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COMPOSITES

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NUMERICAL CALCULATION OF THE THERMAL CONDUCTIVITY COEFFICIENT IN DIAMOND-COPPER COMPOSITE

Metal-ceramic composites are becoming widely used in electronic and power generation industries. Applications of these composites are driven by their mechanical and physical property combined with economic price. One of the key properties in this context is their capacity for heat transfer. Diamond-copper composite was chosen for calculation because of very high coefficient of thermal conductivity and small decrease of mechanical properties under high temperature. Analytical results give solution of the thermal conductivity for case with only one particle in composite. Numerical analysis was appropriate to have results for more complex cases. Three model of representative unit volume with one isotropic particle was prepared to calculate cases with standard and high density of the particles. One model with real distribution of particles, which was generated by Micrometer program was used to compare results. In this work analysis of structure and features of phases composite was considered in order to study heat transfer phenomena. Models of three phases composite matrix, filler and interface with discontinuities were analysed. Distance between particles was also considered. Additionally, influence of the increased ambient temperature on thermal conductivity was presented. Analysis of the results indicate to volume fraction of the diamond phase, volume fraction of the discontinuity in interface layer and distance between diamond particles as the most important variable for conductivity. Obtained results for high thermal conductivity composites processing could be used to determine optimal phases characteristic and distance between particles.

Keywords: **geopolymers, composites, adhesion**

OBLICZENIA PRZEWODNOŚCI CIEPLNEJ KOMPOZYTU Cu-DIAMENT

Kompozyty metal-ceramika są coraz szerzej stosowanym materiałem w przemyśle elektronicznym i energetycznym. Ich popularność wynika z możliwości uzyskania unikatowych cech łączących właściwości mechaniczne i fizyczne przy zachowaniu akceptowalnej ceny. W pracy skupiono uwagę na właściwościach termicznych kompozytu, a szczególnie materiałów o wysokich wartościach przewodnictwa cieplnego. Do obliczeń modelowych wybrano kompozyt miedź-diament charakteryzujący się wysokim współczynnikiem przewodzenia ciepła, którego właściwości mechaniczne nie ulegają znaczącej degradacji w wysokich temperaturach. Dostępne rozwiązania analityczne pozwalają na wyznaczenie współczynnika przewodzenia ciepła kompozytu dla przypadku z pojedynczą cząstką, w którym nie dochodzi do oddziaływania między cząstkami. Do wyznaczenia przewodności cieplnej w bardziej złożonych przypadkach użyteczna jest analiza numeryczna, którą posłużono się w niniejszej pracy. Zastosowano metodę elementów skończonych, wykorzystując komercyjny pakiet Ansys. Do obliczeń użyto modelu komórki elementarnej z cząstką izotropową. Zastosowano dwa modele o różnym stopniu gęstości ułożenia cząstek oraz jeden model ze strukturą wygenerowaną w programie Micrometer o parametrach struktury odpowiadającej rzeczywistym kompozytom. Kluczowym parametrem w tego typu kompozytach jest dobór odpowiedniego udziału objętościowego poszczególnych faz. W pracy przedstawiono analizę wpływu struktury, właściwości poszczególnych faz oraz odległości między cząstkami na przewodność cieplną kompozytu przy uwzględnieniu właściwości fazy pośredniej oraz wpływ nieciągłości połączenia cząstka-osnowa. Dodatkowo przedstawiono wyniki analizy wpływu podwyższonej temperatury otoczenia na przewodność kompozytu. Otrzymane wyniki mogą posłużyć do optymalnego doboru składników i struktury, co pozwoli uzyskać założone wymagane właściwości kompozytu.

Słowa kluczowe: **kompozyt izotropowy, metoda elementów skończonych, przewodność cieplna**

ABBREVIATIONS

K_{Cu} - thermal conductivity of Cu matrix
K_{eff} - thermal conductivity of composite
K_{FP} - thermal conductivity of interface layer
L_D - diameter
L_{FP} - thickness of interface layer
L_{SW} - distance between particles edge
V_{FP} - volume fraction of interface layer
V_{vD} - volume fraction of particles
V_{vP} - volume fraction of pores

INTRODUCTION

Metal-ceramic composites are becoming widely used in electronic and power generation industries. Applications of these composites are driven by their mechanical and physical property combined with economic price. One of the key properties in this context is their capacity for heat transfer. Metal-matrix composites can be obtained by variety of fabrication routes with determine final microstructure. These microstructures can be adjusted for specific applications using the rules derived from modeling. Finite Element Method, FEM, is frequently used to develop pertinent relationship, which in particular take into account quantity, size and shape of second phase particles. In this paper, the results are described of FEM application to optimize the structure of Cu-diamond composite for heat management applications.

METHOD AND MODEL

The FEM analyses have been carried out using commercial software Ansys 10. The Solid 45 elements have been employed. The model structure used in computations, with more than 5000 nodes, is shown in Figure 1. Figure 1a illustrates the ”global” microstructure representative of a composite characterized by randomness in geometry of particles and their arrangement and Figure 1b shows so-called Representative Unit Volume RUV. Figure 1c shows a volume representative of the composite with 12 RUV. Figure 1d presents model with thick particles packing which consist of 10 RUV.

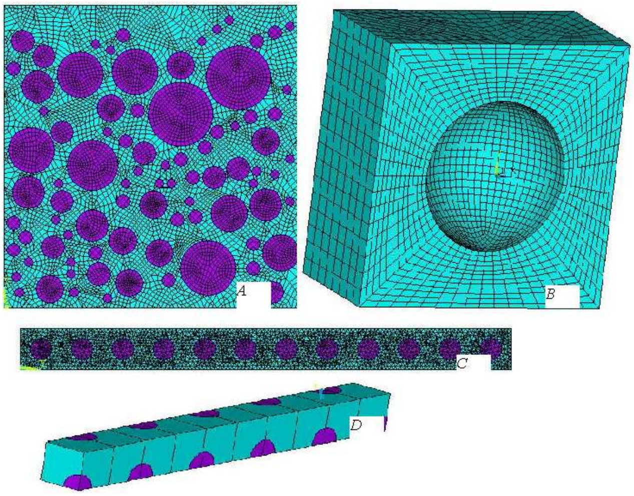

Fig. 1. Geometrical model with mesh (A, B, C) and geometrical model (D)

Rys. 1. Model geometryczny z dyskretyzacją (A, B i C) i model geometryczny (D)

RESULTS

Analysis considers relationship to thermal conductivity of composite by:

- volume fraction of particles,
- changes of interface layer properties,
- volume fraction of discontinuity in interface layer,
- changes of composite conductivity with temperature,
- distance between particles.

Comparison of results for each model is presented in Figure 2. Models (A), (B) and (C) give quite good agreement and results are compatible with theoretical solution for rare volume fraction of particles in work [1]. Only model (D) is characterized by better conductivity. This kind of effect is related to the composite structure, it tight packing of particles is decisive. The composite coefficient of thermal conductivity is grater than coefficient of thermal conductivity for the copper. Maximum value of the composite thermal conductivity is in good agreement with those measured in experiment [8].

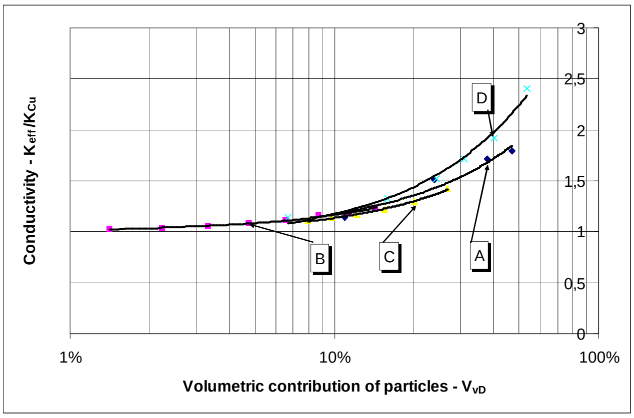

Fig. 2. Results of different models

Rys. 2. Wyniki dla różnych modeli

The influence of the interace layer properties is presented in Figures 3 and 4. The results in Figure 3 are presented as a function of the interface thickness normalized by the particles diameter. It can be noted that the interface thickness has relatively weak effect on the heat conductivity. Much more strong dependence is observed in the case of the heat conductivity of the interface layer (Fig. 4).

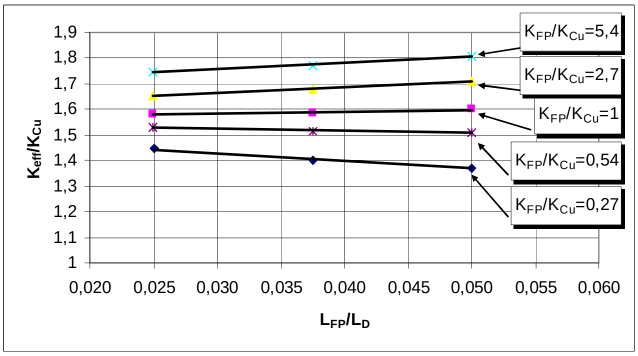

Fig. 3. Results of influence interface layer thickness to thermal conductivity of composite

Rys. 3. Wyniki wpływu grubości warstwy pośredniej na przewodność kompozytu

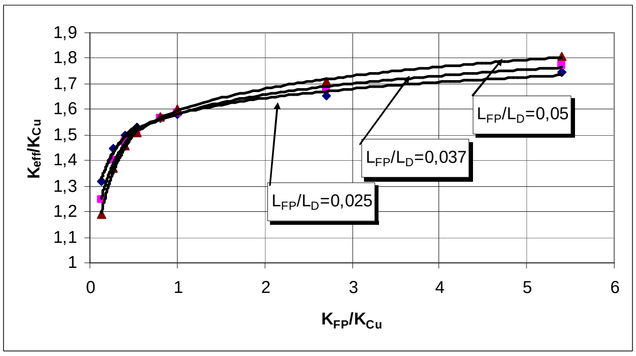

Fig. 4. Results of influence interface layer conductivity to thermal conductivity of composite

Rys. 4. Wyniki wpływu przewodności warstwy pośredniej na przewodność kompozytu

Results in Figures 3 and 4 could be divided in two region. First with conductivity of the interface layer below conductivity of the matrix and second one with conductivity of interface layer higher than matrix conductivity. In Figure 3 the limits between these two region is for conductivity of interface layer normalized by matrix conductivity K_{FP}/K_{Cu} equal about 1. In the second figures the limit is a little below conductivity of matrix. For small values of the interface conductivity, the composite conductivity increase rapidly with its increase. On the other hand with the interface conductivity approaching conductivity of the copper matrix, the changes are rather small.

The effect of interface layer is further elaborated in Figure 5 which shows the changes in the composite conductivity due to the presence of pores at the particle matrix interface.

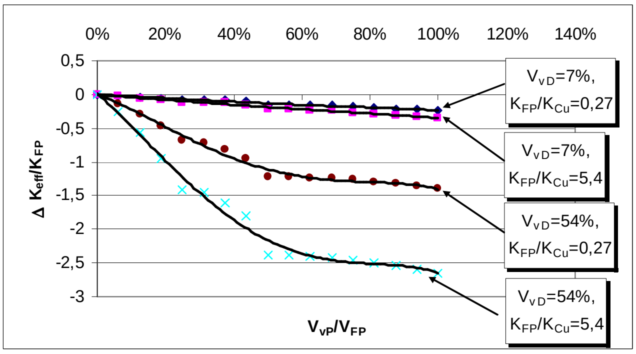

Fig. 5. Results of influence pores in interface layer to thermal conductivity of composite

Rys. 5. Wyniki wpływu porów w warstwie pośredniej na przewodność kompozytu

It can be noted that the presence of pores has especially strong impact on the properties of composite with high conductivity interface layers. In view of high temperature application of the composites modeled in this study, the analysis has been extended to take into account the effect of ambient temperature. The results of this analysis are shown in Figure 6.

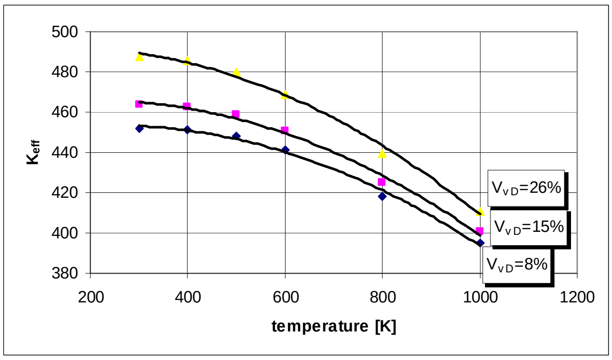

Fig. 6. Dependency of thermal conductivity via ambient temperature

Rys. 6. Zależność przewodnictwa cieplnego w funkcji temperatury otoczenia

As show in Figure 6 the heat conductivity steadily decrease with the temperature and at 1000 K it drops to 80% of the values for room temperature.

The results obtained in the present work clearly indicated the influence of the distance between particles for optimizing the thermal properties of composites. As shown in Figure 7 the effect of inter-particle distance is especially strong for the densely packed structures, in which then distance is smaller than particle diameter.

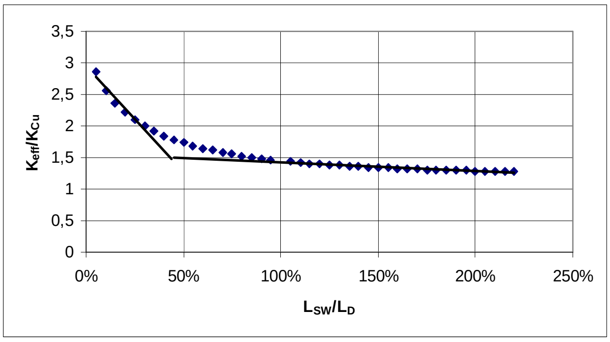

Fig. 7. Influence of distance between particles to composite conductivity

Rys. 7. Wpływ odległości pomiędzy cząstkami na przewodność kompozytu

DISCUSSION

The results of modeling carried out in this study show influence of particle size, shape and distribution on thermal properties of Cu-diamond composites. The results clearly show that heat conductivity and/or porosity of the interface layers have a strong effect on the conductivity of the composite. In view of the results obtained here it is recommended that the interface porosity does not exceed 20%. For the interface layer the effect is becoming negligible.

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