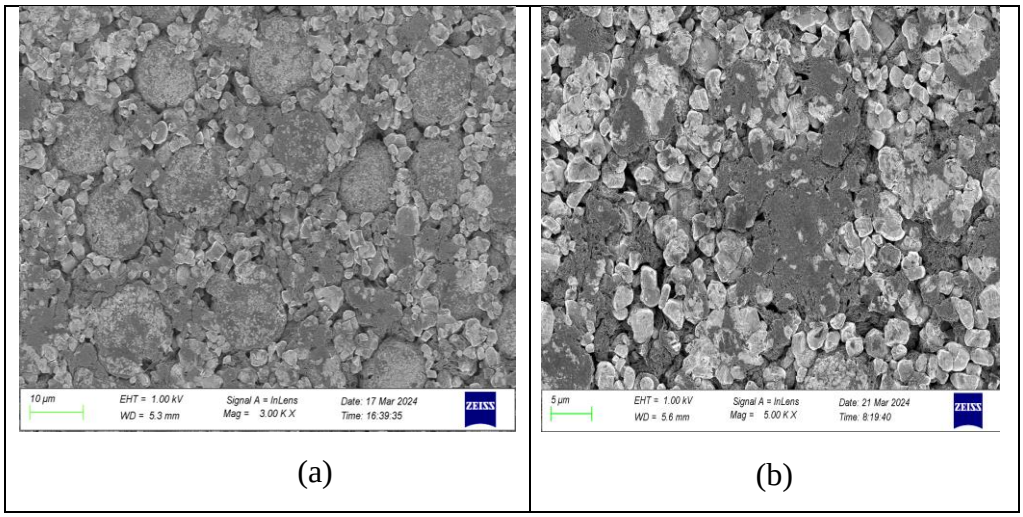



**Figure 1**

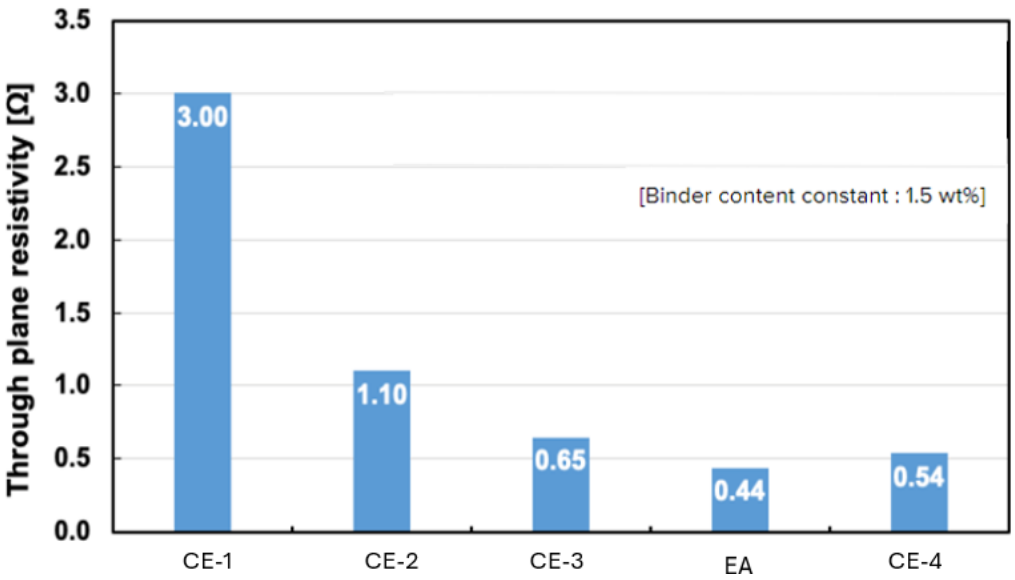



**Figure 2**

**FORM 2**

THE PATENTS ACT, 1970
(39 of 1970)
&
THE PATENTS RULES, 2003

**COMPLETE SPECIFICATION**
**(See section 10, rule 13)**

***1. Title of the invention*:** A PROCESS FOR PREPARING AN ELECTRODE, AND IMPLEMENTATIONS THEREOF

***2. Applicant(s)***

| NAME | NATIONALITY | ADDRESS |
|---|---|---|
| OLA ELECTRIC MOBILITY LIMITED | Indian | Regent Insignia, #414, 3rd Floor, 4th Block, 17th Main, 100 Feet Road, Koramangala, Bangalore, Karnataka 560034, India |

***3. Preamble to the description***

**COMPLETE SPECIFICATION**

The following specification particularly describes the invention and the manner in which it is to be performed.

## FIELD OF THE INVENTION

**[0001]** The present disclosure broadly relates to the field of batteries. Particularly, the present disclosure relates to the process for fabricating the electrode, more particularly the present disclosure relates to processes of preparing electrodes.

## BACKGROUND OF THE INVENTION

**[0002]** The development of efficient fabrication techniques is of paramount importance in the field of battery manufacture due to the increasing demand for batteries worldwide. The major power source for electronics, automobiles, etc. is secondary batteries. Hence, a substantial amount of research is underway to enhance the energy density of existing secondary batteries at a reasonable cost by improving several components of the secondary batteries.

**[0003]** Li-ion batteries, or lithium-ion batteries, are a type of secondary battery that stores energy by means of the reversible intercalation of $Li^+$ ions into electronically conducting compounds. Li-ion batteries have higher specific energy, higher energy density, better energy efficiency, longer cycle life, and longer calendar life in comparison with conventional commercial rechargeable batteries.

**[0004]** The contact between the current collector and the composite film (which comprises an active material, a conductive carbon, and a binder) serves as a gauge for the mechanical integrity of the electrode material. Conductive additive although being a minor component, is a crucial part of the Li-ion battery electrode and makes up to a weight in a range of 1 to 5% of the total weight of the electrode. The adhesion strength and electrochemical performance of the electrode are significantly influenced by the particle size, structure, and aspect ratio of the conductive carbon and active materials.

**[0005]** In addition, the mixing of the conductive carbon with the active material is also challenging due to the agglomeration of the conductive carbon. Generally, the conductive carbons that have been used for the electrode manufacture are graphite, metal powder, metal fibres, and carbon nanomaterials. Based on their morphological structure, conductive carbons (CC) are classified into two types: (a)

particle-like conductive carbons, such as graphite, Super P (SP), and Ketjen black (KB), and (b) fiber-like conductive agents, such as carbon nanotubes (CNT), vapor-grown carbon fiber (VGCF), carbon nanofibers and metal fibers. Morphological structures of conducting carbons affect conductivity and interactions between active material and binder. Owing to high aspect ratio, excellent electrical and thermal conductivity, and ease of preparation, carbon nanomaterials (such as carbon nanotubes and carbon nanofibers) have been extensively used and preferred in Li-ion battery electrodes.

**[0006]** Due to the variations of particle size and difference in the aspect ratio between the binder and carbon particles, agglomeration of carbon can easily occur in the presence of the binder. Also, the improper distribution of the conducting carbon in the electrodes may cause serious issues in terms of the dendritic growth or short-circuiting during prolonged cycling. Therefore, the amount of carbon particles having desirable morphology/aspect ratio is highly critical. Further, the process for preparing is also crucial to avoid the improper distribution, and to attain a homogenous mix and thereby reduce cell impedance and development of internal resistance.

**[0007]** Thus, there is a dire need in the art to develop a cost-effective, efficient and improved manufacturing process to develop electrode with high electrical conductivity.

## SUMMARY OF THE INVENTION

**[0008]** In a first aspect of the present disclosure, there is provided a process for preparing an electrode, the process comprising: a) mixing a primary conductive carbon with a binder solution to obtain a pre-mixture; b) blending a first part of an active material with the pre-mixture to obtain a blend; c) adding a first part of a secondary conductive carbon to the blend and stirring to obtain a first mixture; d) adding a second part of the active material with the first mixture to obtain a second mixture; e) mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and

f) processing of the electrode slurry to obtain the electrode, wherein the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5, and wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1 to 2%, with respect to the total weight of the electrode.

**[0009]** In a second aspect of the present disclosure, there is provided an electrode obtained by the process as disclosed herein, wherein the electrode comprises: a) an active material; b) a binder; c) a primary conductive carbon; and d) a secondary conductive carbon, wherein the primary conductive carbon and the secondary conductive carbon is present in a weight ratio range of 1: 0.75 to 1: 1.5.

**[0010]** In a third aspect of the present disclosure, there is provided an electrochemical cell comprising: (a) an anode; (b) a cathode comprising the electrode obtained by the process as disclosed herein; and (c) an electrolyte.

**[0011]** These and other features, aspects, and advantages of the present subject matter will be better understood with reference to the following description and appended claims. This summary is provided to introduce a selection of concepts in a simplified form. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

## BRIEF DESCRIPTION OF THE FIGURES

**[0012]** The following drawings form a part of the present specification and are included to further illustrate aspects of the present disclosure. The disclosure may be better understood by reference to the drawings in combination with the detailed description of the specific embodiments presented herein.

**[0013]** Figure 1 depicts the field emission scanning electron microscopy (FESEM) images of the (a) electrode EA prepared by the process 1; and (b) electrode CE-5 prepared by the comparative process 2, in accordance with an embodiment of the present disclosure.

**[0014]** Figure 2 depicts the graphical representation of plane resistivity exhibited by different electrodes, in accordance with an embodiment of the present disclosure.

## DETAILED DESCRIPTION OF THE INVENTION

**[0015]** Those skilled in the art will be aware that the present disclosure is subject to variations and modifications other than those specifically described. It is to be understood that the present disclosure includes all such variations and modifications. The disclosure also includes all such steps, features, compositions, and compounds referred to or indicated in this specification, individually or collectively, and any and all combinations of any or more of such steps or features.

*Definitions*

**[0016]** For convenience, before further description of the present disclosure, certain terms employed in the specification, and examples are delineated here. These definitions should be read in the light of the remainder of the disclosure and understood as by a person of skill in the art. The terms used herein have the meanings recognized and known to those of skill in the art, however, for convenience and completeness, particular terms and their meanings are set forth below.

**[0017]** The articles "a", "an" and "the" are used to refer to one or to more than one (i.e., to at least one) of the grammatical object of the article.

**[0018]** The terms "comprise" and "comprising" are used in the inclusive, open sense, meaning that additional elements may be included. It is not intended to be construed as "consists of only".

**[0019]** Throughout this specification, unless the context requires otherwise the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated element or step or group of element or steps but not the exclusion of any other element or step or group of element or steps.

**[0020]** The term "including" is used to mean "including but not limited to". "Including" and "including but not limited to" are used interchangeably.

**[0021]** The term “w/w” means the percentage by weight, relative to the weight of the total composition, unless otherwise specified. The term "at least one" is used to mean one or more and thus includes individual components as well as mixtures/combinations.

**[0022]** The term “active material” refers to the active constituent of an electrode, which comprises the particles that undergo oxidation or reduction, resulting in reversible ion storage. In an aspect of the present disclosure, the active material is selected from lithium nickel manganese oxide (NMC), lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium iron phosphate (LFP), lithium yttrium iron phosphate (LYP), lithium nickel manganese cobalt oxide, lithium nickel cobalt aluminium oxide (NCA), lithium manganese phosphate ($LiMnPO_4$), lithium cobalt phosphate ($LiCoPO_4$), lithium vanadium phosphate (LVP), spinel type alkali metal transition metal oxides, alkali-transition metal oxides ($AMO_2$) oxides, or combinations thereof. The active material of the present disclosure is a cathode active material.

**[0023]** The term “electrolyte” refers to a medium containing ions that are electrically conductive through the movement of those ions, but not conducting electrons. In an aspect of the present disclosure, the electrolyte includes a lithium salt selected from $LiPF_6$, LiFSi, or LiTFSi; and a solvent selected from diethylene carbonate, dimethyl carbonate, ethyl methyl carbonate, or combinations thereof.

**[0024]** The term “conductive carbon” refers to a carbon-based material added to an electrode composition which can form electronically conductive networks to enhance the conductivity of the electrode. In an aspect of the present disclosure, the conductive carbon comprises a primary conductive carbon and a secondary conductive carbon.

**[0025]** The term “primary conductive carbon” refers to a nano-sized tubular carbon-based material which enhances the conductivity and provides mechanical integrity to the electrode. In an aspect of the present disclosure, the primary conductive carbon is selected from single walled carbon nanotube (SWCNT),

multiwalled carbon nanotube (MWCNT), carbon nanofiber, vapour grown carbon nanofiber, or combinations thereof.

**[0026]** The term "secondary conductive carbon" refers to a carbon-based material which enhances the conductivity of the electrode. In an aspect of the present disclosure, the secondary conductive carbon is selected from graphite, graphene, carbon black, acetylene black, or combinations thereof.

**[0027]** The term "electrochemical cell" refers to a device that generates electrical energy from chemical reactions. In the present disclosure, electrochemical cell is comprised of (a) an anode; (b) a cathode and (c) an electrolyte.

**[0028]** The term "current collector" refers to the electric bridging component which collects electrical current generated at the electrodes of electrochemical devices and connects with external circuits. In an aspect of the present disclosure, the current collector includes but not limited to aluminium foil, carbon coated aluminium foil, primer coated aluminium foil, or glossy aluminium foil.

**[0029]** The term "binder solution" refers to a mixture comprising a binder with solvent. The term "binder" refers to a polymeric material that helps to maintain the integrity of the electrode coating, to bind the active material particles and conducting carbon particles together and to ensure that the active material particles adhere well to the current collector. In an aspect of the present disclosure, binder is selected from polyvinylidene fluoride (PVDF), polypropylene carbonate (PPC), poly(vinylidene fluoride-hexafluoropropylene) (PVDF-HFP), polyfluoroxy alkanes (PFA), polyvinyl fluoride (PVF), polyethylene (PE), polyethylene vinyl acetate (PEVA), polyethylene glycol (PEG), polyurethane (PU), polypropylene rubber (PPR), ethylene propylene rubber (EPR), polyisobutylene (PIB), polyvinyl alcohol (PVA), phenoxy resin, polyethylene terephthalate (PET), nylon, polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), polyphenylene sulphide (PPS), poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS), polystyrene (PS), or combinations thereof; and the solvent is selected from N-methyl pyrrolidone, dimethyl formamide, dimethyl sulfoxide, ethylene carbonate, ethylene glycol, glycerol, or combinations thereof.

**[0030]** The term “calendering” refers to the process of compressing or pressing to coat an active material-containing layer upon a substrate/current collector by passing through a set of heated rollers so as to achieve properties such as reducing thickness, reducing the porosity and the like. A material comprising a layer having at least one polymer and at least one active material coated on a substrate (current collector) is calendered to improve adhesion of the layer on to the substrate surface and achieve desired thickness of the material. The process is carried out for incorporating desired properties to the material. In an aspect the present disclosure, the term calendering refers to the process by which the electrode slurry coated on a current collector is pressed to form an electrode having uniform thickness and porosity.

**[0031]** The term “through plane resistance” refers to a measure of the opposition to the flow of current within a material, measured through the thickness of the material. In an aspect of the present disclosure, there is provided an electrode having a through plane resistance in a range of 0.2 to 0.5 Ohms.

**[0032]** Ratios, concentrations, amounts, and other numerical data may be presented herein in a range format. It is to be understood that such range format is used merely for convenience and brevity and should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. For example, blending carried out for a period in a range of 5 to 20 minutes should be interpreted to include not only the explicitly recited limits of 5 to 20 minutes but also to include sub-ranges, such as 8 to 18 minutes, 10 to 15 minutes and so forth, as well as individual amounts, including fractional amounts, within the specified ranges, such as 7.5 minutes, 10.5 minutes, 15 minutes, and 16.5 minutes.

**[0033]** Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the

disclosure, the preferred methods and materials are now described. All publications mentioned herein are incorporated herein by reference.

**[0034]** The present disclosure is not to be limited in scope by the specific embodiments described herein, which are intended for the purposes of exemplification only. Functionally equivalent products, compositions, formulations, and methods are clearly within the scope of the disclosure, as described herein.

**[0035]** As discussed in the background, many challenges exist in developing an efficient battery electrode. The existing processes for the development of electrodes result in agglomeration of conductive additives, leading to dendritic growth or short-circuiting while prolonged cycling. All of these resulted in increasing internal resistance or in other words lowering of electrochemical performance. In view of the existing shortcomings in electrode preparation processes, the present disclosure provides a process for preparing electrodes by varying the battery electrode manufacturing process by utilizing conductive carbon having specific morphology to avoid agglomeration. Two different kinds of conductive carbons, namely nano-sized tubular carbon (primary conductive carbon; like carbon nanotube (CNT), carbon nanofiber (CNF) etc.,) and particle-type (secondary conductive carbon like carbon black (e.g., super P,), graphite etc.,) which were feasible in terms of the particle size and morphology, provides an optimum carbon coverage over the cathode active material surface and also facilitated in the electronic networking.

**[0036]** Among the nano-sized tubular carbons, there are single-walled and multi-walled carbon nanotubes which have been used as conductive carbons in electrodes. Owing to the desired tubular morphology with aspect ratio in a range of 50 to 4000, the present disclosure provides a process for preparing an electrode, wherein the MWCNT is employed as the primary conductive carbon to facilitate electronic networking between the active material particles. Along with a tubular conductive carbon, the process of the present disclosure employes a particle-type carbon such as super P as a secondary conductive carbon for the cathode active material. The MWCNT having a comparable particle size with super P, which helped in achieving

a homogeneous mixture with a cathode active material and a binder. However, when the electrode mixture was prepared using higher amounts of conductive carbons there were challenges of carbon agglomerations, when not mixed properly. Therefore, the present disclosure provides a process wherein stepwise sequential mixing was adopted to reduce the carbon agglomeration which will confer the homogeneous electrical conductivity in the electrodes throughout its length and thereby prevent the development of internal resistance.

**[0037]** Accordingly, the present disclosure provides a process for preparing an electrode, the process comprising: (a) mixing a primary conductive carbon with a binder solution to obtain a pre-mixture; (b) blending a first part of an active material with the pre-mixture to obtain a blend; (c) adding a first part of a secondary conductive carbon to the blend and stirring to obtain a first mixture; (d) adding a second part of the active material with the first mixture to obtain a second mixture; (e) mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and (f) processing of the electrode slurry to obtain the electrode, wherein the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5, wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1 to 2%, with respect to the total weight of the electrode.

**[0038]** In an embodiment of the present disclosure, there is provided a process for preparing an electrode, the process comprising: (a) mixing a primary conductive carbon with a binder solution to obtain a pre-mixture; (b) blending a first part of an active material with the pre-mixture to obtain a blend; (c) adding a first part of a secondary conductive carbon to the blend and stirring to obtain a first mixture; (d) adding a second part of the active material with the first mixture to obtain a second mixture; (e) mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and (f) processing of the electrode slurry to obtain the electrode, wherein the primary conductive carbon and the secondary conductive carbon are in a weight ratio range

of 1:0.75 to 1:1.5, and wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1 to 2%, with respect to the total weight of the electrode. In another embodiment of the present disclosure, the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.8 to 1:1.35, and wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1.2 to 1.8%, with respect to the total weight of the electrode. In yet another embodiment of the present disclosure, the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.9 to 1:1.1, and wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1.4 to 1.6%, with respect to the total weight of the electrode. In still another embodiment of the present disclosure, the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.95 to 1:1.05, and wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1.45 to 1.55%, with respect to the total weight of the electrode.

**[0039]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein the primary conductive carbon is in a weight range of 0.5 to 1%, with respect to the total weight of the electrode; and the primary conductive carbon is selected from single walled carbon nanotube (SWCNT), multiwalled carbon nanotube (MWCNT), carbon nanofiber, vapour grown carbon nanofiber or combinations thereof. In another embodiment of the present disclosure, the primary conductive carbon is in a weight range of 0.6 to 0.9%, with respect to the total weight of the electrode; and the primary conductive carbon is selected from single walled carbon nanotube (SWCNT), multiwalled carbon nanotube (MWCNT), or combinations thereof. In yet another embodiment of the present disclosure, the primary conductive carbon is in a weight range of 0.7 to 0.8%, with respect to the total weight of the electrode; and the primary conductive carbon is multiwalled carbon nanotube (MWCNT).

**[0040]** In an embodiment of the present disclosure, there is provided a process for preparing an electrode, the process comprising: (a) mixing 0.5 to 1% by weight of a primary conductive carbon with a binder solution to obtain a pre-mixture; (b) blending a first part of an active material with the pre-mixture to obtain a blend; (c) adding a first part of a secondary conductive carbon to the blend and stirring to obtain a first mixture; (d) adding a second part of the active material with the first mixture to obtain a second mixture; (e) mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and (f) processing of the electrode slurry to obtain the electrode, wherein the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5, and wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1 to 2%, with respect to the total weight of the electrode.

**[0041]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein the first part of the secondary conductive carbon and the second part of the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5. In another embodiment of the present disclosure, the first part of the secondary conductive carbon and the second part of the secondary conductive carbon are in a weight ratio range of 1:0.8 to 1:1.3. In yet another embodiment of the present disclosure, the first part of the secondary conductive carbon and the second part of the secondary conductive carbon are in a weight ratio range of 1:0.9 to 1:1.1.

**[0042]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein the first and the second part of the secondary conductive carbon combinedly is in a weight range of 0.5 to 1%, with respect to the total weight of the electrode; and the secondary conductive carbon is selected from graphite, graphene, carbon black (ketjen black 600JD, Super P C45, Super P C65, Super P C65T, ketjen black 300, or Vulcan carbon), acetylene black, or combinations thereof. In another embodiment of the present disclosure, the first and the second part of the secondary conductive carbon combinedly is in a weight range of 0.6 to

0.9%, with respect to the total weight of the electrode; and the secondary conductive carbon is selected from carbon black (Super P C45, Super P C65, Super P C65T, or Vulcan carbon), acetylene black, or combinations thereof. In yet another embodiment of the present disclosure, the first and the second part of the secondary conductive carbon combinedly is in a weight range of 0.7 to 0.8%, with respect to the total weight of the electrode; and the secondary conductive carbon is carbon black (Super P C45, Super P C65, or Super P C65T).

**[0043]** In an embodiment of the present disclosure, there is provided a process for preparing an electrode, the process comprising: (a) mixing 0.5 to 1% by weight of a primary conductive carbon with a binder solution to obtain a pre-mixture; (b) blending a first part of an active material with the pre-mixture to obtain a blend; (c) adding a first part of a secondary conductive carbon to the blend and stirring to obtain a first mixture; (d) adding a second part of the active material with the first mixture to obtain a second mixture; (e) mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and (f) processing of the electrode slurry to obtain the electrode, wherein the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5; wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1 to 2%, with respect to the total weight of the electrode; wherein the first and the second part of the secondary conductive carbon combinedly is in a weight range of 0.5 to 1%, with respect to the total weight of the electrode; and the second secondary conductive carbon is selected from graphite, graphene, carbon black, acetylene black, or combinations thereof.

**[0044]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein the binder solution is a mixture of a binder with a solvent.

**[0045]** In an embodiment of the present disclosure, there is provided a process for preparing an electrode, the process comprising: (a) mixing a binder with a solvent to obtain a binder solution; (b) mixing a primary conductive carbon with the binder solution to obtain a pre-mixture; (c) blending a first part of an active material with

the pre-mixture to obtain a blend; (d) adding a first part of a secondary conductive carbon to the blend and stirring to obtain a first mixture; (e) adding a second part of the active material with the first mixture to obtain a second mixture; (f) mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and (g) processing of the electrode slurry to obtain the electrode, wherein the secondary conductive carbon is carbon black. In another embodiment of the present disclosure, the carbon black is ketjen black 600JD, Super P C45, Super P C65, Super P C65T, ketjen black 300, or Vulcan carbon. In yet another embodiment of the present disclosure, the carbon black is Super P C45, Super P C65, or Super P C65T.

**[0046]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein the binder is in a weight range of 1 to 2%, with respect to total weight of the electrode; the binder is selected from polyvinylidene fluoride (PVDF), polypropylene carbonate (PPC), poly(vinylidene fluoride-hexafluoropropylene) (PVDF-HFP), polyfluoroxy alkanes (PFA), polyvinyl fluoride (PVF), polyethylene (PE), polyethylene vinyl acetate (PEVA), polyethylene glycol (PEG), polyurethane (PU), polypropylene rubber (PPR), ethylene propylene rubber (EPR), polyisobutylene (PIB), polyvinyl alcohol (PVA), phenoxy resin, polyethylene terephthalate (PET), nylon, polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), polyphenylene sulphide (PPS), poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS), polystyrene (PS), or combinations thereof; and the solvent is selected from N-methyl pyrrolidone, dimethyl formamide, dimethyl sulfoxide, ethylene carbonate, ethylene glycol, glycerol, or combinations thereof. In another embodiment of the present disclosure, the binder is in a weight range of 1.2 to 1.8%, with respect to total weight of the electrode; the binder is selected from polyvinylidene fluoride (PVDF), polypropylene carbonate (PPC), poly(vinylidene fluoride-hexafluoropropylene) (PVDF-HFP), polyfluoroxy alkanes (PFA), polyvinyl fluoride (PVF), polyethylene (PE), polyethylene vinyl acetate (PEVA), or combinations thereof; and the solvent is selected from N-methyl pyrrolidone, dimethyl formamide, dimethyl sulfoxide, or combinations thereof. In yet an embodiment of the present disclosure, the binder is

in a weight range of 1.4 to 1.6%, with respect to total weight of the electrode; the binder is polyvinylidene fluoride (PVDF), or poly(vinylidene fluoride-hexafluoropropylene) (PVDF-HFP); and the solvent is N-methyl pyrrolidone.

**[0047]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein the solvent is in a weight range of 20 to 25%, with respect to total weight of the electrode slurry. In another embodiment of the present disclosure, the solvent is in a weight range of 21 to 24.5%, with respect to total weight of the electrode slurry. In another embodiment of the present disclosure, the solvent is in a weight range of 23 to 24%, with respect to total weight of the electrode slurry.

**[0048]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein the binder solution is a mixture of 1 to 2% by weight of a binder (with respect to total weight of the electrode) selected from polyvinylidene fluoride (PVDF), polypropylene carbonate (PPC), poly(vinylidene fluoride-hexafluoropropylene) (PVDF-HFP), polyfluoroxy alkanes (PFA), polyvinyl fluoride (PVF), polyethylene (PE), polyethylene vinyl acetate (PEVA), polyethylene glycol (PEG), polyurethane (PU), polypropylene rubber (PPR), ethylene propylene rubber (EPR), polyisobutylene (PIB), polyvinyl alcohol (PVA), phenoxy resin, polyethylene terephthalate (PET), nylon, polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), polyphenylene sulphide (PPS), poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS), polystyrene (PS), or combinations thereof, with 20 to 25% by weight of a solvent (with respect to total weight of the electrode slurry) selected from N-methyl pyrrolidone, dimethyl formamide, dimethyl sulfoxide, ethylene carbonate, ethylene glycol, glycerol, or combinations thereof.

**[0049]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein the first part of the active material and the second part of the active material are in a weight ratio range of 1: 0.75 to 1: 1.5. In another embodiment of the present disclosure, the first part of the active material and the second part of the active material are in a weight ratio range of 1: 0.8 to 1: 1.2. In

yet another embodiment of the present disclosure, the first part of the active material and the second part of the active material are in a weight ratio range of 1: 0.9 to 1: 1.1.

**[0050]** In an embodiment of the present disclosure, there is provided a process for preparing an electrode, the process comprising: (a) mixing a primary conductive carbon with a binder solution to obtain a pre-mixture; (b) blending a first part of an active material with the pre-mixture to obtain a blend; (c) adding a first part of a secondary conductive carbon to the blend and stirring to obtain a first mixture; (d) adding a second part of the active material with the first mixture to obtain a second mixture; (e) mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and (f) processing of the electrode slurry to obtain the electrode, wherein the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5; wherein the combined weight of the primary conductive carbon and the secondary conductive carbon are in a range of 1 to 2%, with respect to the total weight of the electrode; and wherein the first part of the active material and the second part of the active material are in a weight ratio range of 1: 0.75 to 1: 1.5.

**[0051]** In an embodiment of the present disclosure, there is provided a process for preparing an electrode, the process comprising: (a) mixing a primary conductive carbon with a binder solution to obtain a pre-mixture; (b) blending a first part of an active material with the pre-mixture to obtain a blend; (c) adding a first part of a secondary conductive carbon to the blend and stirring to obtain a first mixture; (d) adding a second part of the active material with the first mixture to obtain a second mixture; (e) mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and (f) processing of the electrode slurry to obtain the electrode, wherein the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5, wherein the combined weight of the primary conductive carbon and the secondary conductive carbon are in a range of 1 to 2%, with respect to the total weight of the electrode, wherein first and the second part of the active material

combinedly is in a weight range of 96 to 98% with respect to total weight of the electrode; and the active material is selected from lithium nickel manganese oxide (NMC), lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium iron phosphate (LFP), lithium yttrium iron phosphate (LYP), lithium nickel manganese cobalt oxide, lithium nickel cobalt aluminium oxide (NCA), lithium manganese phosphate ($LiMnPO_4$), lithium cobalt phosphate ($LiCoPO_4$), lithium vanadium phosphate (LVP), spinel type alkali metal transition metal oxides, alkali-transition metal oxides ($AMO_2$; A is alkali metal and M is transition metal) oxides, or combinations thereof. In another embodiment of the present disclosure, first and the second part of the active material combinedly is in a weight range of 96.5 to 97.5% with respect to total weight of the electrode; and the active material is selected from lithium nickel manganese cobalt oxide, spinel lithium nickel manganese oxide, or lithium iron phosphate. In yet another embodiment of the present disclosure, first and the second part of the active material combinedly is in a weight range of 96.8 to 97.2% with respect to total weight of the electrode; and the active material is lithium nickel manganese cobalt oxide.

**[0052]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein mixing in step (a) is carried out at a speed in a range of 200 to 800rpm for a time period ranging from 10 to 20 minutes. In another embodiment of the present disclosure, mixing in step (a) is carried out at a speed in a range of 300 to 700rpm for a time period ranging from 12 to 18 minutes. In yet another embodiment of the present disclosure, mixing in step (a) is carried out at a speed in a range of 400 to 600rpm for a time period ranging from 14 to 16 minutes.

**[0053]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein blending in step (b) is carried out by stirring at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes. In another embodiment of the present disclosure, blending in step (b) is carried out by stirring at a speed in a range of 900 to 1100 rpm, for a period in a range of 7 to 17 minutes. In yet another embodiment of the present disclosure, blending in step (b) is carried

out by stirring at a speed in a range of 950 to 1050 rpm, for a period in a range of 9 to 12 minutes.

**[0054]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein stirring in step (c) is carried out at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes. In another embodiment of the present disclosure, stirring in step (c) is carried out at a speed in a range of 900 to 1100 rpm, for a period in a range of 7 to 17 minutes. In yet another embodiment of the present disclosure, stirring in step (c) is carried out at a speed in a range of 950 to 1050 rpm, for a period in a range of 9 to 12 minutes.

**[0055]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein step (d) comprises agitation at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes. In another embodiment of the present disclosure, step (d) comprises agitation at a speed in a range of 900 to 1100 rpm, for a period in a range of 7 to 17 minutes. In yet another embodiment of the present disclosure, step (d) comprises agitation at a speed in a range of 950 to 1050 rpm, for a period in a range of 8 to 12 minutes.

**[0056]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein mixing in step (e) is carried out at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes. In another embodiment of the present disclosure, mixing in step (e) is carried out at a speed in a range of 900 to 1100 rpm, for a period in a range of 7 to 17 minutes. In yet another embodiment of the present disclosure, mixing in step (e) is carried out at a speed in a range of 950 to 1050 rpm, for a period in a range of 9 to 12 minutes

**[0057]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein the high-speed mixing in step (e) is carried out at a speed in a range of 1600 to 2500 rpm for a period in a range of 130 to 200 minutes. In another embodiment of the present disclosure, high-speed mixing in step (e) is carried out at a speed in a range of 1700 to 2400 rpm, for a period in a range of 140 to 190 minutes. In yet another embodiment of the present disclosure, high-speed

mixing in step (e) is carried out at a speed in a range of 1800 to 2000 rpm, for a period in a range of 170 to 190 minutes. In still another embodiment of the present disclosure, high-speed mixing in step (e) is carried out in two steps: first high-speed mixing at a speed in a range of 1700 to 1900 rpm, for a period in a range of 50 to 80 minutes, followed by second high-speed mixing at a speed in a range of 1900 to 2100 rpm, for a period in a range of 100 to 130 minutes.

**[0058]** In an embodiment of the present disclosure, there is provided a process for preparing an electrode, the process comprising: (a) mixing a primary conductive carbon with a binder solution at a speed in a range of 200 to 800rpm for a time period ranging from 10 to 20 mins to obtain a pre-mixture; (b) blending a first part of an active material with the pre-mixture at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes to obtain a blend; (c) adding a first part of a secondary conductive carbon to the blend and stirring at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes to obtain a first mixture; (d) adding a second part of the active material with the first mixture at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes to obtain a second mixture; (e) mixing a second part of the secondary conductive carbon with the second mixture at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes, followed by high-speed mixing at a speed in a range of 1600 to 2500 rpm for a period in a range of 130 to 200 minutes to obtain an electrode slurry; and (f) processing of the electrode slurry to obtain the electrode, wherein the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5; and wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1 to 2%, with respect to the total weight of the electrode.

**[0059]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein processing comprises coating the electrode slurry on a substrate, drying, calendering, or combinations thereof.

**[0060]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein the substrate is a current collector selected from

aluminium foil, carbon coated aluminium foil, primer coated aluminium foils, or glossy aluminium foil. In another embodiment of the present disclosure, the current collector is aluminium foil.

**[0061]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein processing comprises coating the electrode slurry on a current collector selected from aluminium foil, carbon coated copper aluminium foil, primer coated aluminium foil, or glossy aluminium foil, drying, calendering, or combinations thereof.

**[0062]** In an embodiment of the present disclosure, there is provided a process for preparing an electrode, the process comprising: (a) mixing a primary conductive carbon with a binder solution to obtain a pre-mixture; (b) blending a first part of an active material with the pre-mixture to obtain a blend; (c) adding a first part of a secondary conductive carbon to the blend and stirring to obtain a first mixture; (d) adding a second part of the active material with the first mixture to obtain a second mixture; (e) mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and (f) processing of the electrode slurry to obtain the electrode, wherein the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5; wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1 to 2%, with respect to the total weight of the electrode; and wherein processing comprises coating the electrode slurry on a substrate which is a current collector selected from aluminium foil, carbon coated aluminium foil, primer coated aluminium foil, or glossy aluminium foil, followed by drying, and calendering.

**[0063]** In an embodiment of the present disclosure, there is provided a process as disclosed herein, wherein processing comprises: (a) coating the electrode slurry on a substrate to obtain a coated substrate, (b) drying the coated substrate by passing through a chamber maintained at 90 to 140°C and at a speed in a range of 1 to 5 m/min to obtain a dried substrate, and (c) calendering the dried substrate by passing through a set of rollers wherein roller temperature is in a range of 50 to 70 °C, roller

speed is in a range of 60 to 80 m/min and the load applied on the dried substrate is in a range of 380 to 430kN to obtain the electrode.

**[0064]** In an embodiment of the present disclosure, there is provided a an electrode obtained by the process as disclosed herein, wherein the electrode comprises: (a) an active material; (b) a binder; (c) a primary conductive carbon; and (d) a secondary conductive carbon, wherein the primary conductive carbon and the secondary conductive carbon are present in a weight ratio range of 1: 0.75 to 1: 1.5.

**[0065]** In an embodiment of the present disclosure, there is provided an electrode as disclosed herein, wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1 to 2%, with respect to the total weight of the electrode. In another embodiment of the present disclosure, the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1.2 to 1.8%, with respect to the total weight of the electrode. In yet another embodiment of the present disclosure, the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1.4 to 1.6%, with respect to the total weight of the electrode.

**[0066]** In an embodiment of the present disclosure, there is provided an electrode as disclosed herein, wherein the electrode is a cathode.

**[0067]** In an embodiment of the present disclosure, there is provided an electrode as disclosed herein, wherein the electrode is a cathode, and the cathode has a through plane resistance in a range of 0.2 to 0.5 Ohms. In another embodiment of the present disclosure, the cathode has a through plane resistance in a range of 0.3 to 0.5 Ohms. In yet another embodiment of the present disclosure, the cathode has a through plane resistance in a range of 0.35 to 0.45 Ohms.

**[0068]** In an embodiment of the present disclosure, there is provided an electrochemical cell comprising: (a) an anode; (b) a cathode comprising the electrode obtained by the process as disclosed herein; and (c) an electrolyte.

**[0069]** In an embodiment of the present disclosure, there is provided an electrochemical cell comprising: (a) an anode selected from synthetic graphite,

natural graphite, or silicon-graphite composite; (b) a cathode comprising the electrode obtained by the process as disclosed herein; and (c) an electrolyte.

**[0070]** In an embodiment of the present disclosure, there is provided an electrochemical cell comprising: (a) an anode; (b) a cathode comprising the electrode obtained by the process as disclosed herein; and (c) an electrolyte comprising a lithium salt selected from $LiPF_6$, LiFSi, or LiTFSi, and a solvent selected from diethylene carbonate, dimethyl carbonate, ethyl methyl carbonate, vinyl carbonate, or combinations thereof.

**[0071]** In an embodiment of the present disclosure, there is provided an electrochemical cell comprising: (a) an anode selected from synthetic graphite, natural graphite, or silicon-graphite composite; (b) a cathode comprising the electrode obtained by the process as disclosed herein; and (c) an electrolyte comprising a lithium salt selected from $LiPF_6$, LiFSi, or LiTFSi, and a solvent selected from diethylene carbonate, dimethyl carbonate, ethyl methyl carbonate, vinyl carbonate, or combinations thereof

**[0072]** In an embodiment of the present disclosure, there is provided a use of the electrode obtained by the process disclosed herein as a cathode in an electrochemical cell.

**[0073]** Although the subject matter has been described in considerable detail with reference to certain examples and implementations thereof, other implementations are possible.

**EXAMPLES**

**[0074]** The disclosure will now be illustrated with following examples, which is intended to illustrate the working of disclosure and not intended to take restrictively to imply any limitations on the scope of the present disclosure. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which this disclosure belongs. Although methods and materials similar to or equivalent to those described

herein can be used in the practice of the disclosed methods and compositions, the exemplary methods, devices, and materials are described herein. It is to be understood that this disclosure is not limited to particular methods, and experimental conditions described, as such methods and conditions may apply.

**Materials and Methods**

**[0075]** The various chemicals and solvents used in the present disclosure are as follows:

a. Active Material:

Cathode material- lithium nickel manganese cobalt (NMC811)

b. Conductive carbon-

Multi-walled carbon nanotube (MWCNT; primary conductive carbon) having a particle size of 7-100 nm and an aspect ratio of 50 to 4000; and

Super P65T (carbon black; secondary conductive carbon),

c. Binder- Polyvinylidene fluoride (PVDF)

d. Solvent- N-methyl pyrrolidone (NMP).

For full cell preparation:

Anode active material synthetic graphite (96) was procured from Zichen, binder carboxymethyl cellulose (CMC), binder styrene butadiene rubber (SBR), Super-P, and polypropylene (PP) separator was procured from SEMCORP.

**EXAMPLE 1**

**Preparation of the Electrode of the present disclosure**

**[0076]** The present example explains the process 1 for preparing the electrode.

**[0077]** A binder solution was prepared by mixing 100mL of N-methyl pyrrolidone (solvent) and 1.5 wt% of polyvinylidene fluoride (binder) at a stirring speed of 1300 rpm for 12 hours at room temperature. 0.75 wt% of MWCNT (primary conductive carbon) was added to the binder solution and was mixed at a speed of 500 rpm for

15 minutes to obtain a pre-mixture (step a). To the pre-mixture, 48.5 wt% (first part) of NMC811 (active material) was added and blended at a speed of 1000 rpm for 10 minutes to obtain a blend (step b). Followed by this, 0.375 wt% (first part) of Super P (carbon black; secondary conductive carbon) was added to the blend and stirred at a speed of 1000 rpm for 10 minutes to obtain a first mixture (step c). The remaining 48.5 wt% (second part) of the NMC811 was added to the first mixture and agitated at a speed of 1000 rpm for 10 minutes to obtain a second mixture (step d). Subsequently, the remaining 0.375 wt% (second part) of Super P was added to the second mixture and mixed for another 10 minutes at 1000 rpm, followed by a high-speed mixing which was carried out in two steps: in first high-speed mixing, the mixing was carried out at a speed of 2000 rpm for 60 minutes, and in second high-speed mixing, the mixing was carried at 1800 rpm for 120 minutes to obtain an electrode slurry (ES) which was then subjected to degassing.

**[0078]** The electrode slurry (ES) was coated upon aluminium foil (a current collector) and dried by passing it through a chamber maintained at 90 to 140℃ and at a speed in a range of 1 to 5 m/min. Further, the dried electrode slurry coated substrate was calendered by passing it through a set of rollers wherein roller temperature was in a range of 50 to 70 ℃, roller speed was in a range of 60 to 80 m/min and the load applied was in a range of 380 to 430kN to obtain the electrode (EA).

**EXAMPLE 2:**

**Preparation of the comparative electrode CE-1**

**[0079]** The present example provides a comparative process 2 for preparing comparative electrode CE-1. The comparative electrode CE-1 was prepared by obtaining the electrode slurry via following the process as explained in Example 1, except the combined weight% of primary and secondary conductive carbons was 0.7%, and the secondary conductive carbon was added as a whole instead of adding in two parts (first part and second part). Further, the electrode slurry was coated upon an aluminium foil (current collector) to obtain the comparative electrode CE-1. The detailed process for preparation of CE-1 is provided below.

**[0080]** A binder solution was prepared by taking N-methyl pyrrolidone (solvent) and 1.5 wt% of Polyvinylidene fluoride (binder) and mixed at a speed of 1300 rpm for 12 hours at room temperature. 0.5 wt% of MWCNT (primary conductive carbon) was added to the binder solution and was mixed at a speed of 1500 rpm for 15 minutes to obtain a mixture-1. Further, 48.5 wt% of the NMC811 (active material) was added to the mixture-1 and was blended at a speed of 2000 rpm for 30 minutes to obtain mixture-2. Followed by this, the remaining 48.5 wt% of the NMC811 was added to the mixture-2 and was mixed at a speed of 2000 rpm for 60 minutes to obtain mixture-3. Subsequently, 0.2 wt% Super P (secondary conductive carbon) was mixed with the mixture-3, at a speed of 1500 rpm for 40 minutes to obtain a mixture-4. Finally, the mixture-4 was mixed for 120 minutes at 1800 rpm to obtain a mixture-5, followed by degassing to obtain the electrode slurry CS-1.

**[0081]** The slurry CS-1 obtained by the comparative process 2, was then coated upon a current collector aluminium foil (substrate) and dried by passing through a chamber maintained at 90 to 140℃ and at a speed in a range of 1 to 5 m/min. Further, the dried substrate was calendered by passing through a set of rollers wherein roller temperature was in a range of 50 to 70 ℃, roller speed was in a range of 60 to 80 m/min and the load applied was in a range of 380 to 430kN to obtain the electrode CE-1.

**[0082]** Similarly, various comparative electrodes employing binder and conductive carbons (primary and secondary) in different weight percentages using the comparative process 2 as provided above were prepared. The composition of various comparative electrodes is provided in the Table 1.

**Table 1**

| Sample Code | NMC (weight %) | PVDF (weight %) | MWCNT (weight %) | Super P (weight %) |
|---|---|---|---|---|
| CE-1 | 97.8 | 1.5 | 0.5 | 0.2 |
| CE-2 | 97.0 | 1.5 | 0.5 | 1.0 |
| CE-3 | 97.0 | 1.5 | 0.75 (SWCNT) | 0.75 |
| CE-4 | 97.0 | 1.5 | 0.75 | 0.75 |

| | | | | |
|---|---|---|---|---|
| CE-5 | 97.3 | 1.2 | 0.75 | 0.75 |

**[0083]** In electrode CE-3, single walled carbon nanotube (SWCNT) of aspect ratio more than 10000 and length of 0.5 to 2.5nm was used instead of MWCNT. Meanwhile, the MWCNT used in other electrodes CE-1, CE, 2, CE-4, and CE-5 had an aspect ratio of 50 to 4000 and length of 7 to 100nm.

**EXAMPLE 3**

**Characterisation of the electrodes**

**[0084]** The present example shows the characterization results of the electrodes EA (prepared by the process 1), along with CE-1, CE-2, CE-3, CE-4 and CE-5 (prepared by the comparative process 2).

**Field emission scanning electron microscopic (FESEM) analysis of the electrodes**

**[0085]** The topographic morphology of the electrodes prepared from the processes disclosed herein was analyzed using FESEM technique. The scanning electron microscopic (SEM) images for the electrode EA prepared by the process 1, and electrode CE-5 prepared by the comparative process 2 are shown in Figure 1(a) and Figure 1(b), respectively.

**[0086]** The FESEM Figure 1(a) of the electrode EA showed that the particles of conductive carbons MWCNT (primary conductive carbon) and Super P (secondary conductive carbon), PVDF, and cathode active material NMC811 were distributed homogeneously. Hence, it was confirmed that the electrode EA obtained by the process 1 of the present disclosure resulted in enhanced distribution of the active material, conductive carbons (primary and secondary), and binders (fibrillating and adhesive) in the electrode.

**[0087]** FESEM image in Figure 1 (b) of the electrode CE-5 clearly exhibited carbon agglomerates on the surface. Hence, the electrode EA of the present disclosure was found to exhibit better homogenous distribution of conductive carbons throughout the bulk of the electrode, than the electrode CE-5 prepared using the comparative process 2.

**Through plane resistivity of the electrodes**

**[0088]** The through plane conductivity was analyzed by studying conductivity in the direction perpendicular to the plane of the electrode film with two probe electrode system. The various electrodes (EA, along with comparative electrodes CE-1, CE-2, CE-3, and CE-4) exhibited a through plane conductivity around 0.2 to 3 mS/cm at 25 ℃. Figure 2 depicts the graphical representation of plane resistivity exhibited by different cathode composition with various conducting additives.

**[0089]** Among all the electrodes analyzed, 1.5 wt% of conductive carbon content with primary and secondary carbon in a weight ratio of 0.75: 0.75 (or 1:1) showed the lowest resistance (0.44 Ohms) when the process 1 of the present disclosure was adopted for the electrode preparation. Therefore, the weight ratio of primary and secondary conductive carbons in a range of 1:0.75 to 1:1.5, along with the sequential addition of components in parts were found to be critical to achieve an electrode with better compactness and lesser resistance.

**EXAMPLE 4**

**Preparation of an electrochemical cell**

**[0090]** The electrochemical cell setup was obtained by sequentially assembling the cathode prepared by the process as explained in Example 1, and an anode on either side of an electrolyte.

**[0091]** For the purpose of electrochemical analysis of the cathode as explained in Example 1, a full-cell was prepared using below cell components:

Cathode comprising the electrode EA prepared by the process as explained in Example 1.

Anode comprising a synthetic graphite (96 wt%) from Zichen, CMC (1.5 wt%) binder, SBR (1.8 wt%) binder, and Super-P (0.7 wt%) conducting additive in aqueous medium coated on an anodic current collector.

Separator: polypropylene (PP) film.

Electrolyte comprising $LiPF_6$ dispersed in a solvent mixture of ethylene carbonate (EC), vinylene carbonate (VC) and dimethyl carbonate (DMC)

**[0092]** An electrochemical cell was prepared by assembling the cathode comprising the electrode EA as explained in example 1, the above-mentioned anode disposed

to face the cathode, the above-mentioned electrolyte injected between the cathode and anode, and the above-mentioned separator placed between cathode and anode. The electrochemical cell obtained from the process explained above was analysed for its electrochemical performance, C-rate performance, and charge-discharge capacity.

**Electrochemical analysis of the electrodes**

**[0093]** The electrodes prepared using the process 1 and comparative process 2, were subjected to electrochemical analysis in the form of a full-cell prepared by the process as explained above. Various samples cells were prepared using the electrode EA. The DCIR of these cells comprising the electrode EA as cathode, was analyzed after the cell was subjected to formation cycle, before performing rate test and after carrying out rate test, as provided in Table 2. The DCIR is an internal resistance gradually developed in an electrode as a result of flow of current that in turn leads to conductive carbon agglomeration.

**[0094]** Formation cycle is a protocol by which the cell or battery is subjected to sequential charging-discharging steps to facilitate the formation of SEI layer in the battery so as to result in ready usage of the battery with high electrochemical performance and better capacity. The charge-discharge cycles of the nominal capacity measurements were carried out at a rate of 0.5C charge/ 1C discharge for different samples of the cells comprising the electrode EA.

**[0095]** Rate test is the analysis technique where the cells were assessed for the electrochemical charge-discharge cycles, with c-rates of 0.1C/0.1C, 0.2C/0.2C, 0.5C/0.5C, 0.5C/1C, 0.5C/2C and 0.5C/3C. After the rate test, the cells were subjected to DCIR measurement.

**[0096]** The below Table 2 shows the DCIR measurement of various cell samples comprising electrode EA as cathode.

**Table 2**

| **Cell number** | **Formation Cycle** | | | **DCIR** [after subjecting | **DCIR [Total]** [Before rate test; mΩ] | **DCIR** [After rate test mΩ] |
|---|---|---|---|---|---|---|
| | **Charge** | **Discharge** | **ICE%** | | | |

| | **(mAh)** | **(mAh)** | | to formation cycle; mΩ] | | |
|---|---|---|---|---|---|---|
| EA-1 | 25.34 | 23.24 | 91.73 | 5.17 | 5.01 | 5.19 |
| EA-2 | 25.48 | 23.38 | 91.73 | 5.42 | 5.50 | 5.65 |
| EA-3 | 25.46 | 23.25 | 91.32 | 5.33 | 5.79 | 5.79 |
| EA-4 | 25.33 | 23.21 | 91.63 | 4.63 | 4.40 | 4.40 |
| EA-5 | 25.45 | 23.37 | 91.84 | 5.88 | 5.96 | 5.96 |
| EA-6 | 25.32 | 23.22 | 91.72 | 5.08 | 4.73 | 4.79 |

**[0097]** The below Table 3 shows the DCIR measurement of various cell samples comprising electrode CE-1 as the cathode.

**Table 3**

| **Cell number** | **Formation Cycle** | | | **DCIR** [after subjecting to formation cycle; mΩ] | **DCIR [Total]** [Before rate test; mΩ] | **DCIR** [After rate test mΩ] |
|---|---|---|---|---|---|---|
| | **Charge (mAh)** | **Discharge (mAh)** | **ICE%** | | | |
| CE-1-1 | 25.83 | 23.30 | 90.18 | 4.74 | 4.73 | 6.04 |
| CE-1-2 | 25.83 | 23.43 | 90.70 | 4.36 | 4.47 | 5.33 |
| CE-1-3 | 25.87 | 23.44 | 90.60 | 4.49 | 4.54 | 5.10 |
| CE-1-4 | 25.82 | 23.40 | 90.63 | 4.41 | 4.51 | 4.96 |
| CE-1-5 | 26.49 | 22.72 | 85.77 | 5.20 | 6.45 | 9.89 |
| CE-1-6 | 26.59 | 22.87 | 86.02 | 4.66 | 5.90 | 8.07 |

**[0098]** The below Table 4 shows the DCIR measurement of various cell samples comprising electrode CE-2 as the cathode.

**Table 4**

| **Cell number** | **Formation Cycle** | | | **DCIR** [after subjecting to formation cycle; mΩ] | **DCIR [Total]** [Before rate test; mΩ] | **DCIR** [After rate test mΩ] |
|---|---|---|---|---|---|---|
| | **Charge (mAh)** | **Discharge (mAh)** | **ICE%** | | | |
| 1 | 26.54 | 22.87 | 86.17 | 4.99 | 5.27 | 6.72 |
| 2 | 26.45 | 22.73 | 85.91 | 4.95 | 5.22 | 6.87 |
| 3 | 26.49 | 22.68 | 85.64 | 4.80 | 4.81 | 6.18 |
| 4 | 26.52 | 22.69 | 85.54 | 4.69 | 5.22 | 6.10 |
| 5 | 26.53 | 22.62 | 85.26 | 4.98 | 4.90 | 5.47 |
| 6 | 26.66 | 22.80 | 85.50 | 4.58 | 4.63 | 5.03 |

**[0099]** The below Table 5 shows the DCIR measurement of various cell samples comprising electrode CE-3 as the cathode.

**Table 5**

| **Cell number** | **Formation Cycle** | | | **DCIR** [after subjecting to formation cycle; mΩ] | **DCIR [Total]** [Before rate test; mΩ] | **DCIR** [After rate test mΩ] |
|---|---|---|---|---|---|---|
| | **Charge (mAh)** | **Discharge (mAh)** | **ICE%** | | | |
| 1 | 26.52 | 22.63 | 85.35 | 4.79 | 5.32 | 5.93 |
| 2 | 26.45 | 22.65 | 85.63 | 4.49 | 4.41 | 5.07 |
| 3 | 26.58 | 22.72 | 85.49 | 4.77 | 4.76 | 5.31 |
| 4 | 26.68 | 22.82 | 85.54 | 4.98 | 4.86 | 5.54 |
| 5 | 25.91 | 23.58 | 90.99 | 5.65 | 5.78 | 6.56 |
| 6 | 26.57 | 22.67 | 85.31 | 5.19 | 5.63 | 6.10 |

**[0100]** The below Table 6 shows the DCIR measurement of various cell samples comprising electrode CE-4 as the cathode.

**Table 6**

| **Cell number** | **Formation Cycle** | | | **DCIR** [after subjecting to formation cycle; mΩ] | **DCIR [Total]** [Before rate test; mΩ] | **DCIR** [After rate test mΩ] |
|---|---|---|---|---|---|---|
| | **Charge (mAh)** | **Discharge (mAh)** | **ICE%** | | | |
| 1 | 25.69 | 23.34 | 90.85 | 5.07 | 4.76 | 5.61 |
| 2 | 25.86 | 23.51 | 90.92 | 4.80 | 4.63 | 5.40 |
| 3 | 25.62 | 23.32 | 91.01 | 5.39 | 5.27 | 5.97 |
| 4 | 25.98 | 23.68 | 91.16 | 4.38 | 4.20 | 5.29 |
| 5 | 25.89 | 23.56 | 90.98 | 4.55 | 4.39 | 5.21 |
| 6 | 25.97 | 23.72 | 91.34 | 4.06 | 3.88 | 4.94 |

**[0101]** The below Table 7 shows the DCIR measurement of various cell samples comprising electrode CE-5 as the cathode.

**Table 7**

| **Cell number** | **Formation Cycle** | | | **DCIR** [after subjecting to formation cycle; mΩ] | **DCIR [Total]** [Before rate test; mΩ] | **DCIR** [After rate test mΩ] |
|---|---|---|---|---|---|---|
| | **Charge (mAh)** | **Discharge (mAh)** | **ICE%** | | | |
| 1 | 26.49 | 23.72 | 89.55 | 5.35 | 6.54 | 7.98 |
| 2 | 25.79 | 23.46 | 90.94 | 6.78 | 6.49 | 7.28 |
| 3 | 25.97 | 23.54 | 90.64 | 5.79 | 5.54 | 6.51 |
| 4 | 25.91 | 23.58 | 90.99 | 4.85 | 4.78 | 5.86 |
| 5 | 25.82 | 23.42 | 90.69 | 5.89 | 5.27 | 5.97 |
| 6 | 25.97 | 23.72 | 91.34 | 4.06 | 3.88 | 4.94 |

**[0102]** The results showed that the cells comprising the electrode EA prepared by the process 1 as disclosed in Example 1, exhibited improved electrochemical performance in terms of the direct current internal resistance (DCIR). It was found that the DCIR for the electrode EA, was lesser than 6 mΩ. In addition, the initial coulombic efficiency (ICE) of the cell prepared using the electrode EA was found to be 92% because of proper electronic networking and enhanced particle connectivity as found in the SEM results. Furthermore, the cell comprising the electrode EA showed a coulombic efficiency of 91% along with better charge/discharge capacity of the cell. Meanwhile, the electrode prepared using the comparative process 2 showed a DCIR of more than 7mΩ, and an ICE of 89%. Further, it was observed that there was no change in DCIR value after subjecting the battery/cell to a formation protocol or after nominal capacity measurement. This indicated that the electrode comprising high conductive carbon content (of about 1.5%) had formed a stable, electronically conductive and homogenously distributed electrode structure.

**[0103]** The cells comprising electrode EA as cathode (EA-1 to EA-6) exhibited

improved rate performance and there was only negligible increment in DCIR after rate test as shown in the Table 2. Hence, it was concluded that there was an improvement in the energy retention percentage from 90 to 94% when the cathode was electrode EA of the present disclosure.

**[0104]** Therefore, the electrode EA having higher amount of conductive carbon (~1.5%) ensured proper electronic networking throughout the electrode by enabling enhanced networking among the active material particles and conductive carbon particles.

**[0105]** Meanwhile, the other cells comprising comparative electrodes CE-1 to CE-5 as the cathode, showed high DCIR before and after rate test. Furthermore, the DCIR for some of the cells comprising these comparative electrodes as their corresponding cathodes showed extremely high values of up to 9.89 mΩ. However, the sample cells comprising electrode EA as the cathode showed a maximum DCIR value of ~5.9 mΩ even after rate test. This showed that the disclosed process of the present disclosure along with the disclosed ratios of conductive carbons (primary and secondary) led to the enhanced conductivity and reduced internal resistance in the electrode EA.

## ADVANTAGES OF THE PRESENT DISCLOSURE:

**[0106]** The present disclosure provides a process for preparing battery electrodes such as anodes and cathodes. The process of the present disclosure incurs less cost, consumes less energy and are economically viable processes. The present disclosure provides a process of preparing battery electrode which involves stepwise sequential mixing to reduce the possibility of the carbon agglomeration into the slurry which will confer the homogeneous electrical conductivity in the electrodes throughout its length. The present disclosure further involves utilization of optimum conductive carbon by with a keen consideration of morphology, and aspect ratio of the conductive additives. Further, the amount of conducting additives also improved the electronic conductivity along with the energy density of the cell. The electrode prepared by the process of the present disclosure therefore exhibits improved electrochemical efficiency. The process of the present disclosure is

suitable for preparing an anode as well as a cathode. Further, the electrochemical cells prepared using the electrodes prepared by the process of the present disclosure exhibits a very less through plane resistance of 0.44 Ohms.

**I/We Claim:**

1. A process for preparing an electrode, the process comprising:
    a. mixing a primary conductive carbon with a binder solution to obtain a pre-mixture;
    b. blending a first part of an active material with the pre-mixture to obtain a blend;
    c. adding and stirring a first part of a secondary conductive carbon with the blend to obtain a first mixture;
    d. adding a second part of the active material with the first mixture to obtain a second mixture;
    e. mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and
    f. processing of the electrode slurry to obtain the electrode,

    wherein the primary conductive carbon and the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5; and

    wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1 to 2%, with respect to the total weight of the electrode.
2. The process as claimed in claim 1, wherein the primary conductive carbon is in a weight range of 0.5 to 1%, with respect to the total weight of the electrode; and the primary conductive carbon is selected from single walled carbon nanotube (SWCNT), multiwalled carbon nanotube (MWCNT), carbon nanofiber, vapour grown carbon nanofiber or combinations thereof.
3. The process as claimed in claim 1, wherein the first part of the secondary conductive carbon and the second part of the secondary conductive carbon are in a weight ratio range of 1:0.75 to 1:1.5.
4. The process as claimed in claim 1, wherein the first and the second part of the secondary conductive carbon combinedly is in a weight range of 0.5 to 1%, with respect to the total weight of the electrode; and the secondary conductive carbon is selected from graphite, graphene, carbon black, acetylene black, or combinations thereof.

5. The process as claimed in claim 1, wherein the binder solution is a mixture of a binder with a solvent.

6. The process as claimed in claim 5, wherein the binder is in a weight range of 1 to 2%, with respect to total weight of the electrode;

the binder is selected from polyvinylidene fluoride (PVDF), polypropylene carbonate (PPC), poly(vinylidene fluoride-hexafluoropropylene) (PVDF-HFP), polyfluoroxy alkanes (PFA), polyvinyl fluoride (PVF), polyethylene (PE), polyethylene vinyl acetate (PEVA), polyethylene glycol (PEG), polyurethane (PU), polypropylene rubber (PPR), ethylene propylene rubber (EPR), polyisobutylene (PIB), polyvinyl alcohol (PVA), phenoxy resin, polyethylene terephthalate (PET), nylon, polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), polyphenylene sulphide (PPS), poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS), polystyrene (PS), or combinations thereof; and

the solvent is selected from N-methyl pyrrolidone, dimethyl formamide, dimethyl sulfoxide, ethylene carbonate, ethylene glycol, glycerol, or combinations thereof.

7. The process as claimed in claim 1, wherein the first part of the active material and the second part of the active material are in a weight ratio range of 1: 0.75 to 1: 1.5.

8. The process as claimed in claim 1, wherein the first and the second part of the active material combinedly is in a weight range of 96 to 98% with respect to total weight of the electrode; and the active material is selected from lithium nickel manganese oxide (NMC), lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium iron phosphate (LFP), lithium yttrium iron phosphate (LYP), lithium nickel manganese cobalt oxide, lithium nickel cobalt aluminium oxide (NCA), lithium manganese phosphate ($LiMnPO_4$), lithium cobalt phosphate ($LiCoPO_4$), lithium vanadium phosphate (LVP), spinel type alkali metal transition metal oxides, alkali-transition metal oxides ($AMO_2$) oxides, or combinations thereof.

9. The process as claimed in claim 1, wherein mixing in step (a) is carried out at a speed in a range of 200 to 800rpm for a time period ranging from 10 to 20

minutes.

10. The process as claimed in claim 1, wherein blending in step (b) is carried out by stirring at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes.

11. The process as claimed in claim 1, wherein stirring in step (c) is carried out at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes.

12. The process as claimed in claim 1, wherein step (d) comprises agitation at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes.

13. The process as claimed in claim 1, wherein mixing in step (e) is carried out at a speed in a range of 800 to 1200 rpm, for a period in a range of 5 to 20 minutes.

14. The process as claimed in claim 1, wherein the high-speed mixing in step (e) is carried out at a speed in a range of 1600 to 2500 rpm for a period in a range of 130 to 200 minutes.

15. The process as claimed in claim 1, wherein processing comprises coating the electrode slurry on a substrate, drying, calendering, or combinations thereof.

16. The process as claimed in claim 15, wherein the substrate is a current collector selected from aluminium foil, carbon coated copper aluminium foil, primer coated aluminium foil, or glossy aluminium foil.

17. An electrode obtained by the process as claimed in claim 1, wherein the electrode comprises:

    a) an active material;
    b) a binder;
    c) a primary conductive carbon; and
    d) a secondary conductive carbon,

wherein the primary conductive carbon and the secondary conductive carbon are present in a weight ratio range of 1: 0.75 to 1: 1.5.

18. The electrode as claimed in claim 17, wherein the combined weight of the primary conductive carbon and the secondary conductive carbon is in a range of 1 to 2%, with respect to the total weight of the electrode.

19. The electrode as claimed in claim 17, wherein the electrode is a cathode, and

the cathode has a through plane resistance in a range of 0.2 to 0.5 Ohms.

20. An electrochemical cell comprising:
    a. an anode;
    b. a cathode comprising the electrode obtained by the process as claimed in claim 1; and
    c. an electrolyte.
21. The electrochemical cell as claimed in claim 20, wherein the anode is selected from synthetic graphite, natural graphite, or silicon-graphite composite.
22. The electrochemical cell as claimed in claim 20, wherein the electrolyte comprises a lithium salt selected from $LiPF_6$, LiFSi, or LiTFSi; and a solvent selected from diethylene carbonate, dimethyl carbonate, ethyl methyl carbonate, vinyl carbonate, or combinations thereof.

Date **01 October 2024**

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To,
**The Controller of Patents**
The Patent Office at **Chennai**

## ABSTRACT

## A PROCESS FOR PREPARING AN ELECTRODE, AND IMPLEMENTATIONS THEREOF

The present disclosure provides a process for preparing an electrode, the process comprising: (a) mixing a primary conductive carbon with a binder solution to obtain a pre-mixture; (b) blending a first part of an active material with the pre-mixture to obtain a blend; (c) stirring a first part of a secondary conductive carbon with the blend to obtain a first mixture; (d) adding a second part of the active material with the first mixture to obtain a second mixture; (e) mixing a second part of the secondary conductive carbon with the second mixture, followed by high-speed mixing to obtain an electrode slurry; and (f) processing of the electrode slurry to obtain the electrode. The present disclosure further relates to an electrode and an electrochemical cell thereof.