Experimental multiparameter analysis of wear of 100Cr6 steel: scattering and limits of Archard's law

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One of the major challenges in the investigation of wear is the considerable scattering of test results [1].
In the first part, the influence of widely varied operating parameters and different tribometers on the reproducibility and repeatability of volumetric wear was studied taking advantage of a big dataset (416 data) for reciprocating ball-on-plane tests with self-mated 100Cr6 steel.
Subsequently, the limits of Archard's law [2] are examined. Experiments with additional variation of the normal force and of the ball radii show that, below a certain initial pressure, the wear coefficient is not constant, i.e., Archard's law cannot be applied.

Keywords: scattering, wear coefficient, Archard's law, 100Cr6 steel, big dataset

1. Introduction

Values of the wear coefficient usually show large scattering and thus poor repeatability and reproducibility. This hinders researchers from identifying tribological laws and effects of operating parameters. In particular, serious limits of Archard's law have been ascertained in several studies. Hence, the general applicability of Archard's law and the wear coefficient need to be verified (or rejected) through a comprehensive analysis.

2. Methods

Big datasets are mandatory to get reliable statistical results and to study phenomena affected by large scattering. Results of own tests and data collected in a databank (TRIDAS) of the Federal Institute for Material Research and Testing have been employed to perform a statistically meaningful analysis.
All tests were unlubricated, with 100Cr6 ball on 100Cr6 plane under reciprocating sliding and with temperature between 17 and 36 °C and relative humidity between 8 and 70 %.
Conditions and parameters were varied as shown in Table 1.

Table 1: Ranges of experimental conditions and parameters

N° of tribometers	4
Frequency ν	0.1–511 Hz
Stroke Δ*x*	20–9688 µm
N° of cycles *N*	110–10^7
Normal force F_N	0.1–400 N
Ball radius *R*	2–6.35 mm

2.1. Results

- The fit of 325 values of the volumetric wear as a function of sF_N (product of normal force and sliding distance) for $F_N \leq 20$ N yields $W_v = 126\,(sF_N)^{0.79}$, with sF_N in mN and W_v in 10^{-6} mm³, (Fig. 1). Hence, Archard's law cannot be applied.
- The probability of Welch's test performed with the residuals of the fit are 99 % (ν), 72 % (N), 96 % (Δx), and 98 % (F_N). Hence, the parameters do not affect the wear volume W_v and its fit with a function of sF_N.
- Measurements with $F_N \geq 40$ N or different ball radii show that the initial pressure determines whether the wear coefficient is constant or not, i.e., whether the volumetric wear follows Archard's law or not.

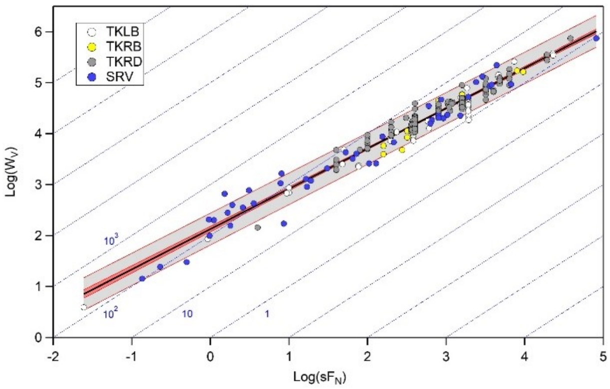

Figure 1: Total wear volume vs product of normal force and sliding distance for tests performed on four tribometers with $F_N \leq 20$ N. The fit is shown as a black line, confidence and prediction band in pink and light grey. Dashed lines have a constant wear coefficient, given in 10^{-6} mm³/Nm.

3. Discussion

The analysis shows that measurements of the volumetric wear are repeatable and reproducible. They are affected neither by different devices nor by operating parameters such as frequency and stroke. Data for $F_N \leq 20$ N can be fitted with an equation in the form $W_v = c\,(sF_N)^m$, with $m < 1$, showing that no wear coefficient $k = W_v/sF_N$ can be defined and Archard's law cannot be applied. The initial pressure is crucial for the applicability of Archard's law. This phenomenological analysis is suitable as basis for future theoretical studies and simulations.

4. References

[1] Wallbridge, N. C., Dowson, D., "Distribution of wear rate data and a statistical approach to sliding wear theory", Wear, 119, 1987, 295-312
[2] Archard, J. F., "Contact and rubbing of flat surfaces", J. Appl. Phys., 24, 1953, 981–988