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Analysis of Characteristics of All Solid-State Batteries Using Linear Regression Models

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Abstract

This study used a total of 205,565 datasets of 'voltage', 'current', '°C', and 'time(s)' to systematically analyze the properties and performance of solid electrolytes. As a method for characterizing solid electrolytes, a linear regression model, one of the machine learning models, is used to visualize the relationship between 'voltage' and 'current' and calculate the regression coefficient, mean squared error (MSE), and coefficient of determination (R^2). The regression coefficient between 'Voltage' and 'Current' in the results of the linear regression model is about 1.89, indicating that 'Voltage' has a positive effect on 'Current', and it is expected that the current will increase by about 1.89 times as the voltage increases. MSE found that the mean squared error between the model's predicted and actual values was about 0.3, with smaller values closer to the model's predictions to the actual values. The coefficient of determination (R^2) is about 0.25, which can be interpreted as explaining 25% of the data.

Keywords: *All Solid-State Battery, Mean Squared Error, Coefficient of determination, linear regression models*

1. Introduction

Currently, energy storage technologies are gaining importance due to the need for sustainable energy sources [1]. Due to the limitations of existing lithium-ion batteries and the increasing risk of fire, solid-state batteries are attracting attention and have the potential to surpass existing battery technologies in terms of stability, energy density, and charge-discharge efficiency [2]. The research and development of solid-state cells is driving breakthroughs in energy storage in power grids, electric vehicles, and mobile electronics, and research institutions and companies around the world are facing technological challenges to commercialize solid-state cells [3]. With the current limitations and safety concerns of lithium-ion batteries, solid-state electrolyte cells offer new possibilities in terms of high energy density, stability, and environmental friendliness [4]. This solid-state electrolyte cell technology is based on a method proposed by Armand and Taraskon in 2008 [5]. They were the first to put forward the possibility that solid electrolytes can provide safer and more stable

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performance than traditional liquid electrolytes. A recent study by Manthiram and colleagues is investigating the potential for advances in solid-state electrolyte technology [6]. This study aims to systematically analyze the characteristics and performance of solid electrolyte cells. It consists of a total of 205,565 data sets with time, voltage, current, and temperature to characterize solid electrolyte cells. As a method to analyze the characteristics of solid electrolyte cells, linear regression analysis, one of the machine learning models, was used.

2. Analysis for All-Solid-State Battery Characterization

It consists of a total of 205,565 datasets with time, voltage, current, and temperature to analyze the characteristics of solid electrolyte cells. As a method to characterize solid electrolyte cells, linear regression analysis, one of the machine learning models, was used to visualize the relationship between 'Voltage' and 'Current' and output performance indicators such as regression coefficient, mean squared error (MSE), and coefficient of determination (R^2). Figure 1 shows the process for analyzing the sideality of a solid electrolyte lithium-ion battery.

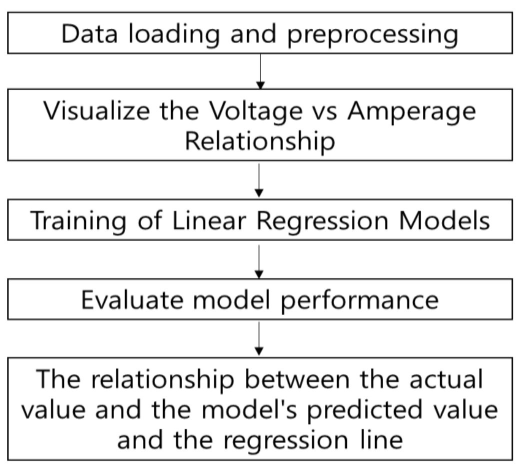


Figure 1. Processes for Solid-State Battery Analysis

3. Designed for the characterization of solid-state batteries

Figure 2 shows the regression coefficients, mean squared error, and coefficient of determination to analyze the results of the linear regression model.

```
output regression coefficient // 'regression coefficient:', model.coef_
MSE (Mean Squared Error) // mse = mean_squared_error(y_test, y_pred
R^2 (coefficient of determination) output // r2 = r2_score (y_test, y_pred)
```

Figure 2. Pseudocode for analyzing the results of linear regression models

Here, the regression coefficient represents the linear relationship between 'Voltage' and 'Current'. MSE represents the mean squared error between the model's predicted and actual values. R^2 represents the percentage of variation that the model describes out of the total variation of the dependent variable.

```
sns.scatterplot(x='Voltage', y='Current', data=df, label='Measure', color='blue')
sns.lineplot(x=X_test['Voltage'], y=y_pred, color='red', label=' Regression Line')
```

Figure 3. Output summary statistics of data and visualize relationships between variables

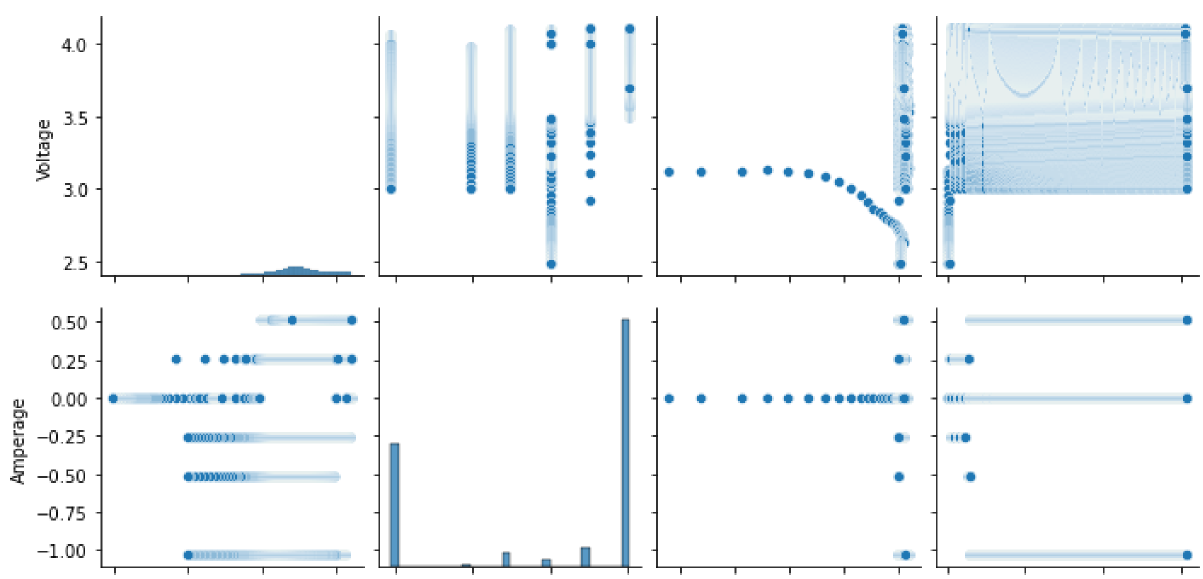
The program in Figure 3 outputs summary statistics of the data, visualizes the relationships between variables, and expresses the relationship between 'voltage' and 'current' as scatter plots and regression lines.

Table 1. Descriptive statistics of datasets

	Voltage	Current	℃	Time(s)
Count	205,565	205,565	205,565	205,565
Mean	3.741513	0.004844	70.502443	3.082990e+06
Std	0.184334	0.691191	0.294037	1.753744e+06
Min	2.492490	-1.027210	27.900000	3.000000e+02
25%	3.645260	-1.024660	70.300000	1.564966e+06
50%	3.740690	0.514118	70.500000	3.084728e+06
75%	3.854350	0.514149	70.700000	4.601979e+06
Max	4.100060	0.514212	71.800000	6.117205e+06

4. Implementation and Results

The statistical summaries of the datasets used in this paper provide statistics for voltage, current, temperature, and time. Therefore, you can check the mean, standard deviation, minimum, and maximum values of the data in the form of Table 1. Figure 4 shows the correlation between voltage, temperature (°C), and time (time) on current as a scatter plot.



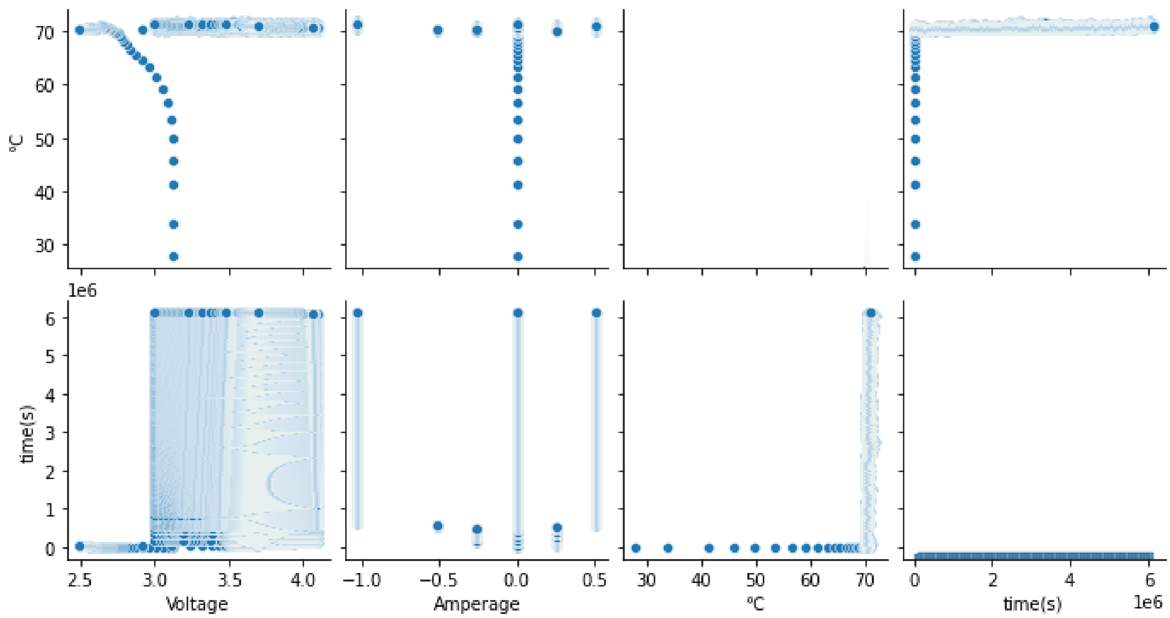


Figure 4. Correlation between Voltage, Temperature (°C), and Time

Table 2 provides the regression coefficients and performance indicators of the linear regression model as a result of the regression analysis. The regression coefficient represents the effect of each variable on the dependent variable (Current). MSE (mean square error) represents the prediction error of the model, while R^2 (coefficient of determination) represents the explanatory power of the model. Here you can see a regression coefficient that describes the effect of voltage, temperature (°C), and time (time) on current. A lower MSE value indicates that the model's predictions are accurate, while a higher R^2 value indicates that the model explains the data well. Scatter plot matrices and regression lines are provided to visually see the relationship between each variable.

Table 2. Results of Regression Analysis

Division	Result Value
Regression coefficient	1.81379087e+00, -2.63417372e-01, 2.31093270e-08
Mean Squared Error (MSE)	0.3518796665918118
Coefficient of determination (R^2)	0.2651379085956129

Analyzing the results of the linear regression model in Table 2 and Figure 5, the regression coefficients show a linear relationship between 'voltage' and 'current'.

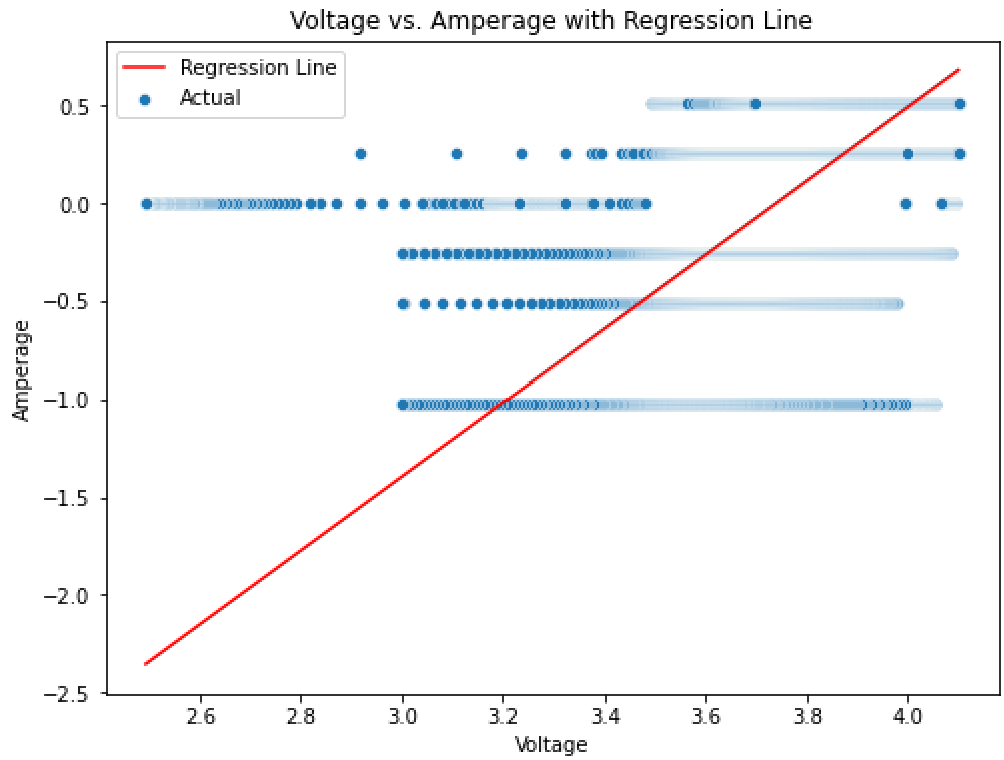


Figure 5. Results of Regression Analysis graph

The regression coefficient here is about 1.89. This means that 'Voltage' has a positive effect on 'Current'. As the voltage increases, the Current is also expected to increase by about 1.89 times. MSE represents the mean squared error between the model's predicted and actual values. Here, the MSE appears to be around 0.36. The smaller the value, the closer the model's prediction is to the actual value. The coefficient of determination (R^2) refers to the proportion of variation that the model describes out of the total variation of the dependent variable. The closer the R^2 value is to 1, the better the model describes the data. Here, R^2 is about 0.25, which can be interpreted as the model describing 25% of the data. The lower the value, the lower the explanatory power of the model.

In summary, the current linear regression model shows a quantitative relationship between voltage and current, and although the model's predictions are somewhat consistent with the actual values, it does not yet appear to be sufficient to account for variation in the data.

5. Conclusion

This study aims to systematically analyze the properties and performance of solid electrolyte cells. To do this, we use a full dataset of 205,565 datasets of 'Voltage', 'Current', '°C', and 'time(s)' to characterize solid electrolyte cells. As a method for characterizing solid electrolyte cells, linear regression, one of the machine learning models, is used to visualize the relationship between 'voltage' and 'current' and calculate and output the regression coefficient, mean squared error (MSE), and decision coefficient (R^2).

Analyzing the results of the linear regression model reveals a linear relationship between 'Voltage' and 'Current'. Here, the regression coefficient is approximately 1.89, indicating that 'Voltage' has a positive effect on 'Current'. As the voltage increases, the current is also expected to increase by about 1.89 times. The MSE represents the mean squared error between the model's predicted and actual values, where it is approximately 0.36. The smaller the value, the closer the model's prediction is to the actual value. The coefficient of determination (R^2) represents the explanatory power of the model, which in this case is about 0.25, which can be interpreted as the model explaining 25% of the data.

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