of retained austenite in sample “B” balls was reduced by about 66% compared to sample “A”.

Table 2. Retained austenite content

% Retained Austenite – X-Ray Diffractometer (XRD)						
Sample	Measure					Average
	1	2	3	4	5	
A	15.3	15.0	14.9	14.3	16.0	15.1
B	7.0	4.1	3.8	7.1	4.0	5.2

Figure 3 shows the retained austenite profiles across the entire section. The difference between the two samples is much higher in the first layer (from surface to about 3 mm depth) of the balls compared to the core of the balls where the trends are quite identical.

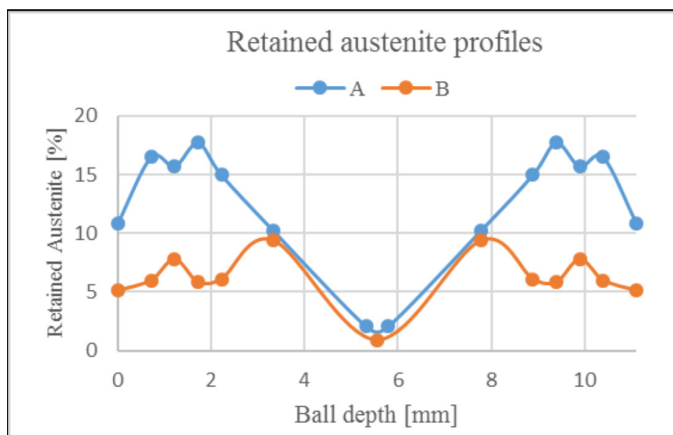


Figure 3. Retained austenite profiles

5) Compressive Stress Profiles

Samples “A” and “B” show the same compression status trend (from surface to 4% radius) obtained by the “peening” manufacturing process phase, which is fundamental to reach proper fatigue performances. Sample “B” shows a higher compression status though not highly different from sample “A”, considering the process variation and the measurement error by X-Ray Diffractometer (XRD) method; the influence of the lower retained austenite amount on residual stress must be deepened.

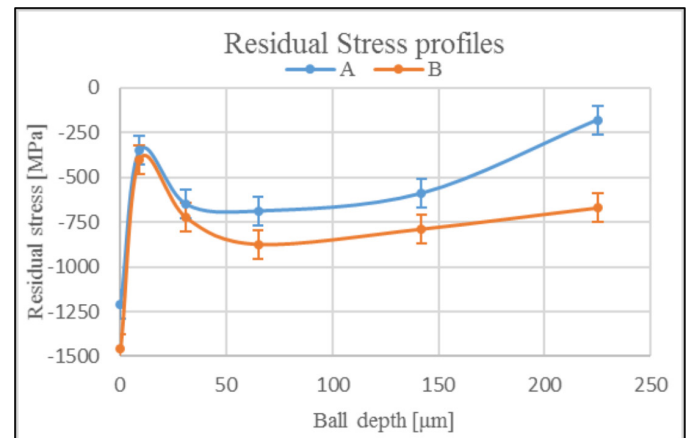


Figure 4. residual stress profiles

6) Microstructure

Ball bearing steels typically show a microstructural change during cyclic stressing (RCF), related to the load conditions. Subjecting the sectioned rolling element to few seconds of initial etching (25 ml HNO₃ in one liter ethanol) highlights the dark etching region (DER); the subsurface region is darker due to the contact fatigue stress, which does not affect microstructure at greater depths. The DER depth range roughly coincides with the depth range of subsurface load induced stress [4].

After testing samples “A” and “B,” a different microstructure status was detected: only non-subcooled balls (sample “A”) showed DER microstructure, while the subcooled ones did not show it. Figure 5 shows an example of DER on sample “A.”

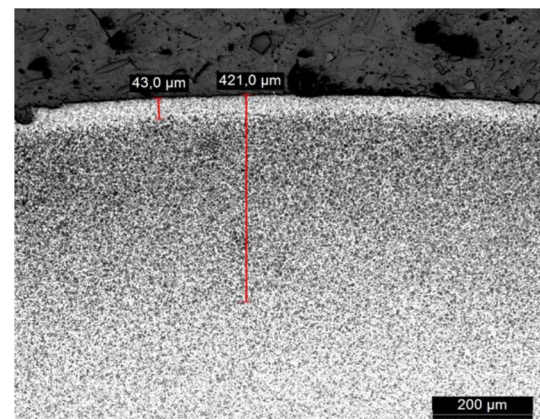


Figure 5. Sample "A" DER