JJMIE

Volume 17, Number 3, September. 2023
ISSN 1995-6665
Pages 367– 375
https://doi.org/10.59038/jjmie/170305
Editor-in-Chief: Prof. Ali M. Jawarneh

Jordan Journal of Mechanical and Industrial Engineering

Classifying Cutout Shapes and Predicting Cutout Location using Regression and Classification Techniques

Ufuk Demircioğlu *

PhD student, Department of Mechanical Engineering, Sivas University of Science and Technology, /Sivas, Turkey.

Received 25 Feb 2023 *Accepted 11 May 2023*

Abstract

The shape and location of cutouts in sandwich structures are important factors that can greatly affect the natural frequencies of these structures. Cutouts can change the overall stiffness and mass distribution of the structure, which can result in changes to the natural frequencies. Cutout shape can also affect how the structure deforms under load, which can further impact the natural frequencies. The location of the cutout is also critical, as it can change the way the load is distributed throughout the structure. So, understanding how the shape and location of cutouts affect the natural frequencies of sandwich structures is important for the design and optimization of these structures. It can help engineers to minimize the influence of cutouts on the natural frequencies and ensure that the structures perform as desired. Using machine learning techniques to classify cutout shapes and predict cutout locations can also help engineers to better understand these effects, and allow them to make more informed decisions during the design process. Therefore, this study investigates the classification of cutout shapes and the prediction of the cutout locations using different machine-learning methods. Natural frequencies of sandwich structures are obtained using the finite element method to use as input to machine learning methods. Cutout shapes and cutout locations are used as output for classification and regression studies respectively. From the result, it was obtained that the cutout shape was classified with an accuracy of 99.5 %. Also, the cutout location is predicted with an RMSE value of 0.000090883.

Keywords: Sandwich Structures, Influence of Cutout, Prediction and Classification, Machine Learning.

1. Introduction

A sandwich structure is a type of composite material that consists of three layers: a low-density core sandwiched between two thin, high-density skins. The core material is typically foam, such as polystyrene or polyurethane, while the skins are typically made of a strong, lightweight material such as glass fiber or carbon fiber. Sandwich structures are employed in a wide range of fields, such as aerospace, marine, and construction, because of their favorable strength-to-weight ratio and ability to absorb impact energy[1].

Sandwich structures are significant for many different reasons. One of the most important benefits of sandwich structures is their lightness, which makes them ideal for use in applications when the influence of weight is crucial, such as aerospace and marine industries [2][3]. In the aerospace industry, the primary function of a sandwich structure is to reduce weight without compromising strength. This allows for the design of aircraft and spacecraft that are both lightweight and strong, which in turn improves performance, fuel efficiency, and payload capacity [4]. In the marine industry, sandwich structures are used to build lightweight and strong boats and ships, which improves overall performance and fuel efficiency. In construction, sandwich structures are often used to create insulated walls and roofs, which can help to improve the energy efficiency of buildings. In addition, Sandwich structures also have good impact resistance and good stability under loads [5]. They also have good insulation properties and are suitable for use in environments with high humidity or temperature variations [6]. Overall, sandwich structures are a diverse and significant material that is used in a wide range of applications, from aerospace and marine to construction, because of their favorable strength-to-weight ratio, good impact resistance, and energy efficiency properties [7].

For some reason, cutouts must be made in sandwich structures. One reason is that cutouts can be used to reduce weight in the structure [8]. By removing material from the structure, the overall weight of the sandwich structure can be reduced, which can be beneficial in applications where weight is a critical factor, such as aerospace or marine industries [9]. Another reason is that cutouts can be used to accommodate other features or components in the structure. For example, cutouts can be used to create openings for doors, windows, or other equipment in a building. In aerospace, cutouts can be used to accommodate engine, passenger, or cargo compartments. Cutouts can also be used to improve the structural performance of the sandwich structure. By strategically removing material, it can be possible to create a structure that is more efficient and better able to withstand loads [10]. Cutouts can be used to improve

* Corresponding author e-mail: udemircioglu@sivas.edu.tr.

the aerodynamics of the structure, which can be particularly important in aerospace and marine applications [11]. For example, cutouts can be used to reduce drag and improve the flow of air or water over the structure. Cutouts can be used to provide access to internal components or systems, such as electrical wiring or mechanical systems. However, it's also important to note that cutouts can also reduce the overall strength and stiffness of a sandwich structure, and can introduce stress concentrations and potential failure points . Therefore, the design of cutouts in a sandwich structure should be done carefully and with consideration of the potential impact on the overall performance of the structure. Overall, cutouts in sandwich structures can be an important design feature, providing benefits such as weight reduction and improved structural performance, but it's also important to consider the potential downsides, such as reduced strength and potential failure points, during the design process.

As a result of the aforementioned importance of cutouts, researchers have studied the influence of cutouts on the free-vibration behavior of sandwich structures. One possible cutout is triangular which may be included in a sandwich structure for aesthetic reasons, to create a specific shape or design. However, its effect on the Natural Frequencies (NF) of the sandwich structure was not studied widely. Therefore, just one study is discussed here. Harsh Kumar Bhardwaj et al. investigate the vibration behavior of sandwich structures with triangular cutouts at the center of the sandwich structure. The influence of different parameters on the free vibration of the sandwich structure is evaluated using the finite element software ANSYS APDL. According to the simulation, the frequencies increase as the number of layers, plate modulus ratio, and angle of lamina increase. Furthermore, the frequencies fall as the aspect ratio, thickness ratio, cutout size, and distance increase [12]. Rectangular cutouts are the most common type of cutout shape used in sandwich structures. They are often used to accommodate features such as doors, windows, and other equipment in buildings, or to create openings for engines, passengers, or cargo in aerospace and marine applications. Due to its importance its effect on the vibration behavior of sandwich structures has been widely studied in the literature [13],[14],[15][16],[17]. These researchers have investigated the effect of the rectangular cutout on the vibration behavior of sandwich structures numerically, experimentally, or interconnection of them. These studies revealed the effect of rectangular cuts on the NF of the sandwich structure. it is observed from these studies that rectangular cutout significantly changes the NF of sandwich structures compared to sandwich structures with no cutouts. One of the most commonly used cutouts is circular-shaped cutouts. Circular cutouts are used in situations where a round opening is needed, for example, to accommodate a cylindrical object or to create a circular window. Since circular cutouts shape is commonly used in sandwich structures, researchers evaluated the influence of circular cutouts on the NF of sandwich structures [18],[19],[20],[21],[22]. It is observed from these studies that the size of the cutout and cutout locations have a significant effect on NF. Another cutout shape is elliptical cutouts which are similar to circular cutouts. These are used in situations where an elliptical opening is needed, for example, to accommodate an elliptical object or to create an elliptical window. As a result, the elliptical cutout is as important as other cutout shapes. So researcher evaluated the influence of elliptical cutouts on the vibration characteristics of composite structures [23],[24]. From studies effects of cutout size, cutout orientation, and hole geometric ratio on the NF of the plate are evaluated. It is concluded that elliptical cutout also significantly affects the vibration behavior of composite structures. Complex cutouts are another cutout shape that can be used in sandwich and composite structures. These are used in situations where the cutout shape is not a simple rectangle, circle, or ellipse, for example when the cutout must conform to a specific shape or follow a specific pattern. These types of cutouts are used in aerospace, marine, and construction fields. Therefore, researchers studied the influence of complex-shaped cutouts on the free-vibration behavior of structures [25],[26]. These studies revealed the effect of complex cutouts on the natural frequency of the structure. Multiple Cutouts are also employed. These are used in situations where multiple openings are needed, for example, to accommodate multiple pieces of equipment. Due to the importance of multiple cutouts, researchers evaluated the influence of multiple cutouts on the free vibration behavior of sandwich structures [27]. It's important to note that the choice of cutout shape and location is highly dependent on the specific application and the mechanical properties of the materials used in the sandwich structure. Therefore, some researchers investigated the effect of different cutout shapes on the NF of sandwich structure [28],[29]. They revealed how differently shaped cutouts affect the NF of sandwich structures.

All of the analyses mentioned above are performed numerically, experimentally, or by the interconnection of them while considering specified material, geometry, and loading variables. Stochastic frequency analysis of a sandwich structure with a cutout involves using statistical methods to determine the NF and corresponding modes of vibration of the structure when subjected to random loads. This type of analysis can take into account the effects of uncertainty in material properties and manufacturing tolerances, as well as the presence of the cutout, which can significantly affect the structural behavior. It can be done using numerical methods such as the Finite Element Method or the Boundary Element Method combined with statistical techniques like the Monte Carlo method. Stochastic frequency analysis is important because it can provide a more accurate representation of the real-world behavior of a structure. In many cases, the loads and material properties of a structure are not known exactly but rather have a range of possible values. By using statistical methods to account for this uncertainty, a more realistic estimation of the structure's performance can be obtained. Therefore, some other researchers investigated vibration analysis of sandwich structures [30],[31],[32][33][34][35][36][37]. However, this method possesses some drawbacks. One drawback of stochastic frequency analysis is that it can be computationally intensive, especially when using numerical methods like Finite Element Method. Additionally, it can be challenging to accurately model the distribution of uncertain variables, which can lead to errors in the analysis results. Machine learning techniques can be used to investigate the influence of cutout on the free vibration of sandwich structures because it allows for the efficient and accurate analysis of large amounts of data [38][39][40]. By training a model on a dataset of simulated or experimental results, it can be used to predict the effect of cutouts on the vibration characteristics of the structure, such as NF and mode shapes. Additionally, machine learning can also be used to optimize the design of sandwich structures by identifying the optimal location and size of cutouts for a desired set of vibration characteristics. Overall, the use of machine learning in this context can lead to significant advancements in the design and analysis of sandwich structures.

1.1. Motivation

It's worth mentioning that while these studies are providing more information about the effects of cutouts on the free vibration behavior of sandwich structures, it's also important to consider that the results of these studies may not be directly applicable to all cases, as they may have used different types of sandwich structures, core materials, boundary conditions, and loading scenarios. Besides these studies do not cover all possible scenarios, which means that they deal with specific cutout shape at a fixed location. Stochastic frequency analysis can be difficult to validate the results of stochastic frequency analysis since it is not always possible to conduct experiments to directly measure the uncertain variables. However, these studies indicate that cutouts have a significant effect on the NF and mode shapes of sandwich structures and that the shape and size of the cutout play an important role in determining the degree of this effect thanks to which NF can be used for machine learning algorithms. Therefore, this study aims to develop a mathematical algorithm using machine learning methods. To that purpose, differently shaped cutouts will be subtracted from the sandwich structure. Then the cutout will be swept all over the sandwich structure using the COMSOL MULTIPHYSICS sweep command. The first six NF will be obtained in each case to train the machine learning algorithm. MATLAB machine learning toolbox will be used to predict the location and classify the cutout shapes.

2. Novelty and motivation

Sandwich structures are widely used in a variety of engineering applications due to their high strength-to-weight ratio and excellent energy absorption capabilities. However, the presence of cutouts in these structures can greatly affect their performance by altering their natural frequencies, which can have a significant impact on their overall stability and reliability. Designing sandwich structures with cutouts that minimize the effects on the natural frequencies requires a deep understanding of how the shape and location of the cutouts affect the structure's behavior. In the past, researchers have typically used analytical or numerical methods to investigate these effects, which can be time-consuming and computationally expensive.

The proposed approach offers several advantages over traditional methods. By using machine learning, one can reduce the computational cost and time required to perform the analysis while also improving the accuracy of the results. Our method can also be used to better understand how the shape and location of cutouts affect the natural frequencies, allowing for more informed design decisions.

Overall, the study provides valuable insights into how machine-learning techniques can be used to optimize the design of sandwich structures with cutouts. By improving our understanding of the effects of cutouts on natural frequencies, we can design more efficient and reliable structures for a wide range of engineering applications.

Materials and Methods

This study consists of the classification of the cutout shapes and the prediction of the cutout location in sandwich structures using machine learning methods. As explained in the previous section both the cutout shapes and the cutouts' location distinctly affect the NF of sandwich structures. Therefore, in this study, NF is used in the classification and regression studies as inputs, and the location and shape of the cutout are used as outputs. Sandwich structures are modeled in COMSOL MULTIPHYSICS with various cutouts at different locations. Free vibration analysis of sandwich structure is carried out numerically. The first six NF are found through simulation studies. Sandwich structures are laid out in a particular way $90^0/0^o/Foam/0^o/90^0$ as shown in Figure 2. The sandwich structures have 40 mm in width and 400 mm in length. Sandwich structures have 10 mm polyvinyl chloride (PVC) foam as core materials and 0.2 mm thick glass fiber as the face sheet materials. Table 1 lists the properties of the materials used in this study.

Table 1. Properties of materials employed in the simulation study taken from[41].

Property	Glass Fiber	PVC Foam
Density (Kg/m^3)	2000	60
Young’s Modulus in Ex (Pa)	4.5e10	7e7
Young’s Modulus in Ey (Pa)	1e10	-
Young’s Modulus in Ez (Pa)	1e10	-
Poisson’s Ratios in vxy	0.3	0.3
Poisson’s Ratios in vyz	0.4	0.3
Poisson’s Ratios in vzx	0.3	0.3
Modulus of Rigidity in Gxy (Pa)	5e09	2.6923e7
Modulus of Rigidity in Gxz (Pa)	3.8462e9	2.6923e7
Modulus of Rigidity in Gyz (Pa)	5e9	2.6923e7

Different cutout shapes can be used in the sandwich structures. It is crucial to remember that the choice of cutout location and shape depends heavily on the particular application as well as the mechanical characteristics of the materials used in the sandwich structure. However, in this study, only four different commonly used cutout shapes, namely, triangular, rectangular circular, and elliptical are investigated.

Different sandwich structures with different cutout shapes are modeled in COMSOL MULTIPHYSICS as shown in Figure 1. Triangular, rectangular, circular, and elliptical cutouts are introduced to sandwich structures. All cutouts are swept from the left-hand side which is fixed and to the right-hand side which is the free end with a 1 mm step interval. The first six NF of sandwich structures under cantilevered boundary conditions is obtained for each case and for all sandwich structures to use in Machine Learning.

2.1. Validation study

To validate the accuracy of the developed model a series of validation studies is performed. COMSOL MULTIPHYSICS default mesh setting is employed in this study. Normal mesh, fine mesh, finer mesh, extra fine mesh, and extremely fine mesh are used in the validation study. Results are compared with one in the literature [42]. A comparison study is given in Table 2. The time taken to compute is also compared for each mesh. From the results, it is obtained that it takes the computer to calculate normal mesh, fine mesh, finer mesh, extra fine mesh, and extremely fine mesh 15 seconds, 22 seconds, 40 seconds, 2 minutes 9 seconds, and 45 minutes 24 seconds respectively. Extremely fine mesh gives the closest results. However, solution time is so much in this mesh. Additionally, the study will make use of a parameter sweep tool with a 1 mm step, which means that around 2000 different cases must be solved. So in this study, an Extra fine mesh setting is used to reduce the solution time. It also gives accurate results as can be seen in Table 2.

After validation studies, vibration analysis of the sandwich structure is performed. Six NF of sandwich structures is obtained using the parameter sweep tool. A small part of data obtained from simulation studies is given in Table 3 (data set for classification) and in Table 4 (data set for regression). X in Table 4 represents the cutout distance in meters from the fixed end of the sandwich structures. The dataset is composed of four different classes namely triangular, rectangular, circular, and elliptical-shaped cutouts. All shaped cutouts are parametrically swept over the Sandwich Structure (SS) from the left-hand side (fixed end) to the right-hand side (free end) with a 1 mm step in the COMSOL MULTIPHYSICS environment. The parametric sweep operation starts at the center of the shaped cutouts. The center of the cutouts starts at 20 mm from the left-hand side and finishes at 380 mm at the free end, and thus, 361 samples are obtained for each class. So, the total number of samples in the dataset is 1444.

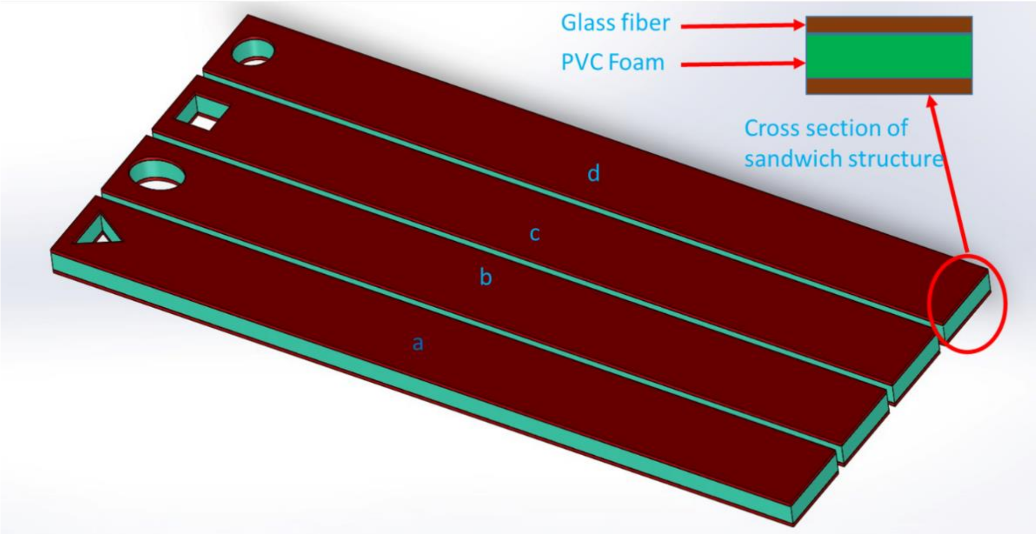

Figure 1. Modeled sandwich structures with different cutouts a) triangular cutout, b) elliptical cutout c) rectangular cutout, and d) circular cutout.

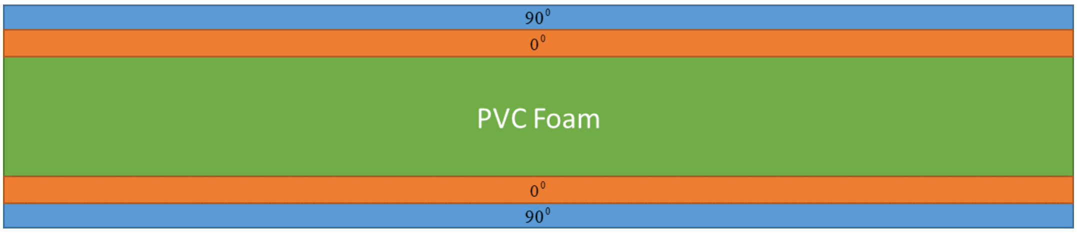

Figure 2. Layout configuration of sandwich structure

Table 2. Results of validation studies.

Natural	Pushparaj and Suresha[42]	COMSOL MULTIPHYSICS results									
		Normal mesh	Error (%)	Fine mesh	Error (%)	Finer mesh	Error (%)	Extra fine mesh	Error (%)	Extremely fine mesh	Error (%)
Mode 1	35.055	35.229	0.49	35.155	0.28	35.108	0.15	35.078	0.06	35.064	0.02
Mode 2	126.4	128.91	1.98	127.72	1.04	127.06	0.52	126.65	0.19	126.45	0.03
Mode 3	218.46	221.88	1.56	220.22	0.80	219.12	0.30	218.66	0.09	218.53	0.03
Mode 4	420.57	433.48	3.06	427.12	1.55	423.67	0.73	421.58	0.24	420.78	0.05
Mode 5	606.05	625.88	3.27	615.42	1.54	609.43	0.55	606.89	0.13	606.24	0.03

Table 3. A part of the data set for classification study.

Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Class
49.653	126.63	284.68	346.83	688.1	725.1	Circular
49.601	126.61	284.84	346.90	688.64	724.58	Circular
49.583	126.57	285.16	346.45	689.43	724.4	Circular
49.575	126.58	285.48	346.50	690.29	724.41	Circular
49.574	126.59	285.8	346.55	691.17	724.42	Circular
49.601	126.63	286.35	346.29	692.81	724.77	Circular
49.554	126.58	286.31	345.94	692.35	724.33	Circular
49.561	126.58	286.65	345.96	693.18	724.35	Circular
49.571	126.59	287.00	346.00	694.01	724.34	Circular
49.593	126.61	287.37	346.24	694.9	724.39	Circular
49.617	126.63	287.86	346.44	696.19	724.52	Circular

2.2. Machine Learning

The process of teaching algorithms to make predictions or take actions based on data is known as machine learning (ML) [43][44][45], [46]. Classification is a type of ML in which the algorithm learns to assign a label or class to a given input, such as determining whether an email is spam or not. On the other hand, regression entails estimating a continuous value, like a house's price, based on its attributes [47][48], [49]. Both classification and regression are supervised learning tasks, meaning that the algorithm is provided with labeled training data[47], [50].

In this study, it has been explored how machine learning can be used to predict the cutout location and to classify the shape of cutouts in composite materials. To accomplish this, a step-by-step procedure has been developed, which is illustrated in the flowchart below (see Figure 3.), that allowed us to extract natural frequency data from finite element models and use it to build both regression and classification models. Each step of the process played a critical role in helping to achieve the goal.

Construct the FEM model and obtain natural frequencies: This step involves building a Finite Element Method (FEM) model and extracting the natural frequencies associated with it. These natural frequencies can be used as input features for regression and classification models.

Extract data to Excel file: Once the natural frequencies have been obtained, they need to be saved to a data file for later use. Excel is a commonly used file format for this purpose. So in this study dataset has been collected in an Excel file.

Separate data for regression and classification and feature determination: In this step, the data is split into separate sets for regression and classification analysis. Feature determination involves selecting which input features will be used in each type of analysis. Cutout location and natural frequencies were used as output and input respectively in the regression study. On the other hand, cutout shapes and natural frequencies were used as output and input respectively in the classification study

Regression model selection and classification model selection: For regression analysis, different models can be tested and compared to determine which one gives the best results. The same is true for classification analysis. So all available classification and regression methods have been tested and the best methods have been employed in the study.

RMSE, MSE, and R-Squared value and Accuracy and ROC curve: Once the regression and classification models have been selected, they need to be evaluated using various metrics such as root mean squared error (RMSE), mean squared error (MSE), R-squared value, accuracy, and receiver operating characteristic (ROC) curves. These metrics help to determine how well the models are performing and whether they are accurately predicting the outcome variables.

Table 4. A part of the data set obtained from the sandwich structure with a circular cutout for regression study.

x	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
0.02	49.653	126.63	284.68	346.83	688.10	725.10
0.021	49.601	126.61	284.84	346.90	688.64	724.58
0.022	49.583	126.57	285.16	346.45	689.43	724.40
0.023	49.575	126.58	285.48	346.50	690.29	724.41
0.024	49.574	126.59	285.8	346.55	691.17	724.42
0.025	49.601	126.63	286.35	346.29	692.81	724.77
0.026	49.554	126.58	286.31	345.94	692.35	724.33
0.027	49.561	126.58	286.65	345.96	693.18	724.35
0.028	49.571	126.59	287.00	346.00	694.01	724.34
0.029	49.593	126.61	287.37	346.24	694.90	724.39
0.03	49.617	126.63	287.86	346.44	696.19	724.52
0.031	49.664	126.66	288.13	346.35	696.48	724.59

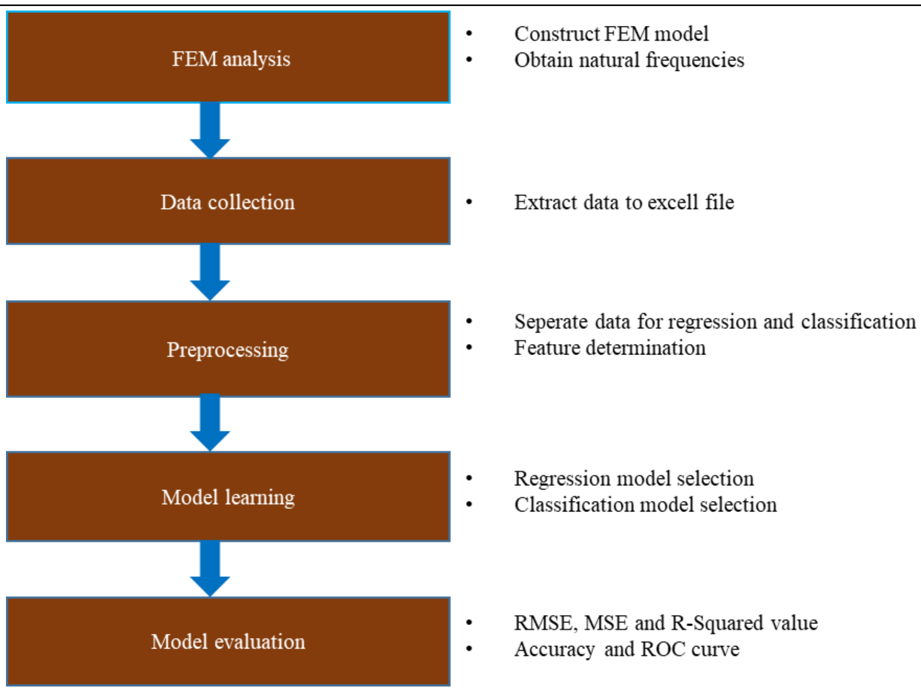

Figure 3. Machine learning workflow for regression and classification studies

3. Results and Discussions

This study consists of free vibration analysis sandwich structure and machine learning algorithms. Vibration analysis is explained in the previous section. In this section, machine learning algorithms are used to classify the cutout shapes and to predict the location of the cutout. The classification and regression studies are discussed in the following.

3.1. Classification Study

In this section, a classification study is performed using MATLAB classification learner and neural network toolbox. NF of each sandwich structure is used as input whereas the cutout shape is used as output. In all methods, 15 % of data is set aside for testing and 15% data for validation. Additionally, in the classification tool box default setting is employed. In a neural network, a 30-layer size is used. The accuracy of each algorithm was measured using only accuracy and a Receiver Operating Characteristic (ROC) as a metric. Cutout shapes (triangular, rectangular circular, and elliptical) have been classified using different machine-learning algorithms. The goal of the classification was to distinguish between cutout shapes (triangular, rectangular circular, and elliptical). The features used for classification were obtained from the natural frequencies of the sandwich structure, which were extracted from the FEM model. Classification accuracy was defined as the percentage of correctly classified samples out of the total number of samples in the dataset.

Simulation has been run in Matlab using different Machine learning methods. Machine learning algorithms that gave the best result are given in Table 5. SVMs, neural networks, and, KNN algorithms gave the best results as can be seen in Table 5. Machine learning algorithms are sorted in Table 5, with the method that gives the best results at the top. Generally speaking, the accuracy of all machine learning methods is perfect and acceptable. The lowest accuracy is obtained with the KNN algorithm whereas the best accuracy is obtained by Cubic SVM with 99.5 % accuracy as given in Table 5. Both SVMs and neural networks are powerful Machine learning techniques that can be used for classification. In general, neural networks are considered to be more powerful and flexible than support vector machines, as they can learn more complex decision boundaries. However, support vector machines can be more efficient and easier to interpret than neural networks, and they may perform better on smaller, simpler datasets. After all, the best approach depends on the specific characteristics of your dataset and the requirements of your task. Therefore, considering our unique data, it is fair for support vector machines to give better results than neural networks because the data set is simple and has only six features.

A Receiver Operating Characteristic (ROC) curve illustrates graphically how a binary classification system performs as the discrimination threshold is altered. The graph illustrates the interaction between the true positive rate (TPR) and the false positive rate (FPR) for various threshold values. The ROC curve can be used to assess how well various classifiers perform and to choose a threshold for a classifier that maximizes a particular performance parameter. Measuring the area under the curve is one approach to evaluating the effectiveness of a classifier using the ROC curve (AUC). A classifier that has an AUC of 1.0 is considered a perfect classifier, while an AUC of 0.5 represents a classifier that is no better than random guessing. The ROC curve obtained in this study is given in Figure 4. One can see in the legend of Figure 2 that the minimum AUC is 0.9974 for the elliptical cutout and the maximum AUC is 1 rectangular cutout.

Table 5. Classification results.

Machine Learning Methods	Accuracy %
Support Vector Machine (Cubic SVM)	**99.5**
NN Medium NN	99.3
Support Vector Machine Quadratic SVM	99.2
NN Narrow NN	99.2
NN toolbox	99.1
NN Trilayered NN	99.0
NN Wide NN	98.9
NN Bilayered NN	98.7
KNN Fine KNN	98.0

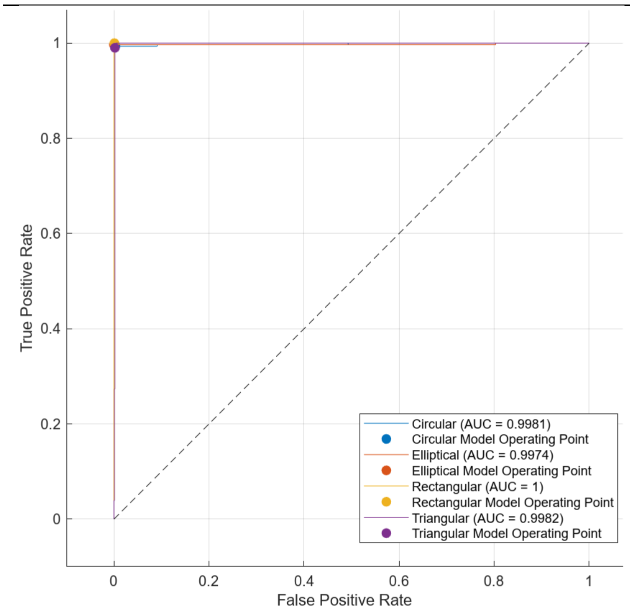

Fig. 4. ROC curve obtained in this study.

3.2. Regression Study

Within this section, a regression study is performed to find the location of circular cutouts. Different machine learning methods are employed and results are discussed in terms of Root Mean Squared Error (RMSE), Mean Squared Error (MSE), and R-Squared. Both the MATLAB regression learner toolbox and neural networks toolbox are employed. In all methods, 15 % of data is set aside for testing and 15% data for validation. Additionally, in neural networks, a 30-layer size is used. The methods that gave the best result are selected and the results are given in Table 6 in ascending order in terms of RMSE. When R-Squared is considered one can see that all machine learning methods gave 1. R-squared is a statistical indicator of how closely the data resemble the regression line that was fitted. It ranges from 0 to 1, where 1 means all the data fit the line perfectly, and 0 means the line does not fit the data at all. As a result, one can say that all machine learning methods can perfectly fit our unique data set.

RMSE is the square root of the MSE and is used to provide a more interpretable measure of the prediction error. RMSE provides a measure of the average error in the model's predictions and is expressed in the same units as the target variable. The neural network toolbox has the highest RMSE and MSE. On the other hand, Neural Network with a Wide Neural Network kernel has the lowest RMSE and MSE. GPR is the second-best algorithm after the Neural network toolbox as can be seen in Table 6. GPR resulted in good RMSE and MSE. As can be seen from Table 6 linear regression gave better results than neural network algorithms in the regression toolbox. Both linear regression and neural networks can produce good results in different scenarios. Linear regression is a simple model that is good for linear relationships between inputs and outputs, while neural networks can handle non-linear relationships and more complex patterns in data. However, neural networks can be more computationally intensive and require more data to train effectively. Ultimately, the choice between linear regression and neural networks should be based on the specific problem and the characteristics of the data being used. Since our data set is not so complicated and linear, Linear regression algorithms gave rather good results. To sum up, the neural networks toolbox is perfect for this kind of application. Furthermore, it can be applied for example for delamination and crack prediction in sandwich structures.

Table 6. Prediction result of machine learning methods

Machine learning methods	RMSE	MSE	R-Squared
Neural network toolbox	0.000090883	8.2597e-09	1
Gaussian Process Regression (Matern 5/2 GPR)	0.00045685	2.0817e-07	1
Gaussian Process Regression (Rational Quadratic GPR)	0.00045778	2.0956e-07	1
Gaussian Process Regression (Squared Exponential GPR)	0.00045778	2.0956e-07	1
Linear Regression (Interaction Linear)	0.00064479	4.1575e-07	1
Gaussian Process Regression (Exponential GPR)	0.00077038	5.9348e-07	1
Stepwise Linear Regression (Stepwise Linear)	0.00091739	8.416e-07	1
Linear Regression (Linear)	0.0012973	1.6831e-06	1
Neural Network (Narrow Neural Network)	0.001334	1.7796e-06	1
Linear Regression (Robust Linear)	0.0014484	2.0978e-06	1
Neural Network (Medium Neural Network)	0.0017795	3.1665e-06	1
Neural Network (Trilayered Neural Network)	0.0017911	3.2081e-06	1
Neural Network (Wide Neural Network)	0.0019615	3.8476e-06	1

4. Conclusion

In this study, the effect of cutout shapes and locations on the natural frequencies of sandwich structures was investigated using machine learning algorithms. The results showed that the Neural Network toolbox algorithm outperformed other algorithms in predicting the cutout locations, while the Support Vector Machine algorithm was more reliable for cutout shape classification. The developed model was validated using the literature study, and a maximum of 0.24% error was observed. The constructed dataset contained six features representing the natural frequencies and two target outputs, "class" for cutout shape and "distance" for cutout location. The classification accuracy for cutout shapes was 99.5%, and the cutout location was predicted with an RMSE value of 0.000090883. These findings demonstrate the effectiveness of machine learning algorithms for the classification of cutout shapes and the prediction of cutout locations in sandwich structures. The practical applications of this research include the optimization of design and the prevention of structural failure due to resonance. The proposed method can be extended to other structural analyses such as delamination shape classification and delamination location prediction. Future studies can explore the integration of these algorithms with other technologies for improved performance in more complex scenarios. Additionally, the effect of cutout removal and the addition of small masses on the natural frequencies of sandwich structures can be investigated using the trained regression algorithms.

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