RESEARCH RELATED TO RETAINED AUSTENITE ON RAIL AND WINDMILL BEARINGS

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Bearings used in some application like rail and windmills require keeping the dimensions within strict limits during operation. Retained Austenite is a factor influencing dimensional stability of the bearing rings so it should be controlled and maintained within certain limits in bearing steel microstructure. This paper presents some experimental results regarding retained austenite measurement on samples coming from bearing components. A sample made from SAE 3311 steel grade was used in order to check if the amount of retained austenite is the same on different surfaces of the sample at different depths. SDAR-OES, Optical microscopy and X-ray diffraction were performed.

Keywords: retained austenite, bearing steel, microstructure, SAE 3311, XRD

1. Introduction

The mechanical engineering parts used in demanding applications must be as damage- tolerant as possible with highly reliability. In order to select the proper combination of design, material and heat treatment for each application, the microstructure of the material must be adapted to resist to mechanical damage. Investigational studies of how the bearing material's microstructure responds to the mechanical loads of its actual application and the material's resultant lifetime bring direct insights into the design and development of damage-resistant and highly reliable engineering components. For making bearings more reliable and durable in required applications, their microstructure must be adapted to the application conditions. One of the examples represent bearings for wind turbine gear box applications. It has been multiple reported in literature that bearings in this kind of application experience early damage because of the development of cracks in the bearing steel. After studying several field damaged wind turbine

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bearings, it was discovered that case-carburized bearings with high amounts of retained austenite (> 20%) deliver relatively high lifetimes in such applications [1].

In various applications and industries bearings experience challenging to meet the demands for high efficiency and high loads. According to this, high carbon martensitic steels are used for their high strength and for their wear resistance case structure with tough core [2]. Retained austenite with a near crystallographic orientation is found in the microstructure of heat-treated low-alloy, high-strength steels that have medium or higher carbon contents. Although the presence of retained austenite may not be evident in the microstructure and may not affect the bulk mechanical properties such as hardness of the steel, the transformation of retained austenite to martensite during service can affect the performance of the steel [3]. The case microstructure of carburized bearings steels is composed of tempered martensite, carbides and as much as 30 - 40% retained austenite (RA). It has been observed that the presence of high content of RA, which has a relatively low hardness, would lead to a decrease in the overall strength of the component [2]. Bearing steels are heat treated to get martensitic microstructures providing high hardness necessary for good rolling contact fatigue performance. Austenite is generally retained after heat treatment in the final component, with a more or less important content. Depending on the requirements of each application, retained austenite is desired because of beneficial effects such as improvement of rolling contact fatigue performance, mostly in contaminated lubricating conditions, or when dimensional stability is needed for instance in cases of bearings working at high temperature for long times [4].

The measurement of retained austenite using XRD has importance in quality control and assurance. The presence of austenite in the steel can have either positive or negative consequences in terms of component performance and service life [5,9]. Generally, a high percentage of retained austenite content can affect the mechanical properties and in our case the RA amount can play a significant role in affecting some properties of bearing steels such as: performance, dimensional stability, and longevity of a steel component. Depending on the application, its presence can be either harmful or beneficial [6]. We know that austenite is the normal phase of steel at high temperatures, but not at room temperature. Because retained austenite exists outside of its normal temperature range, it is metastable. This means that when given the opportunity, it will change or transform from austenite into martensite. In addition, a volume change (increase) accompanies this transformation and induces a high level of internal stress in a component, often manifesting itself as cracks [7].

Carburizing is a remarkable method of enhancing the surface properties of shafts, gears, bearings, and other highly stressed machine parts. Low-carbon steel bars are fabricated, by forging and machining, into finished shapes and then are

converted by carburizing into a composite material consisting of a high-carbon steel case and low-carbon steel core [11]. During the carburization treatment, the material close to the surface (case) is enriched with carbon; therefore, the case develops higher hardness than the core [1,17].

When this steel composite is quenched to martensite and tempered, the high hardness and strength of the case microstructure, combined with the favorable case compressive residual stress developed by interactions between the case and core during quenching, produce very high resistance to wear, bending fatigue, and rolling-contact fatigue [12,13].

The tempering of carburized parts is a special instance in which the combination of toughness, strength, hardness, residual stress and retained austenite when selecting tempering time and temperature must be taken into account. Core properties cannot always be controlled by tempering when trying to achieve maximum case properties and a favorable compressive residual stress pattern may be retained overall toughness [14,15].

Carburization causes some steels to retain excessive amounts of austenite at the surface after heat treating. The proper etchant must be selected so that austenite is distinguished from ferrite and from massive carbide. Because both austenite and ferrite are soft, microscopic examination should be used to distinguish a sample with excessive retained austenite from one that has become decarburized [16].

Microstructure inspections shall be conducted for each process path/tempering furnace in production of bearing components. RA evaluation by XRD should be checked periodically in production. Practically in bearing steel for small rings is sacrificed a component and for rings greater than 12 in (305 mm) OD, coupons of the same grade and section may be used in place of actual components. Retained Austenite, when measured by X-ray Diffraction (XRD), usually is measured at a depth of 0.003” in (0.076 mm) below the finished raceway. When testing after heat treatment, the visual microstructure and XRD evaluations shall be conducted considering the grind stock.

The research consisted in a study on hardstock samples to establish a fastest and easier method for RA evaluation by XRD. Coupons were made from the same steel grade and followed each step of process together with the raceways.

2. Material and methods

A sector from the middle of test coupon was cut and prepared for XRD analysis. A longitudinal sample was cut from the remaining sectors and prepared for metallographic inspection. For this test was used one coupon made from SAE 3311 steel grade. Bearing quality of this type of steel is ideal for new design

solutions in a wide array of demanding applications in many industries that require longer performance and higher loads [7]. SAE 3311 bearing steel is a steel which has good corrosion resistance properties. This steel is termed as high carbon steel and is widely used in many engineering components [10].

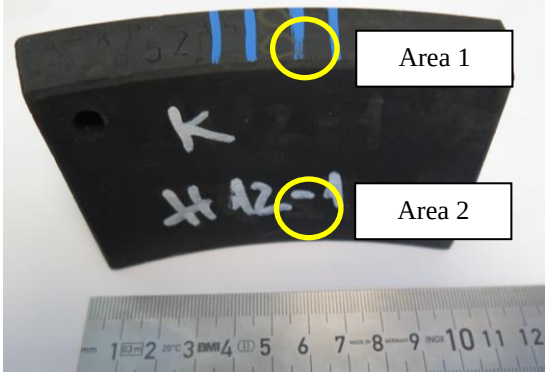


Fig. 1 Photograph of test coupon. Yellow circles marked on the sample represent the areas in which the RA content was evaluated by X-Ray. Area 1 in the mid front face of test coupon and Area 2 in the mid raceway of test coupon.

The dimension of the analyzed coupon presented in figure 1: l=50mm, H= 90mm, L=app. 50mm. The main analysis methods used in this paper were: electropolishing and grinding used to reach the desired depths for further investigation; Spark discharge in argon optical emission spectrometry (SDAR-OES) was used for chemical composition analysis in order to confirming the steel type; Optical microscopy and X-Ray Diffraction were performed on the sample for measuring retained austenite content by two methods. For visual evaluation a sample was cut, mounted and polished according to standard procedures and then etched with 2% Nital solution to be evaluated under an optical microscope. Of course, one may approximate the retained austenite amount with an optical microscope according to the company standards but only if it is more than 5%. X-ray diffraction (XRD) can accurately measure retained austenite concentrations less than 1%. In order to characterize the RA concentration in a sample, four X-ray diffraction peaks are collected by the instrument: two for the martensite phase and two for the austenite phase. The comparison between the intensities of the four peaks give the volume percent concentration of RA on the sample. [18]

a) Area 1 was prepared for XRD analysis by grinding.

Yellow arrow indicates the location for measuring RA by XRD.

b) Area 2 was prepared for XRD analysis by electropolishing.

Yellow arrow indicates the location for measuring RA by XRD.

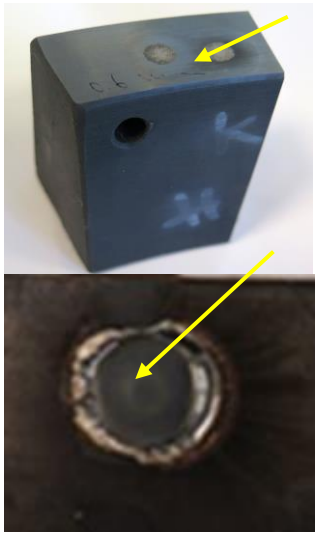


Fig. 2. Areas prepared for XRD analysis

Area 1 was prepared by grinding to reach the each required depth. Using grinding specific parameters for this type of steel the follows time for preparation were obtained:

a) Depth 0.05 mm - by grinding up to 0.05 mm from surface. Preparation time 2 min

b) Depth 0.40 mm - by continuing grinding up to 0.40 mm from surface. Preparation time 14 min

c) Depth 0.60 mm – by continuing grinding up to 0.60 mm from surface. Preparation time 8 min

Area 2 was prepared in one step to reach the each required depth. Using electropolishing specific parameters for this type of steel the follows time for preparation were obtained:

a) Depth 0.05 mm - by electropolish up to 0.05 mm. Preparation time 6 min

b) Depth 0.40 mm - by electropolish up to 0.40 mm from surface. Preparation time 42 min

c) Depth 0.60 mm - by electropolish 0.60 mm from surface. Preparation time 24 min

Electropolishing is an electrochemical process which consists in removal of material from the sample's surface by levelling reducing the surface roughness. This happens using a mixture solution based on perchloric acid. Electrochemical Layer can be accomplished (electro-polishing) is the preferred method used to remove material from surface and smooth the surface of metals due to minimal thermal effect compared to other methods and there are no mechanical work on the surface.

As one may observed from the description of the two methods the preparation time by method 1(grinding) is one third of the preparation time by method 2 (electropolishing). In order to grind the samples**,** the optimal parameters were set to remove the desired amount of material from the surface.

3. Results and discussions

3.1. Chemistry

A sample from coupon was prepared for chemical analysis using spark discharge argon optical emission spectrometry (SDAR - OES). As shown in TABLE 1 the coupon was made from SAE 3311 steel grade.

Table 1

Chemical analysis results[1]

Alloy	Chemical composition,%wt.										
	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	Sn
Coupon	0.15	0.41	0.005	0.010	0.31	1.37	3.39	0.03	0.090	0.022	0.007
SAE 3311 Chemistry Limits	0.10-0.15	0.40 - 0.60	max. 0.015	0.005 - 0.015	0.15 - 0.35	1.35- 1.60	3.25-3.75	max. 0.15	max. 0.30	0.012 - 0.055	max 0.020

[1]Determined by optical emission spectrometry.

3.2 Microstructures

After metallographic preparation the sample was evaluated under the microscope in order to rate the visual content of retained austenite in the same point and to the same depth where was measured by XRD. Visual amount of retained austenite is presented in Table 2. Micrographs showing representative microstructures are presented Figures 3-6. The microstructure of the finished product is the one presented in Figure 6 being a homogeneous martensitic microstructure with some retained austenite content uniformly distributed.

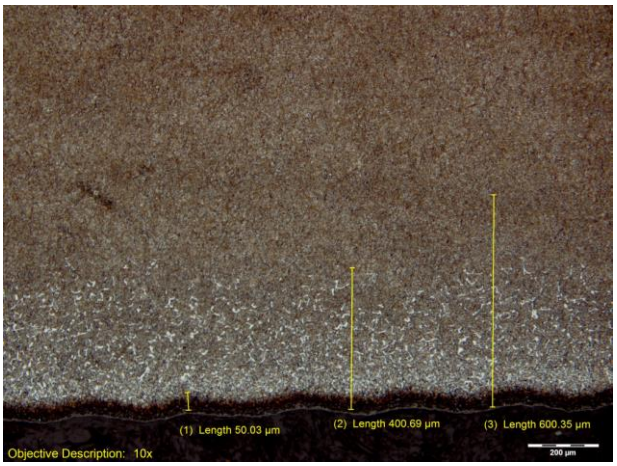
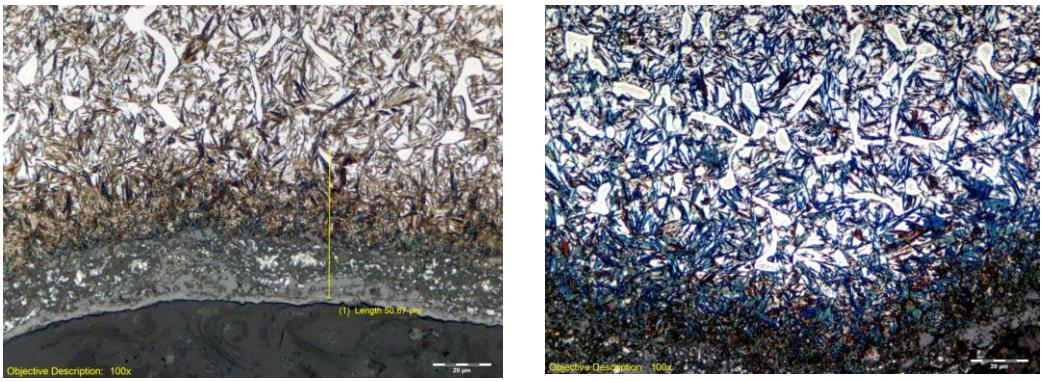
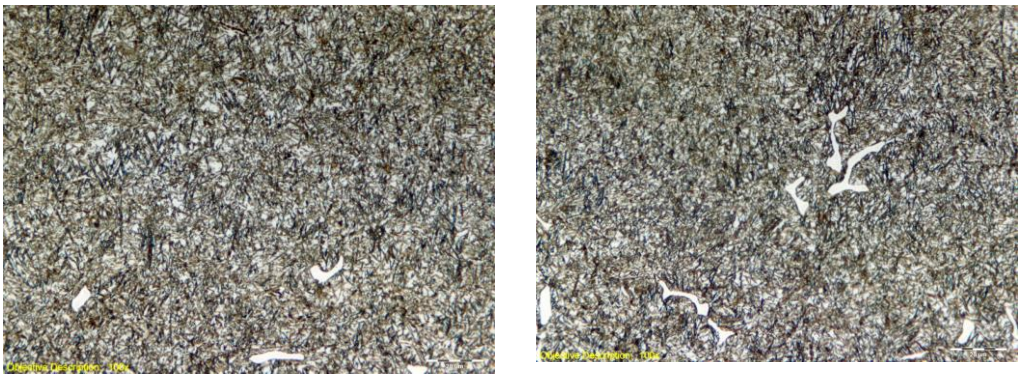


Fig 3. Optical micrograph of the coupon, longitudinal sample. Nital etch, 100x. The yellow lines indicate depth where RA was visually evaluated.



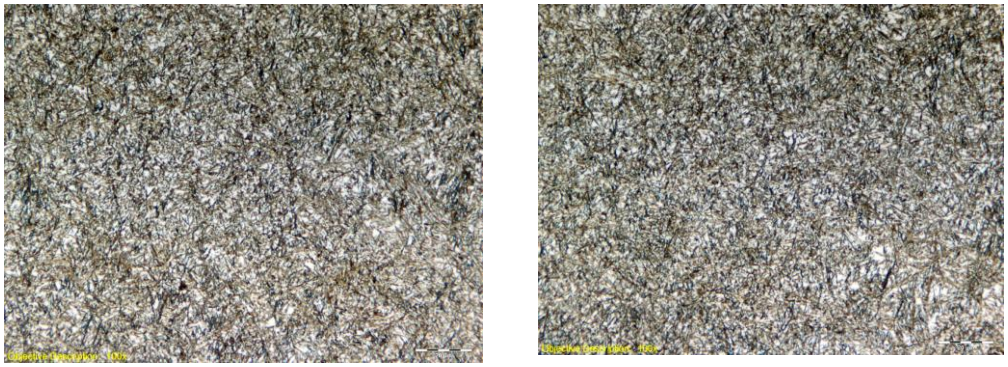
a. Front face b. Raceway

Fig. 4. Optical micrograph of the coupon at 0.05 mm depth. (Nital etch, 1000x)



a. Front face b. Raceway

Fig. 5. Optical micrograph of the coupon at 0.40 mm depth. (Nital etch, 1000x)



a. Front face b. Raceway

Fig. 6. Optical micrograph of the coupon at 0.60 mm depth. (Nital etch, 1000x)

3.3 X-Ray Diffraction

RA by XRD was measured in Area 1 and Area 2 at different depth, results are presented in Table 2. The measurements were performed on a Proto Model LXRD diffractometer with a chromium α X-ray source with a vanadium metal filter; λ= 2.291 Å; aperture used had 2mm round.

Table 2

Retained austenite content

Depth	RA by XRD, %		RA visual, %		C %
	Area 1 - FF	Area 2 - Race	Area 1 - FF	Area 2 - Race	Area 1 - FF
0.05 mm	41.9	42.4	40	40	1.41
0.40 mm	35.8	35.6	25-30	25-30	1.20
0.60 mm	32.3	33.1	25-30	25-30	1.15

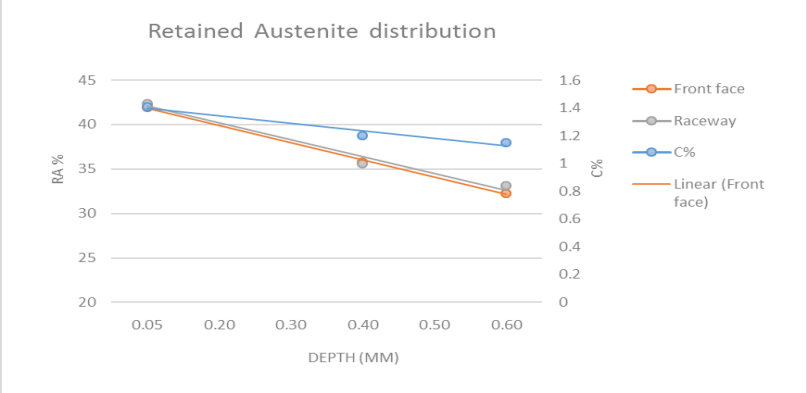


Fig. 7. Graphical representation of RA results evaluated by X-Rays Diffraction. Evident correlation between C% content and RA%.

4. Conclusions

For bearing rings greater than 12 in (305 mm) OD, coupons of the same grade and section are used in place of actual components. The raceway surface of test samples needs to be electropolished a long time to reach the depth required for evaluation. Considering the average of hardstock for samples which need RA evaluation, the electropolishing time for one sample is 72 minutes. After the test, subject of this investigation, the method of preparing and evaluation of RA on the front face considerably reduce the time of sample preparation.

Microstructure of SAE 3311 test sample showed uniform distribution of visual RA on the raceway and on front face. RA by XRD measured at three different depth had similar values for both surfaces, front face and raceway. The

differences of RA values between these two surfaces were in the range of 0.2-0.8%.

For evaluation of RA by XRD, the preparation time for front face surface is one third of the preparation time for raceway surface. The test provides an useful method for retained austenite measurement by X-ray diffraction due to their shorter preparation time. It was found to be an optimal solution to measure the retained austenite content on the grind face of the sample instead of the evaluation on the raceway. In this way is optimized results delivery time. Using grinding, where possible, instead electropolishing as method for samples preparation, a significant saving of chemical substances (like perchloric acid) and neutralization solution (to avoid pollution of residual water) is also noted.

R E F E R E N C E S

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