

Predictive Technology for Engine Oil Adhesion as the Core of Intake-System Engine Deposits

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The deposits generated within the engine's intake and exhaust pathways during vehicle operation are caused by the adhesion of degraded engine oil mist (hereafter referred to as degraded oil) to the component surfaces. Excessive accumulation on engine components can lead to a decline in component functionality, potentially adversely affecting driving performance, such as reducing engine output. In modern powertrains, intake components often have complex geometries and are exposed to varied thermal and durability environments, verifying every design by physical testing is consequently therefore costly and labor-intensive. In parallel, accelerated electrification and hybridization are diversifying engine operating conditions, and the anticipated shift toward next-generation fuels (e.g., bio-derived fuels) introduces new uncertainties about degradation pathways and deposit behavior. These factors motivate the development of a desktop method to predict adhesion propensity prior to hardware trials.

Against this background, we constructed a predictive framework by combining experiments and simulations. We used nylon 66, the base material of the intake manifold, as the substrate and measured static and dynamic contact angles for multiple surface specifications—SiO₂ (hydrophilic), TiN/TiCN/TiC/CrN (slippery), SiC (acid-resistant), and CrO₂ (anti-fouling/oil-repellent). In parallel, we computed interfacial interaction energy between degraded-oil monomers and wall-surface polymers using molecular dynamics (MD) simulations, and used this value as an adhesion index and—as shown in Fig. 1—found a clear correlation that smaller interaction energy corresponds to larger static contact angles, confirming that weaker intermolecular interaction yields higher oil repellency and lower adhesion tendency. This allows the MD-derived energy to act as a surrogate for solid–liquid interfacial tension, enabling on-desktop ranking of coating materials by adhesion propensity.

To assess post-adhesion removability, we performed particle-based simulations on flat surface inclined at 10° and—as depicted in Fig. 2—the results show that Nylon 66 leaves extensive residual oil films, SiO₂ keeps the surface continuously wetted by film formation, CrO₂ maintains droplet sphericity, enables rapid sliding, and leaves little residue. Fluorinated coatings are highly repellent yet retain small droplets, posing a nucleation risk. Altogether, predicting adhesion using MD-derived interaction energy and confirming residue and sliding speed through the particle-based simulations enables rapid, desktop screening of materials and surface designs.

We conclude that suppressing degraded-oil adhesion requires not only high oil repellency but also moderate spreading that fosters droplet →coalescence and subsequent gravity-driven sliding. Notably, CrO₂ consistently demonstrated superior performance across experiments, the MD correlation analysis, and the particle-based simulation visualization. Looking ahead, clarifying the applicable parameter range that ensures predictive fidelity (permissible bands of contact angle and interaction energy) and the extending evaluation to diverse material systems, —including next-generation fuels and recycled materials— will further accelerate the design of intake-deposit suppression.

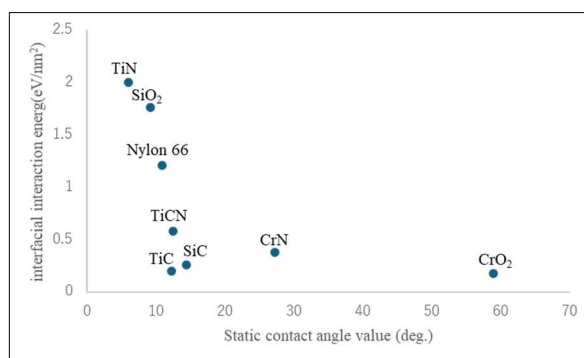


Fig. 1 Correlation between static contact angle and interfacial interaction energy

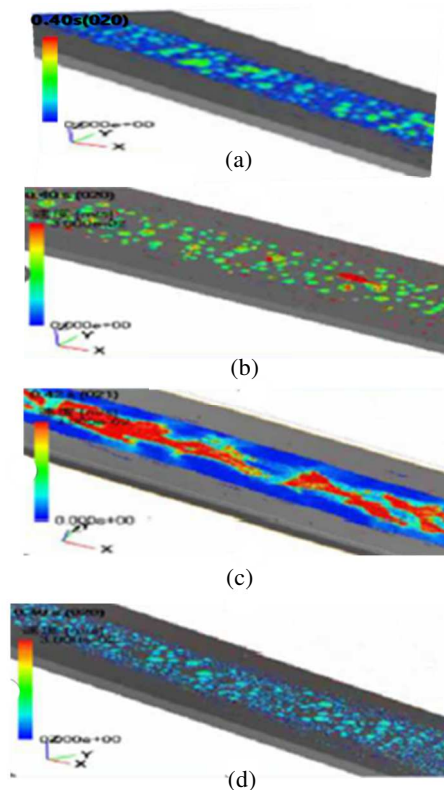


Fig. 2 Visualization of the sliding behavior of degraded oil using particle methods
(a)Nylon 66, (b)CrO₂, (c)SiO₂, (d)F-coating