FINITE ELEMENT SIMULATION OF METAL MATRIX COMPOSITES — EFFECTIVE COEFFICIENTS OF FRICTION AND TEMPERATURE FIELDS UNDER FRICTIONAL LOADING

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INTRODUCTION

Computational predictions on the tribological behavior of metal matrix composites (MMCs) are carried out. The influence of particle volume fraction and clustering of particles is investigated at different length scales. Finite Element simulations are performed on unit cells utilizing approaches from the field of 'continuum mechanics of materials'. Models are based on the work of Segurado et al. [1], who used homogeneous, randomly distributed inclusions in a matrix phase with 30% particle volume fraction. In addition, the present work introduces modified unit cells with 10% volume fraction, with both homogeneous random and clustered distribution (Fig. 1). These modifications are derived from the original cell by either randomly removing inclusions in the first case, or from a predefined area in the second case.

MODELING

A modified periodic microfield approach is used to investigate the mechanical and thermal response of the composite material subjected to macroscopic frictional loading. Rectangular multi-inclusion unit cells represent the MMC by modeling various distributions of particles embedded in a matrix phase. The tribo-surfaces of the cells show cut particles and allow for interaction with the counter-body (Fig. 1). At the two lateral sides the periodic matrix-inclusion geometry is forced to deform periodically and to show equal temperature fields by applying appropriate coupling equations. The temperature and the deformations are fixed at the bottom surface. Plain stress assumptions are used. The matrix material as well as the circular particle domains are taken to behave thermo-elastic. A perfect mechanical and thermal interface between the matrix and its inclusions is assumed. Each phase has its individual coefficient of friction with respect to the counter-body. The cells are loaded by a macroscopic contact pressure and a tangentially moving counter-body, and are analyzed by the Finite Element program ABAQUS (ABAQUS Inc., Pawtucket, RI).

EXAMPLES AND RESULTS

Such investigations are carried out in order to predict the frictional behavior of Ti-matrices reinforced by TiC-particles. The Young’s moduli, Poisson ratios, coefficients of thermal expansion, thermal conductivities, and coefficients of friction against steel for matrix, m, and particles, p, read $E^m = 103\text{GPa}$, $E^p = 440\text{GPa}$, $\nu^m = 0.3$, $\nu^p = 0.19$, $\alpha^m = 9.6 \cdot 10^{-6}\text{K}^{-1}$, $\alpha^p = 8.0 \cdot 10^{-6}\text{K}^{-1}$, $k^m = 6.5\text{Wm}^{-1}\text{K}^{-1}$, $k^p = 18\text{Wm}^{-1}\text{K}^{-1}$, $\mu^m = 0.33$, and $\mu^p = 0.6$. An overall contact pressure of 1MPa and a sliding speed of 2mm/s are used for the simulations. The thermo-mechanical interaction at and underneath the tribo-surface determines the local contact pressure distribution and,
Figure 1. UNIT CELL MODELS WITH HOMOGENEOUS (TOP) AND CLUSTERED (BOTTOM) DISTRIBUTION OF 10% VOL PARTICLES.

hence, the local frictional forces.

Figure 2 (left) shows the predicted contact pressure for the 10% vol clustered configuration for steady state conditions. In the reinforced region, high fluctuations are caused by individual particles. Due to the higher stiffness of this region, the cluster average is higher than the global value of the contact pressure. The predicted averaged coefficients of friction for various configurations are listed in Table 1. The local contact pressure and the local coefficient of friction determine the frictional heat dissipation, which acts as thermal loading within a heat transfer analysis solving for the local temperature fields. At the cluster more heat is dissipated, giving rise to an elevated temperature despite the higher thermal conductivity in the cluster. Figure 2 (right)

Table 1. PREDICTED AVERAGE VALUES FOR THE COEFF. OF FRICTION, $\mu$, CONTACT PRESSURE, $p$, HEAT FLUX, $q$, AND TEMPERATURE RISE, $T$, FOR THE DIFFERENT MODELS AND REGIONS WITH VOLUME FRACTION $\xi$. 

<table>
<thead>
<tr>
<th>$\xi$</th>
<th>$\mu$</th>
<th>$p$</th>
<th>$q$</th>
<th>$T$</th>
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<tr>
<td>[%]</td>
<td>[-]</td>
<td>[MPa]</td>
<td>[Wm$^{-2}$]</td>
<td>[K]</td>
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<td>-</td>
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<td>0.602</td>
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<tr>
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<td>-</td>
<td>1.16</td>
<td>0.964</td>
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</table>

Figure 2. PREDICTED CONTACT PRESSURE (LEFT) AND SURFACE TEMPERATURE RISE (RIGHT) FOR THE 10% VOL CLUSTERED CONFIGURATION.

shows the temperature distribution at the contact surface for the clustered cell.

Note that the temperature fields, together with the phase contrast in thermal expansion, cause thermally induced stresses. Their computation lies fully within the capabilities of the models, however, for the present material, this effect is of minor significance. Due to the limited amount of particles at the surface, several generic unit cells sharing the same topological descriptors should be investigated and averaged appropriately in order to obtain quantitatively reliable results [1].

CONCLUSIONS

The thermomechanical behavior of multi-inclusion unit cells with different volume fractions and homogeneous as well as clustered particle distribution is shown. The simulations are done with the Finite Element method utilizing a micro-mechanics of materials approach. Macroscopic, regional, and local values for the contact pressure, coefficient of friction, heat dissipation, and temperatures are predicted.

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REFERENCES