**Prediction of Wear Behavior of Modified Epoxy-based Composites for Orthopaedic Implants using machine learning algorithms**

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*Abstract*— The current work has mainly focused on predicting the wear performance of femur bone fabricated by modified epoxy-resin composites with varying percentage of kenaf natural fiber (12%, 18% and 24%) along with Al2O3 as filler material. The composites were fabricated by vacuum bag method. The experiments of wear behaviour were conducted with parameters such as applied loads, sliding velocity and percentage of fiber. Supervised machine learning algorithms such as k-nearest neighbor (KNN), support vector regression (SVR) and Random Forest (RF) were used to predict the wear loss. Results of adopted machine learning algorithms with the performance rate of R2 for training and testing are closely nearer. RF has yielded the superior results in R2, MAE and RMSE among the constructed models. The findings could aid in replacement of femur bone with the fabrication of light weight polymer composites using vacuum bag method.

Keywords— pin-on-dis wear testing machine, femur bone, k-nearest neighbor, random forest, support vector regression,

vacuum bag method

# Introduction

Engineers nowadays are focusing on designing futuristic innovative materials that meet the realistic needs, materials have shown their value from several years of everyday life. Mainly mechanical parameters improve the performance of the device in modern advanced engineering [1]. Biomaterials are an essential part of medicine for functional restoration and healing from injury or disease. A biomaterial is a substance that is non-viable and used in a medical device to communicate with a biological system. The structure of the skeleton system helps to protect the human body [2]. The human skeletal system provides bone structure and internal organ protection. Over the years, the materials used in the treatment of injury and body disease have been essential for medicinal products (biomaterials). In the late 1800s, the use of biomaterials increased rapidly, especially Dr. Joseph Lister's introduction of aseptic surgical techniques in the 1860s. In the skeleton of the human being, the longest and strongest bone in the body is the femur bone [3-4]. The rapid population growth and increased use of automobiles contribute to a steep rise in everyday accidents. During accidents, involving men or women are directly subjected to fractured or a broken bone. The task of replacing this fracture or severely damaged bone with biocompatible material called implants plays a vital role in the life of the human being, for both the Orthopaedic Surgeon and even for Mechanical Engineers [5-6].

H G Hanumantharaju et al. (2012) conducted wear testing on Alumina and SS316L shows that the alumina material loses very less weight than the SS316L material and has found that Alumina is a low-density material and a low weight compared to SS316L [7]. K R Dinesh et al. (2013) concluded, the natural fibre and epoxy resin can also be used for reinforcement of composites from orthopaedic implants, and the reinforced epoxy composites from sisal fibre have good mechanical properties such as tensile and compressive properties [8]. Kotresh Sardar et al. (2014) experimental results concluded that hybrid fibres (sisal and banana) have good bending strength for various reinforcement, such as 10%, 20%, 30% and 40% HFRPC, of which 30%, and 40% have a good bending strength and are suitable for bone cortical properties. Finally, the results will give a better mechanical property than bending properties to hybrid fiber-reinforced polyester composites by increasing the percentage of hybrid fibre [9]. Chennabasappa Hampali et al. (2020) as alternative materials in orthopaedic applications, Poly Tetra Fluoro Composites Ethylene as well as Titanium Dioxide have been developed. Hom Nath Dhakal et al. (2020) concluded that adding lignocellulosesic hemp fibres, in comparison with the nice PCL sample, improved its properties of a HF/PCL bio-composite samples. All results show that hemp fibres are a promising reinforcement material for the development of sustainable thermoplastic bio-composites that are renewable, cheap, and cargo-bearing, significantly having optimal nano-mechanical as well as thermal properties of a durable HF/PCL bio-composite [10].

This research will focus on developing a bio-composite as an artificial bone material aiming to be used in the femur implant by conducting wear test. Use of prediction methodologies by applying machine learning algorithms such as k-nearest neighbor (KNN), Support Vector Regression (SVR) and Random Forest (RF) is intended to reduce the large time of material fabrication and testing.

# Methodology

## Data acquisition

Development of polymer composite materials using Vacuum Bag Moulding technique with different weight fractions using the rule of mixture. After curing laminates, the laminates are cut into specimens according to ASTM Standards for conducting the Wear test experiments.

Wear test have been conducted under various operating conditions like applied load, 20N, 40N and 60N and sliding speeds 1-m/s, 2-m/s and 3-m/s and 12%, 18%, 24% Natural Fibers Reinforcement. This test technique is a laboratory method for the wears of materials during sliding using the DUCOM TR-20LE pin-on-disk devices and are produced according to standard ASTM G-99. [11-12]

## Machine learning algorithm

The input parameters namely applied load, sliding speed and natural fiber reinforcement are used to train the ML algorithms. The experimental results of wear loss are considered as output parameter. Therefore, depend upon the input variables, the ML algorithms predict the wear rate. Dataset is collected by conducting 27 experiments for natural fiber reinforced composites. The dataset that contains the related inputs and outputs was arbitrarily divided into training and testing sets for utmost ML algorithms. The training set was utilized to train the model to improve the features associated with inputs to the outputs, while the testing set was used to evaluate the model's performance by comparing the model's output to the results of several machine learning techniques described in the below sections. The datasets were split into training sets and testing tests each 70% and 30% of the total datasets respectively [13].

*K-Nearest Neighbor*

This supervised machine learning algorithm used to handle both regression and classification problems. Initially it stores all the available data and then classifies the newly arrived data into the respective group based on the result of Euclidean distance in reference to the K number of neighbors.

*Support Vector Regression*

In multidimensional space, the SVM model is essentially a representation of distinct classes in a hyperplane. SVM will generate the hyperplane in an iterative manner in order to reduce the error. SVM's purpose is to partition datasets into classes so that a maximum marginal hyperplane can be found. A Support Vector Regressor (SVR) is a strong tool that allows to pick the error tolerance, both in terms of an acceptable error margin and in terms of tuning the tolerance for slipping outside of that acceptable error rate.

*Random forest*

Instead, then relying on individual decision trees, the core principle of RF is to merge numerous decision trees to determine the final output. It is based on ensemble learning, which is the process of integrating numerous classifiers to solve a complex problem and improve the model's performance.

# Results and Discussions

The adopted models for deriving a linear relationship among the input features (applied loads, sliding velocity and percentage of fiber) and output (wear loss) for Epoxy-based composites for Orthopedic implants, then the predicted wear loss may be calculated with admire to the given input features. The predicted wear loss of composites via KNN, SVM and RF are shown in Fig. 1, Fig 2 and Fig 3. The training data and test data are represented as red and blue scatter points, the predicted train data and predicted test data are represented as red and blue dashed lines which are plotted over the plane. From the Figs. (1, 2 and 3), it is perceived that epoxy-based composite shows the most values of train prediction and train data are noticeably deviated for individual tests. Table1 shows the predicted R squared values of training dataset and testing dataset for KNN are ~0.830 and ~0.774, for SVM are ~0.904 and 0.834 and for RF are ~0.945 and 0.834.

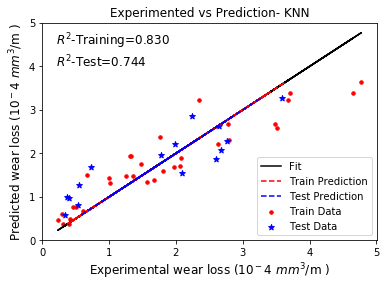


Fig 1. Wear loss prediction using KNN

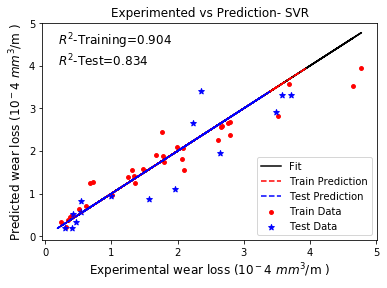


Fig 2. Wear loss prediction using SVR

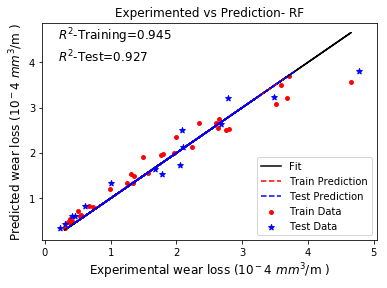


Fig 3. Wear loss prediction using RF

Tabele I. model performances

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | R2 -Training | R2-Test | MAE | RMSE |
| KNN | 0.830 | 0.774 | 1.121 | 1.498 |
| SVM | 0.904 | 0.834 | 0.869 | 1.306 |
| RF | 0.945 | 0.927 | 0.328 | 0.447 |

The MAE and RMSE values for KNN are 1.121 and 1.498, for SVM are 0.89 and 1.306 and for RF are 0.328 and 0.447. The RF predicts the wear loss of epoxy-based composites for orthopedics implant with the maximum accuracy and minimum RMSE and MAE value compared with the other algorithms used in this present study.

# Conclusions

In the present work, the input parameters (applied loads, sliding velocity and percentage of fiber) on the experimentally measured output (wear loss) for epoxy-based composites in orthopaedic implants. The efficacy of three different types of machine learning algorithms to predict the wear loss of composites is explored. The three machine learning algorithms are ranked in order of prediction accuracy: RF, SVM and KNN. The RF algorithm predicts the wear loss of composites with the maximum accuracy, with R2 of training dataset and test dataset are ~0.945 and ~0.927, respectively. RF has yielded the superior results in R2, MAE and RMSE among the constructed models. These findings could aid in replacement of femur bone with the fabrication of light weight polymer composites using vacuum bag method. This research solely dedicated to the human being who creates the world and saves the environment that promotes mechanical engineering in the medical field. This research also benefits the poor people of India by recommending cost-effective, manufacturable, and biocompatible, stable biomaterials for orthopaedic implants.

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