

Application of UNSM (Ultrasonic Nanocrystal Surface Modification) Technology for Prolonging Service Life of Journal Bearing of Railroad Axle and for Reducing Friction Loss

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Abstract

Journal bearings (JBs) of railroad axle are safety critical components of railroad operation, so they have to be checked and replaced periodically. Sixty seven damaged bearings were analyzed and categorized into eleven known failure modes. Damage accumulation due to fatigue, plastic deformation and wear significantly reduces the service life of JB of a railroad axle. Ultrasonic nanocrystal surface modification (UNSM) technology can improve surface integrity and surface hardness, and induces compressive residual stress in surface layers. Therefore, UNSM technology was applied to disk specimens, which simulated the working conditions of journal bearings in order to extend its service life, to reduce friction and to improve wear resistance. The result of disk-on-disk friction and time-to-beginning-surface-scratch (TTBSS) tests showed that friction coefficient of the UNSM-treated surfaces was reduced by 30% and TTBSS was prolonged by 55%. In addition, pin-on-disk wear test was conducted on the UNSM-treated and polished surface specimens and its results showed that wear volume loss of the UNSM-treated surface specimen was reduced by 45%. The basic mechanism and effects of UNSM technology are also explained.

Keywords Journal bearing, friction, wear, Ultrasonic nanocrystal surface modification (UNSM).

Introduction

JBs are considered to be sliding bearings as opposed to rolling bearings such as ball bearings. Despite this categorization, shaft spins within a JB and actually damaged the JB facing surface that prohibits the long life of JB. There are many different approaches to solve these problems, such as the development of new materials, the novel design of JB shapes and lubrication system, the surface modification, and so forth. The UNSM is an emerging technology in which a tungsten carbide (WC) ball attached to the ultrasonic device [1,2] strikes a workpiece surface 20,000 or more times per second. These strikes produce micro-dimples, demonstrated severe plastic deformation to the surface layer, induce compressive residual stress in surface, increase surface hardness and roughness, and refine the grain into nanocrystal. The UNSM technology was applied to a JB surface to obtain low friction of the interaction of JB and shaft. Increasing load capacity and service life, decreasing friction coefficients, and improving reliability are major goals of JB design and manufacturing in order to improve energy efficiency and to reduce life cycle cost of the JB systems.

At some points, the material loses its integrity and fails, and this failure is manifested in the form of wear (the material detaching from the surface and producing debris). Wear is one of the main failure modes of JB, and it results in pitting and spalling on contact surfaces. During the operation, the pitting and spalling formed on the surface of JB can degrade the quality of surface finishing, and they must be prevented in practice [3]. While contacting two surfaces, the wear failure on the JB surface is extended by UNSM technology. Since the wear occurs in the local zone of contact surface and is caused by a cyclic contact stress. However, all of the models focused on the wear with high contact pressure, where a large scale of plastic deformation occurred. Sixty seven failed JB were received from KORAIL in order to study and analyze the failure modes and those JB are failed under the same operating conditions. These JB are divided into eleven groups and are used to determine the failure distribution

and the statistical analysis was established as shown in Figure 1. Flaking (25.5%), wear (19.1%), scoring (18.0%), peeling (8.5%) and false brinelling (8.5%) were major causes of failure. It implies that wear resistance and friction behaviors are very important in discussing the JB and should be investigated clearly by experiments. The objective of the present work is to carry out a performance analysis through visual inspection of JB of a railroad axle. Depending upon the type failure detected, recommendations are then given as how to remedy the specific cause of damage. The main objective of this paper is to demonstrate the prevention of friction and wear through UNSM treatment.

In general, if JB's are used correctly, they will survive to their predicted fatigue life. Bearings, however, often fall prematurely due to avoidable mistakes. In contrast to fatigue life, this premature failure is caused by excessive load, entry of foreign debris, rotating and/or sliding speed, improper mounting, mishandling, poor lubrication or abnormal heat generation.

For example, one cause of premature failure is flaking which is due to excessive load. If all conditions are known for the times both before and after the failure, the operating conditions, and environment, then a countermeasure can be determined by studying the nature of the failure and probable causes. A successful countermeasure will reduce similar failures or mistakes and prevent them from happening again.

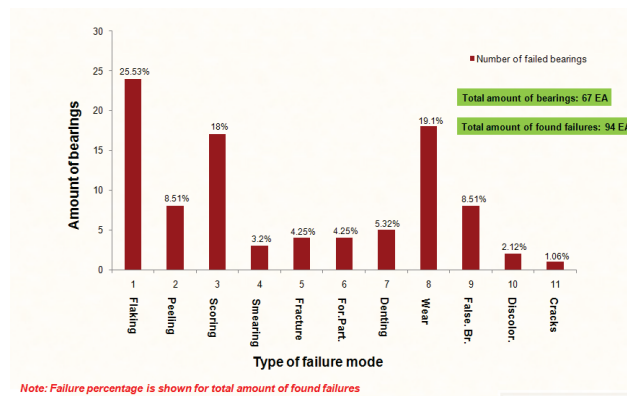


Figure 1. Percentage of Major Causes of JB Failures.

Experimental Methods

The tribometer as shown in Figure 2 consists of the stationary and rotating shaft with its specimen holders pressed at the required load against the specimen rotating at the defined speed. The construction of friction test machine allows measuring the friction coefficient and wear between two disks.

The specimens used in this study are made of Cu-Zn alloy with a surface hardness value of 28 HRC and AISI304 stainless steel with a surface hardness value of 55 HRC. The specimens are prepared as disk specimens 60 mm in diameter and 11 mm in thickness and each made to have the same surface roughness ($R_a=0.10 \mu\text{m}$) in order to eliminated the roughness effect. The UNSM technology treatment conditions were different for each material due to the mechanical properties and are shown in Table 1.

Table 1. Details of UNSM Technology Treatment Conditions.

Type of materials	Feedrate (mm/rev)	Amplitude (μm)	Lathe Spindle Speed (rpm)	Load (N)
Cu-Zn alloy	0.07	10	10	5
AISI304	0.07	20	10	15

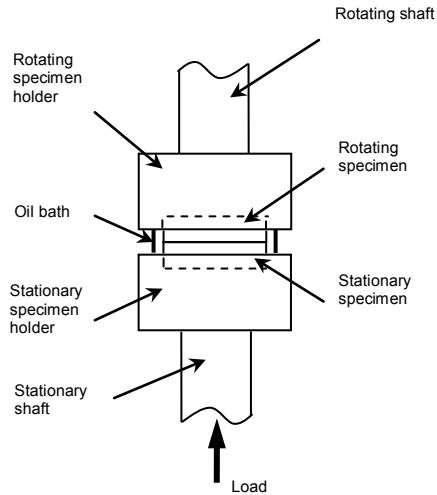


Figure 2. Schematic of the Friction Test Rig.

The surface topology of the polished and UNSM-treated specimens and test conditions are shown in Figure 3 and Table 2, respectively. The friction coefficient is the same in all directions in these below micrographs.

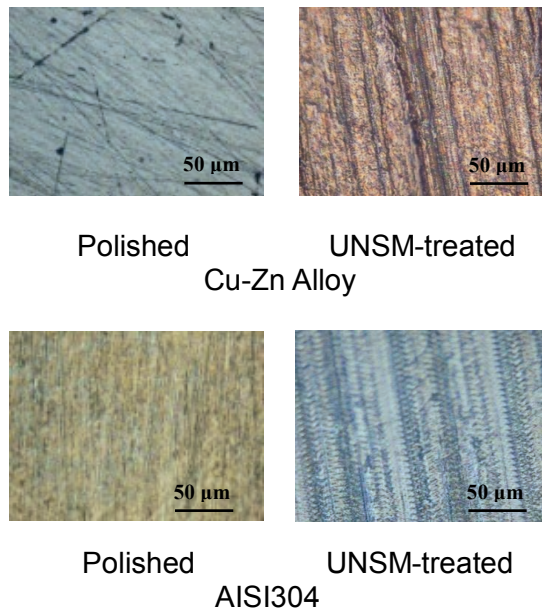


Figure 3. SEM Micrographs of the Polished and UNSM-treated Surface.

Table 2. Major Conditions of the Friction Test.

Load, N	Testing Time, min	Rotating Speed, rpm	Used Oil and Viscosity	Oil Temperature, °C
500	3-9	100-1000	Tonna Oil 32, 0.13 Ns/m ² @ 40 °C	15.4-22

In addition, pin-on-disk wear test was conducted on the UNSM-treated and polished surface specimens. Figure 4 shows typical microstructures of untreated specimen showing α matrix and β phase developed in a confined regions surrounded by Sn rich phase.

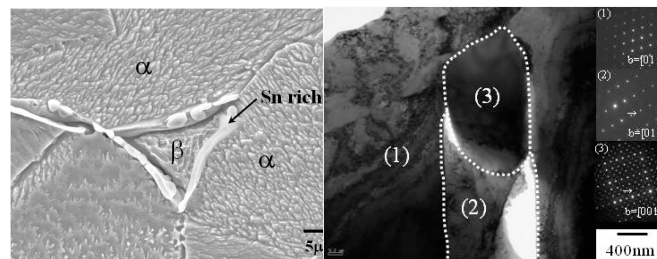


Figure 4. Typical SEM (a) and Plan View TEM (b) Micrographs of a Cu-Zn Alloy Specimen: (1) α Matrix, (2) β Phase, (3) Sn Rich Phase.

Wear properties of the UNSM-treated and untreated surfaces were measured by pin-on-disk type wear tester used in this experiment as shown in Figure 5. Rotating disk specimen which is made of Cu-Zn alloy with hardness of 130 HV was rubbed against a fixed pin under oil-lubricated sliding conditions. A 30 mm diameter disk specimen was polished out and treated by UNSM treatment under five various UNSM conditions, and cylindrical pin with the dimension of 6 mm diameter from hardened WC with the hardness of 1700 HV was utilized. All experiments were carried out at room temperature of 20 ± 2 °C. Prior to the each test, both ball and disk specimens were cleaned in acetone in an ultrasonic cleaner. The wear loss was weighted by an analytic balance with accuracy of ± 0.1 mg.

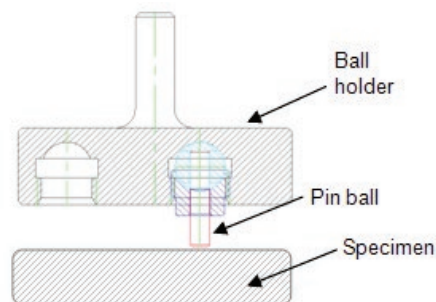


Figure 5. Schematic View of Pin-on-Disk Tribometer.

Results

In the third combination as shown in Figure 6, stationary specimen Cu-Zn alloy is treated by UNSM technology and AISI304 is polished. In the fourth combination, AISI304 is treated by UNSM technology and Cu-Zn alloy is polished. All tests were conducted at constant load, but as a function of rotation speed and also there was only one test for each point. Every rotation speed maintained for 3 min. If no TTBS occurred, specimens were tested until TTBS. Each experiment was repeated two times to get TTBS in a relatively short period of time. Method that estimates TTBS, a time based on an observed specimen surface. The higher the TTBS number is, the higher the reliability of the product. The micro-dimples reduce the coefficient of friction and prolong TTBS as shown in Figure 6 and Table 3. TTBS measurements suggest that UNSM-treated specimen is comparable to polished specimen in observing scratch time. All specimens were scratched, but the scratch scale was different. The first combination both polished surfaces were scratched on average in 4 min, sliding distance D was 1400 ± 5 m. The second combination both UNSM-treated surfaces revealed positive result scratched on average in 9 min, sliding distance D was 3150 ± 5 m. When surface scratch occurred, measured temperature was obviously higher

than at the beginning of the test, but UNSM-treated specimens scratched at considerable higher temperature than polished specimens.

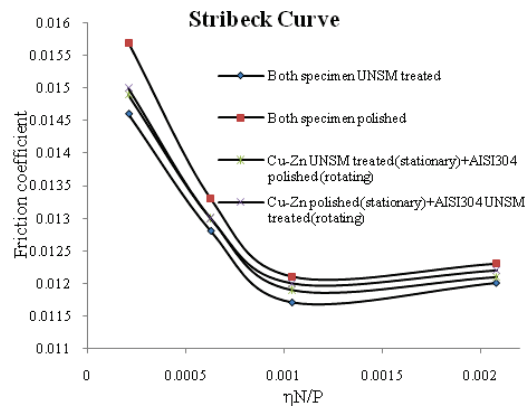


Figure 6. Stribeck Curves of Various Surface Combinations.

The friction coefficient of both UNSM-treated disk specimens is the lowest among four combinations and decreased by about 30% compared to both untreated disk specimens which have the highest friction coefficient. The TTBS of both UNSM-treated disk specimens are the longest period among four combinations and increased approximately 55% compared to both untreated disk specimens which have the shortest period among four combinations.

Table 3. Time-to-beginning-surface-scratch Results of Various Surface Combinations.

Combinations	Type of contact	Time-to-beginning-surface-scratch, min
1	Both specimen polished	4
2	Both specimen UNSM-treated	9
3	Cu-Zn UNSM-treated (stationary)+AISI304 polished (rotating)	6
4	Cu-Zn polished (stationary)+AISI304 UNSM-treated (rotating)	6

Figure 7 shows typical morphologies of plastic deformation layers produced on Cu-Zn alloy before (a) and after UNSM-5 (b) treatment which were produced by TESCAN Mira II. In this comparison only untreated and the strongest UNSM-5 condition which was treated with the smallest tip ball diameter and largest amplitude, showing the severe plastic deformation and the smallest refined grain size among the UNSM-treated specimens.

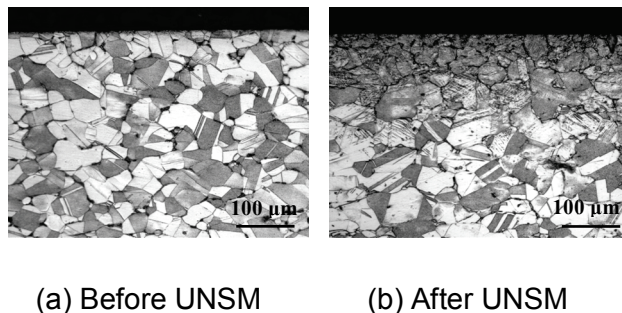


Figure 7. Comparison of Optical Micrographs Before and After UNSM-5 Condition on the Thickness of the Plastic Deformation Layer.

Table 4 compares the deformation depth and microhardness of the surface layers before and after UNSM treatment. In untreated surfaces, the magnitude of microhardness was stable along the depth from the surface, but in UNSM-treated surfaces the magnitude of hardness was high at the surface and decreased with increasing depth from the surface.

Table 4. Deformation Depth and Microhardness of the Specimens Before and After UNSM Treatment Layers.

Specimens	Untreated	UNSM #1	UNSM #2	UNSM #3	UNSM #4	UNSM #5
OM (μm)	-	158.3	175.9	196.3	226.4	226.4
EBSD (μm)	~12	115.6	175.0	192.5	214.5	268.0
depth of the hardness change (μm)	-	200	200	200	220	250
hardness of the surface layer	130	160	190	195	195	210

Table 5 shows the comparison of the wear rate. UNSM #4 and #5 processes show a higher wear resistance due to its high microhardness and the finer precipitates. The optimum structure of high wear resistance ought to have both high hardness and toughness.

Table 5. Comparison of Weight and Volume Loss of Untreated and UNSM-treated Surface.

Specimens	Untreated	UNSM-treated	Test conditions
Weight loss, mg	6.0	3.3	Normal load: 50N Sliding distance: 721.47 m
Volume loss, $\times 10^3 \text{ mm}^3$	703	387	

Conclusions

In this paper, two experiment results were demonstrated and its results lead to the following conclusions:

- Eleven major causes of premature JB's failure modes as found.
- Stribeck curves were built which compare UNSM-treated and polished specimens results. The results show that the friction coefficient was reduced by about 10%.
- It was found that the TTBS for the UNSM-treated surface was prolonged up to 9 min.
- The thickness of the deformation layer, dislocation density, and the microhardness increased with the increase of the amplitude, and decrease of impact ball size of the UNSM.
- Wear volume loss was decreased from $703 \times 10^3 \text{ mm}^3$ to $387 \times 10^3 \text{ mm}^3$ as well as weight loss also decreased from 6.0 mg to 3.3 mg.

References

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