Crystallographic Preferred Orientation

Near the Surface of a Roll-Forged

Tapered Roller Bearing

by

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Crystallographic Preferred Orientation Near the Surface

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The crystallographic texture of retained austenite and martensite near the surface of experimental case-carburized tapered roller bearing cones was determined in the 'as produced' and 'after service' conditions (before and after 4×10^{8} cycles of rolling contact) using a cobalt x-ray source. A method of background and defocussing correction was developed which accounted extremely well for sample curvature, inexact positioning, and beam intensity which varies with incident beam direction. The texture of the near-surface martensite was determined to contain a combination of sheet textures: {031}<213>, {121}<123>, and {311}<121> with magnitudes of approximately 1.22 times-random. The near-surface crystallographic texture of the austenite in the 'as produced' condition was found to contain multiple sheet textures of {313}<132>, {123}<032>, and {123}<331> with magnitudes of approximately 1.5 times-random. The subsurface crystallographic texture of the austenite in the 'after service' condition was found to be void of the original sheet components and contained only the {100}<011> sheet component with a magnitude of 1.65 times-random. The

textural components of the 'as produced' austenite were determined to have been annihilated by deformation to form the {100}<011> texture in austenite and by transformation of the {313}<132> and {123}<032> textures to martensite.

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Fred Kocks, Stuart Wright, John Kallend, Rudy Wenk deserve much credit for their collaborative effort on popLA (preferred orientation package Los Alamos) which was produced under U.S. Government contract (W-7405-ENG-36). This package has greatly simplified the tedium of quantitative x-ray crystallography and is an admirable tool for the instruction of concepts.

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Introduction

Brenco Incorporated of Petersburg Virginia in conjunction with the Department of Mechanical Engineering at the University of Nebraska have been working for many years towards improving the performance of case-carburized roll-forged railroad bearings. The search for basic knowledge concerning the behavior of case-carburized structures in service is an important step in understanding how the product functions and how it may be improved. This study is such a basic investigation aimed at understanding how the microstructural components of tempered martensite and retained austenite behave under rolling contact forces.

Tapered Roller Bearings

Tapered roller bearings (Figure 1) have provided the mechanism by which to support loads encountered in the railroad industry, and optimization of the tapered roller bearing is one ongoing goal of this industry. The tapered roller bearing design is limited by the need for compatibility between existing axles, and trucks, much like the spacing between rails dictates the wheel separation. Contrary to this limitation, the service requirements have continued to increase to meet the needs of customers for higher speeds, heavier loads, and longer life. Since the introduction of the tapered roller bearing to railroad freight cars in 1953, these demands put forth by increased traffic have been compensated for and met by several improvements which include better

manufacturing processes, materials enhancements, and scheduling and maintenance improvements. The last major advancement in tapered roller bearing capability was achieved by case carburizing which increased load carrying capacity while increasing fatigue and wear resistance. At present, there is no foreseeable solution to the increased future demands of the industry unless it becomes economical to redesign the entire rolling system. Thus, the small increments toward optimization are recognized with increasing value.

A tapered roller bearing may see more than a half-billion revolutions in its initial service life and, barring failure, may be reconditioned and put back into service. Bearings have been removed from service upon failures which are typically observed in the form of burn-offs (Figure 2), overheating, strong vibrations, and loud noises. Most catastrophic failures stem from loose cones and spalling[1]. Bearing cones (see Figure 3) are press fit onto rail axles with an interference fit of 0.002 to 0.005 inches *(0.05 to 0.13 mm)*. During service a bearing cone sometimes grows and loses this interference fit. This phenomenon is referred to as cone-bore growth and it may lead to fretting, overheating, bearing seizure, and possible axle burn-off[2a]. Spalling is the most common form of bearing failure[2b] in properly maintained systems and generally arises from sub-surface fatigue failure due to the stresses of rolling contact. Cone-bore growth and fatigue have both been shown to be dependent upon the amount of retained austenite present within the microstructure of tempered martensite[1].

Figure 1. Tapered Roller Bearing. Cone and roller assembly atop bearing cup.

Figure 2. Axle burn-off resulting from catastrophic bearing failure.

Tapered Roller Bearing

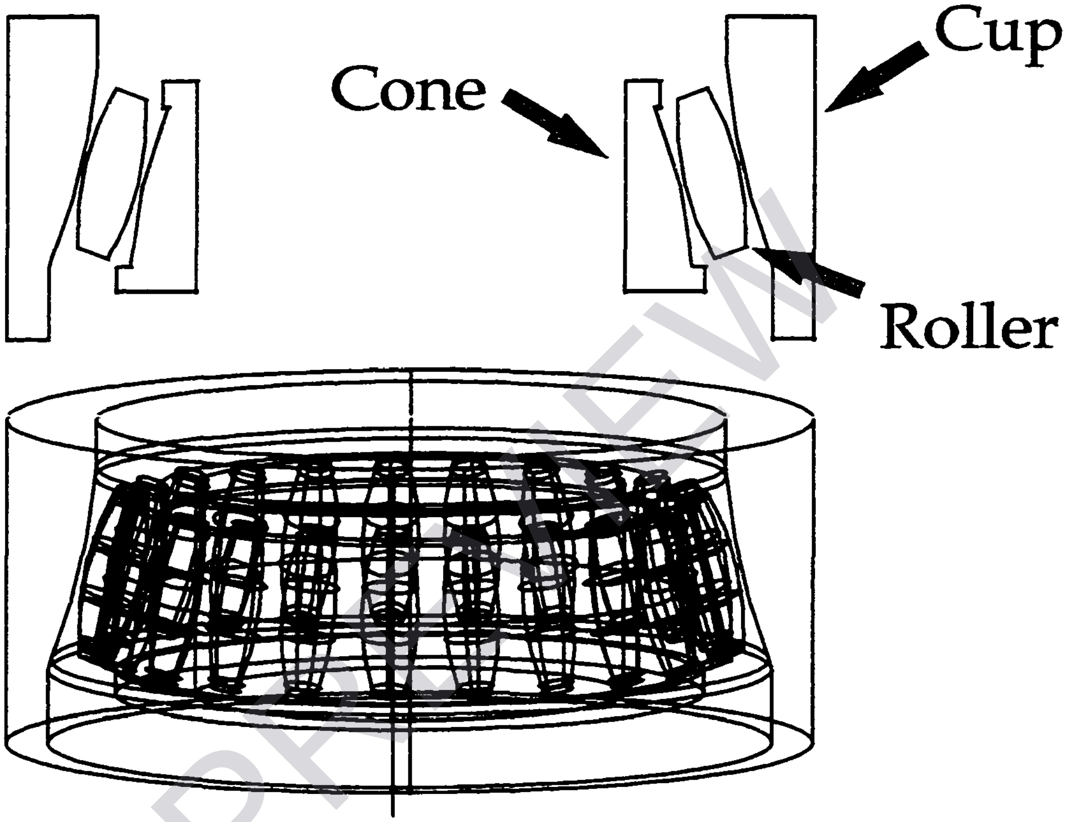

Figure 3. Schematic of tapered roller bearing - rolling components.

Figure 4. Cross-section of a case-carburized bearing cone, heavily etched with nital.

The case carburized layer (Figure 4) of bearing cones contain a microstructure of retained austenite and tempered martensite. The amounts of each of these microconstituents can effect the hardness and the residual stress distributions in the cone, and changes in the amounts of each constituent can alter the material properties and performance of the cone [3,4,5].

Retained Austenite

Studies have shown some amount of retained austenite to be beneficial, and bearing components typically contain up to 40% retained austenite in their microstructure. Retained austenite in the case of carburized components has been shown to increase contact fatigue resistance [4,5] while decreasing strength, wear resistance, and dimensional stability [6,7,8]. Too little retained austenite in the microstructure of the case can lead to higher frequency of rolling contact fatigue and impact problems during normal service applications [3,4]. These effects of retained austenite in the microstructure are generally understood, but the proper amount of retained austenite that a component should have is dependent upon the particular application and service conditions. Regulating the optimum amount of retained austenite has been accomplished fairly well by careful control of heat treatments and material chemistry [9]. However, the processing method also plays a role in the amount and distribution of retained austenite as well as the martensite.

Processing

Railroad bearings are commonly made by two processes: roll-forging and machining of seamless pipe. During roll-forging, the bearing component is forged between rotating dies, one on the inner diameter and one on the outer diameter. Evidence [10,11,12] suggests that there is a beneficial effect from roll-forging with respect to impact and fatigue strength. This benefit is believed to be due to elongation and alignment of the grains in the circumferential direction and the *texture* developed.

Research Goals

Evidence has provided a correlation between texture and dislocation structure [13] and texture and fatigue [14, 15]. This evidence leads one to the belief that the method of processing will affect time-dependent material behavior such as fatigue. Controlled texture and controlled transformation of austenite may lead to a superior product and may be accomplished through different methods of processing and heat treatment. Understanding the development and transformations of the austenite and martensite textures may lead to the production of bearings with improved performance. The goal of this work was to quantify the texture of the austenite and martensite phases present near the rolling surface of a case-carburized tapered roller bearing cone before and after service. Furthermore, the explanation of the texture origin will indicate the

crystallographic processes occurring in this application so that they can be controlled or modified to further optimize bearing performance.

Anisotropy

Anisotropy is a word used to describe properties which show directional dependance. Wood is an example of an anisotropic material whose directional properties may be seen to correspond to the wood grain. Metals may also exhibit directional properties. Anisotropy in a polycrystalline metal is the result of grain size and shape distribution, differences in microstructure and chemical composition, and non-random orientation distributions of crystallites. Crystallographic ***texture*** is defined as non-random orientation distributions of crystallites. Materials with perfectly random crystallite orientation distributions are said to contain no texture, but may still exhibit anisotropic properties due to other differences such as grain shape. A perfect single crystal may be thought of as containing the strongest texture possible; when the alignment of the crystallites in a polycrystalline material are more pronounced, the properties of the polycrystalline material will more closely resemble those of a single crystal.

Anisotropy in metallic materials may lead to significant non-uniformities when the materials undergo plastic deformation. In addition, crystal anisotropy (texture) develops in any material when experiencing plastic deformation. Therefore, eliminating

anisotropy is not usually possible and neglecting its effects can cause significant non-uniformities which lead to material waste or component failure. In some cases, the anisotropy may actually be taken advantage of to yield properties whose directionality may be matched to the need at hand. Therefore, controlling and predicting these non-uniformities is important and allows one to design processes which at least account for these inconsistencies.

Non-uniformities resulting from plastic deformation processes have been studied and shown to correlate to a great extent to the crystallographic texture present in the component. One example of this effect can be seen during deep drawing of materials with a sheet texture resulting in the well-known earing problem in deep drawn materials. In general, the directionality of a single crystal will be exhibited in a material's properties and is dependent on the degree to which its grains are crystallographically aligned. Texture usually develops in a polycrystal through the process of slip by dislocation motion. Slip in a single crystal occurs when the shear stress on any plane in the crystal reaches a critical value (Schmid's Law). In order to apply this theory to a polycrystalline material, one must take into account the compatibility between grains. G.I. Taylor [64] explored this reasoning on the basis of a minimum work principle assuming each grain in a random oriented polycrystal underwent a homogeneous shape change. He determined, with quite good experimental agreement, the stress-strain curve for aluminum from single crystal shear stress and

strain values. This pioneering work has endured and is still the basis for many theories of polycrystal plasticity although many modifications and additions have been proposed to better fit each individual case studied.

The measurement of crystallographic texture in a polycrystal can be made using x-ray diffraction and Bragg's law. The difference in the polycrystal diffraction peak intensities for more than one Bragg condition, or pole, is compared to the pole diffraction peak intensities for a random sample, usually a powder, of the same material. The texture is then described as an intensity in units of "times-random". The texture of a specimen may be seen using techniques such as the measurement of Laue patterns, step scans, and pole figures. The most common measurement method utilizes pole figures where intensity measurements are made for many positions of the sample in question, while holding the measurement apparatus (x-ray beam, sample, and detector) in a position (at a pole) that satisfies Bragg's law. The resulting data set from each pole is referred to as a pole figure. Sample position is usually indexed (see Figure 8) with a rotation about the sample normal (φ rotation) and a tilt about the intersection of the sample surface and the plane containing the incident and diffracted x-ray beam (χ tilt).