THERMODYNAMICS BASED APPROACH TO PREDICT FRETTING FATIGUE LIFE AND THE ADHESIVE WEAR RATE

Sarosh Mumtaz Quraishi
M.S. Candidate

Faculty Advisor: Dr. Michael M. Khonsari

ABSTRACT

The aim of this research is to use the principles of thermodynamics to predict the tribological damages like fretting [1] and wear [2]. The thermodynamics based theory [3] of Continuum Damage Mechanics (CDM) has been used for this purpose. The CDM [4] has been classically used to solve creep, fatigue, and creep-fatigue interaction problems. Fretting is a surface damage that occurs due to repeated slippage of contacting assemblies. Fretting fatigue is due to oscillating nature of surface tractions. Fretting can also lead to surface wear and corrosion under specific circumstances. Fretting is commonly observed in contacting assemblies such as bearings, mechanically fastened joints (e.g. riveted joints), turbine blade pair (e.g. dovetail joints), and artificial hip joints.

We have used the thermodynamic theory of CDM for predicting crack nucleation life in fretting fatigue. This is done by calculating subsurface shear-stress distribution due to fretting loading conditions and obtaining corresponding principal plane location. For given fretting conditions such as the load, the coefficient of friction and the bulk material properties (Table 1), the model predicts the number of cycles to crack nucleation. The results are validated with published experimental data and show a reasonable match for the materials simulated (Fig 1 & 2).

Table 1. Tensile and cyclic material properties-taken from Bhattacharya [3], and Boller [5].
* COF obtained from [6], [7].

<table>
<thead>
<tr>
<th>Material</th>
<th>Al-2024-T4</th>
<th>S45C</th>
<th>SCM 435</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$ (GPa)</td>
<td>70.4</td>
<td>210</td>
<td>193</td>
</tr>
<tr>
<td>$H$ (MPa)</td>
<td>856</td>
<td>740</td>
<td>965</td>
</tr>
<tr>
<td>$M$</td>
<td>9.1</td>
<td>4.78</td>
<td>6.2</td>
</tr>
<tr>
<td>$\sigma_f$ (MPa)</td>
<td>683</td>
<td>1105</td>
<td>1903</td>
</tr>
<tr>
<td>$S_e$ (MPa)</td>
<td>138</td>
<td>100</td>
<td>566</td>
</tr>
</tbody>
</table>

Figure 1: SN curve for initiation of fretting cracks in Al-2024.

Figure 2: SN curve for initiation of fretting cracks in S45C.

Wear is a very commonly occurring phenomena, it results in removal of material from a surface. It can be
classified based on various mechanisms; adhesive wear is the most common.

Our research on wear deals with application of continuum damage mechanics (CDM) in predicting sub-asperity crack nucleation in adhesive wear. The existing theories (e.g. delamination theory [8]) on adhesive wear implicates that there is a phenomena of crack nucleation and subsequent propagation in adhesive wear, resulting in asperity breakage. The broken asperities cling to the other surface and in due time they come loose of the surface in the form of wear debris. In this research a simple asperity contact model is made where a single asperity is being subjected to intermittent shear loading. The number of cycles of shear load a single asperity can sustain prior to crack nucleation is obtained from CDM model. This would give us a lower bound to the probability an asperity has to form a wear particle; the inverse of this probability is by definition the wear coefficient appearing in the Archard’s Wear equation. So the wear coefficient from this simulation will give a higher bound when compared to experiments (Fig 3).

![Figure 3: Wear rate (mm³/mm sliding) versus Load (Newtons) of SCM 435 on a log-log plot.](image)

The only input parameters of the model are the materials properties (Table 1) and loading conditions. One of the shortcomings of the wear model is that we have used the bulk material properties to simulate crack nucleation in an asperity, while it is a known fact that the material properties can be significantly different in the asperity due to the size dependency effects.

To overcome this difficulty a parametric study is done to investigate the role of significant parameters that affect wear rate coefficient. The most sensitive parameter is the work hardening modulus. Our simulations show that for certain materials (Al 2024), doubling the work hardening modulus can result in up to 400 times reduction in wear rate coefficient. This behavior is commercially utilized to produce wear resistant coating and wear resistant surfaces by certain engineering processes.

REFERENCES