PREDICTING FIRE-INDUCED SPALLING IN CONCRETE TUNNEL LININGS USING MACHINE LEARNING TECHNIQUES

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Fire-induced spalling is the phenomenon where the outer cracked or delaminated layer of a concrete element detaches due to the exposure to high temperatures during a fire. Spalling is a phenomenon that has raised concerns in the research community since the 19th century. Since then, many experimental, analytical, numerical, and other studies have been conducted around the world to explain this phenomenon. However, an accurate model to predict the occurrence of spalling remains elusive, particularly for tunnel linings.

Tunnel fires have drawn increasing attention and raised more concerns in recent decades. The rapid growth of freight transportation, particularly flammable ones such as fuel, increases the potential to cause a rapid-fire spread. When compared to building fires, tunnel fires can be more destructive due to their high temperatures, quick heating rates, prolonged duration, and uneven temperature distribution inside the tunnel.

Spalling is a complex phenomenon with a high degree of randomness that interdepends on too many factors. The occurrence of spalling phenomena is significantly influenced by various microstructural properties of concrete. Internal factors such as concrete permeability, moisture content, water-cement ratio, and aggregate type have a significant impact on spalling. Furthermore, temperature, heating rate, humidity, and loading conditions are some of the external factors that affect spalling. To gain a comprehensive understanding of this phenomenon, it is crucial to consider the interdependencies among these various factors and their combined effects.

The current method used in industry to evaluate the performance of a concrete tunnel lining is to test the specimen in large-scale furnaces. However, this method has several limitations. It requires the use of large-scale furnaces, which is time-consuming, expensive, and difficult to replicate due to their dependence on specific concrete mixtures and test setups.

Alternative approaches, such as Machine Learning (ML), can be considered to overcome these challenges. Recent advancements in data analytics & ML have demonstrated their capability to solve such complex problems. This study aims to create a framework for predicting fire-induced spalling in tunnel linings using several ML techniques.

Python programming language was utilised to develop this framework and Jupyter Notebook was used as the web based interactive platform. Using the previously published fire test data, a new dataset was created, and after performing the appropriate preprocessing, it was fed into 10 distinct ML techniques. These includes 7 ensemble techniques and 3 traditional ML techniques. Then the developed model was further refined using hyperparameter tuning & k-fold cross-validation techniques. The results of this model revealed that it is possible to forecast the occurrence of spalling with an accuracy of more than 90% using ensemble ML techniques.

Keywords: Spalling, Tunnel linings, Machine learning, Ensemble machine learning

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Fire Induced Spalling

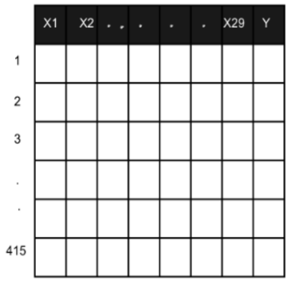
Spalling refers to the detachment of the cracked or delaminated surface layer from a concrete member.

The current method used in industry to prevent fire induced spalling is to test tunnel lining using special furnaces.

- Time consuming
- Much expensive
- Limited to specific concrete mixtures & testing setups
- Requires large scale furnaces

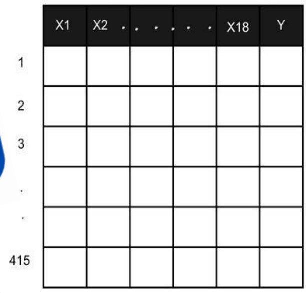
Aim of the study:
Development of a framework for predicting the fire-induced spalling in tunnel linings using advanced ML techniques.

1 Raw dataset
Using published fire test data
(29 input features)



EDA*

2 Preprocessed dataset
(18 input features)



Inputs

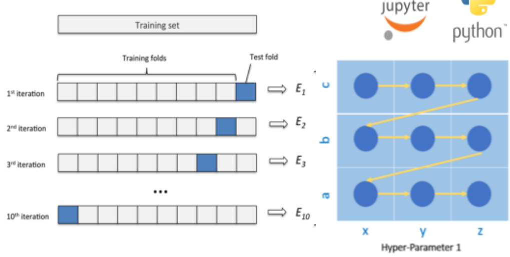
Specimen length, bottom cover, poly fiber %, W/C ratio, max. aggregate size, bar diameter, heating rate etc.

Output

Occurrence of spalling (0 or 1)

3 Development of the model

01 Adaptive Boosting (ADABoost)
02 Extreme Gradient Boosting (XGBoost)
03 Gradient Boosting
04 Random Forest
05 Artificial Neural Networks
06 Bagging
07 Support Vector Machine
08 K – Nearest Neighbours
09 Light Gradient Boosting
10 Categorical Boosting (CATBoost)



The developed model was further refined using K-fold cross-validation and hyperparameter optimisation.

4 Results

Model	Accuracy score on test set	Mean CV score
Adaptive boosting	0.9038	0.9357
XG boosting	0.9038	0.9390
Gradient boosting	0.9231	0.9485
Random forest	0.9327	0.9356
Artificial Neural Network	0.6635	0.8068
Bagging	0.9038	0.9419
Support Vector Machine	0.7596	0.8168
K nearest neighbors	0.7788	0.8166
Light gradient boosting	0.9423	0.9358
Categorical boosting	0.9231	0.9421

Occurrence of spalling can be accurately predicted using several ML techniques (up to about 90% accuracy), except ANN, SVM & KNN

EDA*- Exploratory Data Analysis
- Remove redundant input features in a logical manner
- Make the model less sensitive to noises & outliers
- Address the overfitting issue