

Development of A Multi-Stage MATLAB Algorithmic Quantification Using Computational Processing of Stress-Strain Data in Carbon/Glass Epoxy Composites

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Abstract

Composite materials have long been in great demand for industrial purposes, particularly in the field of lightweight automobile and aircraft applications. The theory of numerical analysis provides a useful account of how Fibre-reinforced composites can be developed to prevent failure analyses and produce new composite materials. Therefore, to get an advantage from this theory, an effort has been made in this research. A systematic, Multi-stage algorithm based on MATLAB software was established to generate a code that can manipulate data of tensile and flexural tests for composite materials made from glass fibre epoxy composites (GF/Ep) and carbon fibre epoxy composites (CF/Ep). The current numerical framework was implemented using suggested code to handle data from stress-strain curves and predict ultimate strength, strain, and fracture toughness values, undergoing a validation process. The key findings were the GF/Ep-based composite showed better strain failure and an energy absorption value of 12.3 MJ/m³ and 7.0 MJ/m³ in tension and flexure, respectively. This is suggested to have better performance in fracture toughness. Furthermore, the outcome results also showed that on GF/Ep, it is less stiff, with a value of 21.3 GPa and a bending failure value of 400 MPa.

Keywords: Composite, Mat lab, ALGORITHM, Carbon-Glass/Epoxy, Woven

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1. Introduction

Woven laminate composites have attracted tremendous attention due to their exceptional mechanical properties, i.e., stiffness, lightweight, and specific strength and sound reinforcement in all directions. Through various process methods, laminates can be tailored into many forms and used in extensive applications, such as aerospace, maritime, transportation industries, and civil infrastructure [1, 2].

Fiber-reinforced polymer composites have drawn the attention of researchers for the last 20 years, and the tensile behaviour of these materials has been investigated through both experimental and numerical methods. The outcomes of some published papers have primarily focused on fibre orientation, stacking sequence, material hybridization, and simulation approaches using finite element analysis (FEA), particularly in ANSYS, to predict and improve mechanical performance. A fibre orientation has been suggested to be a critical parameter in determining tensile

properties. Vijayanandh et al. [3] used ANSYS to optimise fiber orientation in carbon/epoxy laminates, resulting in the orientation powerfully influencing deformation and energy distribution under tensile loads. Setyabudi et al. [4] demonstrated that [0/90] lay-ups achieved more tensile strength (494 MPa) associated with [45/-45] laminates, with ANSYS simulations closely validating experimental results. Zmindak et al. [5] further confirmed this in 3D-printed carbon fibre composites, where 0° fibre alignment has shown the maximum tensile strength (191.6 MPa), while 90° fibres showed minimal values of performance in comparison.

Further efforts reinforced these outcomes through different situations. Yasser [6] stated higher tensile strength (2857 MPa) at 0° orientation, with modulus following a U-shaped relation with fibre angle. Feki et al. [7] indicated that ±15° orientations in carbon/epoxy laminates showed considerably greater strength (361.4 MPa) than ±30° or mixed compositions, while Cz' [8] established that [0°]_s glass fibre/epoxy laminates verified

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the highest tensile stress (~520 MPa). Together, these studies confirmed that longitudinal fibre orientations reliably produce greater load-bearing capacity related to angled configurations. Moreover, in the same field of study, hybrid composite systems have been seen as a means to improve mechanical performance by joining different fibres or optimising stacking sequences.

Luo et al. [9] numerically examined sisal–glass fibre laminates and documented that increasing layers decreases residual stresses, whereas stacking angles affect deformation. A study by Kebede and Guttata [10] examined glass–carbon hybrids and stated that the [0°/90°/45°]s stacking preparation achieved the maximum tensile strength (~1935 MPa), emphasising the role of carbon fibres at laminate surfaces. A study by Rajak et al. [11] investigated glass fibre reinforced polyester (GFRP) composites, which found that bidirectional [0°/90°] arrangements enhanced load distribution; however, the inclusion of fillers reduced tensile strength. These studies collectively suggest that hybridization and strategic stacking would balance strength, stiffness, and residual stress, thereby contributing to design flexibility for engineering requests.

The role of fibre and matrix types on tensile properties has also been extensively documented. Hamza [11] revealed that polyphenylene sulphide (PPS)-based composites reinforced with glass and carbon fibres showed substantial enhancements in tensile strength, with carbon outperforming glass. Asthana et al. [12] did a comparison for glass, carbon, and Kevlar composites, confirming that Kevlar reinforcement provided the peak tensile strength (51.42 MPa) and elongation at break (13.67%), beating traditional fibres. Maneendra et al. [13] explored coconut fibre–epoxy composites with rice hull and sawdust refinements; their finding showed brittle failure behaviour, highlighting the need for design precision when incorporating natural reinforcements.

In terms of incorporating nanomaterial and advanced processing research, additional highlights material-dependent performance. Duleba et al. [14] presented that adding 1% carbon nanotubes to carbon/epoxy systems enhanced tensile strength, with diagonal fabrics outdoing unidirectional ones. Szpoganicz et al. [15] revealed that prepreg thickness and low-temperature testing have a higher impact on the tensile strength, with thinner 0°/90° laminates exhibiting greater resistance. Cryogenic conditions, which provide whole performance due to resin curing, were also considered.

Beyond bulk tensile testing, micromechanical analyses have been applied to characterise interfacial behaviour. Qi et al. [16] suggested a 45° fibre bundle tensile test (45FBT) to assess interfacial shear strength in carbon/epoxy structures, recording values of ~107.5 MPa for T700S/epoxy and ~114.1 MPa for T800H/epoxy. This approach was shown to be effective in quantifying interfacial bonding and presents a consistent alternative to conventional tests.

Several studies have been conducted to predication the material properties by using mat lab code. A Gaussian Process Regression was employed to and linked with Machine Learning Toolbox to predict and optimize the mechanical strength of composite concrete. In the same field of study, fracture mechanics was predicted by developing MATLAB with a Graphical User Interface (GUI). The outcomes were a topology optimization, ductile iron fracture toughness, and the other for fracture toughness in fiber-reinforced concrete [17-19]

Material parameters that can be extracted from numerical analysis would be a powerful tool to serve as direct inputs for finite element analysis (FEA), enabling more accurate simulation of composite structural behaviour under different loading conditions. In this current proposal algorithm, it would be considered to be an integrated connection between the experimental data and numerical analyses to optimize the fibre reinforcement composite design, thereby enhancing the structural performance based on experimental data of the stress–strain plots. A systematic, Multi-stage algorithm based on MATLAB software was established to generate a code that can manipulate data of suggested (GF/Ep) and (CF/Ep) based fibre composite. Many mechanical properties could be extracted from this analysis, such as the tensile stress, strain, and toughness value based on the area under the load-displacement curve. The key results obtained from this algorithm can provide insight into future modelling

2. Methodology

Within this research, a systematic, Multi-stage algorithm based on MATLAB software was developed to create a code that can handle data of tensile and flexural tests for composite materials made from (GF/Ep) and (CF/Ep) composites. The current numerical framework was implemented using suggested code to manipulate data from stress-strain curves and predict ultimate strength, strain, and fracture toughness values, with undergoing to validation process.

2.1 Experiential procedures

The present research employs the mad layup method to prepare fibre reinforcement composite materials. The materials being utilized here are epoxy E44 resin as a matrix reinforced with carbon and glass fibre that have a plain woven arrangement. A total of five sheets with approximately 0.4 mm thickness were set into a mould with a square shape, with an edge length of 16 cm. The resin was poured into the mould that already had a woven structure settled based on the desired thickness.

After that, the produced block was pressed to produce a proper compaction, arrange layers, and remove any unwanted resin. It is worth mentioning that the curing process was applied for 48 hours at ambient temperature. A water jet machine was employed to cut the samples according to the ASTM D638 and ASTM D790, as shown in Figs. 1 and 2, which were used to obtain the tensile and flexural strength data, respectively. Prior to data

extraction, a crosshead speed of 2mm/min was used for a universal testing machine; after that, the data were plotted and saved to feed them into the MATLAB code. It is worth mentioning that the 60:40 resin-to-fiber weight ratio is a standard target for both glass fibre/epoxy (GF/Ep) and carbon fibre/epoxy (CF/Ep) composites used in the work.

2.2 Multi-stage algorithm

In this section, a Multi-stage algorithm was generated using MATLAB code as shown in Fig 3. This MATLAB algorithm processes experimental stress-strain data. The outcome will characterize the mechanical properties of both (GF/Ep) and (CF/Ep) materials. The code loads the file containing the test data set, then calculates the elastic modulus, ultimate strength, and fracture strain. It implements quality checks to validate linear region fitting and compares results against published material ranges. The toughness and fracture toughness metrics will be computed and plotted.

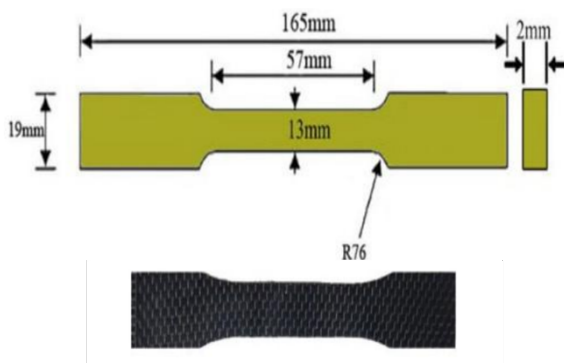


Fig. 1 Dimensions of tensile and flexion test specimens for both carbon epoxy and glass fiber

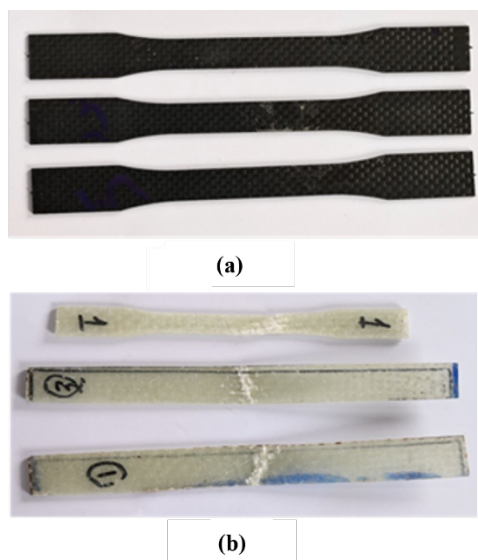


Fig. 2 Tensile and flexion test samples for both carbon epoxy and glass fiber

3. Results

The results obtained from the preliminary analysis of (GF/Ep) and (CF/Ep) composite materials are set out in Fig. 4. It shows individual stress-strain curves, annotated with their respective modulus lines. The blue line represents the experimental data obtained from stress-strain test and flexural test, while the red line refers to the initial slope that was used to predict the ultimate stress and toughness values. From the graph, it can be seen that the CF/Ep material is stronger and stiffer than the GF/Ep composite. The CF/Ep material showed a frailer start at 506 MPa, while the GF/Ep material showed 352 MPa.

In the case of the flexural test, it can be noticed that CF/Ep can stand out to reach a value of 81.7 GPa, with an extremely strong 832 MPa under bending force. Turning now to the experimental evidence on GF/Ep, it revealed that it is less stiff with a value of 21.3 GPa and a bending failure value of 400 MPa. Closer inspection of the graph shows the CF/Ep material showed over 6 times stiffer in bending than it was in the tension test.

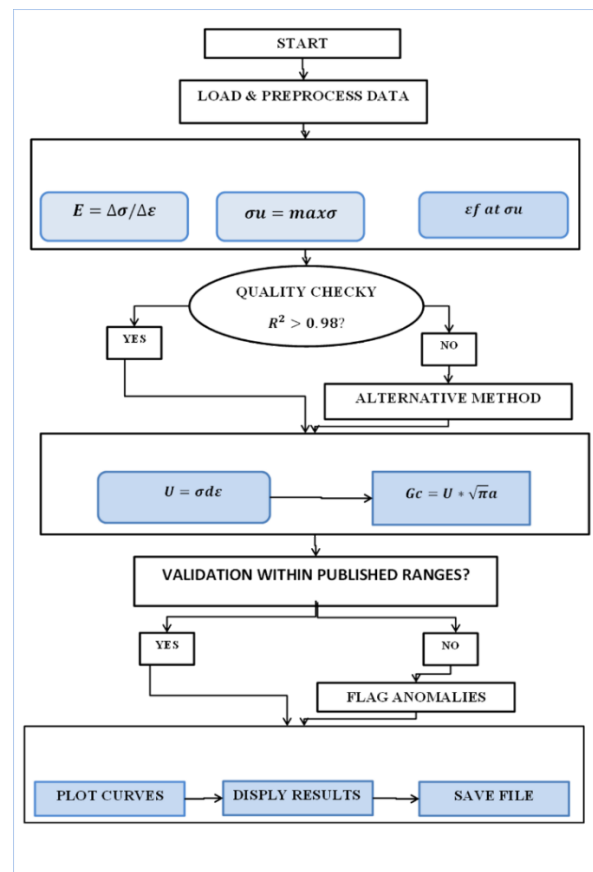


Fig. 3 Computational framework for composite material characterization extraction from stress-strain data

In this study, experimental tests on two types of composites were conducted, as mentioned in the previous section. The first set of questions aimed to validate the results predicted from this numerical approach, as shown in Fig. 4.

Table 1 shows results that closely matched the expected theoretical ranges for woven composites. According to the data obtained from this code, which is presented in Table 1, it can be clearly noticed that predicted values showed a reliable consistency in published range data for these types of materials used as a verification process.

It can be seen from the data presented in Table 1 and Fig. 5, and Fig. 6 The most surprising aspect of the data is in the Fig. 5, which shows the area under curve of stress strain plots for both composite (GF/Ep) and (CF/Ep) used to calculate the toughness. This is a strong, remarkable result outcome that could be obtained for this code, which is (CF/Ep) showed higher values for flexural and tensile, which were (61.94 MJ/m³) and (32.64 MJ/m³), respectively. On the other hand, GF/Ep) showed values for both test (54.79 MJ/m³ and 21.84 MJ/m³. This provides strong evidence that carbon fibre has strong interracial bonding with high stiffens, allowed to it to carry high load without failure.

The one of the important set of analysis examine in this proposed algorithm is to predict the toughness index, the value her was shown in a normalized toughness index for (GF/Ep) and (CF/Ep) composites. Normalize toughness value means a proper comparison was conducted, which denoted to (GF/Ep) value equal to 1, whereas the (CF/Ep) toughness value has 17 % higher than

the lower value, so it is simply divided higher value obtained over lower vale. This method is used to provide a better understanding of the compassion for same scale, which indeed provides an enhancement in energy absorption. What stands out from this figure is the high rate of resistance to crack initiation and propagation in the composite matrix and fibre combination.

In order to assess this approach in terms of predicted data, there was a good agreement and be consistency with available data [20] [21, 22] for these types of fibre composite. The more surprising correlation is with the developed algorithm, which provides a systematic framework for extracting key mechanical properties directly from experimental stress–strain data. It demonstrates the ability to automate these mathematical formulas and present results, combined with stress–strain plots, the method ensures a consistent and dependable assessment of composite performance.

Elsewhere, validating the present findings against published data, this approach demonstrates robust ability for further applications in both academic investigation and the engineering industry. Furthermore, these efforts are able to develop more synthesis composites, which could assist in optimizing formulations and provide accurate input parameters for numerical simulations. Notably, the algorithm can serve as a robust tool for benchmarking their performance, unlike conventional systems, thereby speeding up material innovation and implementation.

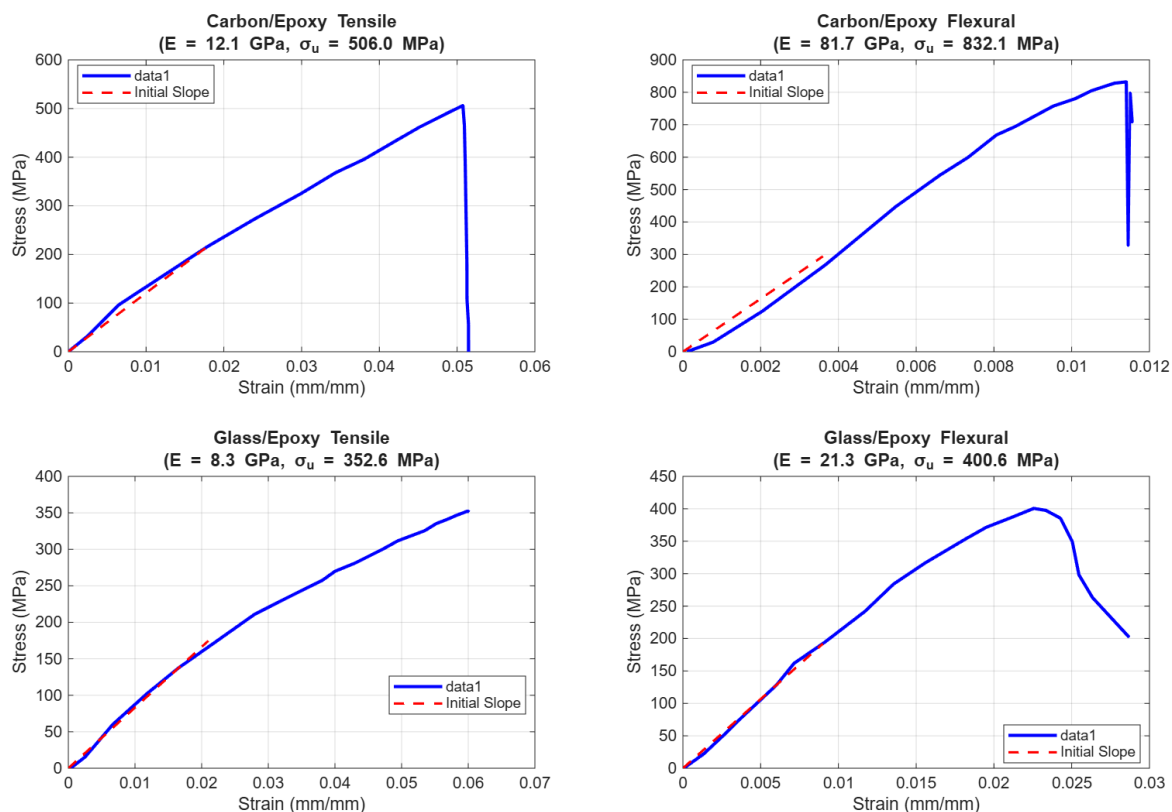


Fig. 4 Discrete stress–strain curves with module lines

Table 1: Comparison of predicted data with published ranges for woven architectures [20-22] *

Property	Published Range Carbon/Epoxy Woven*	Published Range Glass/Epoxy Woven*	Current work Carbon/Epoxy	Current work Glass/Epoxy	Within Expected Range
Young's modulus - Tensile (GPa)	10-16	7-11	12.1	8.3	✓ ✓
Young's modulus - Flexural (GPa)	70-85	18-26	81.7	21.3	✓ ✓
Tensile Strength (MPa)	450-580	300-380	506	352.6	✓ ✓
Flexural strength (MPa)	780-920	380-480	832.1	400.6	✓ ✓
Tensile Failure Strain (%)	4.0-6.5	5.0-7.5	5.07	5.99	✓ ✓
Flexural Failure Strain (%)	1.0-1.6	2.0-2.8	1.14	2.26	✓ ✓
Tensile Toughness (MJ/m ³)	12-18	10-16	14.3	12.3	✓ ✓
Flexural Toughness (MJ/m ³)	4.5-6.5	6.0-9.0	5.1	7.0	✓ ✓

*The data were extracted from published studies [20–22] and employed for validation purposes

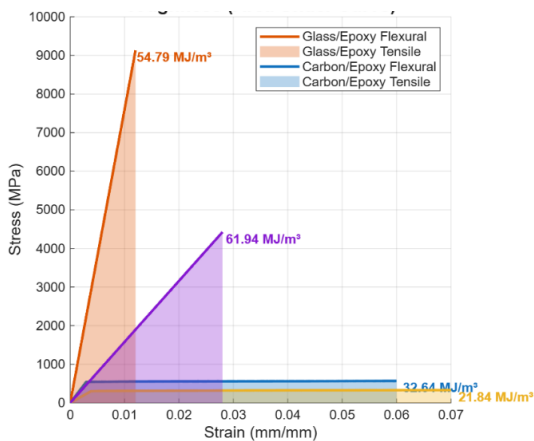


Fig. 5 Toughness Area under the curve for (GF/Ep) and (CF/Ep) predicted from the code.

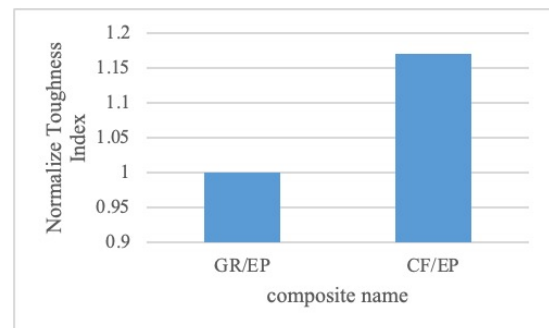


Fig. 6 Normalize Toughness Index for (GF/Ep) and (CF/Ep) predicted from the code

4. Conclusion

From the study, several findings have been remarked as shown below:

- The results showed that CF/Ep composites attained tensile modulus values in the range of 12.1 GPa and a flexural modulus of 81.7 GPa. However, GF/Ep composites provided tensile modulus of 8.3 GPa and flexural modulus of 21.1 GPa.
- Ultimate strength values spanned 830 MPa for CF/Ep and 400.6 MPa for GF/Ep.
- It has been concluded that the toughness values range from 12-14 MJ/m³. These results largely conformed

to published ranges, confirming the accuracy of the digitization and processing framework.

- Notably, the extracted material parameters can serve as direct inputs for finite element analysis (FEA), enabling more realistic simulation of composite structural behaviour under tensile and flexural loading. This integration bridges experimental findings with computational modelling, supporting future optimization of composite designs and predictive structural performance studies.
- This code confirms the consistent analysis of both tensile and flexural test data for both materials, in case researchers with standardized material characterization suitable for both academic and industrial purposes utilize them.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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