Postprint: Prediction and Simulation Analysis of Rough Interface Thermal Resistance in Vehicle Thermal Protection Structures

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Abstract

Thermal protection structures for hypersonic vehicles are typically composed of materials with significantly different properties, and the influence of contact thermal resistance at rough interfaces on the overall heat transfer characteristics and thermal protection effectiveness of the structure cannot be neglected. The interface contact thermal resistance between thermal insulation materials and metallic materials in thermal protection structures is investigated using theoretical prediction and numerical simulation methods. An improved method is proposed to address issues such as computational difficulties and the inability to easily describe the complex microscopic morphology of rough interfaces in the commonly used CMY (Cooper-Mikic-Yovanovich) contact thermal resistance model. The mechanical and heat transfer processes of contact are simulated using finite element software. In numerical examples, the accuracy of the method is verified by comparison with experimental data from literature, the influence patterns of interface temperature, contact pressure, and roughness on thermal resistance are investigated, and the role of contact thermal resistance in the overall temperature distribution of the structure is discussed. Results show that both contact pressure and surface roughness affect contact thermal resistance by influencing the actual contact area, while interface temperature primarily changes contact thermal resistance by affecting the thermophysical properties of materials. Under high-temperature conditions, radiative heat transfer between contact interfaces is enhanced, and the introduction of contact thermal resistance has a relatively significant impact on the insulation layer of thermal protection structures.

Full Text

Preamble

This section introduces the fundamental mathematical concepts and notation used throughout the paper.

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Section 1

We begin by establishing the basic theoretical framework and preliminary results.

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Section 2

This section presents the core mathematical derivations and main theoretical contributions.

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Section 3

The following analysis extends the previous results to more general cases.

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Section 4

We now examine specific applications and special cases of the general theory.

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Section 5

This section discusses the implications of our findings and connections to existing literature.

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Section 6

The following results demonstrate the practical utility of our theoretical framework.

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Section 7

We conclude with final remarks and suggestions for future research directions.

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Section 8

Additional technical details and supplementary material are provided below.

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Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv — Machine translation. Verify with original.