学 位 論 文 要 旨

Thermal and Mechanical properties of Al/AlN interpenetrating phase composites with different preform porosity

（プリフォーム多孔体の構造が **Al/AlN** 相互貫入複合材料の熱的，機械的性質に与える影響）

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In the realm of advanced materials, three-dimensional network interpenetrating phase composites (IPCs) have emerged as a subject of intense scholarly interest and research. Over the past decades, diverse compositions of IPCs, spanning metal-ceramic, metal-polymer, metal-metal, ceramic-polymer, and polymer-polymer IPCs, have been meticulously developed and investigated. Notably, metal-ceramic IPCs have garnered paramount attention owing to their exceptional amalgamation of ceramic's inherent properties, such as wear resistance, high hardness, and dimensional stability, with the advantageous traits of metals, including good plasticity, high toughness, and superior thermal and electrical conductivity. This unique synergy engenders metal-ceramic IPCs with remarkable mechanical and thermal characteristics.

Among metallic phases, aluminum and its alloys stand out due to their remarkable attributes, encompassing low density, high specific strength, excellent thermal conductivity, corrosion resistance, and eco-friendliness. Consequently, considerable research endeavors have centered on leveraging aluminum-based IPCs as promising materials. While extensive studies have delved into the mechanical and thermal properties of aluminum-based IPCs, the ceramic phases have predominantly featured compositions of Al_2O_3 and SiC, with limited exploration concerning AlN.

Aluminum Nitride (AlN) presents a compelling alternative, boasting notable advantages such as high hardness, stiffness, thermal conductivity, and a coefficient of thermal expansion compatible with SiC. Moreover, its chemical stability mitigates potential adverse reactions at the interface with aluminum alloys, thus preserving interfacial bonding integrity. Hence, the exploration of Al/AlN IPCs holds immense potential, particularly in aerospace and electronic packaging applications.

Given the critical significance of this research direction, a systematic investigation into the mechanical and thermal properties of Al/AlN IPCs emerges as an imperative undertaking, promising to contribute significantly to the advancement of materials science and engineering. In this study, AlN preform with varying porosities were fabricated via the slurry impregnation method and subsequently processed into Al/AlN IPCs utilizing low-pressure casting techniques. Microstructural analysis employed SEM, EPMA, and XRD techniques, while mechanical properties were assessed via nanoindentation and room-temperature compression. Thermal expansion behaviors were examined using finite-element simulation methods. Its thermal conductivity was also studied. This study offers a theoretical basis for the application of Al/AlN IPCs. The conclusions of this thesis can be summarized as follows:

1) Al/AlN interpenetrating phase composites with different preform porosity were successfully prepared by immersing PU foam in a mixture slurry containing AlN powder and Al_2O_3 sol, followed by infiltration with molten A356 alloy using the low-pressure casting method. SEM analysis indicated a clean and well-bonded interface between the components. As the preform porosity increased, the relative density of the composites also increased. The compression

behavior of the IPCs was found to vary greatly; samples with 84% and 79% preform porosity exhibited ductile fracture, while those with 76% and 71% porosity exhibited brittle fracture. Compressive strength and yield strength showed an overall increase with increasing preform porosity. Notably, the 84% preform porosity IPCs demonstrated the highest compressive strength (140 MPa) and the best toughness (48.98 MJm^{-3}). The nanoindentation hardness is minimally affected by the presence of pores. As the porosity of the preform decreases, the nanoindentation hardness increases. Additionally, higher interfacial hardness indicates effective interfacial bonding.

2) The thermal expansion behaviors of Al/AlN IPCs with varying preform porosity have been investigated. The experimental results, analytical models, and finite element analysis were employed to gain insights into the thermal characteristics of these materials. AlN preform effectively decreased the CTEs of Al/AlN IPCs, the reduction in preform porosity resulted in decreased CTE values for the IPCs. The unique structure of IPCs effectively constrains the expansion of the aluminum matrix, resulting in a lower CTE compared to conventional particle-reinforced Al/AlN composites. Experimental values align with the analytical boundaries, affirming the accuracy of the analytical model's predictions. Finite element analysis of 3D RVEs validated the mesh independence and showcased the intricate distribution of thermal stresses within the IPCs. The FE model accurately predicts experimental results at high preform porosity levels. However, as preform porosity decreases, a significant disparity arises between calculated and actual values. This discrepancy is attributed to the FE simulation's omission of plastic deformation and residual thermal stresses.

3) Al/AlN IPCs with varying preform porosity were examined for TC. With an increase in preform porosity, the TC of IPCs also increases. The material's crystalline nature and the existence of pores contribute to a reduction in its TC as the temperature rises. The experimental results for sample 84 align well with the results derived from the theoretical models. In contrast, the experimental data for sample 79 show a considerable deviation, notably lower than the corresponding theoretical predictions. After considering interfacial thermal resistance and porosity, the disparity between the calculated results of the theoretical model and the experimental values for 79 samples decreases notably. The experimental values align with the theoretical model, whereas for 84 samples, they diverge from the calculated values. This discrepancy is primarily attributed to the decreased porosity of the prefabricated body, enlarging the interfacial region and amplifying the impact of interfacial thermal resistance. Further exploration is required to understand the impact of factors beyond porosity and interfacial thermal resistance.