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Interpretable ensemble machine learning framework to predict wear rate of modified ZA-27 alloy

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ABSTRACT

This study investigates the impact of adding manganese (Mn) to ZA-27 alloy on microstructure and tribological properties. The Mn content varied from 0.2% to 1%. Volumetric wear rates were measured under different operating conditions. XRD and SEM were employed for phase identification and surface analysis. Ensemble Machine Learning (EML) regression models, including bagging, decision trees, random forest, ada boost, gradient boosting, and extreme gradient boost, were used to predict wear properties. Results indicate that the lowest wear rate occurred at 0.5% Mn content. Different wear mechanisms were observed for varying Mn contents. Among the EML models, extreme gradient boost showed superior performance with R^2 values of 0.999 and 0.985 in training and testing, respectively.

1. Introduction

In the automotive industry, mechanically propelled machine elements cause significant economic losses due to wear and friction [44]. As a result, materials are highly needed to extend the life of engineering machinery and parts by minimizing wear [38,39,42]. Zinc-aluminum (ZA) alloys with a distinctive blend of features are found to be a substitute for most aluminum casting alloys, bearing bronzes, cast iron, plastics, and steel fabrications [3,2]. These alloys exhibit superior bearing capabilities than traditional bronze bearings, including energy-efficient melting, remarkable castability, intense power, and a variety of other features [1,27]. However, the major problems suffered by these alloys are property deterioration at high temperatures (above 100 –120°C) and dimensional instability with rising temperatures [32]. The dimensional instability is caused by the rapid decomposition of the Al-solid solution into a Zn-base solid solution and $CuZn_4$ phases after aging. To overcome the problem of dimensional instability and improve the wear resistance, earlier attempts have been made by adding different alloys like copper [40], nickel [14], silicon [48], strontium [45], manganese [15] garnet [34], Titanium, Zirconium [49], graphite [28], SiC nano particles [46] etc., to the ZA-27 alloy.

Modern computer systems increased processing capability has facilitated the quick development of creative methods for data-driven analytics that can yield new insights [22]. The use of these methods has given rise to a brand-new branch of tribology called "Triboinformatics" [47]. Artificial intelligence and machine learning (ML) algorithms that are data-driven have made it possible for us to study intricate higher-order correlations among several factors over a greater range, which is particularly challenging when using the conventional two-parameter analysis [23,36]. In addition, it has been noted that minimal effort has been done to understand the wear behavior of materials through ML approaches [4].

The wear loss was estimated with the use of the linear regression (LR) technique [8]. Supervised machine learning models such as ANN, SVM, and KNN were created to evaluate friction and wear efficiency [17]. SVM and ANN algorithms were used to estimate wear resilience and the coefficient of friction [43]. The artificial neural network was used to investigate the wear performance of Al2219 reinforced with different weight percentages of TiC microparticles [10]. Several wear characteristics were investigated to look into the AZ91 alloy's wear performance

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