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# A deep learning approach to estimate the contact force of a fiber metal laminate: a finite element analysis

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***Abstract*- Fiber–metal laminates (FMLs) are high-performance hybrid structures based on alternating stacked arrangements of fiber-reinforced plastic (FRP) plies and metal alloy layers. In this paper, the multi-layer perceptron regression (MLP) algorithm, which is based on neural network in deep learning, has been utilized to estimate the prediction accuracy of contact force obtained from finite element analysis between an impactor and a FML under low-velocity impact. The independent variables of m and v showing mass and velocity of impactor, respectively, and dependent variable of F which indicates the contact force have been used to train the algorithm. The results display that the prediction accuracy of 96 % was obtained for contact force by using MLP algorithm that shows it is an appropriate algorithm for this research.**

***Keywords*** - Contact force, Deep learning, Fiber metal laminate, Finite element analysis

## I. INTRODUCTION

Fiber–metal laminates (FMLs) are hybrid structures consisting of metal sheets and fiber-reinforced plastic layers. The main advantage of the fiber metal laminate is tailoring the best of both the materials i.e.; metal and FRP. Numerous studies have been conducted on the impact behavior of fiber metal laminates. Few of them have been summarized in the review articles [1–3].

In this study, the prediction accuracy of the contact force between an impactor and a FML will be inquired.

## II. MODELING AND SIMULATION

In this simulation, there are two different parts, impactor and FML having their own properties. Furthermore, the FML is divided into two parts, Al 2024-T3 and FRP (glass/polyster). The mechanical properties of Al 2024-T3, FRP, and impactor are shown in TABLE I, TABLE II, and TABLE III, respectively [4- 6].

TABLE I: MECHANICAL PROPERTIES OF AL 2024-T3.

| Property | Value | Unit |
|---|---|---|
| Elastic modulus | 72.4 | GPa |
| Shear modulus | 27.6 | GPa |
| Poisson’s ratio | 0.33 | - |
| Density | 2780 | kg/m$^3$ |

TABLE II: MECHANICAL PROPERTIES OF FRP (GLASS/POLYESTER).

| Property | Value | Unit |
|---|---|---|
| $E_{11}$ | 24.51 | GPa |
| $E_{22}=E_{33}$ | 7.77 | GPa |
| $G_{12}=G_{13}$ | 3.34 | GPa |
| $G_{23}$ | 1.34 | GPa |
| $\nu_{12}=\nu_{13}=\nu_{23}$ | 0.078 | - |
| Density | 1800 | kg/m$^3$ |

TABLE III: MECHANICAL PROPERTIES OF IMPACTOR (STEEL).

| Property | Value | Unit |
|---|---|---|
| Elastic modulus | 24.51 | GPa |
| Poisson’s ratio | 7.77 | - |
| Density | 3.34 | Kg/m$^3$ |
| Tip diameter | 1.34 | mm |
| Mass | 0.078 | Kg |
| Velocity | 1800 | m/s |

In addition, the geometrical parameters of FML plate are illustrated in TABLE IV. Also in this simulation the FML has 10 layers which the first layer and the last layer are Al 2024-T3.

TABLE IV: GEOMETRICAL PARAMETERS OF FML.

| Property | Value | Unit |
|---|---|---|
| Length | 200 | mm |
| Width | 200 | mm |
| Lay-up | $[0/90/0/90/0]_s$ | degree |
| Ply thickness | 0.269 | mm |

In this research, by using multi-layer perceptron regression (MLP) algorithm, which is a neural network and deep learning approach, as can be observed in TABLE V, fifteen random data have been chosen from the velocities in the range of 0.1 to 1 m/s, and the impactor masses of 1, 2, 3, and 4 kg. Then the contact force for each state have been calculated and eventually the prediction accuracy has been estimated. Meanwhile, V and M are the velocity and mass of the impactor, respectively as independent variables, and F is the contact force in Table-5 as a dependent variable.

TABLE V: RANDOM DATA.

| M (kg) | V (m/s) | F (N) |
|---|---|---|
| 1 | 0.3 | 174.51 |
| 1 | 0.9 | 488.04 |
| 2 | 1 | 756.77 |
| 2 | 0.5 | 386.61 |
| 4 | 0.9 | 1193.472 |
| 4 | 0.1 | 113.845 |
| 3 | 0.8 | 895.6442 |
| 1 | 0.7 | 426.214 |
| 3 | 0.5 | 467.63 |
| 1 | 1 | 518.5043 |
| 4 | 0.5 | 592.3724 |
| 4 | 0.7 | 882.322 |
| 4 | 0.3 | 342.056 |
| 2 | 0.9 | 692.836 |
| 3 | 1 | 518.5043 |

The boundary condition of ENCASTR has been chosen for FML and it has been divided into 2048 elements with a mesh type of S4R (a 4-node doubly curved thin or thick shell, reduced integration, hourglass control, finite membrane strains).

The impactor has been divided into 4056 elements with the mesh type of C3D10M (a 10-node modified quadratic tetrahedron).

## III. RESULTS AND DISCUSSIONS

First in order to ensure about the obtained values of contact forces derived from current simulation, a comparison has been done with an exact solution done by Payeganeh et al. [7]. The maximum contact force between the FML and impactor in their exact solution was obtained 730 N with the velocity of 1 m/s, impactor mass of 2 kg, and Al 2024-T3 utilized in the first and the last layer of FML plate (1-10 Al). However, the maximum contact force in this simulation with the properties defined in for the exact solution for both FML plate and impactor was obtained 756.77. There is an error percentage of 3.667 %. Then 80 % of random data in TABLE V was used to train the multi-layer perceptron regression (MLP) algorithm, and 20 % of data was used to test to compare them with the data obtained with finite element simulation. In this neural network algorithm, the activation function of RELU has been considered, the number of hidden layer sizes is 20, and the solver of LBFGS has been used in order to obtain a better accuracy for the predictions gained by MLP algorithm. TABLE VI indicates the results of the contact force obtained from the prediction of RFR algorithm and the results obtained from finite element simulation.

TABLE VI: VALUES OF PREDICTED AND SIMULATED CONTACT FORCE.

| M (kg) | V (m/s) | Fs (N) | Fp (N) |
|---|---|---|---|
| 1 | 0.9 | 488.04 | 512.28075 |
| 3 | 0.8 | 895.6442 | 771.51762 |
| 3 | 0.5 | 467.63 | 542.82972 |

Fs and Fp are simulated and predicted contact force, respectively in TABLE VI. It can be found from TABLE VI that the prediction accuracy of 81.4 % ($R^2$ Score = 81.4 %) exists for contact force.

## IV. CONCLUSION

In this study, by utilizing finite element simulation and MLP algorithm, the prediction accuracy of 81.4 % was obtained for the contact force between an impactor and a fiber metal laminate.

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