Dimensional stability on Fatigue Performance of Wheel Bearing Rolling Elements: Case studies

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Abstract– Rolling bearings are critical automotive and mechanical components. For high loaded bearings, the steel rolling elements are subjected to failure having a direct impact on overall bearing fatigue life performance. Fatigue phenomena involve both rolling contact fatigue and material fatigue damage processes.

Metallurgical, mechanical, geometrical, physical properties affect fatigue behavior and they can be controlled also by precise manufacturing process parameters. Despite accurate manufacturing, during the working condition, dimensional stability of some rolling elements within the bearing can be affected and distribution of stresses can strongly change with respect to design thus affecting fatigue performance. Failure can then occur for load values different and lower from design indications.

In the present research 100Cr6 and 100CrMnSi6-4 steel alloys, undergoing different thermal treatments, involving hardening, undercooling and tempering are analyzed. Rolling elements in the selected alloys are subjected to fatigue tests on automotive wheel hub bearing units and, while testing and after failure, metallurgical and dimensional parameters are measured.

The present paper reports about failure cases in rolling elements and investigates on the relation between dimensional stability and fatigue performance involving metallurgical, processing and dimensional analysis; considering the different fatigue performance as well as the different metallurgical and mechanical behavior obtained by testing rolling elements from different combinations of steel alloys and thermal treatment, it is possible to conclude how the rolling element dimensional stability can sensibly affect the bearing fatigue life, especially under severe conditions in terms of applied load, speed and temperature.

Keywords – Bearing, RCF, Rolling elements, Dimensional stability.

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1. Introduction

The typical factors which influence the fatigue life of rolling elements within bearings are metallurgical, mechanical, and physical properties, considering the same application conditions; focusing on the last category, 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 [1]. Sub-zero heat treatment performed after quenching markedly reduces the amount of not-stable retained austenite. [2]

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].

2. Materials and methods

The fatigue performances of 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 the 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 balls, 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 (3.8 GPa maximum Hertzian pressure on surface, on ball-IR contact).

Tests are designed by testing blocks; races, grease and cages are changed at the end of each of them. At the same moment dimensional parameters of rolling elements are measured and surfaces are inspected.

Fatigue tests were performed on samples described in table 1.

Table 1 - Sample description

Sample id.	Test A	Test B	Test C
Steel alloy	100Cr6	100Cr6	100CrMnSi6-4
Quench	850°C, Oil	850°C, Oil	860°C, Oil
Subcooling	-	-70°C	-
Tempering	150°C	220°C	240°C
Resultant HRC (AVG)	62.1	61.0	60.1

3. Results

Concerning the rolling elements behavior in terms of dimensional stability, it is noteworthy how retained austenite of Sample "A" started transforming into martensite phase in the early testing moments, causing a general volume increase; in the second part of test life, the surface wear phenomena cause a dimensional reduction comparable with the austenite transformation effect.

Sample "B" showed quite absent retained austenite before starting tests, which caused a lower transformation rate respect to Sample "A": such behavior caused the inappreciability of the volume increase effect respect to the reduction one related to surface wear.

Sample "C" showed a retained austenite amount higher than Sample "A" one before test starting, but the different chemical composition caused a higher metallurgical stability which implied a behavior similar to the one occurred to Sample "B".

The above described results are showed by the figure 1, representing the dimensional measurements performed at the end of each testing block (triangles represent ball failures, dots represent measurements at testing block end).

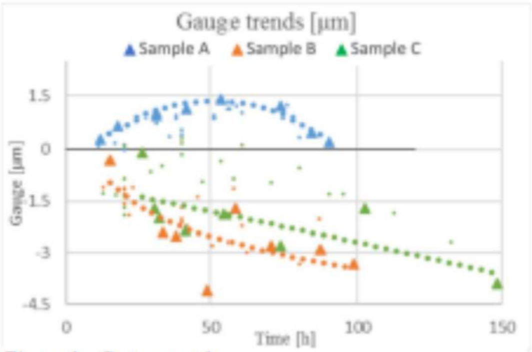

Figure 1 - Gauge trends

Figure 2 and figure 3 show the retained austenite levels measured before and after testing by XRD equipment with ±0.7% accuracy, considering the longest life test for each sample.

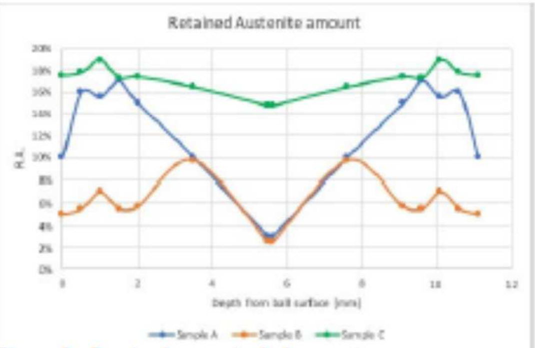

Figure 2 - Retained austenite before testing

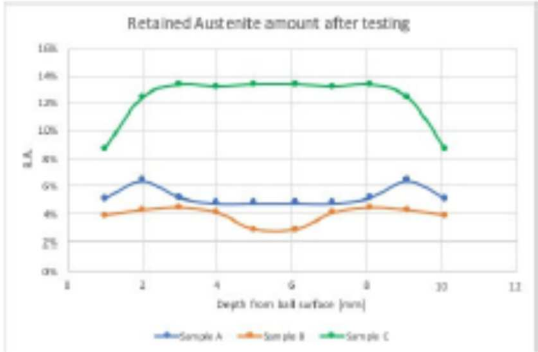

Figure 3 - Retained austenite after testing

The rolling elements failure mode were also inspected: figure 4, figure 5 and figure 6 show an example of fracture surface from sample "A", sample "B" and sample "C": the pictures are considered as representative of the whole samples, since no NMI issue was highlighted neither by the steel inspection, nor by the fracture surfaces. As shown by the below figures, sample "A" and sample "C" reached failure with similar mechanic behavior: subsurface spalling induced by the high RCF stress applied. Contrarywise, sample "B" showed a brittle failure behavior: the absence of retained austenite phase facilitated the crack propagation, causing a faster and more dangerous breakage [4].

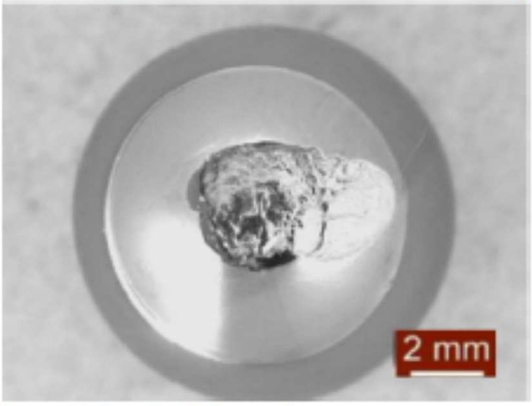

Figure 4 - Sample A failure mode

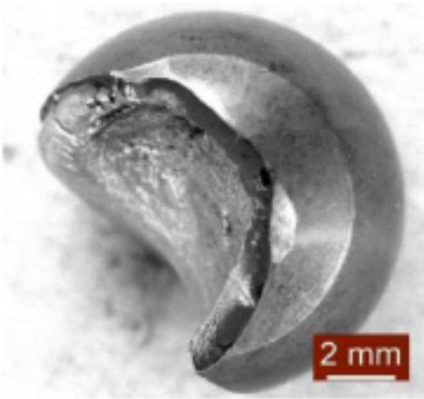

Figure 5 - Sample B failure mode

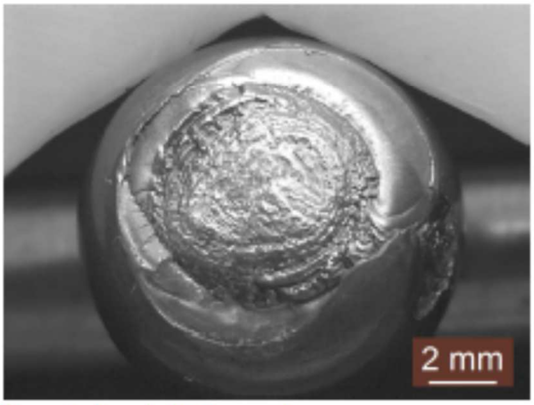

Figure 6 - Sample C failure mode

Moreover, the fracture location respect to ball poles and equator occurred randomly.

4. Conclusions

The goal of this study was to deepen the correlation between rolling contact fatigue performances and bearing rolling elements dimensional stability. To do so, three different rolling elements samples were manufactured following different processes: sample "A" by standard process setup, 100Cr6 steel quenched and tempered at 150°C; sample "B" by adding a sub-cooling at -70°C between quenching and 220°C tempering; sample "C" by applying a different steel composition using 100CrMnSi6-4, quenched and tempered at 240°C. The results obtained by testing such rolling elements showed different behaviors in terms of dimensional stability: sample "A" showed a dimension increase during the first testing phase, which was overcome during the second phase by the wear phenomena; sample "B" and sample "C" showed similar behavior: the dimensional increase related to retained austenite transformation occurred at lower rate respect to fatigue wear phenomena. The dimensional lower increasing rate obtained by samples "B" and "C" is related to the retained austenite stability: the sample "B" showed quite absent Gamma phase due to the subcooling heat treatment suffered, while sample "C" showed higher level of Gamma phase, which was kept stable by the higher Silicon and Manganese content respect to samples "A" and "B".

The below reported figure 7 shows the Weibull Distribution of the three samples: the larger scattering of sample "C" is related to the higher survived specimen's population obtained by fatigue testing. The specimen's quantity considered for the statistical analysis is the same for each sample.

The main difference highlighted by "B" and "C" samples is related to fracture mode: while sample "B" showed a brittle fracture rolling element breakage, sample "C" showed a ductile behavior with the typical subsurface spalling. Considering also that fatigue performances obtained by samples "B" and "C" showed L_{10} increase of 38% and 48% respectively if compared to sample "A", it is possible to conclude how the higher dimensional stability can lead to higher fatigue performance of the whole bearing.

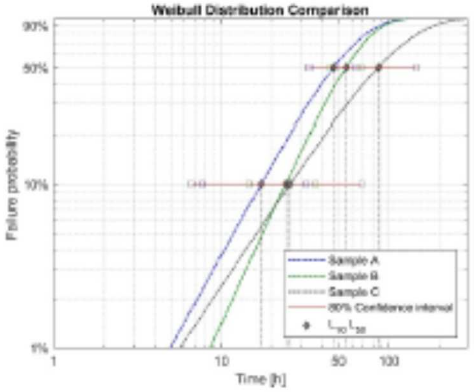

Figure 7 – Weibull distribution

5. References

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