FLOW AND HEAT TRANSFER CHARACTERISTICS OF TPMS STRUCTURE AT THE TRAILING EDGE OF TURBINE VANE

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Triply Periodic Minimal Surface (TPMS) structures are implicit surfaces with zero mean curvature and high specific surface area. With the rise of additive manufacturing, they have gained attention in thermal management. Casini et al. [1] found that among TPMS types, Gyroid offers the best efficiency in gas turbine cooling. Piatti et al. [2,3] showed that channel cross-section shape affects hydraulic properties for large unit cells but becomes negligible as cell size decreases. Gao et al. [4] proposed a spherical-partitioned Diamond TPMS for regenerative cooling, achieving 46% better overall performance than grooved channels. Overall, TPMS structures show promise for high-efficiency heat transfer, with future work needed on multi-physics coupling, graded designs, and surface roughness. This paper numerically investigates TPMS structures for turbine vane trailing edge cooling, comparing pin fins, lattice structures, and Gyroid TPMS.

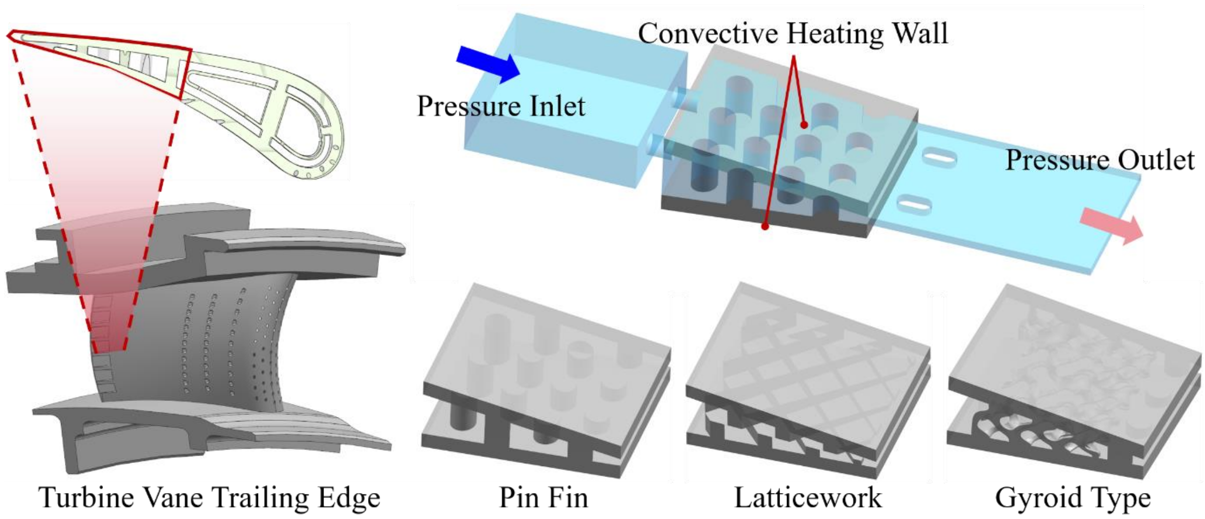

Fig. 1 – The computational domain of the turbine vane trailing edge structure and the different cooling structures investigated in this paper

The trailing edge region of a turbine blade typically employs a compound cooling structure, as shown in Fig. 1. Its basic configuration consists of heat transfer enhancement elements, such as pin fins or impingement holes, arranged within the narrow wedge-shaped trailing edge interior. These elements enable the cooling air to be fully disturbed in the confined space and to remove heat from the trailing edge wall. Subsequently, the cooling air is discharged through trailing edge slots or pressure-side cutbacks, forming a film protection on the external surface. Among these, the internal turbulence structure is an important cooling form for the trailing edge. This paper compares the flow and heat transfer performance of pin fins, lattice structures, and Gyroid-type TPMS structures, as shown in Fig. 1. The inlet of the fluid domain is a pressure inlet, and the outlet is a pressure outlet. Typically, the cooling air pressure head at the turbine blade trailing edge is sufficient. The side walls of the fluid domain are periodic boundary conditions. The upper and lower walls of the solid domain are convective heating walls, simulating the heating from the main combustion gas. Different cooling structures have similar porosities, with the porosity ranging from 0.75 to 0.78.

Under the same inlet-to-outlet pressure ratio condition, the flow rate of the pin fin structure is 0.00257 kg/s, the flow rate of the latticework structure is 0.00233 kg/s, and the flow rate of the gyroid structure is 0.00199 kg/s. Figure 2 shows the temperature distribution of the three structures under the same pressure drop condition. The average surface temperature of the pin fin structure is 1034.56 K, that of the latticework structure is 990.45 K, and that of the gyroid structure is 986.43 K. Under identical inlet-to-outlet pressure ratio conditions, the pin fin structure exhibits the highest flow rate, indicating the lowest flow loss, yet it yields the highest average surface temperature, reflecting the poorest cooling performance. The lattice structure shows an intermediate flow rate and a significantly reduced temperature, achieving a favorable balance between flow and heat transfer. The Gyroid TPMS structure, despite possessing the lowest flow rate and consequently the highest flow loss, attains the lowest surface temperature, demonstrating superior thermal protection. Thus, the choice of cooling configuration for the turbine blade trailing edge should be guided by the specific trade-off between pressure drop tolerance and cooling demand: pin fins are preferable when flow resistance is critical, while Gyroid TPMS structures are more suitable for applications requiring maximum heat load removal, with lattice structures offering a compromise solution.

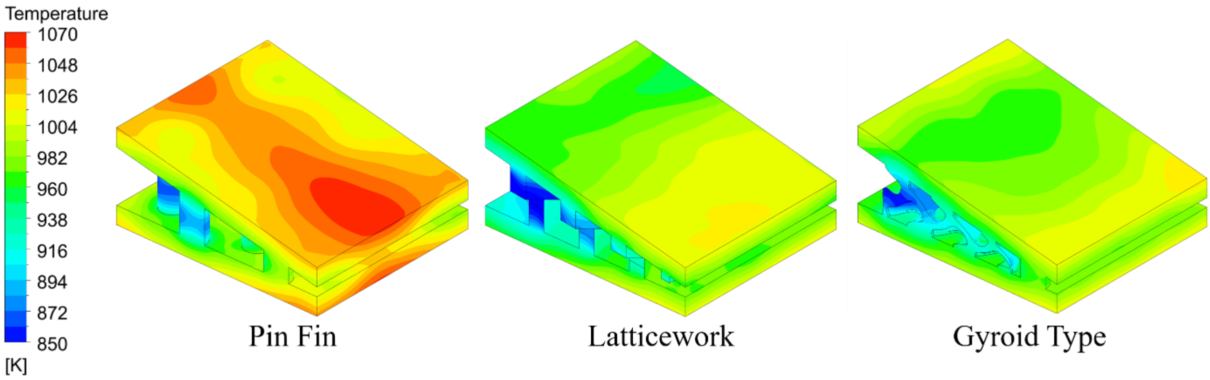

Fig. 2 – Temperature distribution of different trailing edge cooling structures

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