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MATHEMATICAL MODELLING AND PREDICTION ANALYSIS OF THE TENSILE STRENGTH OF DC01 SHEET STEEL BASED ON TESTING SPEED

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Abstract. This paper presents a regression-based mathematical modelling approach for analysing and predicting the tensile behaviour of DC01 sheet steel as a function of tensile testing speed. Experimental tensile tests and regression-based prediction analysis were performed for testing speeds of 2, 4, 5, 7, and 10 mm/min, and the corresponding ultimate tensile strength (UTS) values were obtained from engineering stress–strain curves. Two specimens were tested at each speed level, and the mean values were used for regression analysis to ensure data consistency. A linear regression model was developed to describe the relationship between testing speed and tensile strength, showing a strong correlation between the variables with a coefficient of determination $R^2 = 0.9968$. In addition, a quadratic regression model was introduced to capture slight nonlinear behaviour and improve prediction capability. The developed models were also used to estimate tensile strength at intermediate testing speeds within the investigated testing range. A quadratic response curve analysis was also performed, allowing visualization of the relationship between testing speed and tensile strength. The results indicate that tensile strength slightly increases with increasing testing speed, reflecting the strain rate sensitivity of the material. The developed models provide a simple approach for analysing the influence of testing speed on tensile strength within the investigated range.

1. Introduction

Tensile testing is one of the most frequently used experimental methods for determining the mechanical behaviour of engineering materials [1,2]. It provides important information regarding strength, stiffness, and deformation characteristics under uniaxial loading conditions [10,12]. [1]

For metallic materials, the tensile test is widely applied in both research and industrial practice because it enables the determination of fundamental properties such as yield strength, ultimate tensile strength, and elongation.

DC01 sheet steel is a low-carbon steel commonly used in forming operations and structural applications due to its good formability, ductility, and relatively stable mechanical response. [3,4]. Because of its wide industrial use, understanding the influence of tensile testing parameters on the measured properties is important for obtaining reliable and comparable results.

Among the different testing parameters, the tensile testing speed may affect the measured mechanical response, particularly through its influence on strain rate. Even when the changes are moderate, variations in crosshead speed can produce measurable

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differences in ultimate tensile strength and ductility [5]. For this reason, the interpretation of tensile data should not rely only on direct experimental comparison but may also benefit from mathematical and statistical modelling [6,7].

In recent years, regression analysis and predictive modelling have become useful tools for describing material behaviour based on experimental data. Such approaches allow the development of simplified mathematical relationships between input parameters and measured responses, which can further be used for estimation and prediction within a defined range of conditions.

This paper aims to develop a regression-based mathematical model for describing and predicting the ultimate tensile strength of DC01 sheet steel as a function of tensile testing speed, using experimentally obtained data. The proposed approach extends the interpretation of the experimental results beyond direct observation and provides a predictive framework for future analysis of tensile behaviour [8].

2. Materials and experimental data

The material investigated in this study was DC01 low-carbon sheet steel. Experimental tensile data were obtained from tensile tests performed on sheet steel specimens prepared according to standard tensile specimen geometry for metallic materials [9]. The investigated specimens had an approximate thickness of 2.4 mm, while the cross-sectional dimensions were measured before testing for stress calculation.

The tensile tests were carried out using an electromechanical universal testing machine equipped with a 50 kN load cell and a computer-based data acquisition system [9]. The applied testing parameter in the present analysis was the crosshead speed. Five tensile testing speed values were considered for modelling and prediction analysis: 2, 4, 5, 7, and 10 mm/min. Two specimens were tested at each speed level to ensure the repeatability of the experimental observations.

The main response considered in the present modelling study was the ultimate tensile strength (UTS). Based on the experimental results, the mean UTS values for the selected speed levels were used as input data for the regression analysis. The corresponding average values were 393.42 MPa at 2 mm/min, 395.89 MPa at 5 mm/min, and 401.03 MPa at 10 mm/min.

Table 1. *Experimental input data used for regression modelling*

Testing speed, v (mm/min)	**Mean UTS (MPa)**
2	393.42
4	394.95
5	395.89
7	398.10
10	401.03

3. Mathematical modelling

To describe the relationship between the tensile testing speed and the corresponding ultimate tensile strength, a mathematical modelling approach based on regression analysis was applied. The experimentally obtained mean values of tensile strength were used as data for model development [6].

The tensile testing speed was considered as the independent variable, while the ultimate tensile strength (UTS) was taken as the response variable. A linear regression model was initially adopted due to the relatively simple relationship observed between the investigated variables.

3.1. Linear regression model

The linear regression model can be expressed in the following form:

$$UTS = a + b \cdot v \tag{3.1}$$

where:
UTS is the ultimate tensile strength (MPa),
v is the tensile testing speed (mm/min),
a and b are regression coefficients.

Based on the experimental data, the following regression equation was obtained:

$$UTS = 391.24 + 0.9706 \cdot v \tag{3.2}$$

The coefficient of determination was found to be $R^2 = 0.9960$, indicating a strong correlation between experimental and predicted values.

The obtained model indicates that the tensile strength increases with increasing the testing speed. The regression coefficient b=0.9706 suggests that an increase of 1 mm/min in testing speed results in an approximate increase of about 1 MPa in tensile strength.

3.2. Model accuracy and validation

To evaluate the accuracy of the developed regression model, the predicted values were compared with the experimentally obtained results.

Table 2. *Comparison between experimental and predicted values*

Speed (mm/min)	Experimental UTS (MPa)	Predicted UTS (MPa)
2	393.42	393.18

4	394.95	395.12
5	395.89	396.09
7	398.10	398.03
10	401.03	400.95

The comparison shows very good agreement between experimental and predicted values, with only minor deviations.

The coefficient of determination was calculated as:

$$R^2 = 0.9960 \qquad (3.3)$$

which indicates an excellent correlation between testing speed and tensile strength.

The low deviation between the predicted and experimental values confirms that the proposed regression model is suitable for describing the relationship within the investigated range.

The relationship between the tensile testing speed and the ultimate tensile strength is presented in Figure 1.

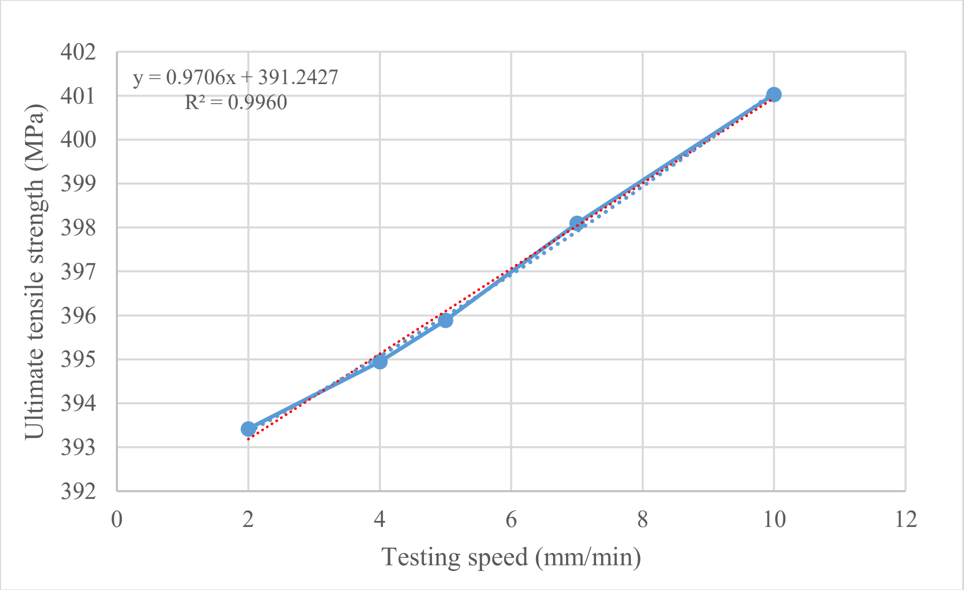

Figure 1. *Relationship between tensile testing speed and ultimate tensile strength with a linear regression model.*

3.3. **Prediction analysis using a quadratic model**

The developed regression equations were additionally used for the prediction of tensile strength at intermediate testing speeds [7].

Using the developed model, the tensile strength can be estimated for intermediate testing speeds. The developed regression models were additionally used for prediction analysis within the investigated range of testing speeds. The predicted values obtained using the quadratic model are presented in Figure 3.

These results demonstrate that the model can be used as a predictive tool for estimating tensile strength within the analysed range of testing speeds.

3.4. **Quadratic regression model**

Although the linear regression model provided a very good approximation of the experimental data, a quadratic regression model was developed to capture the potential nonlinear behaviour of the material response [8].

The quadratic model is expressed as:

$$UTS = a + b \cdot v + c \cdot v^2 \qquad (3.6)$$

where:

- v is the tensile testing speed (mm/min),
- a, b, c are regression coefficients.

Based on the experimental data, the obtained quadratic regression model is:

$$UTS = 391.76 + 0.7551 \cdot v + 0.0177 \cdot v^2 \qquad (3.7)$$

The inclusion of the quadratic term allows a more accurate description of the relationship between the testing speed and tensile strength. The results indicate that the increase in tensile strength is not strictly linear, but follows a slightly nonlinear trend with increasing testing speed.

This confirms that the quadratic model provides a more flexible representation of the material behaviour compared to the linear model.

3.5. **Comparison between linear and quadratic models**

To evaluate the performance of the developed models, a comparison between linear and quadratic regression predictions was performed. Both models showed good agreement with the experimental data. The coefficient of determination for the quadratic regression model was found to be $R^2 = 0.9982$, indicating an excellent fit. The quadratic model also provides a very high level of accuracy, with a slightly improved representation of the data, particularly at higher testing speeds. The quadratic model showed reduced deviation between the predicted and experimental values, suggesting improved prediction capability when compared to the linear model.

The improved performance of the quadratic model can be attributed to its ability to capture slight nonlinear effects associated with strain-rate sensitivity, which cannot be fully represented by a linear relationship. However, the difference between the two models remains relatively small within the investigated range, indicating that the relationship between the testing speed and tensile strength is predominantly linear, with only minor nonlinear effects.

This suggests that for practical engineering applications, the linear model may be sufficient, while the quadratic model offers additional accuracy for predictive purposes.

Figure 2 illustrates the comparison between linear and quadratic regression models together with the experimental data. It can be observed that both models closely follow the experimental trend, while the quadratic model provides a slightly improved fit, particularly at higher testing speeds.

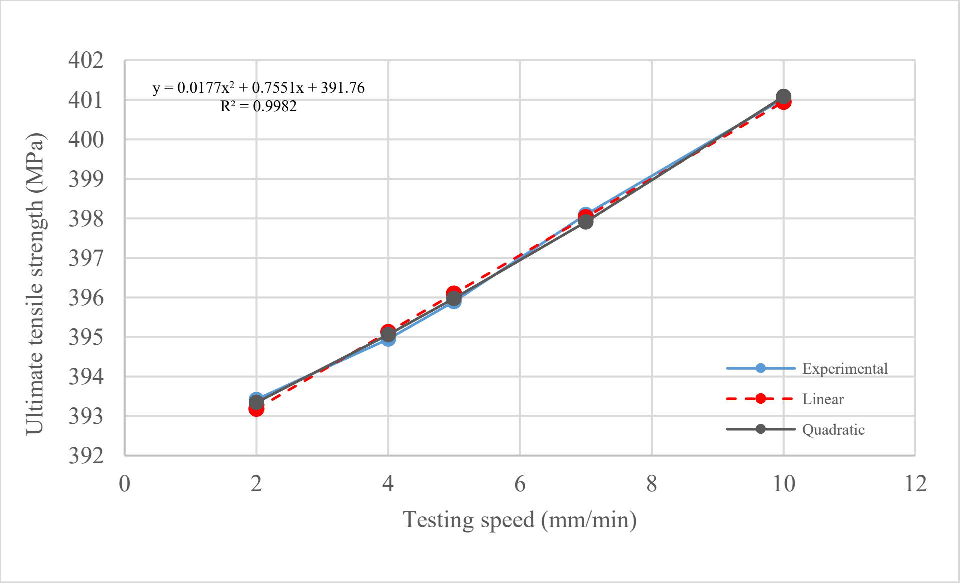

Figure 2. *Experimental and predicted UTS values obtained using linear and quadratic regression models.*

4. **Regression response analysis**

To provide a graphical interpretation of the relationship between the testing speed and tensile strength, a response curve was developed using the quadratic regression model [8].

The response curve illustrates the variation of the ultimate tensile strength as a function of the tensile testing speed. The obtained curve shows a gradual increase in tensile strength with increasing testing speed, confirming the strain-rate sensitivity of the material.

The response analysis indicates that within the investigated range, higher testing speeds result in slightly higher tensile strength values. However, the increase remains moderate, suggesting that the material exhibits relatively stable mechanical behaviour under the applied conditions. The predicted tensile strength as a function of the testing speed, based on the quadratic regression model, is presented in Figure 3.

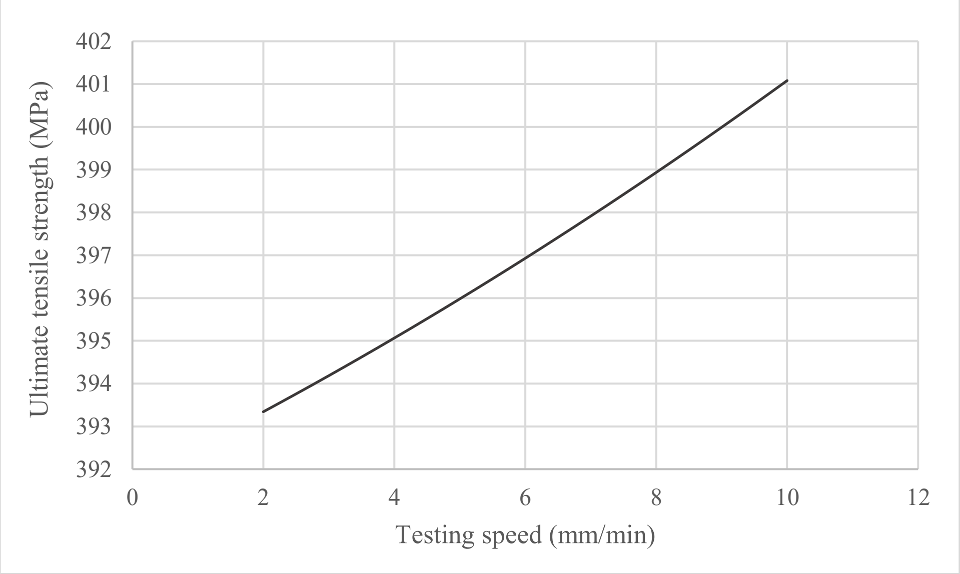

Figure 3. *Quadratic regression-based prediction of the tensile strength as a function of the testing speed.*

5. Results and discussion

5.1. Experimental results

The experimental investigation was conducted in order to evaluate the influence of the testing speed on the ultimate tensile strength (UTS) of the material. Tensile tests and regression-based prediction analysis were performed using the tensile strength values corresponding to the testing speeds of 2, 4, 5, 7, and 10 mm/min.

The results obtained indicate a gradual increase in UTS with increasing testing speed. Specifically, the lowest value of UTS was observed at 2 mm/min, while the highest value was recorded at 10 mm/min. This trend suggests a positive correlation between the testing speed and the tensile strength.

The increase in UTS with testing speed may be attributed to the strain rate sensitivity of the material, where higher deformation rates lead to increased resistance to plastic deformation. The measured values of UTS showed a gradual increase from approximately 393 MPa at 2 mm/min to approximately 401 MPa at 10 mm/min.

5.2. **Model-based interpretation**

The regression models developed in Section 3 confirm the observed experimental trend. Both linear and quadratic models show that tensile strength increases with testing speed, providing a quantitative description of the relationship.

The predicted values showed good agreement with the experimental results.

5.3. **Key observations**

The results indicate that:

- the tensile strength slightly increases with increasing testing speed
- the material exhibits moderate sensitivity to strain rate
- the variation of UTS within the investigated range is relatively small
- the behaviour can be successfully described using regression-based models

5.4. **Discussion**

The obtained results indicate a clear relationship between the tensile testing speed and the ultimate tensile strength (UTS) of the investigated material. Both the linear and quadratic regression models confirm that the tensile strength increases with the increasing testing speed. This behaviour can be explained by the strain rate sensitivity of low-carbon steels. At higher testing speeds, the material experiences higher strain rates, which restrict the movement of dislocations within the crystal structure. As a result, higher stress is required to continue plastic deformation, leading to an increase in the measured tensile strength [11].

Although the increase in UTS was relatively small (approximately 7.6 MPa between 2 and 10 mm/min), the trend remained consistent for all tested specimens. This is consistent with the typical behaviour of low-carbon steels, where mechanical properties remain relatively stable under low to moderate strain rates.

The comparison between linear and quadratic models shows that both approaches are suitable for describing the material behaviour. However, the quadratic model provides a slightly improved representation, particularly for prediction at higher testing speeds. This indicates that even small nonlinear effects can be captured through higher-order modelling.

The prediction results demonstrate that regression-based models can be successfully used for estimating the tensile strength under conditions that were not experimentally tested. This approach may help reduce the number of additional experimental tests required for preliminary estimation of tensile strength.

Overall, the results confirm that mathematical modelling combined with experimental data can support the interpretation of tensile behaviour and provide additional insight into the influence of testing speed. The developed regression models may be further improved in future studies by using a larger experimental dataset and additional modelling approaches.

One limitation of the present study is the relatively small number of experimental points used to develop the regression model. Additional testing speeds and a larger number of specimens would further improve the statistical reliability of the developed models.

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