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Design of a Web-Based Plotting System for Stress–Strain Curve Visualization Based on Tensile Test Data

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Abstract

The stress-strain curve plays an important role in determining the characteristics of a material and serves as a preliminary study in selecting materials for machine and structural design, with the aim of minimizing failure. However, the generation of such curves is still commonly performed manually using calculators and Microsoft Excel, which requires a relatively long processing time, especially when a large amount of data and multiple material types are involved. This study aims to design a web-based computational tool using the Python programming language to automatically process and visualize material stress–strain curves based on tensile test data. Tensile tests were conducted on ST 37 steel, ST 60 steel, and brass specimens machined according to the ASTM E8 standard using a universal testing machine. The test data obtained from the three materials were then uploaded into the developed system for processing, comparison, and visualization in the form of stress–strain curves. The system testing results showed that ST 37 steel had a maximum stress of 323 MPa with a strain of 0.26, ST 60 steel had a maximum stress of 547 MPa with a strain of 0.13, and brass had a maximum stress of 503 MPa with a strain of 0.18. The developed system was proven to generate accurate results while significantly reducing data processing time compared to conventional methods, making it a practical tool for material characterization analysis.

Keywords: *Design, plot diagram, visualization, stress, strain, tensile test*

1. Introduction

The tensile test is a method used to evaluate the strength (tensile strength) of a material by applying a load (static force) to a specimen. The results of a tensile test can be analyzed using a stress–strain curve [1]. Knowledge of the actual stress–strain curve of a material is essential for conducting nonlinear finite element analysis to solve elastoplastic problems [2]. Stress–strain curve visualization serves as a tool for analyzing the mechanical properties of a material, such as elasticity, strength, and toughness. This curve is obtained from changes in the length of a material during tensile testing [3]. Accurate determination of mechanical properties plays an important role in manufacturing design, as the mechanical properties of materials are directly related to user safety [4].

The testing process and the creation of material visualizations require considerable time, expertise, precision, and cost [5]. Calculations for determining stress–strain values are generally performed using calculators, while stress–strain curve visualization is created manually or with Microsoft Excel. Determining stress–strain values and generating graphs manually is certainly inefficient when comparing several stress–strain curves of different materials, as each material possesses distinct stress–strain characteristics. The need for computational tools to analyze and visualize large volumes of data rapidly exists across many scientific disciplines, including quantum chemistry, biophysics, and materials science [6]. Visualization is an essential means of extracting information from scientific data and is required in almost every research field [7]. Rapid advances in computer technology within materials science have encouraged researchers and experts to develop computational data-driven approaches for analyzing, visualizing, and solving various problems in the field of materials engineering [8].

Matplotlib is one of the most widely used Python libraries for data visualization, including the creation of plots, histograms, bar charts, and other graphical representations [9]. In addition, Python enables the development of web-based data visualization applications.

Python has been widely utilized to develop programs and applications for solving complex problems in materials science, such as predicting the stress–strain behavior of aluminum [10], implementing stress–strain curves for stainless steel based on typical tensile tests [11], predicting polymer stress–strain curves using transfer learning methods [4], and developing web-based machine learning systems for predicting the hardness of steel plates [12]. The generation of stress–strain curves plays an important role in engineering design for material selection in machine elements, ensuring user safety, and understanding material characteristics. To date, tensile-test stress–strain curves are generally obtained through two approaches: direct testing using computer-based digital tensile testing machines, and manual generation using Microsoft Excel based on specimen elongation and applied load data obtained from conventional tensile testing machines. In practice, many students, researchers, and materials engineers still rely on the latter approach due to the high operational costs associated with advanced testing equipment.

Although software such as Microsoft Excel can be used to generate stress–strain curves, this approach still requires several manual steps, including calculating stress and strain values separately for each data point and then plotting the curves individually for each material. Furthermore, comparing curves from multiple materials simultaneously in Excel requires repetitive data processing, which is time-consuming and prone to human error. The system developed in the present study offers several distinct advantages over such conventional approaches: full automation from data upload to curve visualization, the ability to compare multiple materials within a single interface, and web-based accessibility that requires no additional software installation on the user's device. Unlike general-purpose data visualization platforms, the proposed system is specifically designed to address the practical needs of materials testing laboratories that still rely on conventional tensile testing machines without integrated digital data acquisition systems, making it a targeted and accessible solution for students, researchers, and laboratory practitioners.

Therefore, this study aims to develop a web-based stress–strain curve visualization system using Python to process and visualize tensile test data . The results of this study are expected to facilitate students, researchers, and materials engineers in visualizing, analysing and comparing stress–strain curves of different materials based on tensile test data. Compared with conventional methods, the implementation of a web-based stress–strain curve visualization system offers several advantages, including improved accessibility, the ability to compare multiple datasets simultaneously, high accuracy, faster processing, and reduced operational costs.

2. Materials and Methods

This study aims to develop a web-based computational tool for the automatic generation of material stress–strain curves from tensile test data using the Python programming language. The data used for the web-based stress–strain curve modeling in this study were obtained directly from tensile tests conducted on several materials, including ST 37 steel, ST 60 steel, and brass, using a universal testing machine. The tensile test data consisted of specimen elongation and applied load values, which were subsequently converted into stress–strain curves, as illustrated in Figure 1.

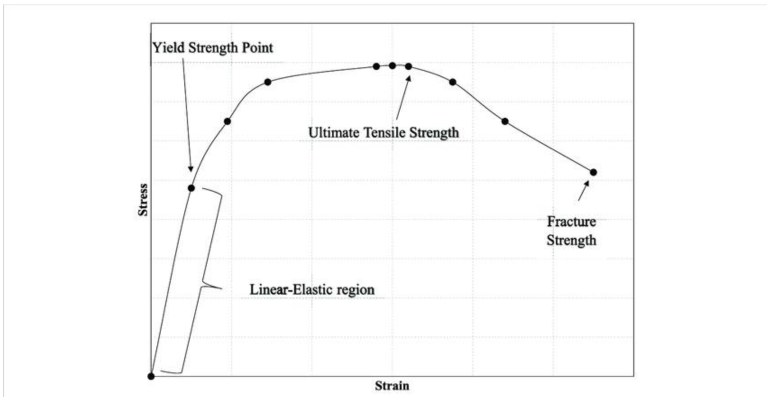

Figure 1. Stress–Strain Curve of Metals [13]

The stress value (σ) on the y-axis and the strain value (ε) on the x-axis form what is known as a stress–strain curve. The shape of the stress–strain curve may vary depending on the type of specimen or material. Based on the initial gauge length of the specimen (L_o) and its initial cross-sectional area (A_o) subjected to an applied load (F), stress (σ) is defined as the applied force per unit area, whereas strain (ε) is defined as the change in length (δ) divided by the initial gauge length (L_o). Therefore, the stress value can be calculated using Equation (1), while the strain value can be calculated using Equation (2) [14].

$$\sigma = F / A_0 \quad (1)$$

$$\varepsilon = \delta / L_0 \quad (2)$$

The data obtained from the tensile test consist of two variables: the applied load on the specimen and the dial elongation. Therefore, to determine the stress and strain values from the tensile test data, Equations (1) and (2) were implemented in Python scripts, allowing users to input the specimen diameter and gauge length of the tested specimen. The tensile test data obtained from ST 37 steel, ST 60 steel, and brass were used as test data for the web-based plotting system. The system uses this facts as input and automatically visualizes them. Figure 2 provides a thorough summary of the steps used to create the web-based stress-strain curve graphing system.

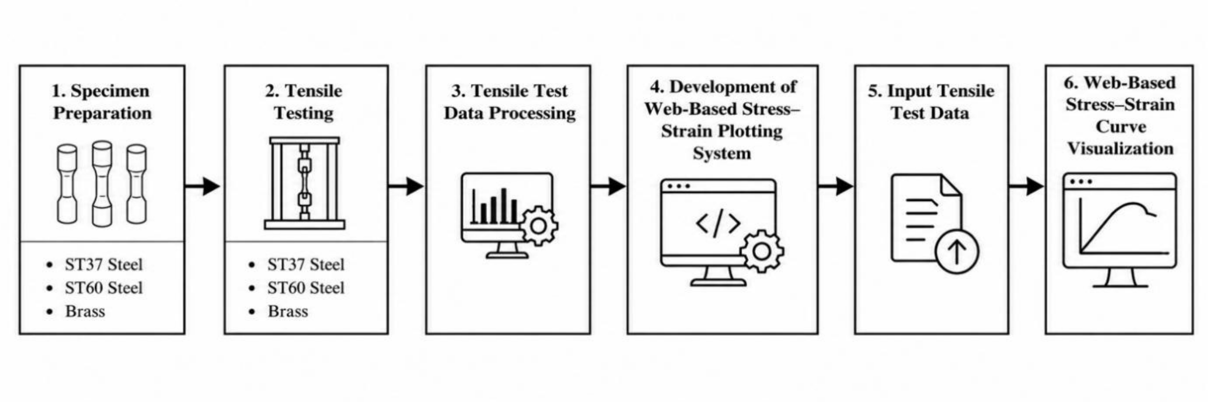

Figure 2. Research Framework

2.1 Tensile Test

A tensile test is performed by applying a tensile load to a specimen until fracture occurs. By subjecting the specimen to tensile loading, it is possible to determine how the material responds to the applied force and to measure the extent of its elongation. In this study, the tensile tests were conducted in the Materials Laboratory of Politeknik Negeri Padang using a universal testing machine, as shown in Figure 3.

Figure 3. Universal Testing Machine

The materials used in this study were ST 37 steel, ST 60 steel, and brass. Prior to tensile testing, specimens of all three materials were machined using a lathe in accordance with the ASTM E8 standard. The specimen geometry is shown in Figure 4, while the specimen dimensions are presented in Table 1.

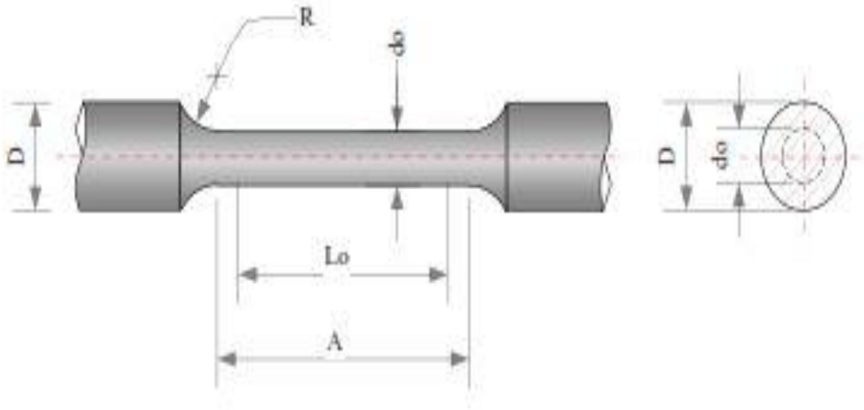

Figure 4. ASTM E8 Standard Specimen

Table 1. Dimensions of ASTM E8 Standard Specimens

Dimension	ST 37 Steel	ST 60 Steel	Brass
L_o (mm)	80	80	80
d_o (mm)	8	8	8
R (mm)	8	6	6
A (mm^2)	88	88	88

The tensile testing process was conducted to determine the mechanical properties of materials, such as the elastic limit and yield point, by applying a continuously increasing uniaxial tensile load to both ends of the specimen [15]. Initially, the gradual increase in load causes a proportional increase in specimen elongation relative to the applied force. This behavior continues until the specimen begins to elongate without any additional increase in load, indicating that the material has reached its yield point. The yielding process continues until further elongation becomes non-proportional, eventually reaching the maximum load capacity, after which the specimen fractures [16]. The tensile test measurements recorded in this study consisted of dial elongation and the magnitude of the applied load. These data were subsequently used to generate the stress–strain curves of ST 37 steel, ST 60 steel, and brass.

2.2 Web-Based Stress–Strain Curve Modeling

The web-based stress–strain curve modeling system allows users to upload tensile test data, consisting of specimen elongation and applied load values, in CSV or Excel format. The web server automatically processes the uploaded data, calculates the corresponding stress and strain values, and visualizes the results in the form of a stress–strain curve.

The workflow of the proposed web-based plotting system is illustrated in Figure 5. With this system, users are not required to manually calculate stress and strain values before converting them into stress–strain curves. The system was developed using the Python programming language with the support of several libraries, including Pandas for data manipulation and reading CSV and Excel files, Matplotlib for data visualization, and Streamlit for transforming Python scripts executed in the command-line interface into a web-based application that can be accessed directly by users [17].

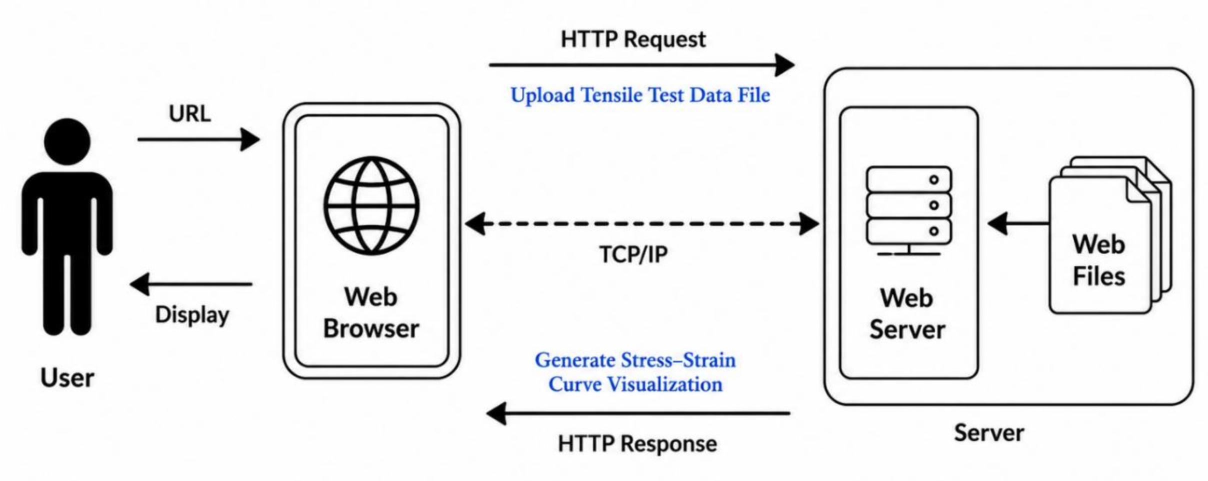

Figure 5. Workflow of the Proposed Plotting System

3. Results and Discussion

3.1 Tensile Test

The materials used in the tensile testing conducted in this study consisted of ST 37 steel, ST 60 steel, and brass. Prior to testing, all specimens were machined using a lathe to conform to the ASTM E8 standard, with each specimen having a diameter of 8 mm and a parallel length of 88 mm. After the machining process was completed, the specimens were subjected to a continuously increasing tensile load using a universal testing machine until fracture occurred. The tensile testing process produced data on specimen elongation and the magnitude of the load applied to the specimens during the test, as shown in Figure 6.

Figure 6. Photograph of Specimens Prepared According to the ASTM E8 Standard.

The tensile test results for the three specimens are presented in Tables 2, 3, and 4. ST 37 steel was able to withstand a maximum load of 16,245 N with a dial elongation of 20 mm, ST 60 steel sustained a maximum load of 27,537 N with a dial elongation of 11 mm, and brass sustained a maximum load of 25,324 N with a dial elongation of 15 mm. These results indicate a consistent trend in which materials with higher maximum loads tend to exhibit smaller dial elongations. ST 60 steel withstood the highest load but showed the smallest elongation, whereas ST 37 steel sustained the lowest load but exhibited the greatest elongation, indicating the highest ductility among the three materials.

At this stage, the test data were still represented in terms of applied load and dial elongation; therefore, they had to be converted into stress and strain values using Equations (1) and (2). Stress values were obtained by dividing the applied load by the initial cross-sectional area, while strain values were obtained by dividing the elongation by the initial gauge length. With an initial cross-sectional area of 50.27 mm^2, the maximum load of ST 37 steel (16.245 N) produced a maximum stress of approximately 323 MPa, ST 60 steel produced approximately 547 MPa, and brass produced approximately 503 MPa. Meanwhile, the dial elongations of the respective materials resulted in strain values of 0.25, 0.14, and 0.19 based on an initial gauge length of 80 mm. In general, this data processing procedure is carried out manually using a calculator, followed by plotting the curves in Microsoft Excel. Such an approach becomes inefficient when a large amount of data or multiple materials need to be compared.

3.2 Web-Based Stress–Strain Curve Modeling

The web-based plotting system developed in this study was built using Streamlit, a Python framework that enables scripts written in Visual Studio Code to be deployed and accessed online by executing the Streamlit run function through the command-line interface (CMD) [18]. The developed plotting system includes several main features, including a Browse File button for uploading tensile test data in CSV or Excel format, a Diameter Input field for entering the specimen diameter, a Specimen Length Input field for entering the specimen length, and a Submit button for executing the stress–strain curve visualization script. The main interface of the web-based plotting system was designed to be user-friendly, allowing users to operate the system easily. The main page of the application is shown in Figure 7.

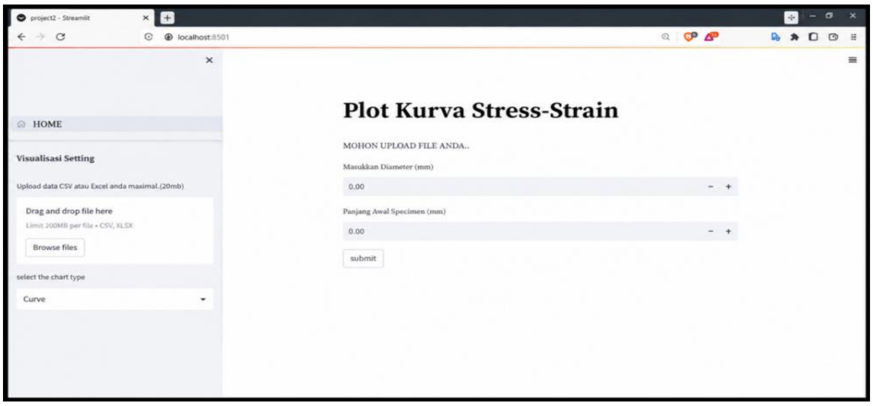

Figure 7. Main Interface of the Plotting System

The web-based stress–strain curve modeling system facilitates users in visualizing tensile test data obtained from a universal testing machine without the need to calculate stress and strain values manually. The workflow of the proposed web-based system is straightforward. Users simply upload tensile test data obtained from materials tested using a tensile testing machine in Excel or CSV format, and the system automatically processes and visualizes the uploaded data in the form of a stress–strain curve. The web-based plotting system also allows user to simultaneously compare the stress–strain curves of multiple materials,, as shown in Figure 8.

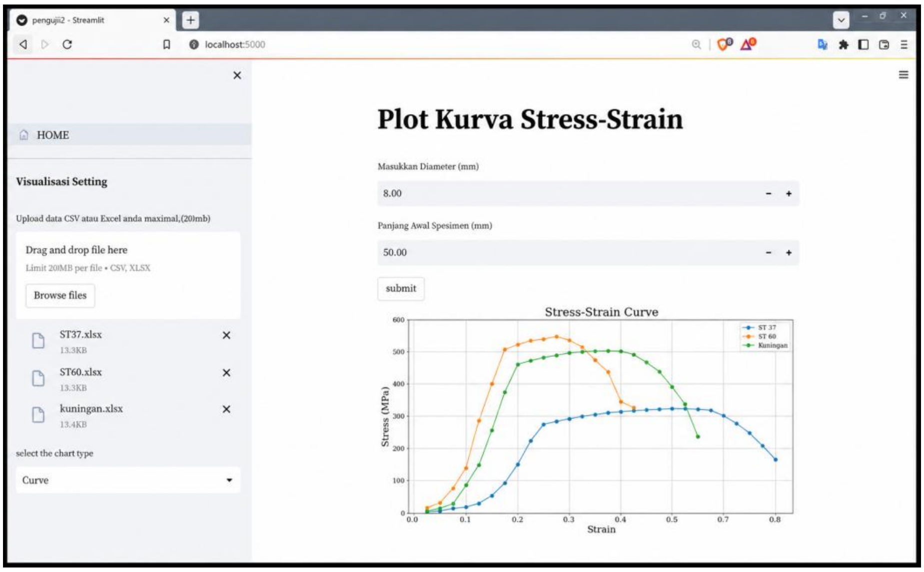

Figure 8. Visualization of Stress–Strain Curves for ST 37 Steel, ST 60 Steel, and Brass

The visualization of stress–strain curves generated using the proposed web-based plotting system showed that ST 37 steel exhibited a maximum stress of 323 MPa with a strain of 0.26, while ST 60 steel achieved a maximum stress of 547 MPa with a strain of 0.13. Brass exhibited a maximum stress of 503 MPa with a strain of 0.18. The tensile strength of ST 37 steel obtained in this study was 323 MPa, which is slightly below the standard range of 340–510 MPa specified in DIN 17100. Several factors may account for this deviation. First, the specimen machining process using a lathe may have introduced residual stresses that affected the mechanical response during testing. Second, the material used was commercially available stock without an accompanying mill certificate; therefore, its exact chemical composition and prior thermal treatment history could not be independently verified. Third, the use of a conventional universal testing machine with manual dial reading introduces a degree of measurement uncertainty that is inherently greater than that of a fully digital testing system. A similar condition applies to ST 60 steel, which yielded a tensile strength of 547 MPa, below the standard range of 590–770 MPa. Despite these deviations, ST 60 steel still demonstrated significantly higher tensile strength than ST 37 steel, consistent with its higher carbon content, which increases strength while reducing ductility. This behavior is reflected in its lower strain value of 0.13 compared to 0.26 for ST 37 steel. These limitations are acknowledged, and the use of certified materials and digital tensile testing machines is recommended in future studies to minimize measurement uncertainty and improve result traceability.

Brass, as an alloy of copper and zinc, exhibited a maximum stress of 503 MPa with a strain of 0.18. This value lies between those of the two steel grades in terms of both strength and ductility, which is consistent with the solid-solution strengthening mechanism provided by zinc in the copper matrix. To ensure the reliability of the developed system, the stress and strain values generated by the system were compared with the results obtained through manual calculations using Equations (1) and (2) at several tensile test data points. The comparison demonstrated that the system outputs were identical to the manually calculated results because the system employs the same fundamental equations to convert load and dial elongation data into stress and strain values.

The primary difference lies in the processing time. Manual calculations and curve generation using a calculator and Microsoft Excel require a relatively long time for each material, whereas the proposed system can display the stress–strain curve within seconds after the data are uploaded. Therefore, the developed system significantly accelerates the data processing workflow while maintaining the accuracy of the generated results.

Compared with previous studies that utilized Python for scientific data visualization, such as PyVT for fluid dynamics dataset analysis [7], the present study likewise employs Python as the programming language but differs in its application domain, which focuses on the mechanical testing of metallic materials and alloys, namely the testing of metallic materials and alloys. The proposed system also differs from machine-learning-based approaches used to predict material properties, such as the hardness prediction of steel plates [12]. Unlike predictive systems, the system developed in this study directly processes and visualizes experimental data. This approach offers the advantage of transparency and traceability, as the displayed values are derived directly from experimental measurements without the need for model training or statistical estimation. A comparison between the conventional procedure for generating stress–strain curves and the proposed web-based plotting system is presented in Figures 9 and 10.

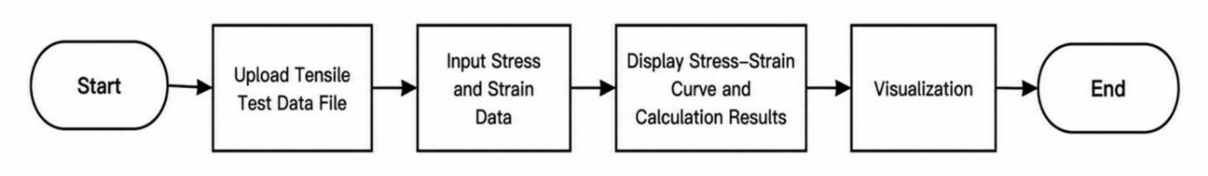

Figure 9. Workflow for Manual Generation of Stress–Strain Curves

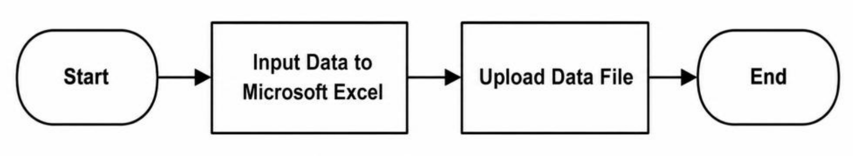

Figure 10. Generation of Stress–Strain Curves Using the Proposed Web-Based Plotting System

The conventional process of generating stress–strain curves can be more challenging, as identifying different types of stress–strain curves and comparing one curve with another requires considerable time and effort. In contrast, generating stress–strain curves using the proposed web-based plotting system is more practical because it can be accessed anytime through an internet connection and is compatible with both mobile devices and personal computers.

This approach is significantly more efficient than the conventional method when dealing with a large number of material tests, as users can upload multiple datasets and compare different stress–strain curves according to their needs. These results indicate that the developed system can serve as a practical tool for students, researchers, and laboratory practitioners who still use conventional tensile testing machines without digital data acquisition systems. Users are not required to make additional investments in specialized software or hardware because the system can be accessed online, making it a cost-effective and easily implementable alternative, particularly for laboratories with limited facilities.

3.3 System Limitations and Future Development

Although the proposed system is capable of automatically visualizing and comparing stress–strain curves, several limitations should be considered for future research. First, the current system can only process input data in CSV or Excel formats with a specific column structure; therefore, users must adjust the data format before uploading. Second, the stress and strain calculations are based on the engineering stress–strain approach, which assumes that the initial cross-sectional area and gauge length remain constant throughout the test. Consequently, the system does not yet represent true stress–strain behavior when necking occurs prior to fracture. Third, the system has only been validated using data from three metallic materials, namely ST 37 steel, ST 60 steel, and brass. Therefore, its applicability to other materials, such as aluminum, polymers, or composites with different stress–strain characteristics, requires further investigation.

In order to provide users with both visuals and mechanical property information at the same time, future research may concentrate on integrating automated analytical elements, such as determining yield strength, elastic modulus, and material ductility directly from the created curves. In addition, export functions for figures and tables can be integrated to facilitate documentation, while database storage capabilities may be developed to support large-scale comparative studies involving multiple materials.

The current validation method relies on confirming that the system produces results identical to those obtained through manual calculation using the same equations. Although this confirms the correctness of the implemented formulas, it does not provide an independent assessment of the system's accuracy against external benchmarks. To strengthen the validation framework, future studies should consider comparing the system outputs with results from a calibrated digital tensile testing machine that records load and displacement data automatically, or with standardized reference datasets available in the materials science literature. Incorporating such independent validation would provide stronger evidence for the reliability of the proposed system and is recommended as a key direction for future development.

4. Conclusion

Based on the design and testing results of the web-based plotting system developed for generating stress–strain curves using tensile test data from ST 37 steel, ST 60 steel, and brass, the following conclusions can be drawn:

1. The developed system is capable of accepting tensile test data, consisting of applied load and dial elongation, as input and automatically processing and visualizing the data into stress–strain curves without requiring users to manually calculate stress and strain values.
2. The visualization results showed that ST 37 steel exhibited a maximum stress of 323 MPa with a strain of 0.26, ST 60 steel exhibited a maximum stress of 547 MPa with a strain of 0.13, and brass exhibited a maximum stress of 503 MPa with a strain of 0.18. These values are consistent with the characteristics of the respective materials, where ST 60 steel demonstrated the highest strength but the lowest ductility, while ST 37 steel exhibited the greatest ductility.
3. The stress and strain values generated by the system were identical to those obtained through manual calculations. However, the processing time was substantially shorter, making the system both accurate and more efficient than conventional methods.
4. The system is also capable of displaying and comparing multiple stress–strain curves from different materials simultaneously, thereby facilitating comparative analysis of material characteristics.

Authors' Contributions

H: Conceptualization, Methodology, Writing (Original Draft). ES: Data Curation, Investigation, Formal Analysis. Z: Software, Validation, Visualization. RM: Resources, Data Curation, Investigation. AUB: Supervision, Writing (Review and Editing), Project Administration. All authors have read and approved the final manuscript.

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