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Thermal stress and microcracking in the processing of the interpenetrating phase composites

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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 with 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 (abrasibility 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 ceramic porous 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 $1200^{O}C$ and for Al/Al_2O_3 about 700 ^{O}C) which is usually associated with the generation of thermal stresses because of largely different coefficients of thermal expansion of the IPC components (cf. Table 1).

Objectives

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 models 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.

Material properties and process conditions

The processing of IPC is a high temperature process. Table 1 presents the material and process properties (input values used in the FEM computation). The thermal stress are calculated for two interpenetrating phase composites: Cu/Al_2O_3 (30% Cu) and Al/Al_2O_3 (70% Al). The high differences in the coefficients of thermal expansion of the ceramic and metal phases in these two IPCs lead to the generation of the thermal stresses.

Table 1. Material and process properties

	Al_2O_3	Copper (Cu)	Aluminum (Al)
Young modulus [GPa]	390	114	69
Poisson ratio	0.2	0.35	0.33
Coefficient of thermal expansion [1/deg]	$6.5\cdot10^{-6}$	$16.5\cdot10^{-6}$	$25\cdot10^{-6}$
Specific heat [J/kg/deg]	800	380	896
Thermal conductivity [W·m/deg]	18	395	160
Density [kg/m^3]	4000	8900	2720
Infiltration temperature [^{o}C]		1200	700

Thermal residual stress

The real microstructure of an IPC is modeled using a simple RVE similar to the one proposed in [3]. This RVE is to account for the spatial nature of the IPC microstructure in which both metal and ceramic phases could be interconnected as continuous networks. The thermal residual stress is computed using FAEP version 7.5. The initial conditions assumed in calculation are given below:

- Cu/Al_2O_3 $\Delta T = T_{room} - T_{eff} = 20 - 420 = -400^{O}C$ where T_{eff} is the effective process temperature at which the cooling down metal starts exerting pressure on the ceramic network
- Al/Al_2O_3 $\Delta T = T_{room} - T_{eff} = 20 - 110 = -90^{O}C$

Below some examples of the calculated thermal stresses are presented.

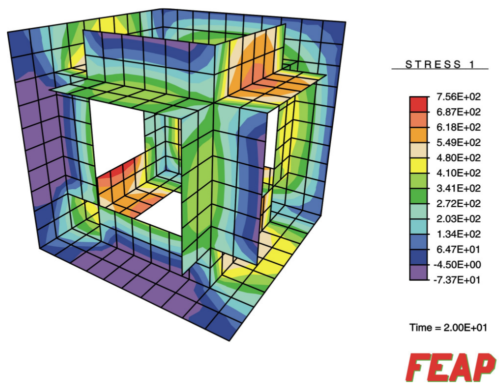

Fig.1. Cu/Al_2O_3, thermal stress in „11” direction. Metal phase.

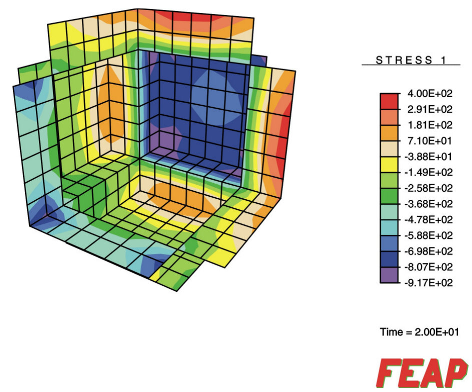

Fig.2. Cu/Al_2O_3, thermal stress in „11” direction. Ceramic phase.

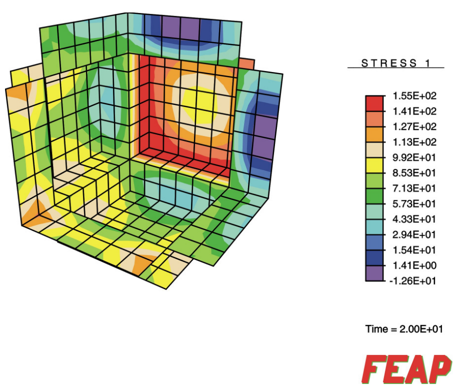

Fig.3. Al/Al_2O_3, thermal stress in „11” direction. Metal phase.

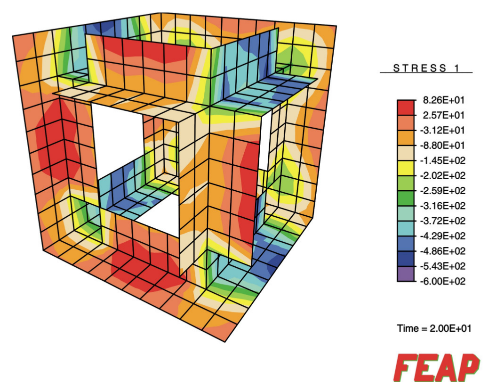

Fig.4. Al/Al_2O_3, thermal stress in „11” direction. Ceramic phase.

Microcracking and its influence on the Young modulus

The thermal stress (cf. Figures 1-4) 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 modelled and compared with the experimental data

References

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