

METHOD FOR RECYCLING POSITIVE ELECTRODE MATERIALS FROM BATTERIES

TECHNICAL FIELD

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The present application relates to battery recycling technology. In particular, the present application relates to a method for recycling positive electrode materials from batteries.

10 BACKGROUND

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With the booming global renewable energy industry, the widespread application of electric vehicles and energy storage systems has led to a surge in demand for lithium-ion batteries. However, when batteries reach the end of their life, if not handled properly, disposal of waste batteries will create serious environmental problems. On the other hand, waste lithium-ion batteries are actually rich in cobalt, nickel, manganese, lithium and other precious metals. Reserves of these elements in the earth's crust are limited. Besides, the cost of mining these elements from the earth's crust is high. Moreover, the production process of these elements will inevitably make damage to the environment.

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As core components of lithium-ion batteries, the positive electrode sheets not only account for a significant share of the cost, but are also the main carriers of rare metal elements. Conventional landfill or incineration disposal of used lithium-ion batteries is undoubtedly a great waste of these valuable elements, and may induce heavy metal pollution and the release of harmful chemicals, which is contrary to the concept of sustainable development.

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It is therefore desirable to provide an improved battery material recycling method to solve at least one of the problems identified above.

SUMMARY

According to one aspect, the present invention provides a method for recycling positive electrode materials from batteries. In one embodiment, the method comprises soaking positive electrode sheets of batteries in a first solution to dissolve binders of positive electrode coating on the positive electrode sheets into the first solution to separate the positive electrode coating from an aluminium foil and disperse positive electrode materials of the positive electrode coating into the first solution; extracting the positive electrode materials from the first solution; soaking the positive electrode materials in a second solution to dissolve waste active materials into the second solution to form a third solution and disperse conductive agents into the third solution; removing copper cations and iron cations from the third solution, adjusting molar ratios of Ni, Co, and Mn into a predetermined first molar ratio in the third solution, and concentrating the third solution to form a fourth solution. The method further comprises subjecting the fourth solution to coprecipitation reaction to form Ni-Co-Mn ternary precursors dispersed in a fifth solution; extracting the Ni-Co-Mn ternary precursors from the fifth solution, forming lithium carbonate with the fifth solution, and forming Ni-Co-Mn ternary active materials with the Ni-Co-Mn ternary precursors and the lithium carbonate.

Preferably, the first solution comprises at least one of NMP (N-Methyl-2-Pyrrolidone), N,N-Dimethylacetamide, and N,N-Dimethylformamide (DMF).

Preferably, the second solution comprises sulfuric acid with hydrogen peroxide.

Preferably, a concentration of the sulfuric acid is between 2.5 to 3.5 mol/L, and a mass ratio of the sulfuric acid and the positive electrode materials is between 1:6.5 to 1:7.8, and a mass ratio of the hydrogen peroxide and the positive electrode materials is between 0.6:1 to 0.85:1.

Preferably, the step of removing copper cations and iron cations from the third solution comprises using an extractant to remove copper cations from the third solution, the extractant being one or more of a ketoxime, an aldoxime, a modified oxime, and a

combination thereof; and heating the third solution at a temperature of 55 °C to 80 °C and at a pH of 1.75 to 1.95 to remove iron cations from the third solution.

Preferably, the predetermined first molar ratio is one of 5:2:3, 6:2:2, 1:1:1, and 8:1:1.

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Preferably, the step of concentrating the third solution is performed under an inert atmosphere.

Preferably, a total metal ions content in the fourth solution is 2.5 to 3.7 mol/L, and the coprecipitation reaction is performed at a pH of 11 to 12 under heating and stirring at 30 rpm to 85 rpm for 10 to 13 hours.

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Preferably, the step of forming the Ni-Co-Mn ternary active materials with the Ni-Co-Mn ternary precursors and the lithium carbonate comprises mixing the Ni-Co-Mn ternary precursors and the lithium carbonate at a predetermined second molar ratio to form a mixture; and calcining the mixture under a predetermined temperature for a predetermined duration to form the Ni-Co-Mn ternary active materials.

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Preferably, the predetermined second molar ratio is between 1:1 and 1:1.1.

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Preferably, the predetermined temperature is between a temperature of 680 °C to 950 °C and the predetermined duration is between 10 hours to 18 hours.

Preferably, a mass ratio of the positive electrode sheets and the first solution is between 1:5 to 1:6, and the step of soaking the positive electrode sheets in the first solution is performed at a temperature of 70 °C to 85 °C.

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Preferably, the method further comprises retracting a cell from a housing of a battery and separating a positive electrode sheet of the cell from a negative electrode sheet of the cell, prior to the step of soaking positive electrode sheets of batteries in a first solution.

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With the solutions provided by embodiments of the present application, the present invention enables positive electrode sheets recycling by effectively obtaining the aluminium

material and waste active material from the positive electrode current collectors of batteries. The method according to the present invention enables aluminium material and active material recycling without cutting, shredding, or calcining the batteries into fragments and achieves aluminium material and active material recycling with high efficiency.

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BRIEF DESCRIPTION OF DRAWINGS

The technical solutions and corresponding technical features of the embodiments will be more comprehensively understood in conjunction with the accompanying drawings, in which:

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Figure 1 is a flow chart showing a method for recycling positive electrode materials from batteries according to a first embodiment of the present invention;

Figure 2 is a flow chart showing further steps of the method shown in Figure 1;

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Figure 3 is a flow chart showing exemplary detailed steps of the method shown in Figure 1;

Figure 4 is a flow chart showing exemplary detailed steps of the method shown in Figure 1;

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Figure 5 is a flow chart showing an exemplary detailed step of the method shown in Figure 1;

Figure 6 is a flow chart showing an exemplary detailed step of the method shown in Figure 1;

Figure 7 is a flow chart showing exemplary detailed steps of the method shown in Figure 1;

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Figure 8 is a flow chart showing a method for recycling positive electrode materials from batteries according to a second embodiment of the present invention.

DETAILED DESCRIPTION

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In the present invention, a “battery” refers to a device including a housing that contains an electrochemical cell; a “cell” refers to a combination of a positive electrode sheet, a separator, and a negative electrode sheet; a “positive electrode sheet” refers to a positive electrode current collector carrying positive electrode coating; a “negative electrode

sheet” refers to a negative electrode current collector carrying negative electrode coating; a “positive electrode coating” refers to a combination of positive electrode active materials, conductive agents, and a binder that binds the positive electrode active materials, the conductive agents, and the positive electrode current collector together; a “negative electrode coating” refers to a combination of negative electrode active materials, conductive agents (if any), and a binder that binds the negative electrode active materials, the conductive agents, and the negative electrode current collector together; “positive electrode active materials” may refer to a single substance or a mixture; “negative electrode active materials” may refer to a single substance or a mixture.

As shown in Figure 1 and Figure 2, according to a first embodiment of the present invention, a method 100 for recycling positive electrode materials from batteries comprises, at step 120, soaking positive electrode sheets in a first solution to dissolve binders of positive electrode coating on the positive electrode sheets into the first solution to separate the positive electrode coating from an aluminium foil and disperse positive electrode materials of the positive electrode coating into the first solution. The method 100 further includes, at step 130, extracting the positive electrode materials from the first solution and at step 140, soaking the positive electrode materials in a second solution to dissolve waste active materials into the second solution to form a third solution and disperse conductive agents into the third solution. The method 100 further includes, at step 150, removing copper cations and iron cations from the third solution (step 152), adjusting molar ratios of Ni, Co, and Mn into a predetermined first molar ratio in the third solution (step 154), and concentrating the third solution (step 156), to form a fourth solution. The method 100 further includes, at step 160, subjecting the fourth solution to coprecipitation reaction to form Ni-Co-Mn ternary precursors dispersed in a fifth solution. The method 100 further includes, at step 170, extracting the Ni-Co-Mn ternary precursors from the fifth solution, at step 180, forming lithium carbonate with the fifth solution and at step 190, forming Ni-Co-Mn ternary active materials with the Ni-Co-Mn ternary precursors and the lithium carbonate.

Preferably, in the first embodiment, as shown in Figure 3, the method 100 further comprises, prior to the step 120 of soaking positive electrode sheets in a first solution, at step 110, retracting a cell from a housing of a battery and at step 112, separating a positive electrode sheet of the cell from a negative electrode sheet of the cell.

Preferably, at step 120, the first solution comprises an organic solvent, e.g. at least one of NMP (N-Methyl-2-Pyrrolidone), N,N-Dimethylacetamide, and N,N-Dimethylformamide (DMF). These organic solvents have high solubility of binders used in lithium-ion batteries and so dissolve the binders to separate the positive electrode coating from an aluminium foil. Upon the binders being dissolved, positive electrode materials of batteries are dispersed in these organic solvents.

Preferably, in the first embodiment, in step 140, the second solution comprises sulfuric acid with hydrogen peroxide. During the process of step 140, elements Ni, Co, and Mn in the positive electrode materials are dissolved while the conductive agents are dispersed in the solution. Co and Mn of high valence state in the positive electrode materials are reduced by the hydrogen peroxide to Co^{2+} and Mn^{2+} that are more soluble, thereby increasing the leaching rate of Co and Mn.

Preferably, in the first embodiment, a concentration of the sulfuric acid is between 2.5 to 3.5 mol/L. Preferably, a mass ratio of the sulfuric acid and the positive electrode materials is between 1:6.5 to 1:7.8. Preferably, a mass ratio of the hydrogen peroxide and the positive electrode materials is between 0.6:1 to 0.85:1.

Preferably, in the first embodiment, as shown in Figure 4, the step 152 of removing copper cations and iron cations from the third solution comprises, at step 1522, using an extractant to remove copper cations from the third solution, the extractant being one or more of a ketoxime, an aldoxime, a modified oxime, and a combination thereof; and at step 1524, heating the third solution at a temperature of 55 °C to 80 °C at a pH of 1.75 to 1.95 to remove iron cations from the third solution.

For a waste positive electrode sheet, the elements of Cu and Fe are brought in during the usage of a battery. The elements of Cu and Fe in a positive electrode sheet, especially one with ternary active materials, compromise the performance of a battery. In particular, the elements of Cu and Fe add to undesired extra mass in a positive electrode sheet fabricated with the ternary active materials formed at step 190, affect the crystallinity of the positive electrode active materials formed at step 190, bring in adverse side reactions at step

160 and step 190 and during the operation of a battery, and so reduce the specific energy capacity and shorten the lifetime of a battery.

Preferably, in the first embodiment, the predetermined first molar ratio is one of 5:2:3, 6:2:2, 1:1:1, and 8:1:1.

Preferably, in the first embodiment, as shown in Figure 5, the step 156 of concentrating the third solution comprises, at step 1562, concentrating the third solution under an inert atmosphere. At step 1562, the volume of the third solution containing valuable elements, i.e. Ni, Co, and Mn, is reduced to facilitate subsequent steps without being polluted by the ambient environment.

Preferably, in the first embodiment, as shown in Figure 6, the step 160 of subjecting the fourth solution to coprecipitation reaction to form Ni-Co-Mn ternary precursors dispersed in a fifth solution comprises, at step 162, subjecting the fourth solution with a total metal ions content of 2.5 to 3.7 mol/L to coprecipitation reaction at a pH of 11 to 12 under heating and stirring at 30 rpm to 85 rpm for 10 to 13 hours to form Ni-Co-Mn ternary precursors dispersed in a fifth solution.

In one example, for a coprecipitation reaction duration of 11 hours, Table 1 shows the molar ratios of nickel, cobalt, and manganese under different pH values and stirring speeds (rpm).

Table 1. The molar ratios of nickel, cobalt, and manganese under different pH values and stirring speeds (rpm) for a coprecipitation reaction duration of 11 hours

pH	35 rpm	40 rpm	50 rpm	55 rpm	65 rpm	70 rpm	75 rpm	80 rpm
11	5:2:2.47	5:2:2.97	5:2:3.05	5:2:2.99	5:2:3.3	5:2:2.98	5:2:3.01	5:2:3.07
11.5	5:2:2.59	5:2:2.99	5:2:3.01	5:2:3.01	5:2:3.18	5:2:3.01	5:2:2.99	5:2:3.09
12	5:2:2.63	5:2:3.02	5:2:3.03	5:2:3.03	5:2:3.21	5:2:3.21	5:2:3.02	5:2:3.08

In another example, for a coprecipitation reaction duration of 12 hours, Table 2 shows the molar ratios of nickel, cobalt, and manganese under different pH values and stirring speeds (rpm).

Table 2. The molar ratios of nickel, cobalt, and manganese under different pH values and stirring speeds (rpm) for a coprecipitation reaction duration of 12 hours

pH	35 rpm	40 rpm	50 rpm	55 rpm	65 rpm	70 rpm	75 rpm	80 rpm
11	5:2:2.61	5:2:2.99	5:2:3.03	5:2:3.02	5:2:3.29	5:2:3.03	5:2:3.04	5:2:3.15
11.5	5:2:2.49	5:2:2.99	5:2:3.05	5:2:3.06	5:2:3.31	5:2:3.07	5:2:3.02	5:2:3.21
12	5:2:2.77	5:2:3.01	5:2:3.07	5:2:3.11	5:2:3.35	5:2:3.05	5:2:3.08	5:2:3.30

In yet another example, for a coprecipitation reaction duration of 13 hours, Table 3 shows the molar ratios of nickel, cobalt, and manganese under different pH values and stirring speeds (rpm).

Table 3. The molar ratios of nickel, cobalt, and manganese under different pH values and stirring speeds (rpm) for a coprecipitation reaction duration of 13 hours

pH	35 rpm	40 rpm	50 rpm	55 rpm	65 rpm	70 rpm	75 rpm	80 rpm
11	5:2:2.48	5:2:3.05	5:2:3.06	5:2:2.98	5:2:3.43	5:2:2.99	5:2:3.01	5:2:3.11
11.5	5:2:2.55	5:2:3.04	5:2:3.05	5:2:3.04	5:2:3.37	5:2:3.04	5:2:2.99	5:2:3.17
12	5:2:2.72	5:2:3.07	5:2:3.01	5:2:3.08	5:2:3.28	5:2:3.15	5:2:3.05	5:2:3.13

During step 160, Ni, Co, and Mn elements react to form Ni-Co-Mn ternary precursors dispersed in the fifth solution while Li element is dissolved in the fifth solution.

At step 180, the fifth solution is employed to form lithium carbonate. In one example, a saturated sodium carbonate solution is added to the fifth solution to prepare lithium carbonate.

Preferably, in the first embodiment, as shown in Figure 7, the step 190 of forming Ni-Co-Mn ternary active materials with the Ni-Co-Mn ternary precursors and the lithium carbonate comprises, at step 192, mixing the Ni-Co-Mn ternary precursors and the lithium carbonate at a predetermined second molar ratio to form a mixture, and at step 194, calcining the mixture under a predetermined temperature for a predetermined duration to form the Ni-Co-Mn ternary active materials.

Preferably, in the first embodiment, the predetermined second molar ratio is between 1:1 and 1:1.1.

Preferably, in the first embodiment, the predetermined temperature is between 680 °C to 950 °C and the predetermined duration is between 10 hours to 18 hours.

Preferably, in the first embodiment, a mass ratio of the positive electrode sheets and the first solution is between 1:5 to 1:6. Preferably, in the first embodiment, the step of soaking the positive electrode sheets in the first solution is performed at 70 °C to 85 °C.

According to a second embodiment of the present invention, as shown in Figure 8, a method 200 for recycling positive electrode materials from batteries comprises, at step 210, soaking positive electrode sheets in a first solution to dissolve binders of positive electrode coating on the positive electrode sheets into the first solution to separate the positive electrode coating from an aluminium foil and disperse positive electrode materials of the positive electrode coating into the first solution. The method 200 further includes at step 220, extracting the aluminium foil from the first solution, at step 230, drying the aluminium foil, and at step 240, cleaning the aluminium foil.

Positive electrode sheets may be obtained from used and/or discarded batteries upon the batteries being fully discharged and disassembled, by separating the positive electrode sheets from the battery housings.

Preferably, in the second embodiment, the first solution comprises at least one of NMP (N-Methyl-2-Pyrrolidone), N,N-Dimethylacetamide, and N,N-Dimethylformamide (DMF).

Preferably, in the second embodiment, a mass ratio of the positive electrode sheets and the first solution is between 1:5 to 1:6. Preferably, in the second embodiment, the step of soaking the positive electrode sheets in the first solution is performed at 70 °C to 85 °C.

Compared to conventional battery material recycling methods, the solutions provided by the present invention achieves advantageous technical effects of highly efficient

recycling of aluminium foils and active materials with lowered material resources wastes, lowered environmental pollutions as well as lowered energy consumption. The aluminium foils and ternary active materials obtained also have relatively high purity due to the implementation of the method of the present invention as described herein.

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Conventional battery material recycling methods may involve calcining positive electrode sheets, resulting in a mixture containing aluminium. Removing aluminium consumes a large amount of base and inevitably leads to loss of nickel, cobalt, and manganese. In contrast, in the present invention, a positive electrode sheet is treated with a solution to separate the positive electrode materials from the aluminium foil without calcination, the use of base, or loss of nickel, cobalt, and manganese.

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Example 1

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The end caps of a discarded lithium-ion battery are removed in an inert gas atmosphere using laser. The cell of the battery is extracted. Then the separator, the positive electrode sheet and the negative electrode sheet are separated using a rewinding process through a rewinding mechanism.

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The positive electrode materials are peeled from the aluminium foil using NMP as an organic solvent with a mass ratio of the positive electrode sheet to the organic solvent of 1:5, at 80 °C. The filtrate of the organic solvent is treated and reused.

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The positive electrode materials are added to a sulfuric acid solution containing a reducing agent for dissolution and leaching, with a sulfuric acid concentration of 3 mol/L. The mass ratio of the positive electrode materials to the sulfuric acid solution is 1:7. The mass ratio of the reducing agent, i.e. hydrogen peroxide, to the positive electrode materials is 0.7:1. After filtration, a solution containing heavy metals, i.e. the leachate, and a filtration residue of conductive agents are obtained.

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M5640 extractant is then used to remove copper ions from the leachate. Afterwards, the leachate is heated to 65 °C and the pH of the leachate is adjusted to 1.85 to remove iron

ions from the leachate. The ratio of nickel, cobalt, and manganese in the leachate is then adjusted to 5:2:3.

The purified leachate is concentrated under inert gas protection with a total metal ion concentration of 3 mol/L. The purified leachate is added to a reaction kettle with a base solution at pH 11.7 to form a reaction solution. The pH of the reaction solution is adjusted to 11.5 using ammonia and sodium hydroxide. The reaction solution is stirred and heated for 12 hours to carry out the coprecipitation reaction. After washing, filtering, and drying the reaction solution, a ternary precursor is obtained.

A saturated sodium carbonate solution is added to the filtered lithium-rich reaction solution during the coprecipitation synthesis to prepare lithium carbonate.

The ternary precursor and the lithium carbonate prepared is mixed in a molar ratio of 1:1.02, and then calcined at 900°C for 15 hours to form the desired high-purity, uniformly sized ternary active positive electrode material.

Example 2

The end caps of a discarded lithium-ion battery are removed in an inert gas atmosphere using laser. The cell of the battery is extracted. Then the separator, the positive electrode sheet and the negative electrode sheet are separated using a rewinding process through a rewinding mechanism.

The positive electrode materials are peeled from the aluminium foil using NMP as an organic solvent with a mass ratio of the positive electrode sheet to the organic solvent of 1:5.5, at 78 °C. The filtrate of the organic solvent is treated and reused.

The positive electrode materials are added to a sulfuric acid solution containing a reducing agent for dissolution and leaching, with a sulfuric acid concentration of 2.8 mol/L. The mass ratio of the positive electrode materials to the sulfuric acid solution is 1:6.7. The mass ratio of the reducing agent, i.e. hydrogen peroxide, to the positive electrode materials

is 0.75:1. After filtration, a solution containing heavy metals, i.e. the leachate, and a filtration residue of conductive agents are obtained.

M5640 extractant is then used to remove copper ions from the leachate. Afterwards, the leachate is heated to 70 °C and the pH of the leachate is adjusted to 1.9 to remove iron ions from the leachate. The ratio of nickel, cobalt, and manganese in the leachate is then adjusted to 6:2:2.

The purified leachate is concentrated under inert gas protection with a total metal ion concentration of 3.3 mol/L. The purified leachate is added to a reaction kettle with a base solution at pH 11.5 to form a reaction solution. The pH of the reaction solution is adjusted to 11.6 using ammonia and sodium hydroxide. The reaction solution is stirred and heated for 13 hours to carry out the coprecipitation reaction. After washing, filtering, and drying the reaction solution, a ternary precursor is obtained.

A saturated sodium carbonate solution is added to the filtered lithium-rich reaction solution during the coprecipitation synthesis to prepare lithium carbonate.

The ternary precursor and the lithium carbonate prepared is mixed in a molar ratio of 1:1.005, and then calcined at 880°C for 14 hours to form the desired high-purity, uniformly sized ternary active positive electrode material.

Example 3

The end caps of a discarded lithium-ion battery are removed in an inert gas atmosphere using laser. The cell of the battery is extracted. Then the separator, the positive electrode sheet and the negative electrode sheet are separated using a rewinding process through a rewinding mechanism.

The positive electrode materials are peeled from the aluminium foil using NMP as an organic solvent with a mass ratio of the positive electrode sheet to the organic solvent of 1:5.1, at 80 °C. The filtrate of the organic solvent is treated and reused.

The positive electrode materials are added to a sulfuric acid solution containing a reducing agent for dissolution and leaching, with a sulfuric acid concentration of 3.1 mol/L. The mass ratio of the positive electrode materials to the sulfuric acid solution is 1:6.3. The mass ratio of the reducing agent, i.e. hydrogen peroxide, to the positive electrode materials is 0.75:1. After filtration, a solution containing heavy metals, i.e. the leachate, and a filtration residue of conductive agents are obtained.

M5640 extractant is then used to remove copper ions from the leachate. Afterwards, the leachate is heated to 82 °C and the pH of the leachate is adjusted to 1.93 to remove iron ions from the leachate. The ratio of nickel, cobalt, and manganese in the leachate is then adjusted to 8:1:1.

The purified leachate is concentrated under inert gas protection with a total metal ion concentration of 3.6 mol/L. The purified leachate is added to a reaction kettle with a base solution at pH 11.8 to form a reaction solution. The pH of the reaction solution is adjusted to 11.7 using ammonia and sodium hydroxide. The reaction solution is stirred and heated for 12.5 hours to carry out the coprecipitation reaction. After washing, filtering, and drying the reaction solution, a ternary precursor is obtained.

A saturated sodium carbonate solution is added to the filtered lithium-rich reaction solution during the coprecipitation synthesis to prepare lithium carbonate.

The ternary precursor and the lithium carbonate prepared is mixed in a molar ratio of 1:1.02, and then calcined at 850°C for 15 hours to form the desired high-purity, uniformly sized ternary active positive electrode material.

Example 4

The end caps of a discarded lithium-ion battery are removed in an inert gas atmosphere using laser. The cell of the battery is extracted. Then the separator, the positive electrode sheet and the negative electrode sheet are separated using a rewinding process through a rewinding mechanism.

The positive electrode materials are peeled from the aluminium foil using NMP as an organic solvent with a mass ratio of the positive electrode sheet to the organic solvent of 1:5.7, at 77 °C. The filtrate of the organic solvent is treated and reused.

5 The positive electrode materials are added to a sulfuric acid solution containing a reducing agent for dissolution and leaching, with a sulfuric acid concentration of 3.4 mol/L. The mass ratio of the positive electrode materials to the sulfuric acid solution is 1:6.6. The mass ratio of the reducing agent, i.e. hydrogen peroxide, to the positive electrode materials is 0.85:1. After filtration, a solution containing heavy metals, i.e. the leachate, and a
10 filtration residue of conductive agents are obtained.

M5640 extractant is then used to remove copper ions from the leachate. Afterwards, the leachate is heated to 82 °C and the pH of the leachate is adjusted to 1.89 to remove iron ions from the leachate. The ratio of nickel, cobalt, and manganese in the leachate is then
15 adjusted to 1:1:1.

The purified leachate is concentrated under inert gas protection with a total metal ion concentration of 2.9 mol/L. The purified leachate is added to a reaction kettle with a base solution at pH 11.5 to form a reaction solution. The pH of the reaction solution is
20 adjusted to 11.5 using ammonia and sodium hydroxide. The reaction solution is stirred and heated for 11 hours to carry out the coprecipitation reaction. After washing, filtering, and drying the reaction solution, a ternary precursor is obtained.

A saturated sodium carbonate solution is added to the filtered lithium-rich reaction
25 solution during the coprecipitation synthesis to prepare lithium carbonate.

The ternary precursor and the lithium carbonate prepared is mixed in a molar ratio of 1:1.0, and then calcined at 800°C for 16 hours to form the desired high-purity, uniformly sized ternary active positive electrode material.

30 This disclosure has been presented for purposes of illustration and description of the embodiments of the present invention, but is not intended to be exhaustive or limiting. For example, while the present invention is presented by making reference to one type of battery

as illustrated in the drawings and the description, it should be appreciated that the present invention may be practiced for batteries of various other types, other structures, other models and other architectures. Many modifications and variations will be apparent to those skilled in the art. The example embodiments are chosen and described to explain principles and practical application of the present invention, and to enable those skilled in the art to understand the disclosure for various embodiments with various modifications that are suitable for the particular technical solution contemplated and described. Further, while some technical details may be omitted from the description and drawings, for the purpose of clarity and conciseness, such omissions are not meant to be understood that the omitted features are necessarily absent or missing in the relevant structures, parts, processes and/or steps, as described herein, for understanding and practicing the invention.

Thus, although illustrative example embodiments have been described herein with reference to the accompanying drawings, it is to be understood that this description is not limiting and that various other changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the disclosure as sets out and defined in the claims appended hereto.

CLAIMS

1. A method for recycling positive electrode materials from batteries, the method comprising:

5 soaking positive electrode sheets of batteries in a first solution to dissolve binders of positive electrode coating on the positive electrode sheets into the first solution to separate the positive electrode coating from an aluminium foil and disperse positive electrode materials of the positive electrode coating into the first solution;

10 extracting the positive electrode materials from the first solution;

 soaking the positive electrode materials in a second solution to dissolve waste active materials into the second solution to form a third solution and disperse conductive agents into the third solution;

 removing copper cations and iron cations from the third solution, adjusting molar ratios of Ni, Co, and Mn into a predetermined first molar ratio in the third solution, and concentrating the third solution to form a fourth solution;

15 subjecting the fourth solution to coprecipitation reaction to form Ni-Co-Mn ternary precursors dispersed in a fifth solution;

 extracting the Ni-Co-Mn ternary precursors from the fifth solution;

20 forming lithium carbonate with the fifth solution; and

 forming Ni-Co-Mn ternary active materials with the Ni-Co-Mn ternary precursors and the lithium carbonate.

2. The method as recited in claim 1, wherein the first solution comprises at least one of NMP (N-Methyl-2-Pyrrolidone), N,N-Dimethylacetamide, and N,N-Dimethylformamide (DMF).

3. The method as recited in claim 2, wherein the second solution comprises sulfuric acid with hydrogen peroxide.

4. The method as recited in claim 3, wherein a concentration of the sulfuric acid is between 2.5 to 3.5 mol/L, a mass ratio of the sulfuric acid and the positive electrode

materials is between 1:6.5 to 1:7.8, and wherein a mass ratio of the hydrogen peroxide and the positive electrode materials is between 0.6:1 to 0.85:1.

5. The method as recited in claim 4, wherein the step of removing copper cations and iron cations from the third solution comprises:

using an extractant to remove copper cations from the third solution, the extractant being one or more of a ketoxime, an aldoxime, a modified oxime, and a combination thereof; and

heating the third solution at a temperature of 55 °C to 80 °C at a pH of 1.75 to 1.95 to remove iron cations from the third solution.

6. The method as recited in claim 5, wherein the predetermined first molar ratio is one of 5:2:3, 6:2:2, 1:1:1 and 8:1:1.

7. The method as recited in claim 6, wherein the step of concentrating the third solution is performed under an inert atmosphere.

8. The method as recited in claim 7, wherein a total metal ions content in the fourth solution is 2.5 to 3.7 mol/L, and wherein the coprecipitation reaction is performed at a pH of 11 to 12 under heating and stirring at 30 rpm to 85 rpm for 10 to 13 hours.

9. The method as recited in claim 8, wherein the step of forming the Ni-Co-Mn ternary active materials with the Ni-Co-Mn ternary precursors and the lithium carbonate comprises:

mixing the Ni-Co-Mn ternary precursors and the lithium carbonate at a predetermined second molar ratio to form a mixture; and

calcining the mixture under a predetermined temperature for a predetermined duration to form the Ni-Co-Mn ternary active materials.

10. The method as recited in claim 9, wherein the predetermined second molar ratio is between 1:1 and 1:1.1.

11. The method as recited in claim 9, wherein the predetermined temperature is between 680 °C to 950 °C and the predetermined duration is between 10 hours to 18 hours.

12. The method as recited in claim 1, wherein a mass ratio of the positive electrode sheets and the first solution is between 1:5 to 1:6, and wherein the step of soaking the positive electrode sheets in the first solution is performed at 70 °C to 85 °C.

13. The method as recited in claim 1, further comprising, prior to the step of soaking positive electrode sheets of batteries in a first solution, retracting a cell from a housing of a battery and separating a positive electrode sheet of the cell from a negative electrode sheet of the cell.