SYSTEMS AND METHODS FOR MANUFACTURING A BATTERY ELECTRODE PLATE

Abstract

The present disclosure relates to systems and methods for manufacturing a battery electrode plate. The system comprises a computing device configured to receive, from the client device, a target process factor among a plurality of process factors associated with manufacturing a battery electrode plate, predict, via a machine-learning model, a change in a characteristic of the battery electrode plate based on a change in a design value of the target process factor, generate information for selecting the target process factor based on predicting the change of the characteristic of the battery electrode plate, and transmit the information to the client device for manufacturing the battery electrode plate.

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Family ID: **94128547**

Appl. No.: **18/811188**

Filed: **August 21, 2024**

Foreign Application Priority Data

KR	10-2024-0021249	Feb. 14, 2024

Publication Classification

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION
[0001] The present application claims priority to and the benefit of Korean Patent Application No. 10-2024-0021249, filed on Feb. 14, 2024, in the Korean Intellectual Property Office, the entire disclosure of which is incorporated herein by reference.
BACKGROUND OF THE INVENTION
1. Field
[0002] The present disclosure relates to systems and methods for manufacturing a battery electrode plate.
2. Description of the Related Art
[0003] In general, unlike a primary battery that is not designed to be recharged, a secondary battery is designed to be discharged and recharged. Low-capacity secondary batteries are used in portable, small-sized electronic devices such as smartphones, feature phones, notebook computers, digital cameras, camcorders, and the like. A high-capacity secondary battery is used, as an example, as a power source and/or a power storage device for driving a motor in a hybrid vehicle and an electric vehicle. In general terms, the secondary battery includes an electrode assembly having a positive electrode and a negative electrode, a case accommodating the electrode assembly, and an electrode terminal connected to the electrode assembly.
[0004] The positive electrode of the secondary battery is manufactured by applying a positive electrode active material onto a positive electrode current collector in the form of a metal thin film or metal mesh. The negative electrode of the secondary battery is manufactured by applying a negative electrode active material onto a negative electrode current collector in the form of a metal thin film or metal mesh. The secondary battery is charged and discharged by repeated insertion and detachment of ions in the positive electrode active material layer of the positive electrode plate and the negative electrode active material layer of the negative electrode plate.
[0005] The ionic resistance characteristics of the electrode plate of the secondary battery can vary depending on the components that configure the electrode plate and the structural characteristics of the electrode plate. The tortuosity of the electrode plate can vary depending on the shape, distribution, and content of each particle of the particles configuring the active material layer. The tortuosity of the electrode plate can affect the movement path and movement length of ions, and act as a factor in determining the ionic resistance characteristics of the electrode plate.
[0006] The above information disclosed in this Background section is for enhancement of understanding of the background of the described technology and therefore it may contain information that does not form the prior art that is already known to a person of ordinary skill in the art.
SUMMARY
[0007] Embodiments of the present disclosure provide systems and methods for manufacturing a battery electrode plate based on predicting in advance the electrode plate characteristics according to design values of process factors during an electrode plate design process of a secondary battery.
[0008] Technical solutions obtainable from the present disclosure are not limited to the above-mentioned technical solutions. Other technical solutions not expressly mentioned herein can be

clearly understood from the following description by those having ordinary skill in the technical field to which the present disclosure pertains.

[0009] A system comprises a computing device configured to receive, from a client device, a target process factor among a plurality of process factors associated with manufacturing a battery electrode plate, predict, via a machine-learning model, a change in a characteristic of the battery electrode plate based on a change in a design value of the target process factor, generate information for selecting the target process factor based on predicting the change of the characteristic of the battery electrode plate, and transmit the information to the client device for manufacturing the battery electrode plate.

[0010] The machine-learning model may be configured to output a characteristic information of the battery electrode plate based on input design values corresponding to the plurality of process factors.

[0011] The computing device may be further configured to obtain tortuosity of the battery electrode plate based on the machine-learning model and calculate ionic resistance based on the tortuosity.

[0012] The computing device may be further configured to automatically set the input design values corresponding to the plurality of process factors other than the target process factor as design values used in a previous prediction of the machine-learning model.

[0013] The computing device may be further configured to receive the input design values corresponding to the plurality of process factors other than the target process factor from the client device.

[0014] The computing device may be further configured to receive design range information including a design value change range and change interval of the target process factor from the client device, and increase or decrease the design value of the target process factor based on the design range information.

[0015] Based on determining that the plurality of process factors include fractions of a plurality of active materials and the target process factor is a fraction of at least one active material of the plurality of active materials, the computing device may be further configured to automatically adjust the fractions of the plurality of active materials to make a sum of the fractions of the plurality of active materials to equal 100 in response to the design value of the target process factor being changed.

[0016] The computing device may be further configured to select a characteristic value of the battery electrode plate that satisfies a condition based on predicting the change in the characteristic of the battery electrode plate, and generate the information to include the selected characteristic value and the design value of the target process factor used to derive the characteristic value.

[0017] The computing device may be further configured to receive a target characteristic value from the client device, select at least one second characteristic value based on predicting the change in the characteristic of the battery electrode plate based on the second characteristic value having a difference with the target characteristic value that satisfies a criterion, and generate the information to include the selected at least one second characteristic value and the design value of the target process factor used to derive at least one second characteristic value.

[0018] The characteristic information may include an ionic resistance of the battery electrode plate. The computing device may be further configured to select at least one ionic resistance among a plurality of ionic resistances obtained based on predicting the change in the characteristic of the battery electrode plate, wherein the at least one ionic resistance has a smallest difference from a target ionic resistance received from the client device, and generate the information to include the selected at least one ionic resistance and the design value of the target process factor used to derive the selected at least one ionic resistance.

[0019] A system according to one embodiment comprises a computing device configured to receive, from a client device, first information for manufacturing a battery electrode plate, predict characteristic information of the battery electrode plate using the first information and a machine

learning-based prediction model, and transmit the characteristic information to the client device for manufacturing the battery electrode plate.

[0020] The characteristic information may include a tortuosity and an ionic resistance of the battery electrode plate. The computing device may be further configured to input the first information into the prediction model to obtain the tortuosity of the battery electrode plate, and calculate the ionic resistance based on the tortuosity.

[0021] The first information may include design values for a plurality of process factors for manufacturing the battery electrode plate. The plurality of process factors may include a type of active material, fraction and physical properties of the active material, binder content, conductive material content, loading level and mixture, density, or process conditions.

[0022] The computing device may be further configured to build the prediction model. The computing device may be further configured to perform a design of experiment (DOE) based on experimental data for a manufacturing process of the battery electrode plate, generate a process design table including design values of process factors for a plurality of different process design conditions through the DOE, obtain tortuosity data of the battery electrode plate by performing a simulation based on a discrete element method based on the process design table, and build the prediction model using the process design table and the tortuosity data as learning data.

[0023] The computing device may be further configured to add thickness data to the process design table using a linear regression model learned using actual process design data of the battery electrode plate and an actual measured value of the thickness of the battery electrode plate.

[0024] A method includes receiving, from a client device, first information for manufacturing a battery electrode plate, predicting a tortuosity of the battery electrode plate using the first information and machine learning-based prediction model, calculating an ionic resistance of the battery electrode plate based on the tortuosity, and transmitting characteristic information including at least one of the tortuosity or the ionic resistance of the battery electrode plate to the client device for manufacturing the battery electrode plate.

[0025] The first information may include design values for a plurality of process factors for manufacturing the battery electrode plate. The plurality of process factors may include at least one of a type of active material, a fraction and physical properties of the active material, binder content, conductive material content, loading level and mixture, density, or process conditions.

[0026] The method may further include building the prediction model.

[0027] The building of the prediction model may include performing DOE based on experimental data for a manufacturing process of the battery electrode plate to generate a process design table including design values of process factors for a plurality of different process design conditions, performing a simulation based on a discrete element method based on the process design table to obtain tortuosity data of the battery electrode plate, and building the prediction model using the process design table and the tortuosity data as learning data.

[0028] The method may further include receiving, from the client device, selection information for selecting a target process factor among the plurality of process factors, predict, via the prediction model, a change in a characteristic of the battery electrode plate based on a change in a design value of the target process factor, generating information for designing the target process factor based on predicting the change of the characteristic of the battery electrode plate, and transmitting the first information to the client device for manufacturing the battery electrode plate.

[0029] The generating of the first information may further include selecting a characteristic value of the battery electrode plate that satisfies a condition based on predicting the change in the characteristic of the battery electrode plate, and generating the information to include the selected characteristic value and the design value of the target process factor used to derive the characteristic value.

[0030] According to the present disclosure, in the process of designing the electrode plate of a secondary battery, and electrode plate characteristics according to design values of process factors,

and design values of process factors for obtaining desired electrode plate characteristics may be predicted in advance.

[0031] Accordingly, the time required to derive optimal design conditions for obtaining desired electrode plate characteristics may be shortened, thereby reducing the cost and time required for the electrode plate manufacturing process of a secondary battery.

[0032] Effects that may be obtained from the present disclosure will not be limited to only the above described effects. In addition, other effects which are not described herein will become apparent to those skilled in the art from the following description.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] The accompanying drawings illustrate embodiments of the present disclosure and, together with the foregoing disclosure, serve to describe aspects, features, and the technical spirit of the present disclosure. However, the present disclosure is not to be construed as being limited to the drawings.

[0034] FIG. **1** is a block diagram of a system for designing a manufacturing process of a battery electrode plate according to an embodiment of the present disclosure.

[0035] FIG. **2** is a three-dimensional image of structural characteristics of a negative electrode plate generated based on a discrete element method according to an embodiment of the present disclosure.

[0036] FIGS. **3**A to **3**D are block diagrams of example user interfaces provided by a system for designing a manufacturing process of a battery electrode plate, according to an embodiment of the present disclosure.

[0037] FIG. **4** is a flow diagram of a process for building a prediction model for predicting the tortuosity of a battery electrode plate according to an embodiment of the present disclosure.

[0038] FIG. **5** is a flow diagram of a method for providing characteristic information of a battery electrode plate predicted according to process design conditions according to an embodiment of the present disclosure.

[0039] FIG. **6** is a flow diagram of a process for designing process factors for a manufacturing process of a battery electrode plate according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0040] Hereinafter, embodiments of the present disclosure will be described in detail with reference to the accompanying drawings. Hereinafter, embodiments of the present disclosure will be described in detail with reference to the accompanying drawings. The terms or words used in the specification and claims of the present disclosure should not be construed as being limited to typical or dictionary meanings, but should be construed as meanings and concepts conforming to the technical spirit of the present disclosure based on the principle that the inventors can be their own lexicographers to appropriately define the concepts of the terms to explain the present invention in the best manner. Accordingly, it is to be understood that the detailed description, which will be disclosed along with the accompanying drawings, is intended to describe the embodiments of the present invention and is not intended to represent all technical ideas, aspects, and features of the present invention. Therefore, it should be understood that various equivalents and modifications can exist which can replace the embodiments described at the time of filing of the application.

[0041] As used herein, the terms "use," "using," and "used" may be considered synonymous with the terms "utilize," "utilizing," and "utilized," respectively. As used herein, the terms "substantially," "about," and similar terms are used as terms of approximation and not as terms of degree, and are intended to account for the inherent variations in measured or calculated values that would be recognized by those of ordinary skill in the art.

[0042] It will be understood that, although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers, and/or sections, these elements, components, regions, layers, and/or sections should not be limited by these terms. These terms are used to distinguish one element, component, region, layer, or section from another element, component, region, layer, or section. Thus, a first element, component, region, layer, or section discussed below could be termed a second element, component, region, layer, or section without departing from the teachings of example embodiments.

[0043] Spatially relative terms, such as "beneath," "below," "lower," "above," "upper," and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" or "over" the other elements or features. Thus, the term "below" may encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations), and the spatially relative descriptors used herein should be interpreted accordingly.

[0044] The terminology used herein is for the purpose of describing embodiments of the present disclosure and is not intended to be limiting of the present disclosure. As used herein, the singular forms "a" and "an" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "includes," "including," "comprises," and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0045] Also, any numerical range disclosed and/or recited herein is intended to include all sub-ranges of the same numerical precision subsumed within the recited range. For example, a range of "1.0 to 10.0" is intended to include all subranges between (and including) the recited minimum value of 1.0 and the recited maximum value of 10.0, that is, having a minimum value equal to or greater than 1.0 and a maximum value equal to or less than 10.0, such as, for example, 2.4 to 7.6. Any maximum numerical limitation recited herein is intended to include all lower numerical limitations subsumed therein, and any minimum numerical limitation recited in this specification is intended to include all higher numerical limitations subsumed therein. Accordingly, Applicant reserves the right to amend this specification, including the claims, to expressly recite any sub-range subsumed within the ranges expressly recited herein. All such ranges are intended to be inherently described in this specification such that amending to expressly recite any such subranges would comply with the requirements of 35 U.S.C. § 112(a) and 35 U.S.C. § 132(a).

[0046] Embodiments of the present disclosure are described below with reference to block diagrams and flow diagrams. Thus, it should be understood that each block of the block diagrams and flow diagrams may be implemented in the form of a computer program product, an entirely hardware embodiment, a combination of hardware and computer program products, and/or apparatus, systems, computing devices, computing entities, and/or the like carrying out instructions, operations, steps, and similar words used interchangeably (for example the executable instructions, instructions for execution, program code, and/or the like) on a computer-readable storage medium for execution. For example, retrieval, loading, and execution of code may be performed sequentially such that one instruction is retrieved, loaded, and executed at a time. In some example embodiments, retrieval, loading, and/or execution may be performed in parallel such that multiple instructions are retrieved, loaded, and/or executed together. Thus, such embodiments can produce specifically-configured machines performing the steps or operations specified in the block diagrams and flow diagrams. Accordingly, the block diagrams and flow diagrams support

various combinations of embodiments for performing the specified instructions, operations, or steps.

[0047] In addition, a feature of embodiments of the present disclosure may be combined or combined with one or more other features, partially or entirely, and may be operated in various ways, and an embodiment may be implemented independently of one or more other embodiments, or in conjunction with the one or more other embodiments.

[0048] In addition, for ease of understanding of the present disclosure, the accompanying drawings are not drawn to real scale, but the dimensions of some components, layers, etc. may be exaggerated. In addition, the same reference numbers may be assigned to the same components.

[0049] Stating that two objects of comparison are "the same" means that they are "substantially the same." Therefore, the phrase "substantially identical" may include a deviation that is considered low in the art, for example, a deviation of less than 5%. In some embodiments, uniformity of a parameter in a certain region may mean uniformity in terms of an average.

[0050] Throughout the specification, unless otherwise stated, each component may be singular or plural.

[0051] It will also be understood that when a first element or layer is referred to as being present (or located or positioned) "on" or "beneath" a second element or layer, the first element may be disposed (or located or positioned) directly on or beneath the second element or may be disposed (or located or positioned) indirectly on or beneath the second element with a third element or layer being disposed (or located or positioned) between the first and second elements or layers.

[0052] It should be noted that if it is described in the specification that one component is "connected," "coupled," or "joined" to another component, a third component may be "connected," "coupled," and "joined" between the first and second components, or the first component may be directly connected, coupled, or joined to the second component. When it is described that an element is "electrically coupled" to another element, the element may be "directly coupled" to the other element or "coupled" to the other element through a third element.

[0053] When referring to "A and/or B" throughout the specification, it means A, B, or A and B, unless specifically stated to the contrary. That is, "and/or" includes all or any combination of the plurality of listed items. When referring to "C to D", it means that it is greater than or equal to C and less than or equal to D, unless otherwise specified.

[0054] FIG. **1** is a block diagram of a system **1** for designing a manufacturing process of a battery electrode plate according to an embodiment of the present disclosure. In one embodiment, the battery electrode plate may include a negative electrode plate or a positive electrode plate of a secondary battery.

[0055] Referring to FIG. **1**, the system **1** for designing a manufacturing process of a battery electrode plate according to an embodiment may include a model building device **10**, a design support device **20**, and a user terminal (also referred to as a client device) **30**. The model building device **10** and design support device **20** may each be referred to as a computing device.

[0056] The model building device **10** may build a machine learning-based model (hereinafter referred to as "prediction model" or a machine-learning model) that predicts electrode plate characteristics (e.g., tortuosity and ionic resistance) according to the design conditions of the manufacturing process of the battery electrode plate.

[0057] The model building device **10** may include a communication device **11**, a storage device **12**, and a control device **13**. The storage device **22** may take the form of volatile memory, non-volatile memory, persistent memory, flash memory, hard drive, and/or the like.

[0058] The communication device **11** may perform a communication function between the model building device **10** and an external device (for example, the design support device **20**).

[0059] The storage device **12** may store various data and information processed by the model building device **10**. For example, the storage device **12** may store a process design table generated by the control device **13**, which will be described later. In some embodiments, the storage device

12 may store a prediction model built by the control device **13**.

[0060] The storage device **12** may also store a program or computer instructions for operating the control device **13**.

[0061] The control device **13** may control the overall operation of the model building device **10**. The control device **13** may build a prediction model to predict the structural characteristics (e.g., tortuosity) of the battery electrode plate.

[0062] The control device **13** may include a data generator **131**, a data complement part **132**, a simulation part **133**, and a model building part **134**. Although the various components **131-134** of the control device **13** are assumed to be separate functional units, a person of skill in the art will recognize that the functionality of the components **131-134** may be combined or integrated into a single component, or further subdivided into further sub-components without departing from the spirit and scope of the inventive concept.

[0063] The data generator **131** may generate a process design table. The process design table may include process design data including design values of process factors (e.g., factor values of process factors) that affect the structural characteristics of the battery electrode plate. The data generator **131** may refer to previously performed experimental results related to battery electrode plate manufacturing to generate the process design data. The data generator **131** may obtain design values of a (e.g., each) process factor by performing a design of experiment (DOE) based on a full factorial design with reference to existing experiment results. For example, the data generator **131** may obtain design values such as active material type, active material fraction and physical properties, binder content, conductive material content, loading level, and mixture (or composition) density through DOE performance.

[0064] The data generator **131** may obtain process design data for one or more (e.g., a plurality of) different process design conditions and generate a process design table to include the obtained process design data. In some embodiments, the data generator **131** may generate a process design table to include design values for one or more (e.g., each) process factor for one or more (e.g., each) of a plurality of process design conditions. The data generator **131** may store the generated process design table in the storage device **12**.

[0065] The data complement part **132** may add process design data that is missing when performing DOE among the process design data to be used (e.g., required) to simulate the structural characteristics of the battery electrode plate to the process design table. In some embodiments, the data complement part **132** may obtain the process design data that was not obtained through the data generator **131** among the process design data that is used to execute a discrete element method (DEM), and store the process design data in the process design table. For example, the data complement part **132** may obtain the thickness of the electrode plate in a state in which stress is removed through a press in the electrode plate manufacturing process as process design data, and add the thickness in the process design table.

[0066] The data complement part **132** may obtain process design data to be added to the process design table using values measured through previously performed experiments or machine learning-based predicted values. In the latter case, the data complement part **132** may obtain process design data using a linear regression model such as Ridge or Lasso to prevent overfitting. The linear regression model may be learned using DOE data including the actual process design information of the battery electrode plate and the corresponding process factor values that have been measured as learning data. For example, the linear regression model may be a model learned using actual process design information of battery electrode plate and actual measurement values of electrode plate thickness as learning data.

[0067] The simulation part **133** may retrieve process design data corresponding to one ro more (e.g, each) process design conditions from the process design table, and simulate the structural characteristics of the battery electrode plate corresponding to the process design condition based on the data. The simulation part **133** may perform simulation based on the discrete element method.

The simulation part **133** may simulate the components of the battery electrode plate (e.g., active material, binder, conductive material, current collector, etc.), the particle shape (e.g., spherical shape, non-spherical shape, etc.), particle size distribution, and/or verticality, using process design data corresponding to the process design condition. A person of skill in the art should recognize that other numerical methods that simulate the behavior of other particulate systems in addition or in lieu of the discrete element method may be used to simulate the components of the battery electrode plate.

[0068] The simulation part **133** may obtain tortuosity data, which is a structural characteristic of the battery electrode plate, through the simulation. FIG. **2** is a three-dimensional image of the structural characteristics of a negative electrode plate generated based the discrete element method according to an embodiment of the present disclosure.

[0069] When the tortuosity data of the battery electrode plate corresponding to one or more (e.g., each) process design condition is obtained through simulation, the simulation part **133** may store the data in the storage device **12**.

[0070] The model building part **134** may build a prediction model that predicts the tortuosity of the battery electrode plate based on process design conditions through machine learning, using the process design table and simulated tortuosity data using the process design table as learning data.

[0071] If process design data is input, the prediction model may predict and output the tortuosity of the battery electrode plate based on the process design data. The model building part **134** may build a prediction model using a portion of the process data stored in the storage device **12** (e.g., 80% of the total process data) as training data for the prediction model, and a remaining portion (e.g., 20% of the total process data) as validation data for the prediction model. In one embodiment, the prediction model for predicting the tortuosity of the battery electrode plate may be a linear regression model such as Ridge, Lasso, or Elastic net. The prediction model for predicting the tortuosity of the battery electrode plate may also be a non-linear model such as Neural Network, Random Forest, Support Vector Machine, or Gradient Boosting Machine.

[0072] If the prediction model is built, the model building part **134** may store the prediction model in the storage device **12**.

[0073] The control device **13** may include at least one processor. The processor may refer to a data processing device that is physically structured with circuits to perform functions (for example, functions of the data generator **131**, a data complement part **132**, a simulation part **133**, and a model building part **134**) expressed in code or instructions included in a program, such as a microprocessor, central processing unit (CPU), processor core, multiprocessor, application-specific integrated circuit (ASIC), and field programmable gate array (FPGA). The instructions of the program may be stored in a memory coupled to the processor.

[0074] The design support device **20** may receive the process design conditions for the manufacturing process of the battery electrode plate from the user terminal **30**, and predict the electrode plate characteristics information (e.g., tortuosity and ionic resistance) corresponding to the received process design conditions using the prediction model built by the model building device **10**. The design support device **20** may also provide predicted plate characteristic information to the user terminal **30** to support the user's process factor design.

[0075] The design support device **20** may receive information on a process factor (hereinafter referred to as "target process factor") selected as an object of interest from the user terminal **30**, and simulate changes in the characteristic of the battery electrode plate according to the change in design value of the target process factor using the prediction model. The design support device **20** may also provide the user terminal **30** with design support information to guide a design of the target process factor based on simulation results.

[0076] The design support device **20** may include a communication device **21**, a storage device **22**, and a control device **23**.

[0077] The communication device **21** may perform a communication function between the design

support device **20** and an external device (e.g., the model building device **10**, the user terminal **30**, etc.).

[0078] The storage device **22** may store various data and information processed by the design support device **20**. The storage device **22** may take the form of volatile memory, non-volatile memory, persistent memory, flash memory, hard drive, and/or the like. For example, the storage device **22** may store a prediction model used to predict tortuosity. The prediction model may be built by the model building device **10** and then transferred to the design support device **20** and stored in the storage device **22**. In some embodiments, the storage device **22** may store data for building a user interface (UI) provided to the user terminal **30** by the design support device **20**.

[0079] The storage device **22** may store a program or computer instructions for operating the control device **23**, which will be described later.

[0080] The control device **23** may control the overall operation of the design support device **20**. The control device **23** may include a tortuosity determiner **231**, an ionic resistance determiner **232**, a reverse engineering part **233**, and an interface provider **234**. Although the various components **231-234** of the control device **23** are assumed to be separate functional units, a person of skill in the art will recognize that the functionality of the components **231-234** may be combined or integrated into a single component, or further subdivided into further sub-components without departing from the spirit and scope of the inventive concept.

[0081] The tortuosity determiner **231** may predict the tortuosity of the battery electrode plate using the prediction model built by the model building device **10**. The design support device **20** may receive process design information including the process factor design conditions (for example, design values of active material type, active material fraction and physical properties, binder content, conductive material content, loading level, and mixture (or composition) density) for the manufacturing process of the battery electrode plate from the user terminal **30**. If process design information is received from the user terminal **30**, the tortuosity determiner **231** may input the received process design information into the prediction model. In addition, if the prediction model outputs the tortuosity of the battery electrode plate in response to the input process design information, the tortuosity determiner **231** may determine the tortuosity as the tortuosity of the battery electrode plate obtained when manufacturing the battery electrode plate under the corresponding process design conditions.

[0082] The ionic resistance determiner **232** may receive the tortuosity predicted by the prediction model from the tortuosity determiner **231**. The ionic resistance determiner **232** may calculate the ionic resistance representing the electrochemical characteristics of the battery electrode plate from the received tortuosity. Equation 1 below represents the relationship between the tortuosity plate and the ionic resistance of the battery electrode according to one embodiment of the present disclosure.

[00001]
$$\tau^2 = N_M \times \epsilon$$
$$N_M = \frac{\sigma_0}{\sigma_{eff}} = \frac{(Rion \times A \times \epsilon_0)}{d} \quad \text{Equation1}$$

[0083] In Equation 1 above, τ represents the tortuosity of the battery electrode plate, Nm represents a MacMullin number, σ.sub.0 represents the conductivity value of pure liquid electrolyte, Jeff represents the conductivity value when the separator and liquid electrolyte are combined, & represents the porosity of the separator, A represents the size of the battery electrode plate, d represents the thickness of the battery electrode plate, and R.sub.ion represents the ionic resistance of the battery electrode plate.

[0084] The ionic resistance determiner **232** may calculate the ionic resistance from the tortuosity of the battery electrode plate based on Equation 1 above. The ionic resistance determiner **232** may correct the ionic resistance calculated using Equation 1 by referring to the ionic resistance previously measured through experiment. In one embodiment, the storage device **22** may store the

tortuosity and the ionic resistance of the battery electrode plate actually measured during the experiment of the battery electrode plate as reference data in the form of a lookup table. The ionic resistance determiner **232** may compare the reference data stored in the storage device **22** with the ionic resistance calculated using Equation 1 above and correct the ionic resistance according to the comparison result.

[0085] The reverse engineering part **233** may provide design support information that supports factor value design for the target process factor selected as an object of interest by the user among a plurality of process factors.

[0086] The reverse engineering part **233** may receive reverse engineering information including selection information about the target process factor from the user terminal **30**. If reverse engineering information is received, the reverse engineering part **233** may sequentially change the design values of the target process factor and input them into the prediction model. As a result, the reverse engineering part **233** may obtain the characteristic values (tortuosity, ionic resistance, etc.) of the battery electrode plate. In some embodiments, the reverse engineering part **233** may obtain the tortuosity using the prediction model, and obtain the ionic resistance using the obtained tortuosity and Equation 1 above. The reverse engineering part **233** may monitor changes in the characteristics of the battery electrode plate according to changes in the design value of the target process factor, based on the obtained information on the characteristics of the battery electrode plate.

[0087] The reverse engineering information received from the user terminal **30** may further include design range information of the target process factor. The design range information may include, for example, upper and lower limits of corresponding process factors, and change intervals. The reverse engineering part **233** may control the change range and change interval of the design value of the target process factor based on the received design range information. In some embodiments, the reverse engineering part **233** may gradually increase or decrease the design value of the corresponding process factor within the design range consisting of an upper limit and a lower limit by a set change interval.

[0088] When there are multiple target process factors, the reverse engineering part **233** may generate one or more (e.g., all) design value combinations that may occur within the design range of the target process factors. In some embodiments, the reverse engineering part **233** may sequentially input the generated design value combinations into the prediction model.

[0089] Among the process factors input to the prediction model, the design values of the remaining process factors that are not the target process factor may be automatically set to default values. The design values of the remaining process factors other than the target process factor may be automatically set to the design values input from the previous prediction of the prediction model. The design values of the remaining process factors other than the target process factor may be set to values received from the user terminal **30**. In some embodiments, the reverse engineering part **233** may additionally receive design values of process factors that are not of interest from the user terminal **30**.

[0090] If the target process factor is the fraction of active materials, the reverse engineering part **233** may automatically adjust the fraction of each active material so that the sum of the fractions of the active materials becomes 100. In some embodiments, whenever the reverse engineering part **233** changes the fraction of the active material selected as an object of interest, the reverse engineering part **233** may also adjust the fraction of the remaining active materials so that the sum of the fractions of the active materials becomes 100.

[0091] The reverse engineering part **233** may analyze the characteristic information of the battery electrode plate obtained by changing the design value of the target process factor and select at least one reference datum to be included in the design support information provided to the user terminal **30**. In some embodiments, the reverse engineering part **233** may change the design values of the target process factor, analyze the obtained characteristic information, select at least one piece of

characteristic information that satisfies the specified conditions, and select the design values of the target process factor used to derive the selected characteristic information as reference data.

[0092] The reverse engineering information received from the user terminal **30** may further include target characteristic information of the battery electrode plate. The target characteristic information may represent characteristic values of the battery electrode plate that the user wishes to obtain.

[0093] The reverse engineering part **233** may change the design value of the target process factor and select reference data by comparing the obtained characteristic information of the battery electrode plate with the target characteristic information.

[0094] The reverse engineering part **233** may arrange the obtained characteristic information of the battery electrode plate in the order of the smallest difference from the target characteristic information. In some embodiments, the reverse engineering part **233** may select at least one piece of characteristic information selected in the order of the smallest difference from the target characteristic information and the design value of the target process factor used to derive the selected at least one piece of characteristic information as reference data. For example, if the target characteristic information includes a target ion resistance, the reverse engineering part **233** may change the design value of the target process factor and select at least one piece of selected ionic resistance in the order of the smallest difference from the target ion resistance among the obtained ionic resistances as reference data. In some embodiments, the reverse engineering part **233** may select the design value of the target process factor used to derive the ionic resistance selected as reference data.

[0095] The reverse engineering part **233** may change the design value of the target process factor and arrange the obtained battery electrode plate characteristic information in order of size. In some embodiments, the reverse engineering part **233** may select at least one piece of characteristic information selected in order of small size or large size, and select the design value of the target process factor used to derive the selected at least one piece of characteristic information as reference data. For example, the reverse engineering part **233** may select at least one ionic resistance selected in order of the smallest size among the ion resistances obtained using the prediction model as reference data.

[0096] In some embodiments, the reverse engineering part **233** may select the design value of the target process factor used to derive the selected ionic resistance as reference data.

[0097] If reference data is selected as described above, the reverse engineering part **233** may generate design support information to include the selected reference data.

[0098] The reverse engineering part **233** may generate a graph showing a trend of changes in the characteristics of the battery electrode plate according to the change in the design value of the target process factor, based on the characteristic information of the battery electrode plate obtained by changing the design value of the target process factor. The reverse engineering part **233** may additionally include graph data for visualizing such graphs in the design support information.

[0099] If the user terminal **30** connects to the design support device **20**, the interface provider **234** may provide the user terminal **30** with a user interface (UI) to support the design of process factors of the battery electrode plate.

[0100] FIGS. **3**A to **3**D are layout diagrams of example UIs provided by the system for designing a manufacturing process of a battery electrode plate, according to an embodiment of the present disclosure.

[0101] The interface provider **234** may provide the user terminal **30** with a UI for receiving design conditions for the manufacturing process of the battery electrode plate from the user terminal **30**.

[0102] FIG. **3**A is a layout diagram of an example UI **310** for receiving design conditions for the manufacturing process of the battery electrode plate.

[0103] Referring to FIG. **3**A, the UI **310** may include a list of process factors (see the bottom of 'Design Factors' in FIG. **3**A) required to predict the tortuosity and the ionic resistance of the battery electrode plate. For example, the UI **310** may include the fraction and physical properties of

each active material, binder content, conductive material content, active material type, loading level, mixture density, process conditions, etc. as process factors. Here, the process conditions may include process conditions (for example, time, pressure, temperature) that affect the structural characteristics of the battery electrode plate. Taking a negative electrode plate as an example, process conditions may include process conditions of a press process that greatly affect the microstructure of the negative electrode plate.

[0104] The UI **310** may further include an input window **311** through which the user may input desired design values for each process factor.

[0105] If the UI **310** is received from the design support device **20**, the user terminal **30** may display the UI **310** on the screen of the user terminal **30**. In some embodiments, if a design value is input from the user through the input window **311** on the UI **310**, the user terminal **30** may transmit the design value to the design support device **20**.

[0106] If the design value of each process factor is received from the user terminal **30**, the interface provider **234** may store the design value in the storage device **22**.

[0107] The design values stored in the storage device **22** may be used by the tortuosity determiner **231** to predict the tortuosity.

[0108] The active material of the battery electrode plate may be used in the form of a mixture of several active materials. If the sum of the fractions of the active materials received from the user terminal **30** is not 100, the interface provider **234** may automatically correct the fraction of each active material so that the sum of the fractions becomes 100. If the fraction of each active material is corrected, the interface provider **234** may store the corrected fraction value in the storage device **22**. Accordingly, the tortuosity determiner **231** may perform tortuosity prediction using the corrected fraction value. The interface provider **234** may also correct the input UI **310** to include the corrected fraction value and provide the corrected input UI **310** to the user terminal **30**.

[0109] The interface provider **234** may provide the user terminal **30** with a UI for outputting the characteristics (tortuosity and ionic resistance) of the battery electrode plate predicted by the design support device **20**.

[0110] FIG. **3**B is a layout diagram of an example UI **320** for outputting characteristic information of the battery electrode plate predicted by the design support device **20**.

[0111] Referring to FIG. **3**B, the UI **320** may include a list of characteristic factors (e.g., tortuosity and ionic resistance) of the battery electrode plate whose values are predicted by the design support device **20**, and an output window **321** in which the predicted value of each characteristic factor is displayed.

[0112] If the UI **320** is received from the design support device **20**, the user terminal **30** may display the UI **320** on the screen of the user terminal **30**. The user may verify the suitability of the process design conditions by checking the characteristic information of the battery electrode plate according to the process design conditions through the UI **320** output on the user terminal **30**.

[0113] The interface provider **234** may provide the user terminal **30** with a UI for receiving reverse engineering information from the user terminal **30**.

[0114] FIG. **3**C is a layout diagram of an example UI **330** for receiving reverse engineering information.

[0115] Referring to FIG. **3**C, the UI **330** may include an input window **331** for receiving target characteristic information. For example, the UI **330** may include the input window **331** for receiving a target value of ionic resistance.

[0116] The UI **330** may further include an input window **332** for receiving a list of target process factors (see X**1** and X**2** in FIG. **3**C) selected by the user and design range information for each target process factor. For example, the UI **330** may further include an input window **332** for receiving input of the lower limit value, upper limit value, and change interval of the target process factor.

[0117] The UI **330** may further include an input/output window **333** for outputting or receiving

design values of the remaining process factors (see x**1** to x**10** in FIG. **3**C) other than the target process factors. If the design values of the remaining process factors other than the target process factors are automatically set by the design support device **20**, the UI **330** may display the automatically set design values in the input/output window **333**. If the user wishes to directly set the design values of the remaining process factors other than the target process factors, the UI **330** may receive design values through the input/output window **333**.

[0118] If the UI **330** is received from the design support device **20**, the user terminal **30** may display the UI **330** on the screen of the user terminal **30**. The user terminal **30** may receive target characteristic information and design range information of the target process factor through the input windows **331** and **332** on the UI **330**. In some embodiments, the user terminal **30** may transmit reverse engineering information generated based on the input information to the design support device **20**. When reverse engineering information is received from the user terminal **30**, the interface provider **234** may store the received reverse engineering information in the storage device **22**. The reverse engineering information stored in the storage device **22** may be used by the reverse engineering part **233** to generate design support information.

[0119] The user terminal **30** may receive design values for remaining process factors other than the target process factors through the input/output window **333** on the UI **330**. The user terminal **30** may also transmit the input design value to the design support device **20** if the design value of the process parameter, which is not the target process factor, is input into the input/output window **333**. The interface provider **234** that received the input design value may store the received design value in the storage device **22**. The design values stored in the storage device **22** may be used to generate design support information in the reverse engineering part **233**.

[0120] The interface provider **234** may also provide the user terminal **30** with a UI for outputting design support information obtained through reverse engineering.

[0121] FIG. **3**D is a layout diagram of an example UI **340** for outputting design support information obtained through reverse engineering.

[0122] Referring to FIG. **3**D, the UI **340** may include a table **341** and a graph **342** for outputting design support information.

[0123] In the 'Target value' row of table **341**, the ionic resistance derived closest to the target ionic resistance through reverse engineering and the design values of the target process factors X**1** and X**2** used to derive the ionic resistance may be output as reference data. In the 'Best value' row of table **341**, the minimum ionic resistance derived through reverse engineering and the design values of the target process factors X**1** and X**2** used to derive the minimum ionic resistance may be output as reference data.

[0124] The graph **342** may represent a change trend in ionic resistance according to changes in design values of the target process factors X**1** and X**2**.

[0125] If the UI **340** including design support information is received from the design support device **20**, the user terminal **30** may display the UI **340** on the screen of the user terminal **30** and provide the UI **340** to the user.

[0126] The control device **23** may include at least one processor. At least one processor configuring the control device **23** may perform the functions of the tortuosity determiner **231**, the ionic resistance determiner **232**, the reverse engineering part **233**, and the interface provider **234** represented by codes or instructions included in the program.

[0127] The design support device **20** may provide the process design support function for the manufacturing process of the battery electrode plate described above to the user terminal **30** in the form of an online tool.

[0128] Hereinafter, with reference to FIGS. **4** to **6**, a detailed description will be given of how the system **1** supports process design for the manufacturing process of the battery electrode plate according to one or more embodiments.

[0129] FIG. **4** is a flow diagram of a process for building a prediction model for predicting the

tortuosity of the battery electrode plate according to an embodiment of the present disclosure. The method of FIG. **4** may be performed by the model building device **10** described with reference to FIG. **1**.

[0130] Referring to FIG. **4**, the model building device **10** may obtain previously performed experimental data related to the manufacturing process of the battery electrode plate (S**11**). The model building device **10** may perform DOE based on the experimental data obtained in act S**11** (S**12**).

[0131] The model building device **10** may obtain process design data for a plurality of different process design conditions from the results of the DOE performed in act S**12**, and generate a process design table to include the data (S**13**). The process design data may include design values of one or more (e.g., each) process factor. In some embodiments, the process design table may include design values for the one or more (e.g. each) process factor for one or more (e.g., each) of a plurality of process design conditions.

[0132] The model building device **10** may obtain missing process design data from the process design table among the process design data to be used (e.g., required) to simulate the structural characteristics of the battery electrode plate, and add the data to the process design table (S**14**).

[0133] In act S**14**, the model building device **10** may additionally obtain the thickness of the electrode plate in a state in which stress is removed through a press in the manufacturing process of the battery electrode plate as part of the process design data, and add the data to the process design table.

[0134] In act S**14**, the model building device **10** may obtain process design data to be added to the process design table using values measured through previously performed experiments or machine learning-based predicted values. In the latter case, the model building device **10** may obtain process design data using a linear regression model.

[0135] The model building device **10** may perform a simulation based on the discrete element method using the process design table and obtain tortuosity data of the battery electrode plate through the simulation (S**15**).

[0136] In step S**15**, the model building device **10** may retrieve process design data corresponding to one or more (e.g., each) process design condition from the process design table, and simulate the structural characteristics of the battery electrode plate corresponding to the process design condition based on the data. In some embodiments, the model building device **10** may simulate the components of the battery electrode plate (e.g., active material, binder, conductive material, current collector, etc.), the particle shape (e.g., spherical shape, non-spherical shape), particle size distribution, and verticality, using the process design data corresponding to the one or more (e.g., each) process design condition. The model building device **10** may obtain tortuosity data, which may be deemed to be a structural characteristic of the battery electrode plate, through the simulation.

[0137] If the tortuosity data corresponding to one or more (e.g., each) process design condition is obtained through simulation, the model building device **10** may build a prediction model that predicts the tortuosity of the battery electrode plate that varies depending on the process design conditions through machine learning (S**16**).

[0138] In act S**16**, the model building device **10** may train the prediction model using the process design table and tortuosity data as learning data. The trained model may predict and output the tortuosity of the battery electrode plate based on input process design data (e.g., input design values of one or more (e.g., each) process factor).

[0139] FIG. **5** is a flow diagram of a method for providing characteristic information of the battery electrode plate predicted according to process design conditions according to an embodiment of the present disclosure. The method of FIG. **5** may be performed by the design support device **20** described with reference to FIG. **1**.

[0140] Referring to FIG. **5**, the design support device **20** may receive process factor design

information of the manufacturing process of the battery electrode plate from the user terminal (S**21**). The process factor design information may include design values such as active material type, active material fraction and physical properties, binder content, conductive material content, loading level, and mixture (or composition) density, which may be process factors of the manufacturing process of the battery electrode plate.

[0141] If process design information is received from the user terminal **30**, the design support device **20** may predict the characteristic values of the battery electrode plate using the prediction model built by the model building device **10** (S**22**).

[0142] In act S**22**, the design support device **20** may input the received process design information into the prediction model to obtain a tortuosity representing the structural characteristics of the battery electrode plate. Once the tortuosity of the battery electrode plate is obtained, the design support device **20** may use the tortuosity to obtain ionic resistance, which is an electrochemical characteristic, of the battery electrode plate.

[0143] If the characteristic value of the battery electrode plate is obtained through act S**22**, the design support device **20** may transmit the characteristic information of the battery electrode plate including the obtained characteristic value to the user terminal **30** (S**23**).

[0144] When characteristic information of the battery electrode plate corresponding to design conditions input by the user from the design support device **20** is provided, the user terminal **30** may display a UI including the characteristic information on the screen of the user terminal **30**. The user may verify whether the current process design is suitable for obtaining the target characteristics of the battery electrode plate by checking the characteristic information of the battery electrode plate according to the design conditions through the UI output on the user terminal **30**. In some embodiments, the battery electrode plate is manufactured according to the current process design based on verifying that the current process design is suitable for obtaining the target characteristics of the battery electrode plate.

[0145] FIG. **6** is a flow diagram of a process for designing a manufacturing process of a battery electrode plate according to an embodiment of the present disclosure.

[0146] The method of FIG. **6** may be performed by the design support device **20** described with reference to FIG. **1**.

[0147] Referring to FIG. **6**, the design support device **20** may receive reverse engineering information from the user terminal **30** (S**31**). Reverse engineering information may include selection information about target process factors selected by the user. The reverse engineering information may further include design range information of the target process factor. The reverse engineering information may further include target characteristic information of the battery electrode plate. The target characteristic information may represent characteristic values of the battery electrode plate that the user wishes to obtain.

[0148] Based on reverse engineering information, the design support device **20** may simulate a change in the characteristic value of the battery electrode plate according to a change in the design value of the target process factor (S**32**).

[0149] In step S**32**, the design support device **20** may sequentially change the design values of the target process factors and input the design values into the prediction model to obtain characteristic values (tortuosity, ionic resistance) of the battery electrode plate.

[0150] In step S**32**, the design support device **20** may determine the change range and change interval of the design value of the target process factor based on design range information in response to the design value of the target process factor being changed. In some embodiments, the design support device **20** may gradually increase or decrease the design value of the corresponding target process factor within the design range consisting of the upper limit and lower limit by a set change interval.

[0151] In step S**32**, when there are multiple target process factors, the design support device **20** may generate various (e.g., all) design value combinations that may occur within the design range

of the target process factors. In some embodiments, the design support device **20** may sequentially input the generated design value combinations into the prediction model to obtain characteristic values (tortuosity and ionic resistance) of the battery electrode plate.

[0152] If the simulation in act S**32** is completed, the design support device **20** may generate design support information to be provided to the user terminal **30** based on the simulation results (S**33**).

[0153] In act S**33**, the design support device **20** may select at least one piece of characteristic information selected according to a condition (e.g., a predetermined condition) among the characteristic information of the battery electrode plate obtained through simulation as reference data to be included in the design support information. For example, the design support device **20** may select at least one piece of characteristic information selected in order of a small difference from the target characteristic information among the characteristic information obtained through simulation, and the design value of the target process factor used to derive the selected characteristic information as reference data. In some embodiments, the design support device **20** may select at least one piece of characteristic information selected in order of a small difference (or in order of a large difference) among the characteristic information obtained through simulation, and the design value of the target process factor used to derive the selected characteristic information as reference data. In some embodiments, the design support device **20** selects at least one piece of characteristic information based on the value of the one piece of characteristic information having a difference with the design value of the target processor factor that satisfies a criterion. The criterion may be that the difference is a smallest (or largest) difference, or a difference that is below (or above) a threshold value.

[0154] In act S**33**, the design support device **20** may generate a graph showing a change in the characteristics of the battery electrode plate according to the change in the design value of the target process factor based on the simulation results. The design support device **20** may additionally include graph data for visualizing such graphs in the design support information.

[0155] Once design support information is generated, the design support device **20** may transmit the design support information to the user terminal **30** (S**34**).

[0156] If design support information is received from the design support device **20**, the user terminal **30** may display a UI including the design support information on the screen of the user terminal **30**. Accordingly, the user may refer to the design support information displayed on the screen of the user terminal **30** and design the optimal factor value of the target process factor of interest. In some embodiments, the battery electrode plate is manufactured based on the optimal factor value.

[0157] While the embodiments of the present disclosure have been described in detail, it is to be understood that the disclosure is not limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

DESCRIPTION OF SYMBOLS

[0158] **1**: Process design support system [0159] **10**: Model building device [0160] **11**: Communication device of model building device [0161] **12**: Storage device of model building device [0162] **13**: Control device of model building device [0163] **131**: Data generator [0164] **132**: Data complement part [0165] **133**: Simulation part [0166] **134**: Model building part [0167] **20**: Design support device [0168] **21**: Communication device of design support device [0169] **22**: Storage device of design support device [0170] **23**: Control device of design support device [0171] **231**: Tortuosity determiner [0172] **232**: Ionic resistance determiner [0173] **233**: Reverse engineering part [0174] **234**: Interface provider [0175] **30**: User terminal

Claims

1. A system comprising a computing device configured to: receive, from a client device, a target process factor among a plurality of process factors associated with manufacturing a battery electrode plate; predict, via a machine-learning model, a change in a characteristic of the battery electrode plate based on a change in a design value of the target process factor; generate information for selecting the target process factor based on predicting the change of the characteristic of the battery electrode plate; and transmit the information to the client device for manufacturing the battery electrode plate.

2. The system as claimed in claim 1, wherein the machine-learning model is configured to output a characteristic information of the battery electrode plate based on input design values corresponding to the plurality of process factors.

3. The system as claimed in claim 2, wherein the computing device is further configured to: obtain a tortuosity of the battery electrode plate based on the machine-learning model; and calculate an ionic resistance based on the tortuosity.

4. The system as claimed in claim 2, wherein the computing device is further configured to automatically set the input design values corresponding to the plurality of process factors other than the target process factor as design values used in a previous prediction of the machine-learning model.

5. The system as claimed in claim 2, wherein the computing device is further configured to receive the input design values corresponding to the plurality of process factors other than the target process factor from the client device.

6. The system as claimed in claim 1, wherein the computing device is further configured to: receive design range information including a design value change range and change interval of the target process factor from the client device; and increase or decrease the design value of the target process factor based on the design range information.

7. The system as claimed in claim 1, wherein based on determining that the plurality of process factors include fractions of a plurality of active materials and the target process factor is a fraction of at least one active material of the plurality of active materials, the computing device is further configured to automatically adjust the fractions of the plurality of active materials to make a sum of the fractions of the plurality of active materials to equal **100** in response to the design value of the target process factor being changed.

8. The system as claimed in claim 2, wherein the computing device is further configured to: select a characteristic value of the battery electrode plate that satisfies a condition based on predicting the change in the characteristic of the battery electrode plate; and generate the information to include the selected characteristic value and the design value of the target process factor used to derive the characteristic value.

9. The system as claimed in claim 8, wherein the computing device is further configured to: receive a target characteristic value from the client device; select at least one second characteristic value based on predicting the change in the characteristic of the battery electrode plate based on the second characteristic value having a difference with the target characteristic value that satisfies a criterion; and generate the information to include the selected at least one second characteristic value and the design value of the target process factor used to derive at least one second characteristic value.

10. The system for supporting process design as claimed in claim 9, wherein the characteristic information includes an ionic resistance of the battery electrode plate, and the computing device is further configured to: select at least one ionic resistance among a plurality of ionic resistances obtained based on predicting the change in the characteristic of the battery electrode plate, wherein the at least one ionic resistance has a smallest difference from a target ionic resistance received from the client device; and generate the information to include the selected at least one ionic resistance and the design value of the target process factor used to derive the selected at least one

ionic resistance.

11. A system comprising: a computing device configured to: receive, from a client device, first information for manufacturing a battery electrode plate; predict characteristic information of the battery electrode plate using the first information and a machine learning-based prediction model; and transmit the characteristic information to the client device for manufacturing the battery electrode plate.

12. The system as claimed in claim 11, wherein the characteristic information comprises a tortuosity and an ionic resistance of the battery electrode plate, and the computing device is further configured to: input the first information into the prediction model to obtain the tortuosity of the battery electrode plate; and calculate the ionic resistance based on the tortuosity.

13. The system as claimed in claim 11, wherein the first information includes design values for a plurality of process factors for manufacturing the battery electrode plate, and the plurality of process factors includes a type of active material, fraction and physical properties of the active material, binder content, conductive material content, loading level and mixture, density, or process conditions.

14. The system as claimed in claim 11, wherein the computing device is further configured to build the prediction model, wherein the computing device is further configured to: perform a design of experiment (DOE) based on experimental data for a manufacturing process of the battery electrode plate; generate a process design table including design values of process factors for a plurality of different process design conditions through the DOE; obtain tortuosity data of the battery electrode plate by performing a simulation based on a discrete element method based on the process design table; and build the prediction model using the process design table and the tortuosity data as learning data.

15. The system as claimed in claim 14, wherein the computing device is further configured to add thickness data to the process design table using a linear regression model learned using actual process design data of the battery electrode plate and actual measured value of the thickness of the battery electrode plate.

16. A method comprising: receiving, from a client device, first information for manufacturing a battery electrode plate; predicting a tortuosity of the battery electrode plate using the first information and a machine learning-based prediction model; calculating an ionic resistance of the battery electrode plate based on the tortuosity; and transmitting characteristic information including at least one of the tortuosity or the ionic resistance of the battery electrode plate to the client device for manufacturing the battery electrode plate.

17. The method as claimed in claim 16, wherein the first information includes design values for a plurality of process factors for manufacturing the battery electrode plate, and the plurality of process factors includes a type of active material, a fraction and physical properties of the active material, binder content, conductive material content, loading level and mixture, density, or process conditions.

18. The method as claimed in claim 16, further comprising building the prediction model, wherein the building of the prediction model comprises: performing a design of experiment (DOE) based on experimental data for a manufacturing process of the battery electrode plate to generate a process design table including design values of process factors for a plurality of different process design conditions; performing a simulation based on a discrete element method based on the process design table to obtain tortuosity data of the battery electrode plate; and building the prediction model using the process design table and the tortuosity data as learning data.

19. The method as claimed in claim 17, further comprising: receiving, from the client device, selection information for selecting a target process factor among the plurality of process factors; predicting, via the prediction model, a change in a characteristic of the battery electrode plate based on a change in a design value of the target process factor; generating information for designing the target process factor based on predicting the change of the characteristic of the battery electrode

plate; and transmitting the first information to the client device for manufacturing the battery electrode plate.

20. The method as claimed in claim 19, wherein the generating of the first information comprises: selecting a characteristic value of the battery electrode plate that satisfies a condition based on predicting the change in the characteristic of the battery electrode plate; and generating the information to include the selected characteristic value and the design value of the target process factor used to derive the characteristic value.