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Tribological Optimization of AZ91/TiB_2 Magnesium Matrix Composites Using Stacked Ensemble Learning and Bayesian Optimization

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This study investigates the tribological performance of AZ91 magnesium matrix composites reinforced with TiB_2 particles, synthesized using the stir casting technique. TiB_2 reinforcements were incorporated at 2, 4, 6, and 8 wt.% to enhance wear resistance. The wear behavior was systematically analyzed by varying normal load, sliding speed, and reinforcement content, structured through a Taguchi L18 orthogonal array. A Stacked Ensemble Learning (SEL) model, integrating multiple regression architectures, was employed to predict wear rate and friction coefficient with high accuracy, ensuring robust generalization across varying test conditions. Additionally, Bayesian Optimization Algorithm was implemented for multi-objective optimization (MOO), effectively balancing wear resistance and mechanical stability while leveraging probabilistic modeling for improved search efficiency. The optimized results indicate that 6 wt.% TiB_2, under moderate loading conditions and controlled sliding speeds, yields significant improvements in wear resistance due to the formation of a load bearing tribolayer and increased dislocation density induced by TiB_2 particulates. The presence of TiB_2 acts as a solid lubricant and hinders the plastic deformation of the soft AZ91 matrix, leading to reduced material loss during sliding contact. Comparative validation between experimental and predicted results confirms the model's reliability, achieving a prediction error of <5%. The proposed hybrid methodology integrating predictive analytics with Bayesian-driven optimization presents a computationally efficient and experimentally validated framework for designing high-performance Mg-based composites with superior tribological properties. This approach advances the development of lightweight structural materials, reinforcing their applicability in aerospace, biomedical, and automotive sectors.

Keywords: AZ91 Magnesium Matrix Composite, TiB_2 Reinforcement, Wear Behavior, Stacked Ensemble Learning, Bayesian Optimization