Proceedings of
2007 ASME/IEEE Joint Rail Conference & Internal Combustion Engine Spring Technical Conference
March 13-16, 2007, Pueblo, Colorado, USA

JRC/ICE2007-40011

EFFECTS OF MICROVOIDS, OXIDE INCLUSIONS, AND SULFIDE INCLUSIONS OF THE FATIGUE STRENGTH OF WHEEL STEELS

Daniel H. Stone
Hunter Holiday Consulting

Francisco Robles
Transportation Technology Center, Inc.

Geoffery Dahlman
Burlington Northern Santa Fe Railroad

INTRODUCTION

The effects of microscopic discontinuities on reducing the fatigue strength of steels are well known. This paper will attempt to quantify the reduction of fatigue strength due to measured quantities of microvoids, oxide inclusions, and sulfide inclusions of the fatigue strength of wheel steels. Murikami and Endo[1] have derived a model that relates the effects of void and inclusion area and hardness on the fatigue endurance limit. In the present work is presented a unique analysis where the effect of microcleanliness is investigated. The Murikami model was used for simplicity and because the goal in this publications is to demonstrate that inclusions play an important role on wheel performance. This work summarizes the microcleanliness analysis of 113 wheels; most of such wheels were removed from revenue service due to failure. The nature of the failure indicates that the wheels failed due to a fatigue related problem. For these reason, it is of paramount interest to determine the effects of defects (i.e. voids or inclusions) on wheel performance. For this reason a simple model (Murikami) was employed to quantify the effect of defects that were measured using the microanalysis.

EXPERIMENTAL WORK

The area and number of voids, oxide inclusions, and sulfide inclusions were measured on 113 new and used wheels. Data was gathered by sectioning six metallographic specimens from each wheel. The specimens were then polished for examination in the as polished condition. The total area evaluated for each sample was not less than 1/4 in.^{2} (161 mm^2). All inclusions greater than approximately 2.5 microns were counted. The area and number of each type of discontinuity were measured using a quantitative, video-based system.

THE MURIKAMI EQUATION[1]

Equation (1) shows the Murikami equation.

$$\sigma_{el} = 1.41(H_V + 120)/(\sqrt{area_{Max}})^{1/6} \quad (1)$$

where:

σ_{el} is the fatigue endurance limit in MPa
H_V is the Vickers hardness
$area_{Max}$ is the projected area of the largest inclusion or void

The Murikami equation is not applicable for discontinuities greater that 1 mm in area. Note that the equation uses the maximum area of the largest inclusion. It is well known that the effect of discontinuities on mechanical properties for materials is a function of shape, number, distribution, size among other parameters[2]. However, the main goal of this research document is the determination of potentially detrimental effects of discontinuities on fatigue performance of railroad wheels. TTCI is currently developing a more complex Finite Element Analysis where size, shape, number, elastic properties, stochastic distribution and location of defects will be considered to determine the shortening on endurance, thus fatigue wheel performance [3].

The data used herein is for the average area of the discontinuity counts, and therefore, the calculated endurance limits will be too high.

Further, it is assumed that the wheels with the highest average discontinuity areas will also have the largest of maximum size discontinuities. The 1.41 coefficient in the Murikami equation was selected based on the already reported data for similar material in Reference 2.

Lonsdale and Dedmon[4] have reported a fatigue endurance limit of 68,000 psi (469 MPa) for Grade C steel with a tensile strength of 164,500 psi (134.2 MPa). Tensile strength may be converted to Brinell hardness[5] by dividing by 489. This corresponds to 357 HBN or 377 HV. Substituting the preceding values for endurance limit, hardness, and the average area of oxide inclusion diameter gives a calculated coefficient of 0.55.

Finally, the specified hardness of AAR Grade C wheel steels can vary from 321 to 363 Brinell hardness (HB) (340 to 383 HV). Therefore, on the basis of hardness alone, the endurance limit may vary between 59,300 and 64,900 psi (409 and 447 MPa).

RESULTS AND DISCUSSION

Data for the new and used wheels are given in Table 1. A statistical t-test performed on the new and used wheel data determined that the two data sets were not statistically different.

TABLE 1. CALCULATED ENDURANCE LIMITS FOR VOIDS, OXIDES, AND SULFIDES IN NEW AND USED WHEELS

	Voids	Oxides	Sulfides
Average Area, mm^2	0.0038	0.0017	0.0022
Calculated Endurance Limit, MPa (Ksi)	421 (60.5)	469 (64.6)	440 (63.3)
Area of Worst Wheel, mm^2	0.0133	0.0036	0.0050
Calculated Endurance Limit, MPa (Ksi)	379 (54.5)	422 60.6	411 (59.1)
Area of Best Wheel, mm^2	0.0010	0.0012	0.0003
Calculated Endurance Limit, MPa (Ksi)	469 (67.5)	463 (66.6)	524 (75.4)
Worst/Average Endurance Limit, %	90	90	93
Worst/Best Endurance Limit, %	81	91	78

The endurance limits for new, used, and derailment wheel data assume that all wheels had hardness of 381 HB (361 HV), which is the average of the specified hardness range of Grade C wheels.

The calculated endurance limits for wheels with the greatest average area of voids, oxides, and inclusions are less than expected for wheels of the softest specified hardness.

Plots of the calculated endurance limits versus average inclusion area are shown in Figures 1, 2, and 3.

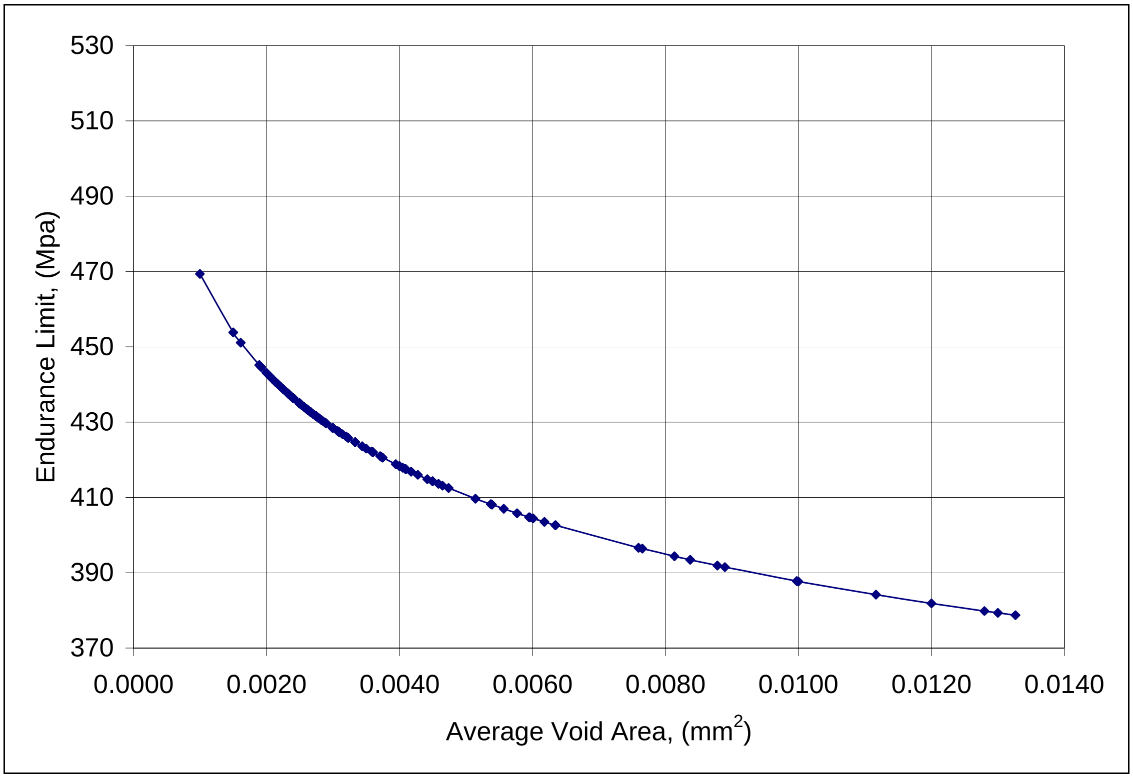

FIGURE 1. AVERAGE VOID AREA VERSUS CALCULATED ENDURANCE LIMIT

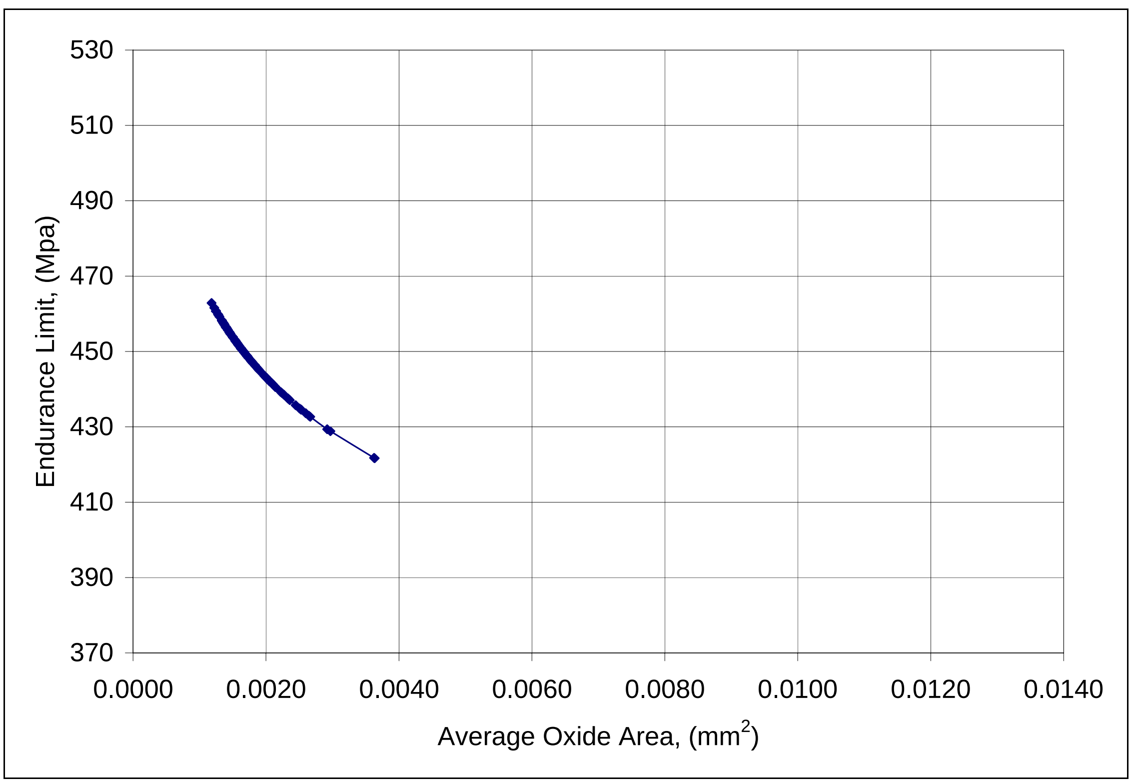

FIGURE 2. AVERAGE OXIDE AREA VERSUS CALCULATED ENDURANCE LIMIT

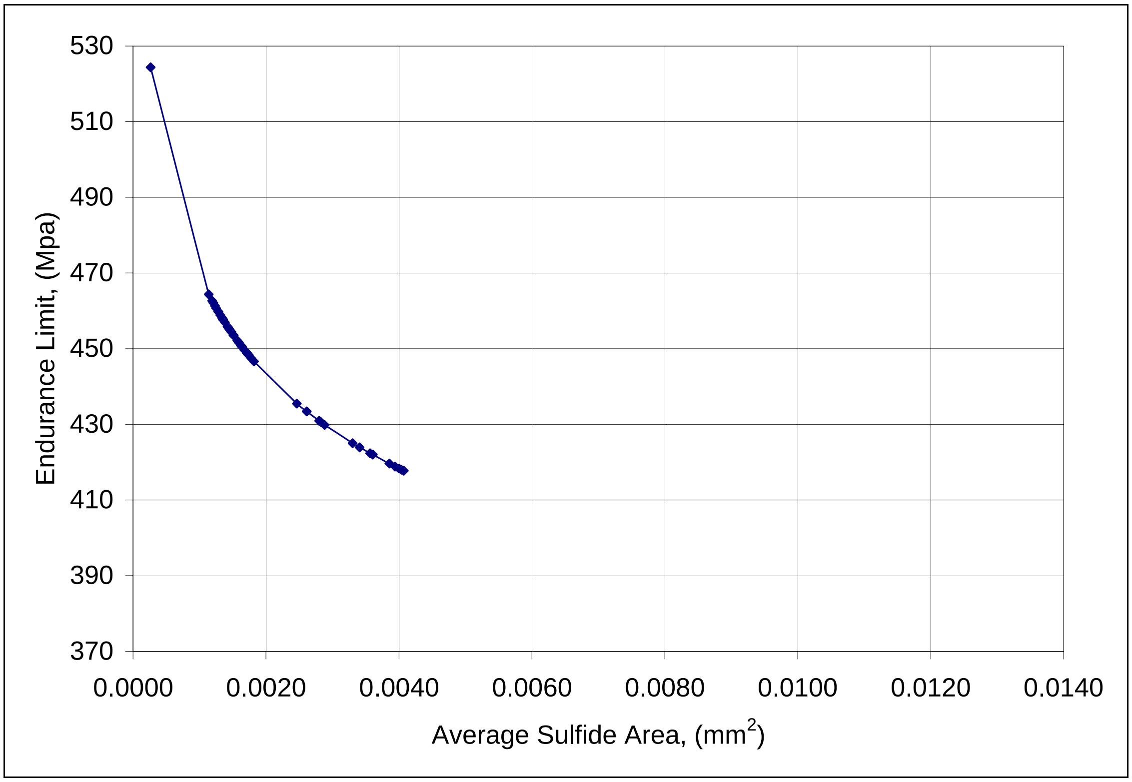

FIGURE 3. AVERAGE SULFIDE AREA VERSUS CALCULATED ENDURANCE LIMIT

Figures 1, 2, and 3 show that the void areas tend to be clustered between 0.0015 and 0.0045 mm^2. Similarly, the oxide areas tend to cluster between 0.0015 and 0.0025 mm^2. The sulfides tend to a tighter cluster, 0.0011 to 0.0018 mm^2, but have a greater number of outliers at higher average areas.

CONCLUSIONS

1. Murikami and Endo have demonstrated that the endurance limits of steels are reduced by the maximum area of micro defects.

2. If the average area of voids, oxide inclusions, and sulfide inclusions are a measure of the maximum area, then the Murikami equation can be modified to give an estimate of the endurance limit.

3. These calculations show that a 7- to 10-percent reduction in endurance limit may occur between a wheel steel with an existing average discontinuity area and a wheel with the largest inclusion area.

4. There is a 20-percent lowering of the calculated endurance limit between the minimum and maximum void and sulfide average areas.

References

1. T. Murikami and M. Endo, "Effects of Defects, Inclusions and Inhomogeneities on Fatigue Strength," *Fatigue*, Vol. 16, April, 1994, pp. 163-182.
2. G. E. Dieter, Mechanical Metallurgy, 2nd Ed., McGraw Hill, USA, Tokyo Japan, 1976.
3. S. Mahadevan, Y. Liu, F.C. Robles H., D. Stone, "Advanced Modeling Capabilities for Railroad Wheel Failure Analysis", TTCI internal report, Pueblo, CO, 81001, USA, December, 2006.
4. Cameron Lonsdale and Steven Dedmon, "Fatigue Testing of Microalloyed AAR Class C Wheel Steel," Paper IMECHE2006-13366, Proceedings of IMECHE2006, November, 2006.
5. George L. Kehl, "The Principals of Metallographic Laboratory Practice," McGraw-Hill (New York, 1949) p. 222.