Fatigue testing for coatings: A systematic approach using micro-impact testing on TiN

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Abstract
A practical and systemic method to quantify coatings' fatigue strength has been outlined and tested on titanium nitride (TIN) coating using multi-cycle and multi-load micro-impact testing with a spherical indent.

1. Introduction

Since the 1960s, tool steels have been coated with titanium nitride (TIN). High hardness and adhesion, strong ductility, excellent lubricity, high chemical stability, and severe resistance to wear, corrosion, and temperature are just a few of the benefits of TiN coating. However, the fatigue strength of coating (including TiN) has not been assessed or appropriately quantified. In this paper, we provide a systematic framework for investigating coatings' fatigue properties using micro-impact testing on TiN, outlining a systemic approach to the experiment, and analysing the data to extract an S–N curve description for coating.

2. Results

Impact testing was performed on tool steels coated by a ~1.5 µm thick TiN layer. The sample was systematically impacted using a spherical indent with a 5 µm indent in multiple sites repetitively. The load used was determined by impact testing the sample 10 times at the same place using different loads (L) that follow the Fibonacci number sequence ($L_n = L_{n-1} + L_{n-2}$) until the coating failed. Once the upper limit was determined, the sample was impact tested using different loads and cycles (Figure 1).

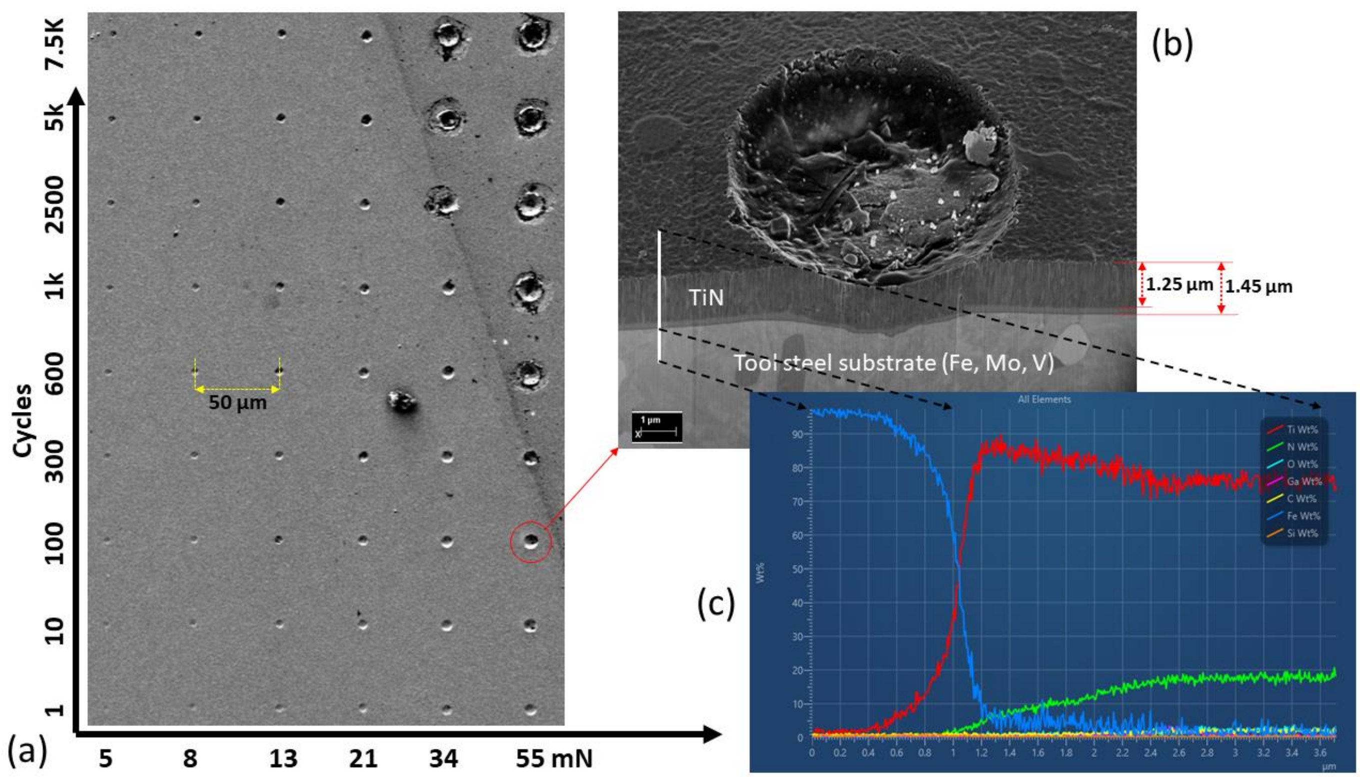

Figure 1: (a) low-voltage secondary electron image (SEM) for the impact cycling test on TiN coating using a spherical 5 µm indent with different cycles and load at room temperature. (b) SEM image for the impact site with 55 mN and after 100 cycles. (c) Energy-dispersive X-ray spectroscopy line profile.

Impact testing depth was recorded four times during each cycle. The depth (D) with cycles (N) relationship before failure was fitted using $D(N) = a\sqrt{N} + c$, where c describes the depth at the 1st impact and a represents the gradient $\left({}^{dD}/_{dN}\right)$. The fitting was limited to data before the coating failure, defined as indent sink-in and hug jump in the depth measurement. Failure was confirmed using secondary electron imaging to validate the correlation between the abrupt change in depth measurement and failure. TiN coating failure is related to the mailability of the steel substrate as it extruded with deformation (Figure 1a). Interrogation for the data from further impact testing using supervised machine learning regression allowed for linking a and c to load. The final relationship between the depth, load and cycles is $D(L, N) = \Delta K^{0.03L}.\sqrt{N} + 30L$, where ΔK equals 2.7 ± 0.6 MPa m0.5 which is within the fracture toughness values reported in the literature. However, caution must be exercised when interpreting the fitting parameters similar to care exercised with coefficients that are assumed in similar fatigue equations, i.e., the Paris-Erdogan equation.

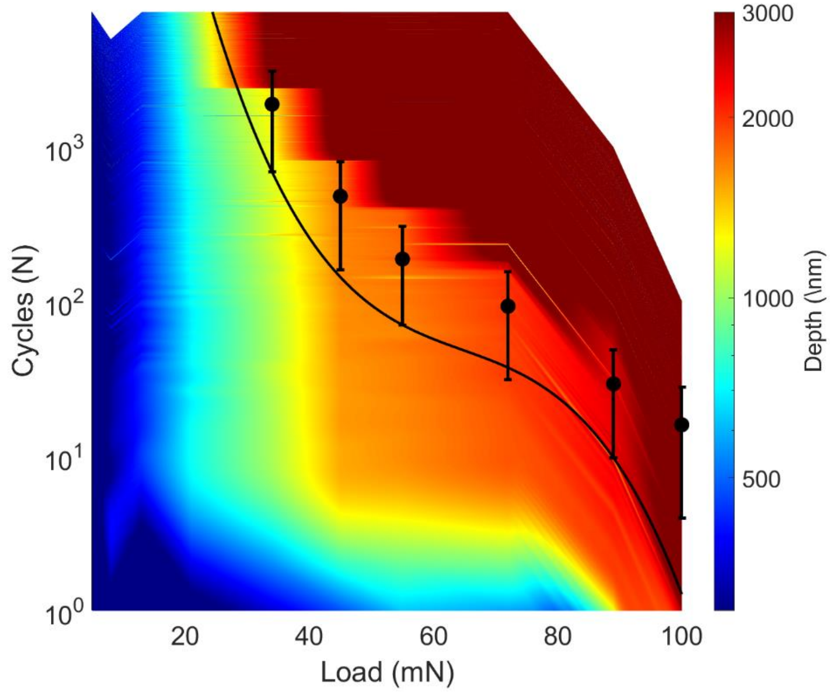

Figure 2: Impact depth data from multi-cycle micro-impact testing on TiN coating using different loads and cycles. The fitting is for the lower variance limits from fitting the surface while ignoring depth information after coating failure (depth > 3µm). Depth or impact depth relates to a portion of the total length that the indent travels in and out of the sample defined by when the software decides where the zero is, which is not necessarily the original surface.

3. Conclusions

A systematic approach to testing coating fatigue strength was explored and validated, allowing defining the fatigue limits of coating. The framework will allow for incorporating data from different coating thicknesses at different operation temperatures, allowing for phenomenological interpretation of their fatigue behaviour.

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