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Enhancing corrosion prediction of friction stir welded Al-SS hybrid joints using GAN-based data augmentation and Machine Learning

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ABSTRACT

Motivation: Corrosion prediction in friction stir welded (FSWed) SS-Al hybrid joints is challenging due to limited experimental data and the complex interactions governing their degradation behavior.

Method: In this work, we present a data-efficient framework that integrates a Generative Adversarial Network (GAN) for numerical data augmentation with robust supervised Machine Learning (ML) models. Eighteen experimental FSW runs were conducted using different tool rotational speeds (TRS), welding speeds (WS), and tool pin offsets (TPO), and corrosion behavior was quantified in terms of mass loss (mL) and corrosion rate (CR) after 360 h immersion in 3.5% NaCl solution. A fully connected GAN was trained on the normalized experimental dataset to generate 100 statistically consistent synthetic samples, forming an augmented dataset of 118 samples. Using this augmented data, we trained and compared thirty Artificial Neural Network (ANN) configurations and nine Gaussian Process Regression (GPR) models for their predictive performance.

Results: Our results demonstrate that data augmentation using the GAN significantly improves the predictive capabilities of both ANN and GPR models. The optimal GPR model provided the best performance, attaining a test R^2 of 0.867 for mass loss and 0.893 for corrosion rate, alongside high training R^2 values of 0.947 and 0.979, respectively.

Significance: The proposed integrated GAN-ML framework provides a robust and practical solution for corrosion prediction in material systems where experimental data are scarce, and it offers a scalable methodology applicable to other manufacturing and materials engineering problems with limited datasets. To the author's knowledge, this study represents the first systematic application of GAN-based data augmentation for corrosion prediction in dissimilar FSWed SS-Al hybrid joints.

1. Introduction

Hybrid structures combining aluminum (Al) and stainless steel (SS) are increasingly adopted in marine and transportation sectors for their favorable combination of low weight and corrosion resistance. The use of Al/SS joints in critical load-bearing or corrosion-prone areas presents a practical solution, but the inherent dissimilarities in thermal and chemical properties make joining these materials challenging, often resulting in brittle intermetallic compounds (IMCs) and defects when using traditional fusion welding. Although the mechanical integrity of such joints is well understood, their corrosion performance, particularly in chloride-rich marine environments, remains less explored. Corrosion resistance in these dissimilar joints is affected by galvanic interactions, localized surface chemistry changes, and FSW induced microstructural heterogeneities. Aluminum, despite its attractive properties, suffers from inadequate corrosion resistance due to its soft surface and unstable oxide layer. While surface coatings have shown promise in improving corrosion protection, they are limited by their vulnerability to mechanical damage, which can trigger aggressive localized galvanic corrosion and lead to premature component failure. This limitation hinders the broader use of Al alloys in marine environments. As a result, researchers are increasingly focusing on simultaneous joining and microstructural refinement through processes like friction stir welding (FSW) a solid-state technique that operates below the melting point, as a more robust and intrinsic approach to enhancing the corrosion resistance of Al alloys in hybrid joints, particularly in SS/Al combinations. For instance, researchers in [1] revealed that FSW provides a clear advantage over Tungsten Inert Gas (TIG) welding for AA6082 Al

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