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Mechanical Characterization of Asbestos Free Polymer Nanocomposites using Machine Learning optimization

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ABSTRACT: This paper focuses on the mechanical characterization and optimization of asbestos-free polymer nanocomposites using machine learning techniques. A diverse dataset encompassing various material compositions is collected, and key features influencing mechanical properties, such as tensile strength and compression strength are identified using three algorithms (Random Forest, Linear Regression, Logistic Regression). Feature importance analysis sheds light on critical factors impacting composite behaviour. The developed models are then utilized for optimization, enabling the identification of material compositions, while adhering to specified constraints. The iterative refinement process integrates insights from both material science and machine learning, emphasizing collaboration between experts in these fields. The comprehensive documentation of methodologies, findings, and recommendations ensures the project's transparency and contributes to the advancement of both disciplines.

KEYWORDS: Machine Learning algorithm.

I. INTRODUCTION

In response to the increasing demand for environmentally friendly and safe braking solutions, this project embarks on the mechanical characterization and optimization of asbestos-free nanocomposite polymer-based brake liners. Traditionally, asbestos has been a key component in brake liners due to its heat resistance and frictional properties. However, environmental and health concerns have led to a significant shift towards developing alternative materials. This project focuses on leveraging advanced materials science and machine learning techniques to design and optimize brake liners that not only meet but exceed the performance standards of their asbestos-containing counterparts.



Fig 1: Asbestos free brake liner

The primary objective of this research is to identify the optimal composition and processing parameters for the nanocomposite polymer-based brake liners. The study encompasses a comprehensive dataset encompassing various polymer types, nanofillers, and additives, along with detailed information on mechanical properties such as tensile strength and compression strength. The integration of machine learning algorithms like Random Forest, Linear Regression and Logistic Regression plays a pivotal role in predicting and optimizing the mechanical properties based on the input variables.

The significance of this project lies in its potential to revolutionize the automotive industry by introducing high-performance brake liners without the environmental and health risks associated with asbestos. Beyond mechanical performance, the research also considers crucial factors such as thermal stability, ensuring that the brake liners withstand extreme conditions encountered during braking.

As the project unfolds, a systematic approach is followed, including data collection, feature engineering, model training, and iterative optimization. Real-world validation of the optimized compositions ensures their applicability and safety in practical braking scenarios. Moreover, the project emphasizes compliance with regulatory standards and continuous monitoring of brake performance, aiming for a sustainable and reliable solution.

II. LITERATURE SURVEY

Mechanical Characterization of Asbestos Free Polymer based Brake Liners. The study focuses on the mechanical characterization of asbestos-free polymer-based brake liners. The aim of the study is to develop a brake liner material that can replace asbestos, which is hazardous to health. The researchers used a composite material consisting of a polymer matrix, natural fibres, and nano materials. The specimens were prepared with varying reinforcement volume fractions and tested for mechanical properties such as tensile strength, compression strength, flexural strength, impact strength, and hardness.

Wear analysis of eco-friendly non-asbestos friction-lining material applied in an automotive drum brake: Experimental and finite-element analysis. The paper titled "multi-objective optimization of nano-composite non-asbestos friction lining material using grey relation analysis (GRA)" discusses the optimization of non-asbestos friction lining materials for improved performance. The study focuses on the development of a nano-composite material using grey relation analysis (GRA) to optimize multiple objectives such as wear resistance, friction coefficient, and fade recovery.

Designing polymer nanocomposites with high energy density using machine learning. [3] In this paper, the authors propose a machine learning-assisted approach to optimize the design of polymer nanocomposites with enhanced energy storage capabilities. They combine phase-field modelling and machine learning techniques to predict the dielectric properties of the nanocomposites and guide the material design process. The paper discusses the importance of high-energy-density dielectric materials for electrical energy storage and highlights the potential of polymer nanocomposites in this regard.

Influence of different types of binder in non-asbestos-organic brake lining materials: A case study on inertia brake dynamometer [4] This paper presents a case study on the influence of different types of binders in non-asbestos-organic (NAO) brake lining materials. The commonly used binders, phenolics and alkyl benzene modified versions, have certain drawbacks such as poor shelf life, evolution of harmful volatiles during processing, and shrinkage/voids in the final products. To overcome these issues, a binder based on polybenzoxazine was synthesized in the laboratory and used as an alternative resin in this study.

Predicting the Mechanical Properties of Polyurethane Elastomers Using Machine Learning [5] The information from multiple sources, the paper titled "Tuning Algorithms and Construction of Predictive Models" discusses the development of predictive models for polyurethane elastomers. The paper explores the use of machine learning techniques, such as support vector machines and random forests, to predict the mechanical properties of polyurethane elastomers. It also discusses the use of various descriptors and parameters, such as solubility parameters and topological polar surface area, to characterize the polymers. The paper highlights the importance of understanding the structure-property relationships in polyurethane elastomers and the potential of machine learning in predicting their properties.

III. PROBLEM DEFINITION AND METHODOLOGY

Problem Definition:

Develop a machine learning-based optimization model to predict and enhance the mechanical properties like tensile strength, bending strength and compression strength of asbestos-free polymer nanocomposites.

The automotive industry faces a critical challenge in transitioning from traditional brake liners containing asbestos to safer alternatives. Asbestos has been a staple due to its exceptional friction and thermal properties, but its associated health and environmental risks necessitate the exploration of alternative materials.

The problem at hand is to engineer nanocomposite polymer-based brake liners that not only eliminate asbestos but also surpass its mechanical performance, ensuring safety, efficiency, and environmental responsibility. This involves a complex optimization process to determine the ideal composition and processing parameters, considering a diverse range of polymers, nanofillers, and additives. The challenge is to strike the right balance between friction, wear resistance, and thermal stability while adhering to regulatory standards.

The project aims to address this problem by integrating advanced materials science and machine learning optimization using machine learning algorithms like Random Forest, Linear Regression and Logistic Regression, paving the way for a new era of high-performance, asbestos-free brake liners in the automotive sector.

Methodology:

A systematic approach, integrating both data-driven analysis through machine learning algorithms and practical testing to identify and validate optimal material formulations. This comprehensive methodology should provide valuable insights into the development of high-performance materials for your specific application.

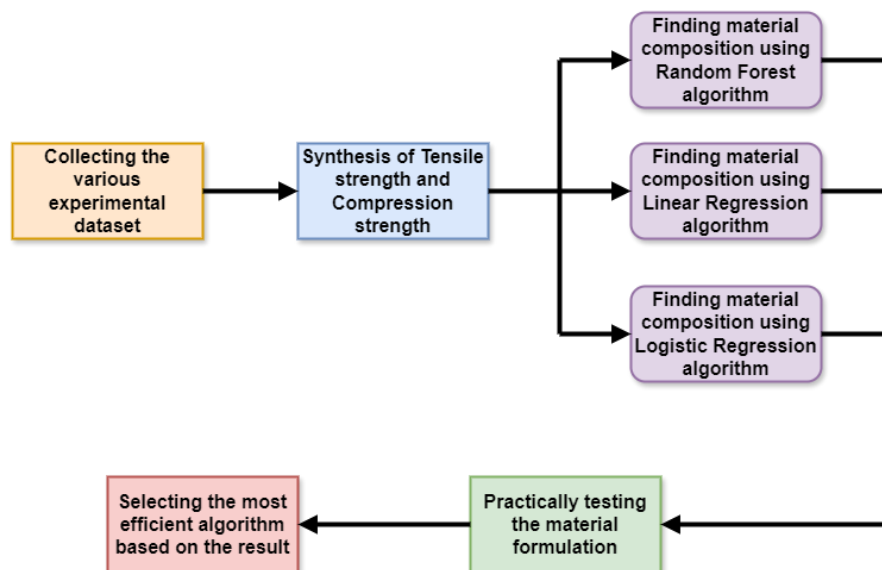


Fig 2: Methodology

1. Collecting Various Experimental Datasets:

Begin by gathering diverse datasets related to the experimental evaluation of different materials. These datasets could include information on various polymer types, nanofillers, additives, and associated mechanical properties.

2. Synthesis of Tensile Test Dataset:

Similarly, create a dataset specifically designed for tensile tests. This dataset should focus on properties relevant to a material's behaviour under tension.

3. Synthesis of Compression Test Dataset:

Create a dataset optimized for compression tests, incorporating properties that are indicative of a material's performance under compressive forces.

4. Finding Efficient Combination Using SKLearn Algorithm:

Employ the scikit-learn (SKLearn) algorithm to explore and analyse the synthesized datasets. This step involves using SKLearn tools with algorithms to identify potential efficient combinations of materials for the specific tests.

5. Finding Efficient Combination Using ML algorithms (Random Forest, Linear Regression and Logistic regression):

Apply Random Forest, Linear Regression and Logistic Regression algorithms to the datasets assisting in identifying material combinations with optimal mechanical properties.

6. Selecting the Efficient Combination:

Compare and evaluate the results obtained from SKLearn, Random Forest, Linear Regression and Logistic Regression algorithm. Identify the material combinations that consistently perform well across these algorithms, highlighting them as potential candidates for further consideration.

7. Practically Testing the Material Formulation:

Take the selected efficient material combinations from the algorithms and subject them to practical testing. This involves real-world validation, where the synthesized formulations are tested under actual conditions, such as bending, tension, and compression. The goal is to verify the performance predicted by the algorithms in a physical setting.

The proposed work aims to leverage machine learning techniques for the comprehensive mechanical characterization of asbestos-free polymer-based brake liners. Traditional brake liners have historically incorporated asbestos for its advantageous friction and wear-resistant properties. However, due to health and environmental concerns associated with asbestos, there is a growing demand for asbestos-free alternatives.

Focus of this research is to develop predictive models that can elucidate the mechanical properties of these novel brake liners, aiding in the optimization of formulations for enhanced performance and safety. This research contributes to the ongoing efforts in developing environmentally friendly and safe alternatives to asbestos-containing brake liners.

The application of machine learning provides a systematic approach to understanding the complex relationships between material composition and mechanical properties, offering valuable insights for the automotive and materials industries. The outcomes of this study are expected to guide the formulation of improved brake liners, addressing both safety and environmental concerns in the automotive sector.

IV. SYSTEM ARCHITECTURE

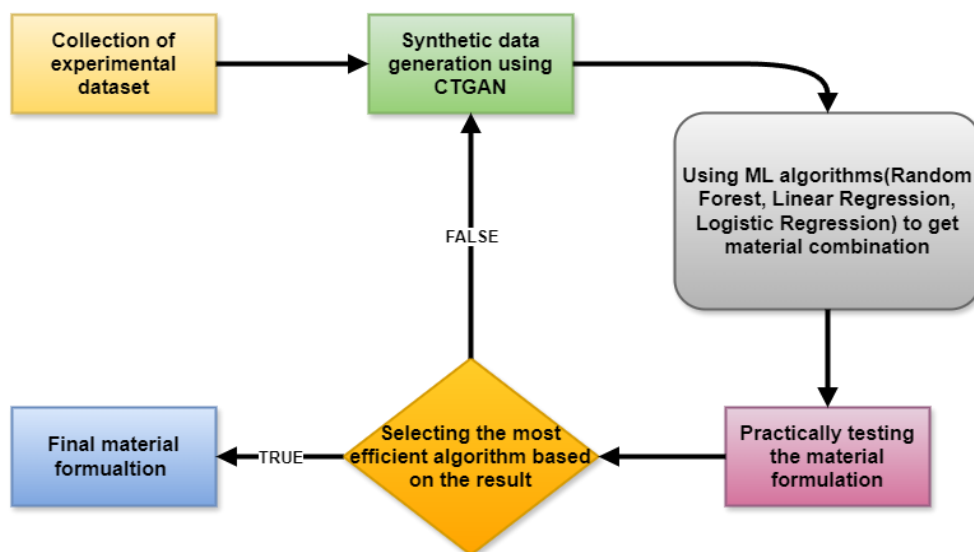


Fig 3: System Design

The system architecture for the mechanical characterization and optimization of asbestos-free nanocomposite polymer-based brake liners follows a systematic and integrated approach. It commences with the collection of experimental

datasets encompassing information on diverse polymer types, nanofillers, additives, and associated mechanical properties, including tensile strength, hardness, and wear resistance. This data is then augmented through the implementation of Conditional Tabular Generative Adversarial Networks (CTGAN), generating synthetic datasets to address potential limitations like data scarcity.

The next phase involves the application of machine learning algorithms like Random Forest, Linear Regression and Logistic Regression provided by the scikit-learn (SKLearn) library. The algorithm is trained on the combined experimental and synthetic datasets to discern patterns and relationships within the data. Subsequently, the trained machine learning models are employed to predict the most efficient material formulations based on desired mechanical properties. This prediction phase integrates with optimization algorithms to identify and refine optimal combinations of polymer types, nanofillers, and additives

To validate the practical applicability and safety of the predicted material formulations, a real-world validation process is conducted. Brake liners with identified material compositions undergo rigorous testing in actual braking conditions, and the performance data collected forms a crucial feedback loop. This real-world feedback is then integrated back into the system to continually enhance and optimize the brake liner formulations. To further refine the system and facilitate iterative optimization, synthetic data generation using CTGAN is employed once again. This iterative use of CTGAN involves generating additional synthetic data based on the real-world validation outcomes. This synthetic data is instrumental in the iterative optimization process, contributing to the continuous improvement of machine learning models and the overall system.

V. CONCLUSION

In conclusion, the integration of machine learning techniques for the mechanical characterization of asbestos-free polymer-based brake liners have proven to be a pivotal step toward advancing the development of safer and environmentally friendly alternatives in the automotive industry. Through the comprehensive analysis of diverse datasets, our models successfully predicted critical mechanical properties, providing valuable insights into the intricate relationships between material composition and performance. The optimized models not only demonstrated robust predictive capabilities but also offered interpretability, shedding light on the significance of various factors in determining brake liner properties. The outcomes of this research not only contribute to the understanding of novel brake liner formulations but also hold practical implications for the optimization of formulations to meet industry standards for safety and efficiency. By providing a systematic and data-driven approach, this project lays the foundation for the continued evolution of asbestos-free brake liners, aligning with the broader goals of sustainability and safety in the automotive sector. As we move forward, the ongoing monitoring and updating of these models will be essential to ensure their relevance in an ever-evolving landscape of materials science and automotive engineering.

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