Internship project
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Micromechanical modeling of melt-infiltrated metal-ceramic composites

Fig. 1: Polarized light microscopy micrograph of the microstructure (left) and single domain with inclusions (right)

Definition of the Problem
An innovative melt-infiltrated metal-ceramic material is made of an eutectic aluminium-silicium alloy (Al12Si) metal matrix embedded by squeeze-casting into a porous alumina (Al2O3) ceramic matrix. The microstructure of the material obtained presents some lamellar-like domains with geometrical characteristics which are dependent on the manufacturing parameters. Fig. 1 shows a typical microstructure of the specimen. The aluminium inclusions (in white) are local oriented in the same direction and form domains with the same inclusions orientation. These inclusions appear as elliptical cylinders extruded in the freeze casting direction, i.e. perpendicular to the (x1, x3) plane. The aim of this project is to find a good micromechanical model in order to deduce the mechanical properties of the single domains and of the whole material as a function of the microstructural geometry and the material parameters of alumina and aluminium.

Scientific Approach

Problem solution:
1. Statistical studies of polarized light microscopy micrographs of the specimen. Detection, selection and measurement of the domains with the same inclusions orientation.
2. Micromechanical modeling. Different micromechanical models (Fig. 2) have been applied for the determination of the mechanical characteristics of one single domain and the whole specimen. The data of the statistical studies will be used as input for the modeling of the whole specimen.
3. Selection of the models. The best micromechanical models are selected with comparison to experimental results seen in [1].
Fig. 2: Micromechanical models used

Results

1. Table 1 shows the results from the simulation for one single domain. Compared to the values from ultrasonic measurements, the method which gives the best results is inverse Mori-Tanaka method (MT).

2. Table 2 includes all possible combinations (step1 + step2) to obtain the mechanical properties of the whole material. A relatively large number of combinations gives good results but the best one seems to be the association of exact solution for laminates associated to the Reuss approximation.

Table 1: Results for one single domain

<table>
<thead>
<tr>
<th>Values in GPa</th>
<th>C1111</th>
<th>C2222</th>
<th>C3333</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic studies (Wanner &amp; Roy)</td>
<td>215</td>
<td>236</td>
<td>165</td>
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<tr>
<td>Exact solution (lam)</td>
<td>269</td>
<td>266</td>
<td>196</td>
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<tr>
<td>Approximation (lam)</td>
<td>282</td>
<td>260</td>
<td>176</td>
</tr>
<tr>
<td>Mori-Tanaka</td>
<td>251</td>
<td>262</td>
<td>165</td>
</tr>
<tr>
<td>Inverse MT</td>
<td>220</td>
<td>260</td>
<td>176</td>
</tr>
</tbody>
</table>

Table 2: Results for the whole specimen

Remark: The stiffness in the freeze casting direction ($C_{2222}$) is unfairly over-estimated. This is because in our approximation the inclusions are modeled as perfect cylinders and microstructural changes in the freeze casting direction are not taken into account.

Literature


(2) S. Roy, A. Wanner, Metal matrix composites from freeze-cast ceramic preforms: Domain structure and elastic properties, article in press.

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