Thermal Loss Reduction in Powertrain Housings by Laser-Induced Oleophobic Surface Textures

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Objectives: The electric vehicle (EV) market continues to grow, and further extension of driving range requires the minimization of energy consumption unrelated to drive power. Thermal losses through transmission oil in powertrain components, particularly within aluminum alloy die-cast housings, account for 5% of the total energy consumption in EVs, and their reduction is therefore highly desirable. The purpose of this study is to reduce heat transfer from transmission oil by introducing oleophobic surface textures on aluminum alloy die-cast housings.

Methods: Surface micro-processing was conducted in two steps: (i) laser polishing of a die-cast aluminum alloy (ADC12) using a picosecond-pulsed laser (wavelength: 515 nm, pulse width: 10 ps), and (ii) micro-processing of oleophobic textures using a femtosecond-pulsed laser (wavelength: 515 nm, pulse width: 277 fs, Fig. 1). The oleophobic texturing employed a hierarchical structure composed of two periodicities, τ_L = 145.0 µm and τ_S = 8.3 µm, to achieve a lotus effect. Thermal transfer characteristics were evaluated under controlled environmental conditions maintained at 10°C. Preheated transmission oil (Toyota Motor Corp., Japan) was dropped onto thermally insulated test pieces, and the time-course changes of heat transferred to the test-pieces was measured.

Results and Discussion: Laser polishing improved the surface waviness from 1.9 µm to 0.6 µm, and surface roughness from 6.9 µm to 1.5 µm. A hierarchical structure with a long-period ratio of f_{L2}/f_{L1} = 5.8 and a short-period ratio of d_S/τ_S = 1.3 resulted in the smallest sliding angle of 8.0°. Using this texture, the amount of heat transferred was reduced by 38.5% compared to the non-textured surface (Fig. 2). This reduction was attributed to two synergistic effects: (1) a decrease in contact area and time of the oil droplets due to the oleophobic texture, and (2) the thermal insulation effect of the air layers formed within the hierarchical microstructure.

Conclusion: The laser-based surface micro-processing demonstrated its effectiveness in reducing heat transfer under conditions involving high-speed and short-duration droplet impact.

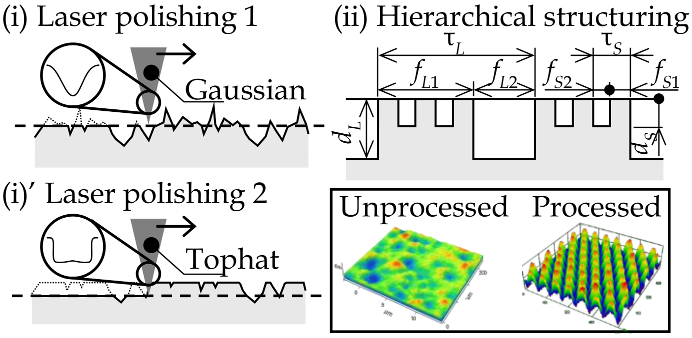

Fig. 1 Processing steps applied to ADC12: (i) Laser polishing, (ii) Hierarchical structuring.

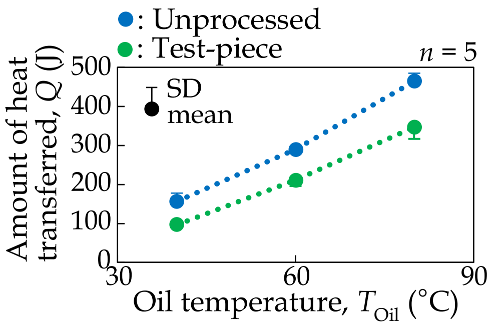

Fig. 2 Amount of heat transferred (ADC12, f_{L2}/f_{L1} = 5.8, d_S/τ_S = 1.3).