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Modelling of thermal stresses and damage in Cu/Al_2O_3 interpenetrating phase composites

Witold Weglewski*, Michal Basista

Institute of Fundamental Technological Research, Polish Academy of Sciences
Pawinskiego 5B, 02-106 Warsaw, Poland
wweglew@ippt.gov.pl, mbasista@ippt.gov.pl

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Introduction

The interpenetrating phase composites (IPC) are strongly different in their morphology, properties and processing than typical metal matrix or ceramic matrix composites. The basic morphological difference in comparison to particulate reinforcement composites is that the two components of IPC form continuous, interpenetrating 3D network. The IPC are more homogeneous, have better mechanical and thermal properties (abrasiveness and fracture toughness, thermal conductivity and mechanical stability) than the matrix composites. The processing of IPC is typically done by a pressure or pressureless infiltration of porous ceramic matrix with a molten metal [1, 2]. The infiltration is a high temperature process (e.g. for Cu/Al_2O_3 IPC the infiltration temperature is above $1200^{O}C$) which is usually associated with the generation of thermal stress because of largely different coefficients of thermal expansion of the IPC constituent phases. The aim of this work is twofold: (i) to build a numerical model of thermal stress generated during the processing of the interpenetrating phase composites, and (ii) to build a numerical model of the initiation and growth of microcracks induced by the thermal stresses during the processing of the IPC. The results yielded by the models will be compared with the experimental data. The model can be used to improve the processing of IPC by providing feedback as to how to reduce thermal residual stresses and how to minimize a risk of the microcracking during the production of the IPC.

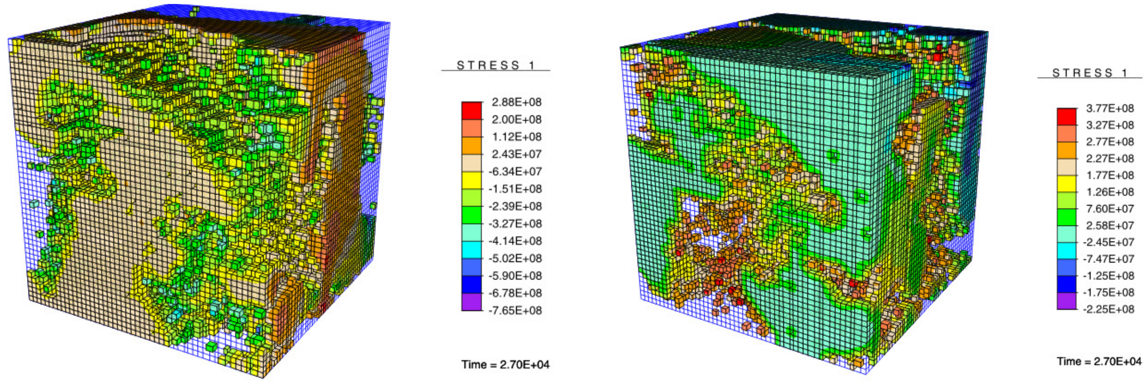
Thermal stress modeling

Typical metal matrix (MMC) or ceramic matrix (CMC) composites with spherical or fiber reinforcements are very well modeled using FEM. The modeling of IPC is more complicated because of the complex 3D microstructure formed by the interpenetrating phases. The best way to make the proper finite element mesh of an IPC is to generate it basing on the real microstructure scans from the computer microtomography [3].

In our modeling the synchrotron radiation computer microtomography was used. The scans were implemented into the commercial software (ScanIP and ScanFE) and the respective FE mesh was generated. The FE mesh was then used in the FEAP software and the thermal stresses were calculated. The cooling process was conducted inside a graphite die from $1200^{o}C$ down to room temperature. In Table 1 material properties used in the modeling are listed. An example of the obtained numerical results of the thermal stresses distributions are presented in Figure 1.

Table 1: Material properties used in the FEM model

	Al_2O_3	Copper
Young's modulus [GPa]	390	114
Poisson's ratio	0.2	0.35
Coefficient of thermal expansion [1/deg]	$6.5\cdot 10^{-6}$	$16.5\cdot 10^{-6}$
Specific heat [J/kg/deg]	800	380
Thermal conductivity [W·m/deg]	18	395
Density [kg/m^3]	4000	8900
Infiltration temperature [^{o}C]		1250



a) b)

Figure 1: Thermal stresses generated in a) Al_2O_3 and b) copper phase of the IPC composite during the cooling process after the infiltration.

Microcracking and its influence on Young's modulus

As one can see from Figure 1, the average thermal stress inside the ceramic phase has a negative sign (compression) . However, large local tensile stresses (about 280 MPa) also appear. These tensile stresses can lead to the initiation and propagation of microcracks during the cooling process. The microcracks can reduce the overall mechanical properties of the composite. The influence of the thermal stress induced damage on the Young modulus will be presented and compared with the experimental data.

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