Simulation of Wear using LiveLink™ for MATLAB®

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Introduction

An incremental wear model is developed using COMSOL Multiphysics 4.3 and LiveLink™ for MATLAB® to predict the evolution of contact surfaces due to the phenomenon of wear. Whilst Archard's wear law is a well-known empirical model for the prediction of wear volume, the design engineer is interested in changes in tolerance, related directly to wear depth, which vary according to the component geometry. The wear model presented uses the solid mechanics interface to solve a quasi-static linear elastic contact problem subject to Coulomb friction, and uses a finite difference discretisation controlled in MATLAB® to integrate forward in time and evaluate wear [1]. Wear calculations apply a local form of Archard's wear law [2] to calculate wear depth during each time step based on the contact pressure distribution. The model geometry is updated at each time step.

Of interest is the ball-on-flat reciprocating contact of an AISI 440C steel ball and a Diamond-Like Carbon coating in deionised water. The model predictions for the wear depth of each surface are validated by experiments.

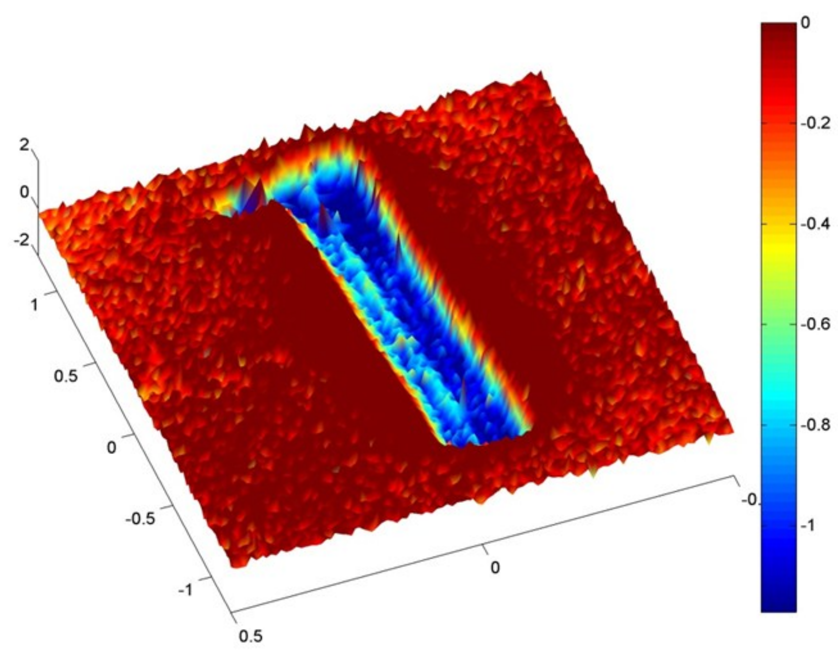

Figure 1: A colour map of the wear scar of a DLC coating after a reciprocating sliding test against an AISI 440C steel ball. A wear scar is 2 mm in length and typically 0.2 - 0.4 mm wide.

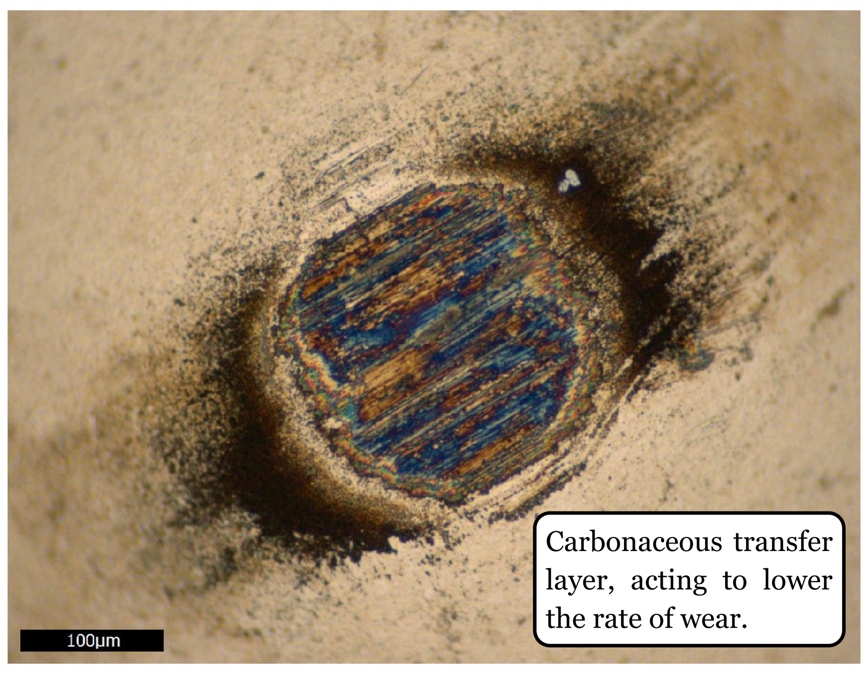

Figure 2: A typical image of the wear scar of an AISI 440C steel ball after a reciprocating sliding test against a DLC coating. A wear scar typically has a 0.2 - 0.4 mm diameter.

Materials and Methods

A Diamond-Like Carbon (DLC) coating is a 0.1—50 μm thick layer composed primarily of carbon atoms bonded in an amorphous configuration, known for high hardness, a low coefficient of friction, and high wear resistance [3]. As a result, DLC coatings may provide longer component lifetime and higher energy efficiency than their uncoated counterparts.

Figure 1 shows a typical wear scar of a DLC coating after reciprocating wear against a 6 mm diameter AISI 440C steel ball. **Figure 2** shows the wear scar of the AISI 440C ball. A *transfer layer* covers the contact region, composed of wear debris from the DLC coating, which acts to lower the specific wear rate (SWR) of each surface as it develops in the contact region throughout the test.

The finite element model comprises a quasistatic point contact of an AISI 440C steel ball and a flat 2 μm thick DLC coating deposited on an AISI 440C steel flat (see **Figure 3a**). The model uses a two-dimensional plane strain approximation, and the contact boundaries are interpolated from a set of coordinates calculated in MATLAB®. The *active region* (see **Figure 3b**) has its elastic properties defined by a polynomial which bisects the region and describes the current thickness of a transfer layer across the contact. In this manner, a quasistatic analysis accounting for the transfer layer growth is provided.

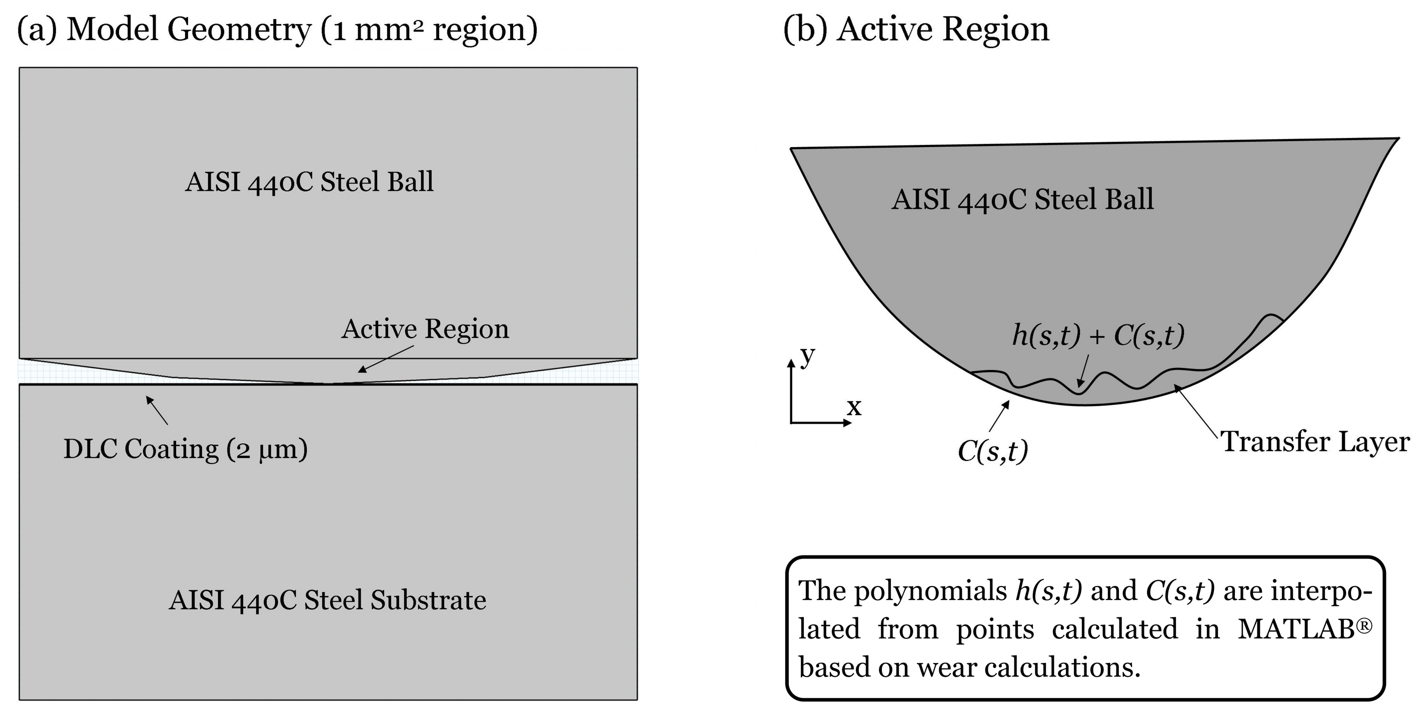

Figure 3: (a) The finite element model geometry, and (b) a sketch of the active region of the ball, where the contact surface and the transfer layer height are defined by polynomials $C(s, t)$ and $h(s, t)$, respectively.

Preston [2] suggested that the rate of change of wear depth should vary proportionally to the contact pressure P and sliding velocity v.

$$\frac{dw_D}{dt} = kPv \tag{1}$$

The specific wear rate k is postulated to decrease from k_o to k_T as the normalised transfer layer thickness h increases from 0 to 1 according to a logistic function.

$$k = k_0 + (k_T - k_0)h \tag{2}$$

$$h = \frac{1-e^{-\alpha t}}{1-e^{-\alpha T}} \tag{3}$$

Wear depth is evaluated at each interpolation point by integration of (1-3) using the Forward Euler method. The finite element model is solved during each time-step to obtain the contact pressure distribution. To minimise solution time and numerical errors, a diffusion equation is solved to artificially smooth the contact pair whilst conserving the macroscopic geometric shape.

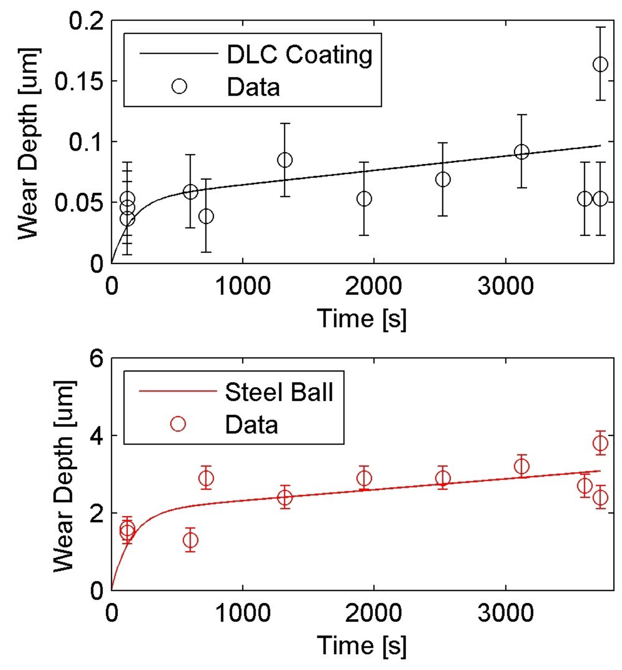

Figure 4: The model predictions for wear depth of a DLC coating (top) and an AISI 440C steel ball (bottom) at 5 N and 5 Hz compared to the experimental data. Error bars represent the error in experimental measurements.

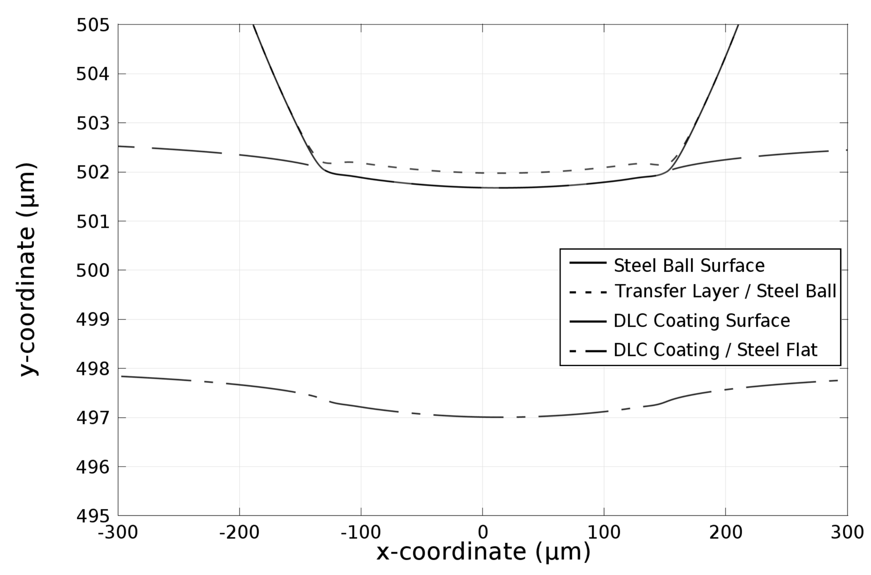

Figure 5: The elastically deformed final geometry after 3600 seconds of sliding between a DLC coating and an AISI 440C steel ball. The steel surface (solid line), transfer layer / steel ball boundary (dotted line), DLC coating surface (dashed line), and DLC coating / steel boundary (dot-dashed line) are as marked.

Results and Conclusion

The model is shown to reproduce faithfully the wear depth of a DLC coating and AISI 440C steel ball as they slide relative to each other (**Figure 4**). The final elastically deformed model geometry is given in **Figure 5**.

- The formulated wear model allows for prediction of wear depth of a generalised geometry based on an experimentally determined wear rate. A diffusion equation is used to minimise the magnitude of numerical error.
- The model presented for a Diamond-Like Carbon coating can be extended to three -dimensions, or to include plastic deformation of the transfer layer.

References

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Acknowledgements

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